



TECHNICAL REVIEW REPORT

Prior Consultation for the Proposed Luang Prabang Hydropower Project



**Procedures for Notification,
Prior Consultation and Agreement**

June 2020



Mekong River Commission

Technical Review Report

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Hydropower Project*

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PREFACE

This final Technical Review Report (TRR) for the proposed Luang Prabang Hydropower Project (LPHP) has been prepared by the MRCS in support of the prior consultation process. It provides a review of the documentation provided by the Lao National Mekong Committee (LNMC), as well as comments received throughout the prior consultation process.

This final version was updated based on comments provided by Member States during the final MRC Joint Committee Working Group (JCWG) meeting on 5 March 2020. It was also prepared to submit to the Joint Committee for taking note at its Special Session to conclude the process on 30 June 2020.

The following Annexes support this final Technical Review Report, and form part of the Report:

- Annex A1: Prior Consultation Road Map
- Annex A2: List of International, National and MRCS Expert contributors
- Annex A3: List of documents used to support the technical review
- Annex A4: Comment matrices from the regional and national consultation processes
- Annex B: Alignment with the MRC PDG2009 and Good Practice based on draft PDG2019
- Annex C: Hydrology and Hydraulics Review Report
- Annex D: Sediment and Geomorphology Review Report
- Annex E: Water Quality and Aquatic Ecology Review Report
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ABBREVIATIONS

AIT	Asian Institute of Technology – Bangkok Thailand
BOD	Biological Oxygen Demand – a measure of the demand on oxygen in the water column exerted by organic and inorganic substances.
CIA	Cumulative Impact Assessment
DSMS	Dam Safety Management System
DSRP	Dam Safety Review Panel
EAP	Emergency Action Plan – required for Dam Safety
EIA	Environmental Impact Assessment
ESIA	Environment and Social Impact Assessment
EPP	Emergency Preparedness Plan
FS	Feasibility Study
GoL	Government of the Lao PDR
HPP	Hydropower project
ISH	Initiative for Sustainable Hydropower – a initiative based in the MRCS.
JAP	Joint Action Plan – a post prior consultation process
JC	Joint Committee
JCWG	Joint Committee Working Group – established to guide the technical review process
JEM	Joint Environmental Monitoring – a monitoring programme being piloted at the Xayaburi and Don Sahong HPPs to evaluate the efficacy of the measures applied.
Joint Platform	A body created by the MRC to help improve the implementation of the Procedures in linked and cooperative manner
LEPTS 2018	Lao Electric Power Technical Standards 2018
LMB	Lower Mekong Basin - The Mekong River Basin falling in the territories of its Member States
LPHPP	Luang Prabang Hydropower Project
LNMC	Lao National Mekong Committee
MC	Member Country, one of the four parties to the 1995 Mekong Agreement; viz. Cambodia, Lao PDR, Thailand, and Viet Nam
MRC	Mekong River Commission – established by the MC to support their efforts towards collaboration
MRCS	Mekong River Commission Secretariat
PAP	Project Affected Persons
PBHPP	Pak Beng Hydropower Project
PLHPP	Pak Lay Hydropower Project
PC	Prior Consultation
PDG2009	Preliminary Design Guidance of 2009 - approved
PDG2019	Preliminary Design Guidance of 2019 – not yet approved
PDIES	Procedures for Data and Information Exchange and Sharing
PFMA	Potential Failure Modes Assessment
PMFM	Procedures for Maintenance of Flows on the Mainstream
PNPCA	Procedures for Notification Prior Consultation and Agreement
PPA	Power Purchase Agreement
Pressure flushing	Use of low-Level outlets to scour sand deposited near the dam wall and turbines, primarily to project the infrastructure and power production.

PWQ	Procedures for Water Quality
PWUM	Procedures for Water Use Monitoring
RAP	Resettlement Action Plan
RCC	Roller Compacted Concrete
RIS	River Information System – a system that may be introduced to facilitate navigation on the Mekong mainstream
SEE	Safety Evaluation Earthquake – a seismic standard applied to possible ground motion.
SIA	Social Impact Assessment
Sediment flushing	Drawing down water levels to periodically induce channel erosion and discharge large volumes of deposited sediment.
SMMP	Social Monitoring and Management Plan – a process initiated with construction to evaluate and adapt to impacts due to construction and operations of the HPP
Sediment routing	Drawing down water level during periods of high inflow to maximise sediment throughput.
TBIA	Transboundary Impact Analysis
TRR	Technical Review Report
XHPP	Xayaburi Hydropower Project

1. BACKGROUND

1.1. Introduction

On 31 July 2019, the Mekong River Commission (MRC) Secretariat received notification from the Lao National Mekong Committee (LNMC) submitting the Luang Prabang Hydropower Project (LPHPP) for prior consultation under the Procedures for Notification, Prior Consultation and Agreement (PNPCA). The proposed LPHPP is the fifth proposed use submitted for prior consultation. The four earlier PC processes are for the Xayaburi (XHPP), Don Sahong, Pak Beng (PBHPP), and the Pak Lay (PLHPP) hydropower projects conducted in 2010-2011, 2014-2015, 2016-2017, and 2018-2019, respectively.

The PNPCA require the notified Member States to acknowledge and review the documents submitted for prior consultation and submit their replies to the MRC Joint Committee (JC). The JC has delegated oversight of the prior consultation process to a PNPCA Joint Committee Working Group (JCWG) which has directed the MRC Secretariat (MRCS) to appoint a task team to assist in the review of the documentation submitted by the LNMC. This Technical Review Report is the result of the review by the MRCS task team.

The proposed LPHPP is the 2nd HPP in the cascade of run-of-river projects on the Mekong mainstream from upstream to downstream in the Lower Mekong Basin (LMB). It is in Luang Prabang province and is situated between the upstream Pak Beng project and the downstream Xayaburi project. Construction of the Xayaburi HPP has been completed and it is currently in operation, the Pak Beng HPP underwent prior consultation in 2016 -2017 and is undergoing the final design process.

The LPHPP prior consultation process was initiated by an internal Scoping Assessment Report which was submitted to the first meeting of the JCWG on 8 October 2019. That report and meeting outlined the scope of the review and agreed the official start date of the initial 6-month prior consultation process would be 8 October 2019. The first draft of the TRR was discussed at the second meeting of the JCWG on the Luang Prabang prior consultation process. A second draft TRR including comments from the JCWG, Member States and the LPHPP developer was produced and circulated. Comments on that 2nd draft as well as feedback from external stakeholders have been taken up in the third and final draft of the TRR. This will assist the notified Countries in formulating their positions and Official Replies to the notification. The 3rd draft of the TRR was considered at the final meeting of the JCWG on 5 March 2020. Comments from that meeting, which also include the comments from the developer, were taken up in this Final TRR and supported the deliberations at the Special Session of the MRC Joint Committee (JC) on 30 June 2020¹.

This 5th prior consultation process has, like the previous 2 processes, focused on measures that can be considered to avoid, minimise and mitigate potential transboundary harm. However, as with the previous processes, there is an expectation that prior consultation on the LPHPP will further improve on the process – addressing some of the stakeholders' concerns outlined in the Pak Beng and Pak Lay processes. In particular, and as outlined in the Scoping Report, the Luang Prabang process will take a broader perspective on aligning proposed measures to limit any adverse transboundary impacts with the commitments the Member States made in Chapter III of the 1995 Mekong Agreement. The current process will also place increased emphasis on the need for the coordinated operation of the mainstream

¹ The original date in the roadmap was 07 April 2020. However, due to COVID pandemic and more time needed for deliberation, the date was moved to 30 June 2020.

hydropower projects in the upper Lao Cascade, and a post prior consultation process to refine the recommendations made in the TRR.

As with the Pak Beng and Pak Lay processes the prior consultation was concluded with a Statement from the JC calling on the notifying country to consider the recommendations in the TRR, and to make every effort to implement the measures that will reduce the potential for transboundary impacts. Moreover, a post prior consultation Joint Action Plan (JAP) was also agreed to support the final design, construction and operational phases of the LPHPP with a view to refining measures to limit transboundary impacts.

1.2. The 1995 Mekong Agreement

1.2.1. Background

The prior consultation process is governed by the Agreement on Cooperation for the Sustainable Development of the Mekong River Basin (the 1995 Mekong Agreement or ‘the Agreement’²), and its associated Procedures. An understanding of the powers and functions conferred on the MRC by its Member States is important to set the context and expectations for prior consultation. A more comprehensive Handbook on Understanding the Mekong Agreement and the Procedures has been approved by the Joint Committee. This will also help provide more understanding of the Agreement. This section aims to clarify key issues raised by the external stakeholders’ around the role of the MRC in the prior consultation process.

1.2.2. Establishment and Powers and Functions

The 1995 Mekong Agreement was signed by plenipotentiaries from Governments of Cambodia, Lao PDR, Thailand, and Viet Nam on 5 April 1995, thereby committing these Countries to upholding the provisions of the Agreement. The Agreement established the MRC’s 3 standing bodies, the Council, the Joint Committee (JC) and the Secretariat (MRCS), and conferred powers and functions on these bodies as outlined in Chapter IV of the Agreement. The MRC’s standing bodies *can only* act in line with these conferred powers.

The Council provides political oversight and ensures that the MRC remains true to the intention of the Agreement, and therefore has approved the 5 MRC Procedures – including the PNPCA and the Basin Development Strategy. The Council addresses any differences and disputes that may be referred to it by the JC or any of the Member States. The JC is the technical and functional body of the Commission and agrees the Technical Guidelines that outline how to implement the Procedures. The JC is also mandated through Article 5 of the Agreement to implement the prior consultation process. The JC has established sub-committees to support its functions and the prior consultation process is managed by the JC Working Group (JCWG) on the PNPCA. The Secretariat provides administrative and technical support to the JC and has undertaken this technical evaluation of the documents submitted. However, the PNPCA Technical Guidelines indicate that the Secretariat should play a pro-active role in supporting prior consultation and has applied that principle to the development of this TRR.

² The 1995 Mekong Agreement is available at:
<http://www.mrcmekong.org/assets/Publications/agreements/95-agreement.pdf>

1.2.3. The PNPCA

Article 5.4.3 of the PNPCA agreed by the Council indicates that:

The MRC JC shall aim to arriving at an agreement on the proposed use and issue a decision that contains the agreed upon conditions. That decision shall become part of the record of the proposed use and of the record of the use of the waters when commenced. The notifying State(s) shall not implement the proposed use without providing the opportunity of the other member States to discuss and evaluate the proposed use. The MRC JC shall take note of replies and place in the record for the proposed use of any concerns or reservations made by the notified State(s).

This TRR is a step towards establishing these “conditions” or measures, which will be captured in the Statement tabled at the MRC Joint Committee Special Session (JCSS) on 8 April 2020. This will be followed up by the JAP which will aim to refine and final design and operational measures together with the notifying country and the project developer.

Implementation of the PNPCA is also subject to the JC’s Rules of Procedure and any decision must be adopted through consensus between all the Member States. When implementing Article 5.4.3 of the PNPCA, the JC therefore strives to find common ground based on the TRR and the recommendations for measures to avoid, minimise and mitigate any potential harmful effects. These recommendations are captured in the Statement urging the Lao PDR to consider the proposed measures.

In Chapter III of the Agreement the Member Countries agree to hold themselves to certain principles and objectives for cooperation. These include *specific commitments* to act in a certain way towards one another; for example in Article 5 to use the waters of the Mekong River System in a reasonable and equitable way subject to notification, prior consultation and agreement under different circumstances; and *general commitments* to act in a certain way within their own territories, for example the general commitment to make every effort to avoid, minimise and mitigate harmful effects (in Article 7), and to protect the environment and ecological balance (in Article 3).

Importantly, the Agreement does not allow the MRC to direct the Member States to comply to these commitments. The Commission can, however, highlight measures that will assist the Member States in fulfilling these commitments. For this reason, the Statement agreed by the JC at the end of the prior consultation process will call on the Government of Lao PDR to *make every effort* to implement the measures summarised in the Statement and to require the developer and operator to take these up in the ongoing final design and operations of the LPHPP. However, it is hoped that the Lao PDR will also find value in recommendations that will better align the development and operation of the proposed LPHPP with international good practices, but which do not necessarily pose a transboundary risk.

1.2.4. The definition of prior consultation

The prior consultation process must be consistent with its definition in Chapter II of the Agreement which is as follows:

“Timely notification plus additional data and information to the Joint Committee, as provided in the Rules for Water Utilisation and Inter-Basin Diversion under Article 26, that would allow the other member riparians to discuss and evaluate the impact of the proposed use on their uses of water and any other affects, which

is the basis of arriving at an agreement [in the JC]. Prior consultation is neither a right to veto the use, nor a unilateral right to use water by any riparian without taking into consideration other riparians' rights."

Any "agreement" is derived by consensus in the JC's final Special Session and is reflected in the Statement. This means that the JC strives to accommodate the concerns of the notified States, while recognising it cannot veto the proposed use. This differs from an unanimity rule where all the Member States must agree (or vote) on a given position³, or a majority rule where the majority vote holds⁴. Consensus rules are common in international water treaties and transboundary River Basin Organisations.

However, given that assessing the technical, engineering and financial viability of the measures is a dynamic process running through the final design, construction and operational phases of the project, a Joint Action Plan (JAP) is also proposed so that the MRC and the notified States can track and contribute to improving or revising the measures on an ongoing basis. The operating rule measures in place at the start of the operations will emerge from the JAP and establish the "conditions" referred to in Article 5.4.3 of the PNPCA and must be captured as such by the JC. Once the proposed use is initiated, the operational measures will be taken up in the Procedures for Water Use Monitoring (PWUM) and their implementation will be reported in the JC on a regular basis.

Importantly, any Statement or JAP does not prevent the Member States from pursuing discussions outside of the MRC and drawing in other sectors like trade or tourism into a broader benefit sharing mechanism. Similarly, the notified States will separately submit any concerns and reservations⁵ in their formal replies to prior consultation, which are also placed on record. These formal replies are not subject to the JC's Rules of Procedure and *need not* align fully with any agreement made by the JC but should also not propose any veto of the proposed use. While the TRR and Statement are adopted by consensus during the JC's special session on the conclusion of the prior consultation process, the Member States may therefore present dissenting options or raise concerns in their Official Reply Forms. The notifying Country may also submit a separate comment on the TRR, as was done in the Pak Lay process, or provide reservations on the Statement.

'Agreement' in Clause 5.4.3 of the PNPCA, therefore, need not be a 'yes' or 'no' decision on the proposed use, and this is not easy to achieve in a 6-month timeframe, given that the JC's Rules of Procedure require a negotiated consensus. The prior consultation and JAP process are therefore, *in practice*, largely cooperative mechanisms leading to a better project with fewer impacts, within the constraints of the financial viability of measures to avoid, minimise and mitigate potential impacts.

Importantly, however, prior consultation and any post-prior consultation process, must be underpinned by the commitment to good faith cooperation. In this sense it must be more than an administrative process and must reflect a genuine desire by the notifying State to address the concerns of the notified countries' in an open and transparent manner, and the genuine

³ The UN Security Council operates on an unanimity rule, where all the permanent members are afforded a veto right. "Agreement" in Article 5.2 (b) is based on an unanimity rule.

⁴ The UN General Assembly operates on a super-majority vote (> 2/3rd) for issues of peace and security, and a simple majority (50% + 1) for other matters.

⁵ A reservation allows any Member State to be party to the Statement, while excluding some of the provisions, or highlighting their rights to seek compensation for any proven substantial damage.

recognition by the notified countries of the notifying country's rights to development and to a reasonable and equitable share of benefits arising from the use of the Mekong River System.

1.2.5. Rights, Interests and Responsibilities

All the MRC Member States have a *responsibility* to make every effort to fulfil the commitments they made in Chapter III of the Agreement, whether these result in transboundary impacts or not. Conversely, all the Member States can expect that the other Member States make every effort to respect these commitments. The Member States' *rights* also extend to their *legitimate interests* in using the waters of the Mekong River System to support their development, as well as the *right* to the reasonable and equitable use of the shared watercourse and that significant transboundary harm is avoided. Reaching consensus on the most appropriate balance between these *rights, interests* and *responsibilities* lies at the heart of the prior consultation process.

Balancing the rights, interests and responsibilities of the notified and notifying States must, however, also consider the financial, technical and engineering viability of the measures proposed in the Statement. Previous experience with the prior consultation process has also highlighted the challenge of attribution of any transboundary harmful effects to individual uses of the Mekong River System, as well as the identification of any cross-border mitigation or compensation measures. These challenges are being addressed in parallel processes within the MRC's Joint Platform which is looking into options to improve the implementation of all the Procedures in an inter-linked way, and potentially to develop a Mekong Fund to support mitigation measures in all 4 Member States.

1.3. Giving effect to Articles 3, 5, 7 and 8 of the Agreement

1.3.1. Background

The preamble to the PNPCA includes the following:

"Reconfirming the commitment to work together to address the protection of the environment and the ecological balance in the Mekong Basin, including the prevention of harmful effects and taking actions in emergency situations as covered by other Rules/Procedures approved by the MRC Council."

This draws the links between Articles 5 (Reasonable and equitable use – and the PNPCA), Article 3 (Protection of the environment and ecological balance), and Article 7 (Prevention and cessation of harmful effects), as well as the other Procedures. This section outlines how these Articles will be considered in the prior consultation process and the TRR.

1.3.2. Article 3 – Protection of the environment and ecological balance

The 1995 Mekong Agreement is a treaty to cooperate for the Sustainable Development of the Mekong River System, and Article 3 of the Agreement reads:

[The Parties Agree...] To protect the environment, natural resources, aquatic life and conditions, and ecological balance of the Mekong River Basin from pollution or other harmful effects resulting from any development plans and uses of water and related resources in the Basin.

Modern approaches to sustainable development are underpinned by the nexus of *all* the Sustainable Development Goals (SDGs), and protection of freshwater ecosystems is just one component of this. The Member States have all accented to the SDGs and hence to this

broader perspective for sustainable development. Importantly, MRC recognises that the Mekong's aquatic ecosystems provide vital goods and services to humans, and that rural poor livelihoods are often directly dependent on these goods and services. However, sustainable development must be more than sustaining the livelihoods of the poor fishing communities or "sustainable poverty", and the SDGs on ending poverty (SDG 1); affordable reliable and sustainable energy (SDG 7); sustained, inclusive and sustainable economic growth (SDG 8), reduced inequality within and among countries (SDG 10), and urgent action on climate change (SDG 13); must be given consideration. Economic growth provides opportunities for less climate vulnerable livelihoods. All the Member States should also pursue other non-hydropower renewable sources of energy which could meet their rapidly increasing power demands.

The prior consultation process therefore recognises the value of inclusive and fair regional economic growth but also that measures must be included to minimise any harm to aquatic ecosystems irrespective of whether these are transboundary or not. This does not, however, necessarily equate to a no-harm principle.

1.3.3. Article 5 - Reasonable and equitable use

The prior consultation process emerges from Article 5 of the Agreement on the reasonable and equitable use of the Mekong River System. The process must therefore balance *all* the impacts that arise from the use of the shared watercourse in *all* the Member States, with the benefits of development in the notifying State and the region. This is a difficult and nuanced concept and requires assessing a range of factors that may impinge on the use of the Mekong River System. Many of these factors may result from developments in the Basin that are not subject to prior consultation, or which may not have been fully considered in the Council Study, including those that originate from outside the LMB like the Lancang cascade in China and climate change.

It would not be fair, for example, to find that a given use of the shared watercourse is *not* reasonable and equitable, while ignoring other existing and future impacts that may be as, or more, significant. For all these reasons a final determination of whether the notified use is reasonable and equitable is difficult within a six-month timeframe, and is not a technical process *per se*. This determination does not therefore form part of the TRR. However, given the growing importance of the need for reasonable and equitable use, the MRC is also exploring how to give effect to the principle in the prior consultation process through its Joint Platform.

1.3.4. Articles 7 and 8 – Prevention and Cessation of harmful effects

Article 7 focuses on measures to avoid, minimise and mitigate harmful effects and actions to be taken in should these harmful effects rise to the level of substantial damage. Article 8 outlines the process for State Responsibility for Damage and Compensation. The relationship between these Articles, as well as Articles 3 and 5 is outlined in Figure 1-1.

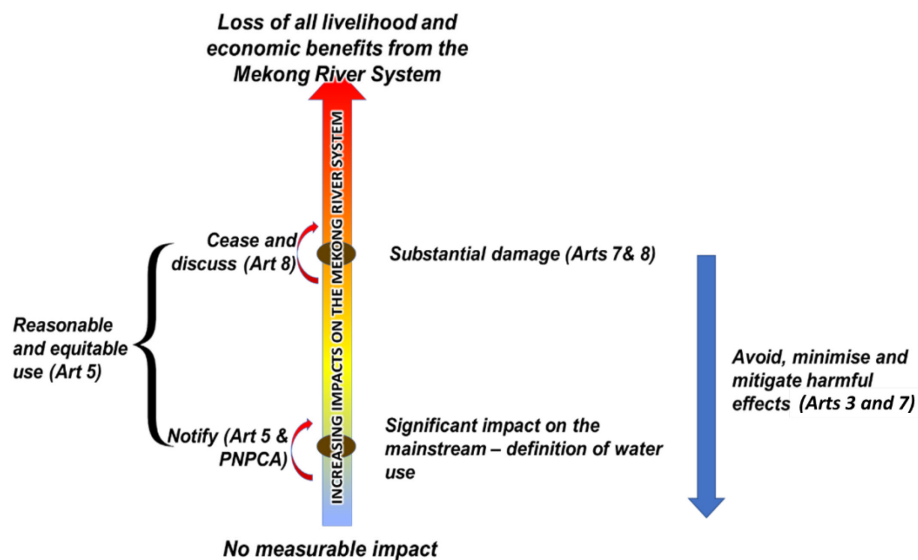


Figure 1 - 1 A conceptual diagram outlining how the measures recommended in TRR deal with Articles 3, 5, 7 and 8 of the 1995 Mekong Agreement.

Before a use is made subject to the PNPCA, it must have a *significant impact on the mainstream*. In the Revised SADC Protocol on Shared Watercourses “significant transboundary impact” is further described as a non-trivial impact, setting the bar for notification quite low. In the Mekong Agreement the Member States have agreed to make every effort to avoid, minimise and mitigate *harmful effects* (Article 7), and this Article applies to all notifications under the PNPCA.

Only when these harmful effects cause *substantial damage*, proven with valid evidence presented by the *notified* States, must the notifying State cease the activity. As such, there is no obligation in the Agreement to have no impact on the mainstream, but only to limit possible impacts as far as is possible. Only when harmful effects rise to the level of substantial damage must the activity be stopped. Reasonable and equitable use would therefore lie between “significant impact on the mainstream” and “substantial transboundary damage”. The conceptual relationship between these terms is illustrated in Figure 1-1.

However, these concepts must also be set against the general principle in international water law for Countries to take all reasonable measures to *prevent* causing significant transboundary harm. In this context “significant transboundary harm” may be analogous or even lower than “substantial damage” referred to in Articles 7 and 8. Herein lies the complexity for prior consultation. While there is an expectation that project developers clearly identify and quantify any potential for transboundary harm, proof that this harm is due to the notified use and that it causes “substantial damage” must be presented by the notified State(s). This must therefore be addressed in the notified States Official Reply forms, and not the TRR *per se*. The International Law Commission’s commentaries on the 1994 draft of the UN Watercourses convention also note that a notifying country should not make itself liable for compensation through the notification process.

For this reason, the prior consultation process primarily focuses on the commitment to avoid, minimise and mitigate harmful effects, and measures that could be considered in this regard. Nonetheless, the presentation of potential cumulative and transboundary harmful effects has

become standard practice in the prior consultation process and has been demonstrated as critical through the Council Study. Chapter 5: Transboundary and Cumulative Harmful Effects has therefore been included in this TRR to provide some perspective on this in the LPHPP context.

1.3.5. Not an impact assessment

The prior consultation process is restricted to an initial 6-months⁶ and has limited resources. Studies that underpin a project of this size typically take place over several years and are costly. This TRR does not therefore constitute an impact assessment. The TRR is only a review of the documentation provided to the MRC through the formal channels, i.e. the National Mekong Committee. It assesses the extent to which that documentation reflects the guidance in the Preliminary Design Guidance of 2009 (see Annex B), while drawing on the good practice guidance in the draft Preliminary Design Guidance of 2019 and other international guidelines for a project of this size. The TRR therefore provides advice on due diligence both in the MRC and international context⁷.

The MRC Joint Committee's Statement makes recommendations for the Lao PDR to consider in its ongoing development of the project as it moves to the detailed design, construction and operational phase. This includes suggestions for the government of the Lao PDR for their ongoing oversight of the developer, as well as recommendations for measures that will further limit the risk of transboundary harm. The prior consultation process also recognises that the LPHPP is still subject to final design, construction and operation and that the proposed measures can be further explored in these phases through the JAP. Indeed, discussions with the developer based on the 1st and 2nd drafts of the TRR have highlighted that many of the recommendations made in the TRR are already being addressed. Due process, nonetheless, requires that the TRR can only be based on the documents that have been formally provided. In these cases, therefore, the TRR notes that further work is being undertaken and that the results will be discussed as part of the JAP process.

1.4. Public participation

As with the previous prior consultation processes the MRC and the Member States have committed themselves to an open and transparent process. This means engagement with and feedback to the stakeholders.

Two main groups of stakeholders are recognised.

- **Internal stakeholders:** This includes the structures of the MRC, the Council, the Joint Committee and the Secretariat, as well as other government agencies in the Member Countries; and
- **External stakeholders:** This includes non-state actors and outside bodies such as development partners, dialogue partners (China and Myanmar), NGOs, implementing partners, civil society organizations, research institutions, academics, individuals and other interested groups.

⁶ While Article 5.5.2 allows the JC to extend the period of prior consultation, this has not been used in practice.

⁷ *Due diligence* is an investigation of the potential investment to confirm all facts have been considered. It refers to the care a reasonable investor should take before making the investment.

External stakeholder engagement has taken place at national and regional levels. National level engagements were conducted by the National Mekong Committees in each Member Country from the 9th to the 22nd of October 2019 and in Thailand on 24 December 2019⁸. A further round of national information sharing sessions and consultations took place during January 2020 and were supported by a Summary of the 2nd draft of the TRR for lay persons which was translated into the national languages. Further, the 3rd round of the national information sharing session and consultation was conducted between February and March 2020. Feedback from these engagements informed this final TRR.. The outcomes of these processes were also used to inform the Member States' positions in the Joint Committee and their Official Reply forms. The comment matrices emerging from these engagements have been included in Annex B.

The Pak Lay process for the first time also included support to the notifying country to undertake national consultations and this has provided a more balanced perspective from external stakeholders. This has also formed part of the Luang Prabang process, and the comments from Lao PDR stakeholders have been addressed in this final TRR and in Annex B.

The regional consultations are managed by the MRCS and have also informed the drafts of the TRR. The regional consultations are part of the MRC's Regional Stakeholder Forums, and the 8th Regional Stakeholder Forum included a separate day on 6 November 2019 to introduce the LPHPP prior consultation process. A second process was undertaken on 5 February 2020 to discuss the results of the review and the outcomes of this process have been taken up in the TRR.

In addition, stakeholders were also provided opportunity to submit comments and feedback online through the MRC website at: <http://www.mrcmekong.org/stakeholder-consultations>.

1.5. The timing of prior consultation

Any project undergoing the Prior Consultation process passes through several phases, as illustrated in Figure 1-2.

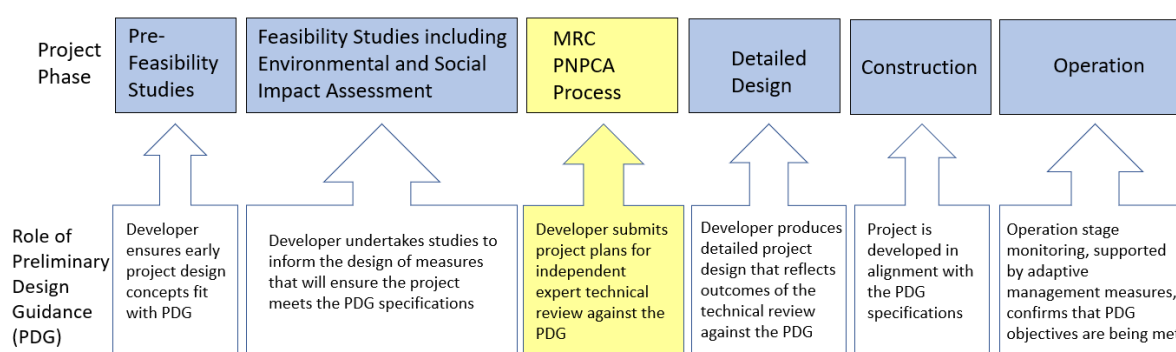


Figure 1 - 2 The timing of the prior consultation process in the life cycle of large projects (from PDG2019 Version 2.5).

Phasing in this way allows the developer to incrementally assess the viability of the proposed project before sinking additional resources into it and allows them to identify specific design

⁸ It was agreed at the 1st PNPCA JCWG Meeting that there should be some flexibility for the dates of relevant national events.

requirements before finalising the design and assessing the bankability⁹ of the proposed project. Each phase provides more information on the economic, technical, social and environmental viability of the project. The draft Preliminary Design Guidance 2019 (version 2.5) recommends initiating the prior consultation process after the Feasibility Studies (Figure 1-2), as is required in the PNPCA Clause 5.2. The Feasibility Studies should therefore identify measures to align the design and operations with the Preliminary Design Guidance.

The LPHPP has been notified as outlined in Figure 1-2, and this review is based on the 6 Volumes that make up the Feasibility Study, as made available on 31 July 2019¹⁰. However, some of the studies are ongoing and additional results were provided later. The list of documents provided by the LNMC to support the prior consultation process for the LPHPP are outlined in Annex A3. This final draft TRR also includes verbal clarifications provided by the developer during the site visit.

There are both advantages and disadvantages to notification at the feasibility stage.

▪ *Advantages:*

- Prior consultation takes place before the final design and can influence the final design and operational plans.
- The notifying Country, the developer, and any potential financiers can make an earlier decision on the viability of the proposed project based on the inputs from the MRC, before sinking additional resources into the project.
- The prior consultation process supports the ongoing project development process, and allows earlier participation by the notified Countries in the impact assessments; and
- The International Court of Justice has indicated that it is preferable for all the affected Countries to participate in the EIA of a notified proposed project. Notification at the feasibility stage and the post prior consultation process allows all the Member States to influence the final assessment of any potential impacts, and the identification of operational measures to address these.

▪ *Disadvantages:*

There may be insufficient information available at the feasibility stage for the JC to formulate a final set of measures for the proposed use or make an evaluation of whether the proposed use is reasonable and equitable.

There may be insufficient information for the notified countries to assess the potential adverse impacts on their use of the Mekong River System, and hence to formulate their replies.

The developer may already plan to implement many of the recommendations emerging from the TRR, and an unnecessarily negative impression of the proposed project may arise; and

Some of the guidelines outlined in the PDG need to only be addressed at the final design stage, and there is often insufficient evidence at the Feasibility Stage to assess alignment with the PDG requirements.

⁹ Bankability = the ability of the project to attract loan financing. This may include its commitment to minimising environmental and social impacts.

¹⁰ The updated versions of the submitted documents were provided by the LNMC on 18 October 2019.

The disadvantages can be addressed through a post prior consultation Joint Action Plan (JAP) process. This tracks the implementation of the Statement agreed at the Special Session of the JC across the final design, construction and operationalising phases. The JC has approved the JAP processes for Pak Beng, Pak Lay and Luang Prabang HPPs in this light.

Similarly, a Joint Environmental Monitoring (JEM) programme is being implemented on a pilot basis at the Xayaburi and Don Sahong HPPs. This will assess the efficacy of the measures applied, potentially allowing for adaptive management to be applied to the design and operations. Given the similarities in the designs for the LPHPP and the XHPP, the efficacy of the measures at Xayaburi are particularly relevant to the JAP process for the LPHPP and the JEM can contribute to the final design of the measures to be applied at the LPHPP.

1.6. Water diplomacy through prior consultation

“Water Diplomacy” has been defined as:

“an approach that diagnoses water problems, identifies intervention points, and proposes sustainable solutions that are sensitive to diverse viewpoints and values, ambiguity and uncertainty as well as changing and competing needs”

(<https://waterdiplomacy.org/>).

This is what the prior consultation process and this TRR aim to do. This review of the LPHPP documentation outlines potential adverse impacts. Some preliminary measures to further avoid, minimise and mitigate these impacts, as well as the need for additional information, have been identified. These will form the basis for discussions in the JC. Ambiguity and uncertainty are recognised as inherent in notification at the Feasibility Stage (and beyond) and are addressed through a combination of the precautionary principle, proposals for adaptive management and the JAP process. This ongoing cooperation will help finalise the agreed infrastructural and operational measures and the latter will be taken up in the PWUM.

Another dimension of cooperation lies in the development of operating rules for the upper Lao cascade of HPP, allowing the HPP operators to optimise the benefits of measures at each project while maintaining the economic viability of their individual projects. However, this lies beyond the remit of an individual developer and must be addressed by the Government of the Lao PDR and / or the MRC. Some initial recommendations are outlined in Chapter 5 on cumulative impacts and will be further elaborated as part of the MRCs Joint Platform and ongoing work on the Sustainable Hydropower Development Strategy.

1.7. Lessons learnt

As early as 2013, and following the PC process for Xayaburi, the MRC recognised the need to improve the implementation of all five MRC Procedures, and particularly the PNPCA. A Joint Platform was established to engage in this process and has held several workshops and meetings to this end.

As part of this process, the Joint Platform arranged a dialogue workshop in Bangkok on 25 February 2016. The key recommendations emerging from this workshop in respect of the prior consultation process were that:

- a. Greater clarity regarding the commencement and conclusion of the Prior Consultation process is needed.
- b. A process for the review and approval of the adequacy of documentation received for Prior Consultation should be included.
- c. Greater clarity regarding the roles of all actors who have a responsibility for implementing the PNPCA is needed.
- d. Appropriate project information disclosure practices for effective stakeholder participation should be developed.
- e. Greater clarity regarding the role of a transboundary EIA is needed.
- f. A six-month timeframe was too short to undertake a comprehensive review, and more time was needed to source additional data and studies to confirm the results; and
- g. “Commentaries” on the PNPCA, to supplement the current Technical Guidelines for the PNPCA, should be developed. These commentaries must place key provisions of the PNPCA in the wider context of international best practice but would not necessarily constitute an amendment to the Procedures.

A Working Paper on Lessons Learnt from Implementation of the Procedures for Notification, Prior Consultation and Agreement (PNPCA) has subsequently been developed by the MRCS and discussed in the Joint Platform, and it has been agreed to treat the Working Paper as a living document. The experiences from each successive prior consultation process are incorporated into this Working Paper on an ongoing basis.

The Pak Beng process was guided by the lessons learnt in the Xayaburi and Don Sahong cases and was perceived by all stakeholders as more successful. This is primarily related to improved engagement with external stakeholders, and the JC’s agreement on the Statement and Joint Action Plan. In response to some Stakeholder’s concerns expressed for Pak Beng, the Pak Lay process provided more context regarding the powers and functions of the organs of the MRC. The Pak Lay process also more clearly defined the start and end points of prior consultation, in effect allowing for a “pre-prior consultation” process to agree the scope and programme of the review.

This current prior consultation process will further build on the lessons learnt in all 4 processes to date.

These key lessons and the responses are:

- **Notification is done at the feasibility stage and there is generally insufficient information to provide a final assessment of the likely on the impacts.**

The PNPCA indicates that notification must be based on the Feasibility Studies, this has now been formalised in the draft PDG of 2019.

The inclusion of the post-prior consultation JAP addresses the disadvantages of notification at the feasibility stage, while still taking advantage of the flexibility to adjust the design and operations throughout the final design, construction and operational phases.

- **The greater focus on identifying additional measures to avoid, minimise and mitigate harm provided the opportunity for the Statement.**
 - The Statements and JAPs for the Pak Beng and Pak Lay HPPs have now been approved by the MRC, and this is becoming the standard practice.

These outline the ‘conditions’ (*as per PNPCA Cl. 5.4.3*) or measures that will be explored throughout the remaining phases of the project development, ultimately leading to a set of operational measures that will be reported through the PWUM.

- **Improved external stakeholders’ understanding of the prior consultation process.**

Following the Pak Beng process, some stakeholders indicated that, in their opinion, the focus on Article 7 of the Agreement was an overly narrow interpretation of the requirements for prior consultation. This current process therefore further expanded on the consultations initiated with the Pak Lay process, building a greater appreciation of the opportunities and constraints of water diplomacy.

The Luang Prabang process will also take a broader view of Chapter III of the Agreement, including discussion of Articles 3, 5, 7 and 8 of the Agreement. The TRR also includes reference to the PDIES, PWQ, and PWUM¹¹.

- **There was limited attention to the cumulative impacts and conjunctive operations of the mainstream cascade:**

The position of the LPHPP between the upstream Pak Beng, and the downstream Xayaburi, as well as the upcoming prior consultation process for the Sanakham HPP means that the full upper Lao Cascade has, or will be soon, made subject to prior consultation. Measures to minimise the potential transboundary impacts must therefore be tied to the operation of the cascade.

Chapter 5 of this TRR outlines some initial options in this regard. However, the cascade operations will be developed further in the Joint Platform and work by the Sustainable Hydropower Strategy.

1.8. Key new features of this prior consultation process

The following are key features of the LPHPP prior consultation process and this TRR:

- The process takes greater cognisance of the post-prior consultation process and involvement of the MRC in supporting the ongoing design, construction and monitoring of the LPHPP. Recommendations for measures and monitoring have been made with this in mind.
- Because the documentation provided is at a feasibility level, measures have been proposed for the Final Design, Construction and Operational phases should the project proceed.
- Greater emphasis has been placed on building an understanding of the mandates conferred by the MRC Member States.
- The recognition for a central authority to assume responsibility for the joint operation of the cascade to minimise transboundary impacts; and
- The need for appropriate studies by the GoL and the MRC to identify cascade operations with the greatest cost-benefit.
- Joint operations on the cascade, and the need for the Government of the Lao PDR and / or the MRC to initiate studies in this regard has received more attention.

¹¹ The PMFM are not directly relevant to the LPHPP.

2. THE LUANG PRABANG PRIOR CONSULTATION PROCESS

2.1. Background

The Mekong River Commission (MRC) Secretariat received notification from the National Mekong Committee of the Lao PDR submitting the Luang Prabang Hydropower Project (LPHPP) for prior consultation, on 31 July 2019. The Secretariat then started preparations for the prior consultation process, through *inter alia* the mobilisation of resources to undertake the process, and the preparation of the Internal Scoping Assessment Report.

The JC, under Article 5.3.3 [c] of the PNPCA, has established a Joint Committee Working Group (JCWG) to support the prior consultation process. Under guidance from the JCWG, and as provided for in the PNPCA, the MRC Secretariat appointed several expert groups, made up of Secretariat, national and international experts, to provide independent specialist evaluations of any potential impacts associated with the LPHPP. In addition, national experts have also been engaged to support the Member States in reviewing the submitted documents and the drafts of the TRR and to help facilitate national meetings. The Secretariat, international and national expert teams are outlined in Annex A2.

The documentation provided by the LNMC was sent to the MRC Member States on 03 September 2019 after an initial review for completeness by the MRCS. The prior consultation process for the LPHPP was tabled at the 49th regular JC meeting on 4 and 5 September 2019, and the draft roadmap for the process was presented. The first meeting of the JCWG for prior consultation on the LPHPP was scheduled on 8 October 2019. The Secretariat prepared the draft Internal Scoping Assessment Report, outlining the proposed scope for the Technical Review Report, and providing an initial assessment of the documentation provided.

The JCWG approved the draft Internal Scoping Report with some changes focused on outlining the key areas that must be addressed in the Technical Review Report. The JCWG also agreed that the meeting marked the official start date for the prior consultation process. The initial 6-month process will therefore end with a special session of the MRC Joint Committee on 8 April 2020. It is anticipated that the JC will, at that meeting, either issue a Statement making recommendations for the ongoing design, construction and operations of the LPHPP, or may propose an extension of the prior consultation period, under Clause 5.5.2 of the PNPCA. This may be contemplated if the Secretariat has faced special difficulty with the detailed review of the documentation, or to provide time to review additional documentation that has been submitted late during the 6-month process. If this is contemplated, an extension would only be for a short period to allow for the review of new information and to include it in the TRR.

It is intended that the Statement will be supported by a Joint Action Plan (JAP) that provides for ongoing engagements between the MRC specialists, the Lao PDR and the developer. This will aim at further improving the design and operating rules throughout the final design, construction and initial operational phases. This process will also draw on the results of the Joint Environmental Monitoring (JEM) at Xayaburi to recommend adjustments to the design. Any final operating rules agreed and implemented by the developer at the end of the JAP process will be taken up in the Procedures for Water Use Monitoring (PWUM), and their implementation will be regularly reported to the MRC Joint Committee.

The detailed roadmap for the prior consultation process is presented in Table 2-1 and summarised in Annex A1.

Table 2 - 1 The detailed roadmap for the Luang Prabang prior consultation process.

4th - 5th September 2019: 49th Meeting of the MRC Joint Committee ○ <i>Inform and update on the Luang Prabang submission for PC</i> ○ <i>Seek discussion, approval or guidance on the road map of the Luang Prabang PC process</i>
8th October 2019: 1st PNPCA JCWG Meeting on Luang Prabang PC, and official start date ○ <i>Presentation of the Luang Prabang Project Overview and draft Scoping Assessment Report (a proposal for undertaking the Luang Prabang PC Technical Review Report)</i> ○ <i>Discussion and agreement on the implementation approach and process including draft Roadmap for the Luang Prabang PC Process¹²</i> ○ <i>Discussion and agreement on the proposed approach for Regional Stakeholder and National Information Sharing/Consultation Meetings, and information disclosure</i> ○ <i>Discussion on the arrangements and contents for the 1st Regional Stakeholder Information Sharing/Consultation Meeting</i> ○ <i>Discussion on arrangements for 2nd PNPCA JCWG Meeting – 3rd December 2019 including field visit to the project site – on 4th December 2019 (to be facilitated by the Lao PDR and developer)</i>
09th – 22nd October 2019: 1st Round of National Information Sharing/Consultation Meetings (in accordance with national regulations and requirements) The contents, approach, details and participants needed to adapt the previous experiences and to be in line with the agreement reached in the 1st PNPCA JCWG Meeting: ○ <i>Present the PC Process and Lessons Learned from previous PCs</i> ○ <i>Present the Project Overview and Scoping Assessment Report – Assessment Approach to be implemented</i> ○ <i>Present the Luang Prabang Implementation Approach and Roadmap</i> ○ <i>Get stakeholders' concerns and issues</i>
6th November 2019 - 1st Regional Information Sharing/Consultation Meeting on Luang Prabang Prior Consultation (cum 8th MRC-RSF: BDS, JAP for PBHPP and PLHPP, and other issues to be identified on 5th November 2019) - 1st RSF for Luang Prabang, the contents, approach, details and participants need to be in line with the agreement reached in the 1st PNPCA JCWG meeting. The agenda items should include: ○ <i>Present the PC Process and Lessons Learned from previous PCs</i> ○ <i>Present the Project Overview and Scoping Assessment Report – Assessment Approach to be implemented</i> ○ <i>Present the Luang Prabang Implementation Approach and Roadmap</i> ○ <i>Get stakeholders concerns and issues</i>
3th – 4th December 2019: 2nd PNPCA JCWG Meeting on LPHPP PC Process (including site visit) ○ <i>Travel to Luang Prabang – 2nd December 2019</i> ○ <i>2nd PNPCA JCWG Meeting – 3rd December 2019</i> ○ <i>Visit to the dam site and technical meeting between MRCS Experts and Developer – 4th December 2019</i> ○ <i>Presentation and discussion of the 1st Draft Technical Review Report (TRR) of the LPHPP PNPCA PC process</i> ○ <i>Presentation and discussion of national review findings, outcomes of the 1st Round of National Information Sharing/Consultation Meeting</i> ○ <i>Discussion and feedback on 1st Regional Stakeholder Information Sharing/Consultation Meeting</i> ○ <i>Discussion on the organisation of the 2nd Regional Stakeholder Information Sharing/Consultation Meeting and the 3rd PNPCA JCWG Meeting</i>

26th Meeting of the MRC Council ○ Inform and update the JC and Council on the progress of the LPHPP PC process and seek guidance where needed.
18th December 2019: 2nd draft of the Technical Review Report completed and sent to MCs
3rd – 17th January 2020: 2nd Round of National Information Sharing/Consultation Meetings (in accordance with national regulations and requirements) ○ <i>Discuss and comments on the findings of the revised draft Technical Review Report</i> ○ <i>Discuss the inputs from the National Stakeholders</i>
6th February 2020: 2nd Regional Stakeholder Information Sharing/Consultation Meeting on Luang Prabang Prior Consultation Contents, details and participants need to be in line with the agreement reached in the 2nd PNPCA JCWG meeting: ○ <i>Discuss and comment on the findings of the revised draft Technical Review Report</i> ○ <i>Get concerns and issues</i>
24th February 2020: Final draft of technical review report, summary of the TRR and draft Statement for LPHPP PC process completed and sent to MCs
5th March 2020: 3rd PNPCA JCWG Meeting on LPHPP PC Process ○ <i>Presentation on the Final Draft of the Technical Review Report for LPHPP PNPCA PC process</i> ○ <i>Discussion of the draft Statement</i> ○ <i>Discussion of the preparation for the MRC-JC Special Session</i>
21st March 2020: Final Technical Review Report for LPHPP PNPCA PC process completed and sent to MCs
2nd April 2020: Reply Forms submitted by the notified countries (official Reply Form filled as Annex II(B) of the PNPCA)
30 June 2020¹³: Special Session of the MRC Joint Committee (conclusion of the LPHPP PC process or agreement on possible extension) ○ <i>Reply Forms from Notified Countries</i> ○ <i>Discussion and decision on the submitted Final Report of the LPHPP PNPCA Technical Review Report</i> ○ <i>Discussion and Agreement on Statement (including a set of measures to avoid, minimize and mitigate the potential adverse transboundary impacts, and options for transboundary mitigation or benefit sharing outlined)</i>

2.2. The drafting process for the Technical Review Report

This Technical Review Report (TRR) has been based on the template used for the Pak Beng and Pak Lay processes. However, recognising the need to continually improve the process, and particularly address external stakeholders' perceptions, the content of the first Chapter has been further expanded to provide a better explanation of the prior consultation context and framework provided by the 1995 Mekong Agreement and Procedures.

Chapter 4 - 'The Technical Review' the TRR was prepared by summarising the key findings of the individual expert team reports and to highlight the recommendations for additional

¹³ The original date in the roadmap was 07 April 2020. However, due to the COVID pandemic and more time required for deliberation, the date was shifted to 30 June 2020.

measures to be considered in the post prior consultation process. The full reports from the expert teams have been included in an unabridged form as Annexes C to I. The other Chapters of the TRR were prepared by the Planning Division of the Secretariat and include inputs from the expert teams, as well as the MRCS management team.

All the drafts of both the TRR and the reports from the expert teams have been internally reviewed by the MRCS to check for consistency and were signed off by the CEO before submission. Table 2-2 outlines the version control system applied to the various drafts of the TRR.

Table 2 - 2 The version control system applied to the drafts of the TRR. The current version is outlined in bold.

Report	Ver.	Date	Comment
Scoping Assessment Report for Prior Consultation for the PLHPP	V 0.1	25 Sep 2019	Submitted to the 1 st JCWG meeting of 8 October 2019, outlining the scope of the TRR
	V 1.0	16 Oct 2019	Final Scoping Assessment Report taking the feedback from the JCWG into account
Drafts of the Technical Review Report	V 1.0	18 Nov 2019	This report: First draft submitted to the 2 nd JCWG meeting of 3 December 2019
	V 2.1	18 Dec 2019	2 nd draft of the TRR: Includes comments from the 2 nd meeting of the JCWG and the site visit.
Final Technical Review Report	V 3.0	24 Feb 2020	3 rd draft of the TRR submitted to the 3 rd meeting of the JCWG on 5 March 2020. Includes stakeholder feedback, and Draft Statement
	V 3.1	23 Mar 2020	Draft Final TRR submitted to the Joint Committee Special Session on 8 th April 2020
			Draft Final TRR for publication on the website.
	V 3.2	10 Apr 2020	Includes information from the notified States Reply Forms as well as any possible commentary from the Notifying State, and comments from the JC SS.
	V 4	10 July 2020	Final, Published on the MRC Website

2.3. Documents used for the Review

2.3.1. Submitted documents

The Technical Review Report is based on the reports and their appendixes submitted by the Lao PDR, through the Lao National Mekong Committee (LNMC). The Technical Teams listed in Annex A2 have used all the documents listed in Table 2-3 in their reviews outlined in Chapter 4, with a focus on those parts directly relevant to their respective fields of expertise.

Table 2 - 3 A list of the documents submitted by the LNMC. These documents are available at: <http://www.mrcmekong.org/topics/pnpca-prior-consultation/luang-prabang-hydropower-project/>

No.	Submitted documents	No. pages
	Full Feasibility Study Report (includes the documents listed below)	2383 pages
Vol. 1	Executive Summary	68 pages
Vol. 2	Main Report	300 pages

No.	Submitted documents	No. pages
	1. Introduction 2. Location and Access 3. Hydropower Development Plan 4. Power Market Study 5. Topography 6. Hydrology 7. Geology 8. Social and Natural Environment 9. Alternative Study and Optimization 10. Energy Production 11. Project Concept and Operational Aspects 12. Hydraulic Design 13. Civil Design 14. Electro-Mechanical Equipment 15. Hydro-Mechanical Equipment 16. Transmission Line 17. Implementation Schedule and Construction Planning 18. Risk Analysis 19. Compliance with MRC Design Guidance 20. Conclusions and Recommendations	
Vol. 3	Drawings	84 pages
Vol. 4	Environment and Social Impact Assessment Reports:	686 pages
	Vol. 4.1: Environmental and Social Impact Assessment	247 pages
	Vol. 4.2: Social Impact Assessment	233 pages
	Vol. 4.3: Environmental Management and Monitoring Plan	206 pages
	Vol. 4.4: Social Management and Monitoring Plan	
	Vol. 4.5: Resettlement and Ethnic Minority Development Plan	
	Vol. 4.6: Executive summary of ESIA, CIA and TBIA ¹⁴	33 pages
Vol. 5	Cumulative and Transboundary Environmental Impact Assessment	115 pages
Vol. 6	Annexes:	1,097 pages
	Annex 6.1: Hydrology	46 pages
	Annex 6.2: Topography	87 pages
	Annex 6.3: Geology	580 pages
	Annex 6.4: PSHA	51 pages
	Annex 6.5: Hydraulic Model	24 pages
	Annex 6.6: ESIA	309

¹⁴ This volume was made submitted with the update version of all submitted documents on 18 October 2019.

2.3.2. Additional documents provided

Additional documents and the PowerPoint presentations made during the site visit were provided via the LNMC on 10 December 2019. These are:

- Design Criteria
- Geotechnical Analysis Report
- Structural Analysis Report
- Addendum to the FS
- Additional Appendices to the FS.

PowerPoint presentations for:

- Sediment management.
- Fish passage.
- Navigation, and
- Hydrology.

Additional documentation was provided on 25 February 2020 to be considered after the 3rd JCWG meeting. These were:

- Matrix of Response to Comments from 2nd draft TRR of LPHPP.
- Feasibility Study Project Area Aerial Map with Provision of 2nd Navigation Lock Layout.
- Hydrological data from 2015 – 2019.
- Xayaburi HPP Hydrological Monitoring and Forecasting System Stations.
- LPHPP Backwater Calculation Report: Velocities.
- LPHPP Baseline Fish Monitoring: from 1st Field Investigation Report to 4th Field Investigation Report.
- Appendix D: Supporting Information on Aquatic Ecology and Fisheries.
- Initial Observations on Xayaburi HPP Fish Pass Monitoring.

These additional documents were considered in the TRR, and where relevant additional comments have been provided. However, due to the limited time and resources available, these were not reviewed in detail.

2.3.3. *Other reference documents*

In addition to the 1995 Mekong Agreement and the MRC Procedures, other documents relevant to the prior consultation process include key reports developed by the MRC, addressing the development of the Lower Mekong, including mainstream hydropower dam projects, and guidelines for the sustainable development of hydropower. These include:

- IWRM-based Basin Development Strategy (BDS) 2016-2020 for the Lower Mekong Basin approved by the MRC Council in 2016.
- MRC Technical Review Reports of the last four prior consultation processes for Xayaburi, Don Sahong, Pak Beng and Pak Lay Hydropower Projects.
- MRCS Review of the Design Changes at the Xayaburi Hydropower Project
- MRC State of Basin Report 2019.
- MRC Council Study on the Sustainable Management and Development of the Mekong River, including Impacts of Mainstream Hydropower Projects.
- The MRC's Assessment of Basin-wide Development Scenarios (with Associated annexes) produced by the former BDP Programme in 2011.
- Review of the Assessments of Basin-wide Development Scenarios conducted by the former BDP Programme in 2015.
- The MRCS working document on Mekong Basin Development Trends and Future Outlook in the Lower Mekong Countries prepared by the former BDP Programme in December 2015.
- Various MRCS technical reports on thematic topics relevant to the review of the LPHPP (e.g. those from the former MRCS programmes including Fisheries Programme, Environment Programme, Initiative for Sustainable Hydropower, Climate Change and Adaptation Initiative, Information and Knowledge Management Programme).
- The Strategic Environmental Assessment (SEA) of Proposed Mainstream Hydropower Projects commissioned by the MRCS and published on 15 October 2010.
- Peer reviewed technical reports and data submitted by the Member States' line agencies, the developer and external stakeholders relevant to the review and consultation process; and
- Other guidance materials for aspects not fully covered in the PDG and which reflect international good practice are made. These include guidelines from PIANC 15 (Navigation Guidelines), ICOLD 16, World Bank Operational Policies, World Bank Environmental and Social Safeguards, and the US Army Corp of Engineers Guidelines. The Lao Electric Power Technical Standards (LEPTS 2018) are also referenced.

Each of the subject matter expert teams have included a list of the documents and reference materials they have used, and these are presented in their respective Annexes.

¹⁵ PIANC = World Association for Waterborne Transport Infrastructure.

¹⁶ ICOLD = International Committee on Large Dams

2.3.4. Use of the Preliminary Design Guidance (PDG) of 2009 and draft PDG 2019

The approved first draft of the PDG has been available since September 2009 and provides guidance to project developers and the MRC Member States for the development of mainstream dams (including hydropower schemes). The PDG includes performance targets, design and operating principles for mitigation measures, as well as compliance monitoring and adaptive management. Annex B outlines the extent to which the current feasibility level design aligns with the PDG 2009.

The Preliminary Design Guidance has now been updated into the draft PDG 2019. However, this has not yet been formally endorsed, and as agreed at the 1st PNPCA JCWG meeting on 8 October 2019, the TRR will cross check the documents submitted with the guidelines listed in the PDG2009 (Annex B). The updated version, nonetheless, reflects the current understanding of good practice for Mekong mainstream dams, and it was used to support the reviews outlined in Chapter 4, particularly with respect to the hydrology and socio-economic aspects which were not addressed in the PDG 2009.

The documents submitted for the LPHPP prior consultation process did, however, indicate that the draft PDG 2019 was used to confirm that the feasibility design of some aspects of the LPHPP aligned with current good practice.

2.4. The structure of the Technical Review Report

The remainder of the main body of the TRR is structured as follows:

- Chapter 3 summarizes the main structural and operational features of the LPHPP. This has been extracted from a more complete summary of the Luang Prabang HPP available at: http://www.mrcmekong.org/assets/Consultations/LuangPrabang-Hydropower-Project/Overview-of-key-features_LPB-Project.pdf.
- Chapter 4 summarises the recommendations and conclusions of each of the expert groups. It includes sections on Hydrology and Hydraulics, Sediment and Geomorphology, Water Quality and Aquatic Ecology, Fish Passage and Fisheries, Navigation, Dam Safety and Socio-economic aspects.
- Chapter 5 considers the cumulative and transboundary impacts in greater detail; and
- Chapter 6 provides some general comments and recommendations for the LPHPP and presents the way forward.

2.5. Use of the TRR

The TRR supports discussions between the Member States and provides the basis for the JC's deliberations. It aims to provide key information that is required to reach a decision under Article 5.4.3 of the PNPCA, or to support a possible extension of the PC process decided by the JC at its final session. The TRR aims to provide a balanced basis for good faith consultations and cooperation, as well as providing some indication of the nature and extent of any possible impacts, and the level of confidence in the findings. It is presented in the spirit of cooperation towards a LPHPP that better addresses the concerns of the notified States, but which recognises the constraints faced by the notifying State.

It is primarily aimed at supporting the JC's discussions around measures that may be considered in the further design, construction and operation of the LPHPP. Those measures considered to be critical to further limiting any transboundary impacts will be included in a concluding Statement and will be supported by the post prior consultation Joint Action Plan. However, it is also hoped that the TRR will support the Lao PDR in its oversight of the development and operation of the LPHPP.

The conclusions drawn, and the recommendations made reflect sound scientifically based opinion from the expert teams, and a long history of experience in the Mekong River Basin. Where alternative opinion has been provided by experts appointed by the Government of Lao PDR or the developer, these are also reflected. The aims of the TRR are therefore to:

- Guide the Government of the Lao PDR in their oversight of the final design, construction and operations of the LPHPP.
- Provide useful input to the developers ongoing efforts to address the PDG and to avoid, minimise and mitigate potential harmful effects; and
- Present the potential transboundary harmful effects, and measures recommended to address these in a fair and balanced manner.

3. THE PROPOSED LUANG PRABANG HYDROPOWER PROJECT¹⁷

Key features of the LPHPP

- ▶ Barrage type Run-of-River hydropower.
- ▶ 2nd HPP in the upper Lao Cascade from upstream to downstream.
- ▶ A powerhouse equipped with seven Kaplan turbine/generator sets with total installed capacity of 1,400 MW, and a maximum gross head of 36.80 m.
- ▶ Auxiliary units using water to create an attraction flow for the fish migration facilities (approx. 180 m³/s), providing a further 60 MW capacity.
- ▶ A spillway structure with six radial surface gates (19 m width x 25 m height, and a sill level 288.0 m).
- ▶ Three low level outlets (12m width x 16 m height, and a sill level 275.0m).
- ▶ A two-step Navigation lock system for 2x500 DWT vessels.
- ▶ A fish pass system for upstream and downstream migration with multiple entrances; and
- ▶ A 500-kV transmission line to Vietnam with an approximate length of 400 km to the Vietnamese border and 200 km to the next suitable substation. Alternatively, power could also be transmitted to Thailand through a power line with an approximate length of 250 to 300 km.

3.1. General description and location

The Luang Prabang hydropower project is the 2nd in the cascade of run-of-river projects on the Mekong mainstream in northern Lao PDR (Figure 3-1). It is located between the upstream Pak Beng project, and the downstream Xayaburi HPP. The Pak Lay HPP lies downstream of the XHPP. All of these have completed their prior consultation processes. The 5th HPP in the cascade, the Sanakham HPP has been notified, and will undergo prior consultation later in 2020. The filling of the Xayaburi HPP is complete and it is currently operational, while the Pak Beng HPP and Pak Lay HPP are in their final design stage.

The project site is located on the Mekong River around 2,036 kilometres from the Delta in the Province of Luang Prabang. It lies approximately 25 km upstream of Luang Prabang town, at the village Ban Houy Yor, and about 4 km upstream of confluence between the Nam Ou and the Mekong mainstream. The reservoir area is expected to cross the provinces of Oudomxay and Luang Prabang.

The Luang Prabang Power Company Limited (LPCL) has been established in the Lao PDR and will undertake the development of the LPHPP under a Memorandum of Understanding (MoU) between the Government of the Lao PDR and PetroVietnam Power Corporation, which was concluded in October 2007. The developer's consultant is Pöyry, who also supported the design of the Xayaburi HPP.

¹⁷ The 3D design drawings used in this Chapter and elsewhere in this TRR have been provided by Pöyry.

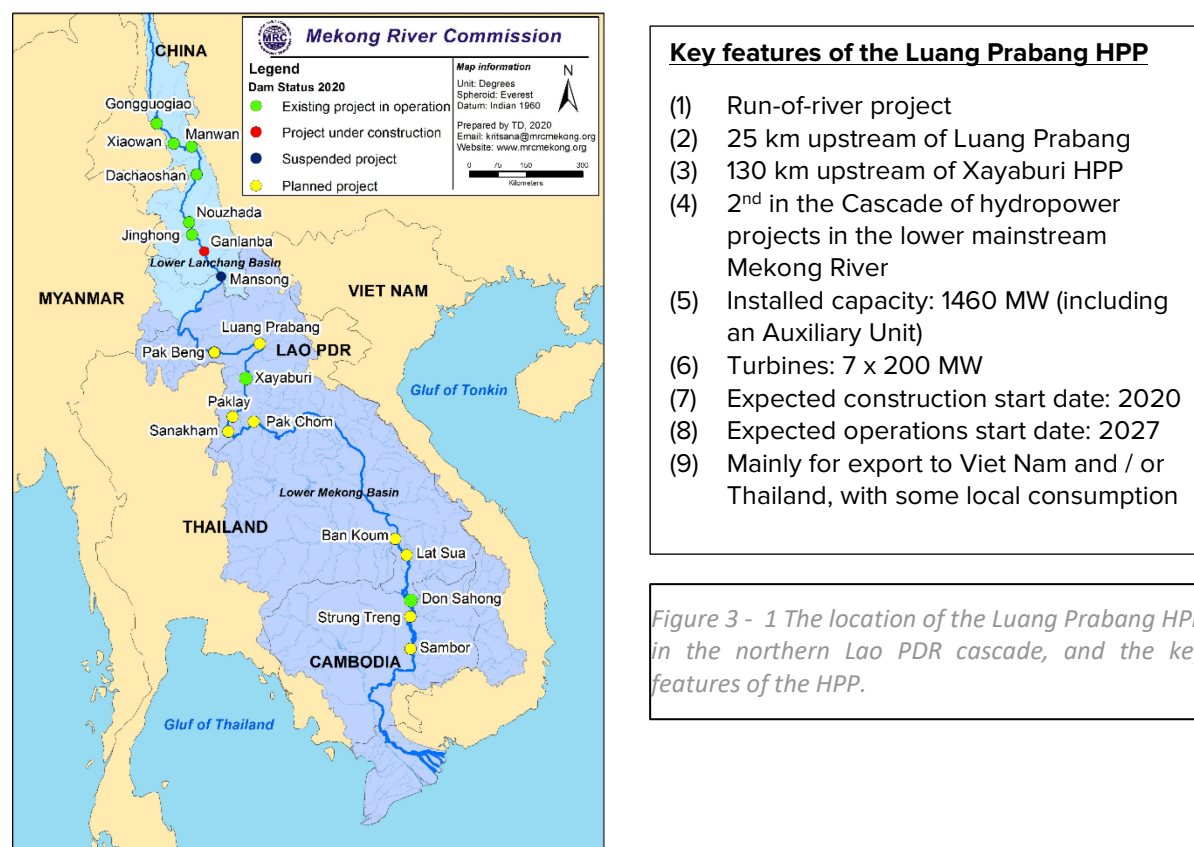
3.2. LPHPP feasibility level design

3.2.1. Engineering structures and construction schedule¹⁸

The Luang Prabang HPP is a barrage type hydroelectric run-of-river scheme. The feasibility level design comprises (see Figure 3-2):

- A powerhouse equipped with seven Kaplan turbine/generator sets with total installed capacity of 1,400 MW, and the maximum gross head is 36.80 m.
- Three Auxiliary Kaplan turbines using water from the fish attraction flows for the upstream and downstream migration facilities (approx. 180 m³/s), totaling to 60 MW capacity.
- A spillway structure with six radial surface gates with the dimension of 19 m x 25 m
- Three low level outlets (LLO).
- Two-step Navigation lock system for 2x500 DWT vessels.
- Fish pass system for upstream and downstream migration.
- 500 kV transmission line to Vietnam with an approximate length of 400 km to the Vietnamese border and 200 km to the next suitable substation, and / or to Thailand with an approximate length 250 to 300 km.

The main structures of the Luang Prabang HPP are made up of the navigation locks, spillway,



powerhouse (including right and left pier), and the closing structure (Figure 3-2). The Luang

¹⁸ The design drawings included in this section are from Pöyry and are gratefully acknowledged.

Prabang HPP is planned to be constructed from the right riverbank (looking downstream). Stage 1 will include a right bank coffer dam designed to withstand a 1:100-year flood and will start from the navigation locks, followed by the spillway which is located between the navigation locks and the Powerhouse, which will be constructed last in Stage 1. During this time the flows will be diverted through a constricted left bank channel of the mainstream where the closing structure will lie. Stage 2 will include the construction of the closing structure, and then flows will be diverted through the Stage 1 infrastructure.

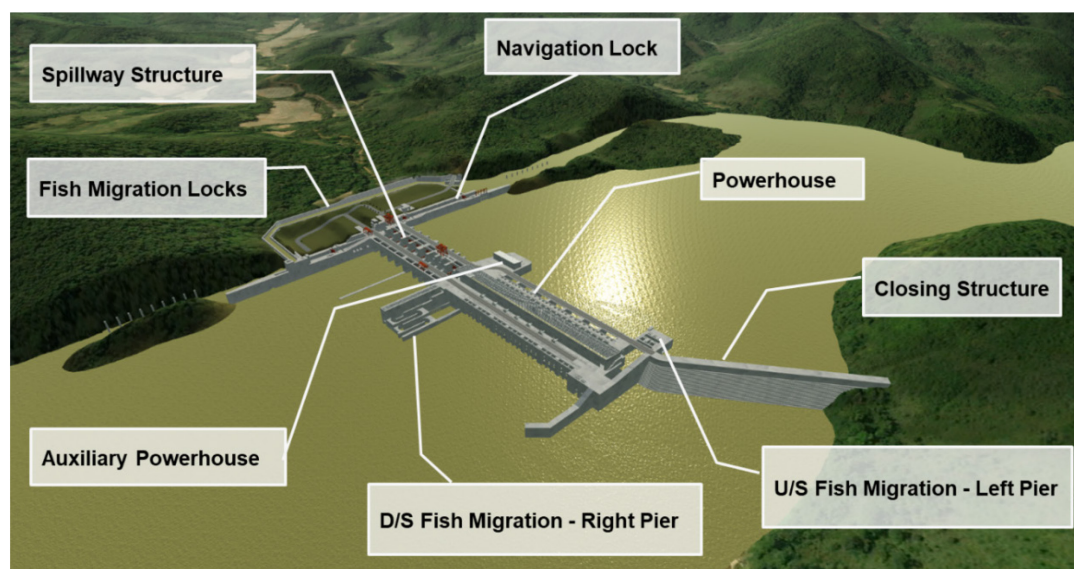


Figure 3- 2 The main structural features of the LPHPP. River flow is from right to left in the figure (modified from a presentation by Pöyry to the MRC – October 2019)

The dam crest elevation is 317 metres above sea-level (m asl), the maximum dam height is about 79 m over the deepest foundation. Three fishpass facilities provide for upstream and downstream migration with multiple entrances. These are located along the powerhouse, in the left pier, right pier and a fish lock alongside the navigation locks (Figure 3-2).

3.2.2. Alternative dam sites

Two possible dam sites were considered (Figure 3-3). Alternative 1 is 1.5 km upstream of Alternative 2, and requires extensive excavation of the right bank, as well as the creation of a navigation channel. Alternative 2 would take longer to construct and would require temporary fish pass facilities. Alternative 2 also entailed greater risks during construction.

These alternatives were evaluated based on:

- Construction costs.
- Construction time.
- Energy generation; and
- Logistics.

Ultimately, Alternative 1 was selected despite its lower generation capacity. This Alternative is described in the Feasibility Study (FS) documentation provided and has been evaluated in this TRR.

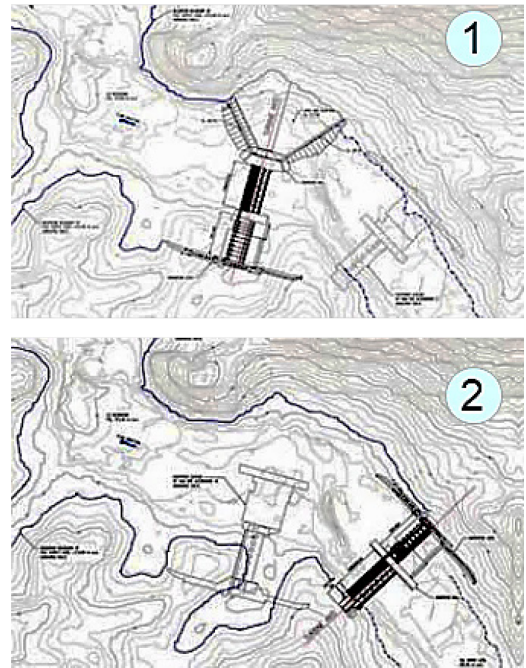


Figure 3-3 The Alternative sites considered for the LPHPP.

3.2.3. Navigation Lock

The navigation lock will be sited in the excavated area on the right bank. It is designed to be operated up to a 1:30 year flood and for 95% of the time under natural conditions. It is a two-step system, as is required under the PDG2009, designed for 2x500 DWT vessels. There are three miter gates, an upstream, middle and downstream gate. Computational fluid dynamics (CFD) modelling of the water conduit system was carried out to assess the hydraulic performance of the water feeding system. The filling of the chambers of the locks is done via a gravity-based feeding system from the headwater of the plant controlled by bonneted gates. The lockage time for a two-step ship lock is expected to be shorter than 50 minutes. The Navigation Lock is designed to be used as additional fish passage during migration periods when it is in normal operation.



Figure 3-4 The two-step navigation lock system.

3.2.4. Spillway

The spillway structure comprises six surface spillway bays and three low level outlet (LLO) bays which are arranged in two main blocks. The first block comprises the three low level outlet bays, with surface spillway bays on each side. The second block includes the remaining four surface spillway bays. This allows for a deeper foundation level for the LLO (although higher than the turbine inlets) and a stilling basin which is divided by a concrete wall. The dimensions of the surface spillways are 19 m wide and 25 m high with a sill level of 288 m asl. These have a capacity to discharge 4,850 m³/s at the Full Supply Level (FSL). The



Figure 3-5 The spillway structures including the surface and Low-Level Outlets. View is from upstream

LLOs are 12 m wide and 16 m high, with a sill level of 275 m asl and have a design discharge of 3,530 m³/s at FSL.

3.2.5. Powerhouse

The Powerhouse is integrated into the barrage and is in the centre of Mekong river. The powerhouse must withstand the full upstream water pressure and is designed as a gravity dam. The powerhouse is equipped with seven vertical Kaplan units (main units), the auxiliaries and an erection bay at each end of the powerhouse. These are integrated with the upstream and downstream fish migration systems in the powerhouse structure, intake channel and tailrace channel. The total length of the powerhouse is 275 m, 97 m wide and 80 m high. The total length of the machine hall is 195.2 m and the total length of erection bays is 130 m (80 m and 50 m on each side). The unit spacing between turbine axes is 32 m and the deepest foundation level (drainage sump) is at 237.5 m asl.

3.2.6. Closing structure

The left bank closing structure will be constructed to close the original main river channel at the left bank. It is designed as a Roller Compacted Concrete (RCC) gravity dam, with a maximum height of 53 m above foundation level and an overall length of 281.23 m. The elevation of the dam crest is 317 m asl and the foundation level is at 264 m asl. The width of the crest is 12 m.

3.3. Water and flood releases

3.3.1. Infrastructure

The overflow and the sediment-flushing sections are composed of six high-level surface bays or surface spillways, three low-level outlets, and the powerhouse/turbines. During flood operations the excess water (that is not used for generation of electricity and/or operation of the Navigation Lock and Fish Migration Facilities) will be discharged through the spillway. The three low level outlets are the primary spillway devices that will be the first bays in operation. During flood events the floods) will be routed through the powerhouse/turbines and the low-level outlets. The low-level outlets will minimize sedimentation in the area immediately upstream of the dam structures.

When the capacity of the low-level outlets is reached the surface spillway will start operation. All gates of the surface spillway will be equipped with flap gates to allow the spilling of floating debris in front of the spillway into the tailwater area.

3.3.2. Operations

The Full Supply Level for the LPHPP presented in the Feasibility Study varies between 312.0 and 312.5 m. The range of operating level is required for operational reasons, and no hydropeaking is proposed. This has been raised from the initial 310.0 m proposed by the Government of Lao PDR and allows for a greater power output. The developer at the Pak Beng HPP has raised an objection to this, remarking that this will push the LPHPP backwaters up to the foot of their structure and will reduce the power output at the PBHPP, thus affecting their profitability.

The PBHPP developer has also noted that they have already accommodated a lower operating level to limit inundation of the Keng Pha Dai reef as was recommended in the PBHPP TRR. The Lao delegation to the 2nd JCWG meeting noted that they are aware of this, and that the choice

was made based on the increased total power output. They also indicated that compensation mechanisms between the LPHPP and PBHPP operators were receiving attention.

The operational rules based on inflows are outlined in the fisheries section of the Feasibility Study as follows:

- Up to 5,355 m³/s, all the flow water passes through the turbines, this will be for about 80% of the time.
- Between inflows 5,355 m³/s and 10,650 m³/s both the spillway (low level outlets and surface gates) and powerhouse are operational. This will occur for some 20% of the time, most likely on an annual basis as follows.

The LLO are opened first, and this will occur between July and October of most years. These LLO have a capacity of 3,530 m³/s.

The surface spillways will come into operation at inflows of some 8,885 m³/s ¹⁹, when the LLO reach their capacity. That will occur for less than 5% of the time, and most likely not every year.

- The turbines are shut down when they reach their minimum required head, which is expected to be around 20,000 m³/s. At flows above this all the flow is passed through the spillways and LLO. During very high flows, the water level in the impoundment may be similar to the 'natural' flow level, with little or no level difference upstream and downstream of the dam. When this occurs, with all gates open, sediment that remained in suspension over the length of the impoundment would be routed through the dam.

¹⁹ Determined from the sum of the turbine and LLO capacities.

3.4. Fish Mitigation Facilities

The Luang Prabang HPP is designed with several fish migration facilities / opportunities, with a similar functionality to the system developed for the Xayaburi HPP (Figure 3-6).

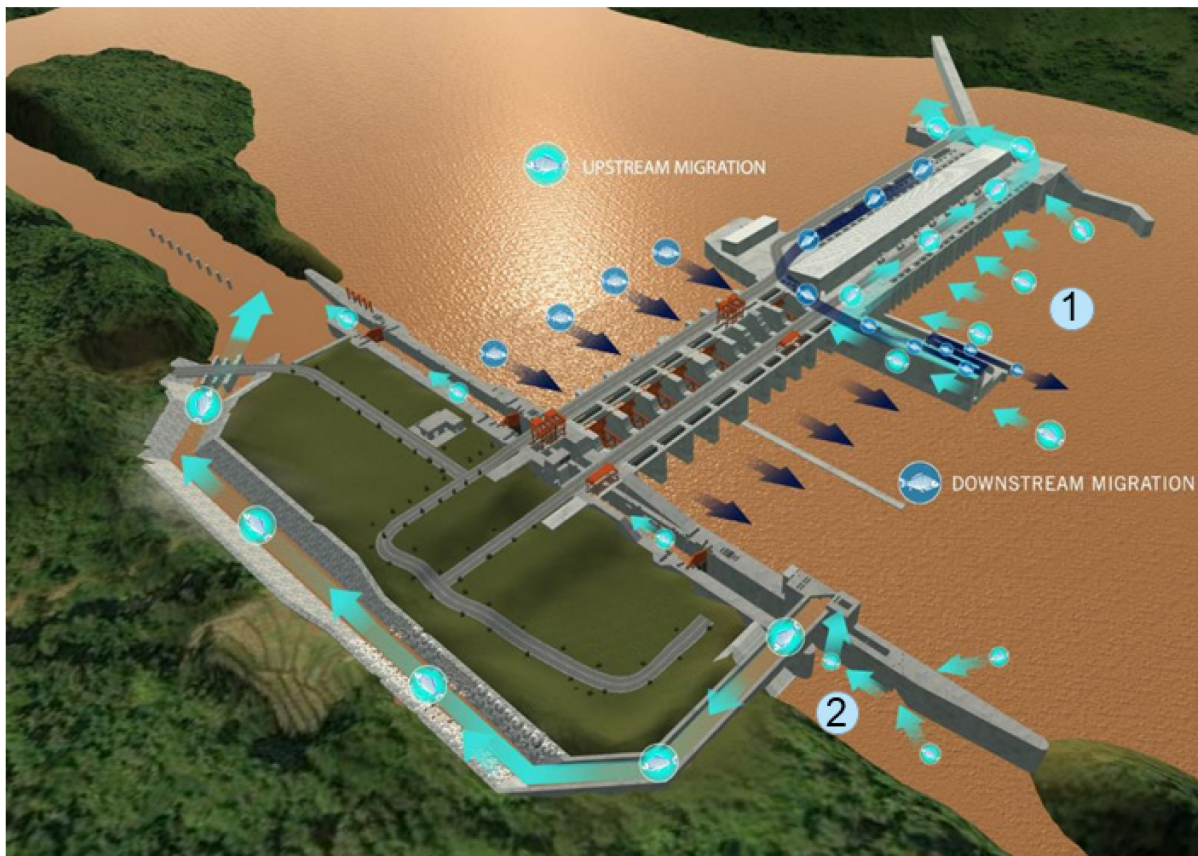


Figure 3-6 Fish migration facilities provided in the Feasibility level design for the LPHPP. 1= Left bank facilities, 2= Right bank facilities. Downstream migration is indicated by dark blue arrows, and upstream migration by light blue arrows.

3.4.1. Upstream migration

1 ON THE LEFT BANK

Fish locks are located at the powerhouse. Fish will be attracted by the powerhouse discharge and will enter into the upstream fish passing facilities over the entire length of the powerhouse, with entrances at the right pier (at the spillway), multiple entrances along the downstream face of the powerhouse, and at the left pier. The fish in the collection galleries are guided by attraction currents to two parallel fish locks, including a fish crowder and movable screen floor, whereby the fish are lifted into the reservoir. A feeding pond and feeding system, with feeders along the collecting gallery and at the back of the fish locks, has been included. However, the exact specifications for this system will be decided at the later stage.

2 ON THE RIGHT BANK

For fishes migrating along the right riverbank, upstream migration facilities will be provided near the navigation lock. This will comprise a fish lock downstream of the stilling basin next to the navigation lock, a culvert crossing the downstream approach channel, providing enough clearance for the moving ships and vessels at the downstream approach channel, and an open channel leading to the upstream approach channel. The fish entering the fish lock will be lifted

to the headwater level and will be released into the upstream culvert and channel leading to the upstream approach channel of the navigation lock.

3.4.2. Downstream fish migration

Downstream fish migration is possible through the powerhouse. A collecting gallery will be installed above the powerhouse intakes and a downstream stepped chute (exit chute) to the tailrace channel will enable downstream migration. Downstream migration is also possible through the turbines, which have been designed to minimise lethal injuries for the smaller fish that will pass through the trash rack of the powerhouse intakes. Fish migration is also possible through the spillway and navigation facilities when these are in operation.

3.5. Dam safety

The Luang Prabang HPP barrage and impoundment area are classified as a storage project in the Lao Electric Power Technical Standards 2018 (LEPTS 2018). Article 17 of these Standards defines the rules for selecting the Inflow Design Flood based on storage capacity, dam height, population at risk and economic damage. This procedure yields a Risk Factor of 38 and consequently classifies Luang Prabang as an “Extreme Risk” project. This requires higher dam safety standards. In documents submitted the structures have been designed to the same standards as those applied at the Xayaburi HPP (as is required by the PDG 2009). However, the developer has indicated that the final design will conform to the design standards required by the Lao PDR.

3.5.1. Flood design standards

The spillway design provides for the safe passage of the design floods (10,000-year flood = 33,500m³/s) with (n-1²⁰) criterion and Safety Check Flood (Probable Maximum Flood [PMF] = 41,400 m³/s) with all the gates in operation. These are the same criteria proposed for the Xayaburi HPP and recommended for the rest of the upper Lao cascade in line with the PDG 2009. However, the LEPTS 2018 propose a more stringent standard, and as above the developer and the Government of the Lao PDR have confirmed that the more stringent standards will be applied.

The spillway capacity for the Luang Prabang has been assessed based on the physical hydraulic model test. Based on the rating curves for the Luang Prabang spillway, the resulting upstream water levels are 314.20 m asl for the PMF and 313.60 m asl for the 10,000-year design flood, with one surface spillway gate not in operation.

3.5.2. Seismic design standards

All the dam and safety-relevant elements have been designed for the worst earthquake ground motion to be expected at the dam site, called Safety Evaluation Earthquake (SEE) ground motion. The SEE ground motion parameters are determined probabilistically considering a return period of 10,000 years, based on all available earthquake catalogues and seismotectonic data (faults in greater project region).

A detailed safety monitoring system is proposed for the LPHPP for the construction, reservoir impounding and long-term operational periods. This consists of sensors and instruments to

²⁰ One of the spillway gates not in operation

monitor; 1) Displacement, movement and settlement, 2) Water level, water pressure, 3) Leakage/seepage, 4) Climate and 5) Dynamic response (Seismicity).

3.6. Power generation and sales

The Feasibility Study includes a power market survey, covering all four MRC Member States. However, it does not appear that Power Purchase Agreements (PPA) have been concluded. The LPHPP can potentially provide power to Viet Nam via a 500-kV transmission line of approximately 400 km to the Vietnamese border, and 200 km to the next suitable substation. Alternatively, or potentially in addition, power can be provided to Thailand through a transmission line of some 250 to 300 km or can feed into the Lao power grid.

The energy output model for the LPHPP is based on 67 years of daily inflow for the years 1951 to 2017, after taking the Lancang Cascade into account (see the Hydrology and Hydraulics section for more detail). Based on these inflows, the average (sellable) output is 6,424 GWh/year, with a maximum and minimum output of 7,258 GWh/a and 5,465 GWh/a respectively.

No information on the financial viability, or financial breakeven points, of the LPHPP has been provided.

3.7. Conclusions

This Chapter has provided an overview of the main features of the design and operation of the LPHPP gleaned from the documents submitted by the LNMC, as well as presentations by Pöyry (the Developer). This has also been a summary of the features relevant to the TRR extracted from the separate more detailed overview of the LPHPP and the submitted documents prepared by the MRCS.

The features of the project detailed above largely dictate the impacts of the LPHPP, and the opportunities for introducing measures to avoid, minimise and mitigate these impacts. The following Chapter presents the MRCS review of these features.

4. TECHNICAL REVIEW

4.1. Introduction

Under direction from the JCWG, the MRC Secretariat established six Expert Groups to support the expert review process:

- Hydrology Expert Group (HEG).
- Sediment Expert Group (SEG).
- Fisheries and Environment Expert Group (FEEG).
- Dam Safety Expert Group (DSEG).
- Navigation Expert Group (NEG); and
- Socio-economic Expert Group (SOEG).

These Expert Groups are comprised of internationally recognised experts working together with experts from the relevant Divisions in the MRCS, as well as national experts from each of the Member States (Annex A2). The Planning Division of the MRC Secretariat has coordinated the development of this final TRR and has guided the prior consultation process. The reports prepared by each expert group are appended in original form in Annexes C to I and are considered as part of the Technical Review Report for the purposes of the Joint Committee's deliberations.

The summary of the reviews in each Annex is presented in this Chapter and draws out the key elements of the expert group's reports and conclusions that are considered directly relevant to discussions in the Joint Committee, and the formulation of a set of measures to be considered in any Statement. The summaries assess the extent to which the design and operation of the LPHPP will avoid, minimise and mitigate potential harmful effects, as well as the extent to which it aligns with the PDG2009. For the purposes of this TRR²¹:

- *Avoid* means the measure, if implemented, would ensure that any harmful effects will be negligible.
- *Minimise* means the measure, if implemented, would reduce harmful effects, or the risk of harmful effects, considerably; and
- *Mitigate* means the measure, if implemented, would reduce the impact of any residual harmful effects on other users of the Mekong River System, including those in the other Member States. These may include Corporate Social Responsibility measures, the promotion of alternative livelihoods strategies or direct compensation measures.

²¹ Infrastructure development projects often refer to avoid, mitigate and "compensate". Avoid, minimise and mitigate are used here to align with Article 7 of the 1995 Mekong Agreement. The Annexes may refer to avoid, minimise and mitigate collectively as mitigation measures.

4.2. Layout of the review for each discipline

The layout of each thematic review of the documentation submitted by the LNMC has been guided by Clause 22 of the draft PDG 2019. While the structure of sub-sections is adjusted to suit specific needs, the content of each has been guided by the following information needs (modified from Clause 22 of the PDG of 2019 for the purposes of the TRR):

- Objectives: This states the objectives of, and need for, the reviews and guidance for each discipline.
- Pre-Project Monitoring and Analyses: This provides comment on the data and analyses that were used to establish the baseline condition before construction starts. The impacts of the project will be assessed against this baseline, and so the monitoring should be sufficiently robust to isolate the impacts due just to the LPHPP. These are provided to support the Government of the Lao PDR's ongoing oversight of the developer.
- Design and Operational Recommendations: This outlines any recommendations for design and operational measures that could be considered to avoid, minimise and /or mitigate any potential harmful effects. These will form the core of the Statement and will focus on measures to limit the risk of transboundary harmful effects.
- Project Monitoring and Adaptive Management: This advises on the monitoring that should be undertaken during construction and operations that will assess the efficacy of the measures, or whether operating rules could be adapted during operations. It is understood that a post prior consultation JAP will refine and finalise this monitoring, which will then be taken up into the PWUM.
- Alignment with the PDG 2009; and
- Considerations for the Joint Committee: This presents recommendations and conclusions that require the attention of the JC at this point in the review.

The transboundary and cumulative impacts are presented in Chapter 5 and are not presented separately for each subject area.

4.3. Hydrology and Hydraulics

Key features of the review of the hydrology and hydraulics:

- ▶ The documents submitted recognize the broad principles the MRC uses to characterize the hydrology and hydraulics of the Lower Mekong Basin.
- ▶ The hydrology and hydraulics of the proposed LPHPP do not pose significant direct risks. But their indirect impacts on ecology, sediment, water quality, navigation, economic returns and livelihoods need to be considered.
- ▶ There has been no long-term monitoring of water-level and discharge at the dam site. During the site visit (Dec 2019) the developer showed their recently installed hydrometric station near the dam site and has also indicated that 5 years of data from the Xayaburi flow monitoring programme was used. Additional flow data were presented after the 3rd JCWG meeting on 05 March 2020.
- ▶ The inflows have been calculated for the period 1960 – 1990 with and without the Lancang cascade. The impacts of the Pak Beng HPP and upstream tributary dams are assumed to be minimal. However, these may play a role in the dry season, and should be considered.
- ▶ There are uncertainties regarding the use of the tailwater rating curve due to both the backwater effects of the Xayaburi reservoir, and possible geomorphological changes in the immediate downstream area. These issues affect the likely power output and the tailwater levels for design purposes. This also has a bearing on the flowing water habitats in the immediate downstream reach. The developer has indicated that detailed modelling of this stretch of river has been done, and has provided a note outlining the flow velocities in this stretch, but no detailed documentation has been provided.
- ▶ The flood peaks determined for the LPHPP tend to higher than those for other studies in the upper Lao cascade and can be considered conservative and therefore on the safe side. However, the impacts of climate change and more frequent and intense rainfall events should be addressed. The developer has indicated that climate change was not considered as the climate change models are speculative and contradicting. Moreover, they indicate that the conservative approaches used would accommodate any changes in inflow due to climate change.
- ▶ It is critical to elaborate joint operating rules for the whole upper Lao cascade to optimise hydropower output, for sediment management operations, and for other environmental purposes. It is also relevant to ensure that the extra discharge is expected and can be handled by the downstream HPPs. However, this must be done but the GoL and / or the MRC.
- ▶ The LPHPP developers have applied increased operating levels over what was assumed for the design of the Pak Beng HPP. This will compromise the power output at the upstream PBHPP. The Lao PDR has indicated measures to address any losses at the PBHPP are being investigated.
- ▶ The design of the infrastructure is largely copied from the Xayaburi HPP.

4.3.1. Objectives and needs

The *hydrology and hydraulics* of the LPHPP will determine the most appropriate design for both the generation of power, and the viability of measures to avoid, minimise and mitigate any potential harmful effects. These aspects are therefore central to the review process. Here:

- “Hydrology” refers to the properties, distribution and circulation of water in the atmosphere and on land. It addresses the amount and timing of water (volume) that reaches the project from runoff processes, and that is transferred through the project.
- “Hydraulics” refers to the flow dynamics of water and its practical applications, and addresses water depths, velocities, turbulence, the transfer of flood waves, and other properties of flow in rivers and reservoirs.

The MRC recognises the risks and impacts associated with:

- Annual/inter-annual changes to flow regimes; and
- Daily/Short-time period changes in flow regimes.

Changes in these flow regimes in turn affect the water quality and aquatic ecosystems, sediment transport processes, fish migration, navigation and dam safety which are addressed in the following sections. The hydrological and hydraulic aspects of the review of the LPHPP are therefore addressed up front. The focus of this review is on the large-scale and transboundary impacts. However, specific details of the design that require more detailed explanation or motivation are also addressed.

The objectives of the draft PDG2019 for hydrology and hydraulics are to ensure that:

- i. Project developers have a detailed understanding of the hydrological resource availability and reliability, to inform project planning, design, construction and operations, accounting for present and potential future trends (such as climate change).
- ii. Mitigation measures and cascade or project operating rules dependent on hydrology and hydraulics are underpinned by sound hydrological and hydraulic assessments.
- iii. Mainstream developments are able to meet the objectives of the Procedures for Maintenance of Flows on the Mainstream (PMFM) and the Procedures for Water Use Monitoring (PWUM), which require that every effort is taken to manage and maintain a minimum flow and to minimise rapid changes in key river flow indicators to avoid harm to downstream users and the ecology.

4.3.2. Pre-project monitoring and analysis

HYDROLOGICAL DATA USED BY THE DEVELOPER

The main hydrological data and information used by the developers are:

- Historic inflows from the Mekong River from the Chiang Saen hydrometric station, and at the Luang Prabang hydrometric station, and stations in the Nam Ou and Nam Kham tributaries.
- Approximations of the impacts on discharge for the future dam development in the upstream reaches, only considering the Lancang cascade.
- MRC Annual flood reports.
- Other MRC publications.

- CNR (2009): Department of Electricity, Department of Energy Promotion and Development, Ministry of Energy and Mines - Lao PDR: Optimization study of Mekong Mainstream Hydropower Final Report; and
- Power Engineering Consulting JS Company 1 (2010): Luang Prabang Hydropower Project: Feasibility Study, Meteo-Hydrological Conditions

Table 4.1 outlines the sources of time-series data used by the developer, for both stations in main river and in some (downstream) tributaries.

Table 4-1 The time series data used by the developer for the hydrological analysis

Gauging station	River	Daily data	Hourly data ^a	15 min data
Luang Prabang	Mekong	05/60–10/18		
Chiang Saen	Mekong	05/60-10/18		
Ban Xiengkong	Mekong		05/16-12/19	
Ban Tonpheung	Mekong		04/16-12/19	04/16-11/16
Pakbeng Bridge	Mekong		09/16-12/19	
Soupanouvong	Mekong		07/16-12/19	
Xayaburi d/s	Mekong			04/16-11/16
Muang Ngoy	Nam Ou	01/88-12/17		08/15-11/16
Ban Hat Nga	Nam Ou			08/15-11/16
Ban Mixay	Nam Khan	01/88-12/17	08/15-12/19	08/15-11/16
Ban Sibounhom	Nam Suang	01/87-12/14	08/15-12/19	

^a Hourly discharge data for the respective stations has been shared with MRC after the 3rd JCWG meeting.

The Luang Prabang HPP is located between the hydrometric stations at Chiang Saen and Luang Prabang. Both these stations were therefore used for further analysis:

- Chiang Saen, Thailand: located about 327 km upstream of dam site. The station has data from May 1960.
- Luang Prabang, Lao PDR: located 25 km downstream of dam site, and downstream of several tributaries between the LPHPP site and the Luang Prabang gauge. Data available since 1950, a maximum flow 25,200 m³/s was recorded on 2 Sept 1966.

These data provide an acceptable length of time series and resolution in time, but there are no data from the upstream tributaries, and there is insufficient information on the QA/QC procedures to judge data quality. The discharge rating curves at key stations are derived from regression and extrapolation of actual measured discharges, and therefore subject to inaccuracies, particularly for flood conditions and as the rating curves are not updated every year. Missing data for water levels and discharges are generally estimated using appropriate hydrological methods such as hydrographic and climatic comparison methods; mathematical translation relationships; and flow routing methods as recommended by the World Meteorological Organization.

The rainfall data used to run the water-balance model has been obtained mainly from remote sensing sources and the manually recorded rainfall data from nearby sites has not been used.

These data are essential for the simulation of discharges at the dam, it is unclear why climate related ground-truth data have not been included.

DERIVED RECORDS FOR DISCHARGE AT THE DAM SITE

There has been no long-term monitoring of water levels and flow at the dam site and discharge records have been derived the data at Chiang Saen and Luang Prabang and a water balance model. Two approaches have been used:

- A water-balance model has been created to simulate the monthly average discharges based on time-dependent input for precipitation, temperature, evapotranspiration for the period 1951-2018, accounting for upstream dams in Lancang cascade.
- A frequency analysis for measured flood discharges at Chiang Saen and Luang Prabang has been extended to the dam site using a Creager approach.

The Creager scaling approach assumes that lateral flows from sub-catchments/tributaries are distributed evenly along the reach between Chiang Saen and Luang Prabang. However, as rainfall in this region is not evenly distributed this is considered an oversimplification for the determination of daily-average flow or flood peaks, which is critical for the determination of flood volumes for dam safety.

The documentation recognises the impacts of the operation of the large storage schemes at the Nuozhadu and Xiaowan hydroelectric stations in China. The monthly inflows have been calculated for the period 1960 – 1990 with and without the Lancang cascade. The impacts of the Pak Beng HPP and upstream tributary dams are ignored, as they are assumed to be minimal. The resulting monthly discharges have been compared with those in the MRC's BDP 2005. The results predict a higher increase of low flows than reported in the BDP (1.8 times increase compared to 1.4 times in the BDP) as shown in Figure 4-1. This reflects the different methodologies used to assess changes in the flow regimes in the two studies and illustrates the uncertainty around the future hydrology that should be accommodated in the design and financial viability assessments of the LPHPP. The results do not include the impacts of other tributary developments, such as hydropower development in the Nam Tha tributary and in Myanmar. More importantly, the operational rules for the Pak Beng HPP are not considered with respect to short term changes in flows²².

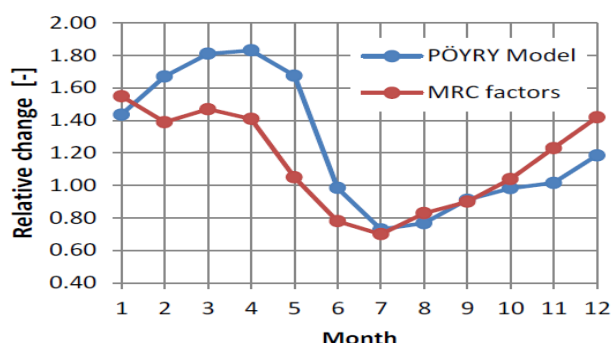


Figure 4-1 The change in monthly discharge reported in the BDP 2005, and using the water balance model.

The developer concludes that the impacts of the upstream hydropower operations on the Lancang Cascade far outweigh any seasonal changes due to climate change, but recognises that potential changes in runoff may occur due to climate change. Various MRC studies have shown that both hydropower development and climate change affect both dry and wet season flows.

²² The PBHPP operator has, at the request of the Government of the Lao PDR, lowered the operating level of their reservoir to prevent impacts on the Keng Pha Dai reef. The LPHPP developer should source any updated operating rules.

As the long-term inflows to the LPHPP determine its financial viability, environmental risks, and the design of measures to avoid, minimise and mitigate harmful effects, it is important that the hydrology is accurate even at the feasibility stage. It is recommended that the differences in the future hydrology forecasts are considered in the ongoing design process.

TAILWATER CALCULATIONS

The tailwater levels of the Luang Prabang dam will be determined by operation of the Xayaburi HPP. The tailwater rating curve is used to calculate the hydropower potential and is relevant for the design of the energy dissipation and scour protection works downstream of the water-release structures. It is also important for the ship lock and fish passage connections.

The tailwater rating curve has been obtained from a 1D numerical simulation with the FLORIS2000 modelling software. The developer has modelled a 27.5 km long section of the river, about 2.5 km upstream and about 25 km downstream of the dam to the Soupanouvong gauge. At the time of the feasibility study this model could only be poorly be calibrated because of a lack of data. However, the developer has indicated that a more detailed modelling effort has carried out with new bathymetric data and hydraulic records of a new hydrometric monitoring station at the dam site. In this respect:

- No details are provided on the validity of the rating curve of at the Soupanouvong gauge. The rating should be based on the period of operation of Xayaburi. This means that only data for the years 2018 and 2019 should be used.
- The rating curve for Soupanouvong is supported by data in the range of 269 to 289 m. The gauge is about 6 km upstream of the Luang Prabang gauge. For this reach the water levels at Soupanouvong are about 1 to 1.5 m higher than at the Luang Prabang gauge. This means that the Luang Prabang gauge could be used to correct for the backwater of Xayaburi dam (two-point method).
- The riverbed downstream of the dam site contains alluvial deposits that may change or disappear due to the changed sediment outflows from the LPHPP and the HPPs on the Nam Ou cascade. If sediment is eroded, the Xayaburi tailwater will become lower. If there is additional deposition the tailwater may become higher. This may affect the operations of the navigation locks and fish passage. It is therefore recommended that the sensitivity of the tailwater curve is evaluated under different scenarios.
- The developer has used hydraulic roughness values based on earlier work for the Xayaburi HPP. Without calibration, the accuracy and implications of this choice should be also be assessed by sensitivity runs. It is recommended that these uncertainties are also explored with respect to the potential impact of on the tailwater curve.
- In flood conditions, the inflow of the Nam Ou River can be substantial, and may affect flows in Mekong and the tributary flow. It is not clear how the FLORIS model deals with the lateral inflows as the Nam Ou has not been included in the model configuration.
- Under flood conditions (>2-year return period, above 15,000 m³/s) the water levels at the Xayaburi dam will be lowered to reduce flood levels at Luang Prabang. It is not clearly mentioned in the documentation or whether this has been included in the rating curves.

The developer has indicated that the tailwater rating curve has been remodelled using new bathymetry data. However, only the flow velocity data have been shared.

HYDROLOGICAL DATA FOR FLOOD FREQUENCY AND DESIGN FLOODS

The derivation of flood frequencies is essential for the design of the dam and spillways and must be based on forecasts of daily flows at the dam site during flood periods. These should be consistent with the design conditions used for the other dams in the cascade. Forecasting extreme flood conditions requires a long time series of historic flood discharges, corrected for the operation of the Lancang storage dams and the Lao tributary dams, and must include the high flows in 1966.

All annual-maximum flood peaks from historic records from 1960 to 2009 for Luang Prabang and to 2018 for Chiang Saen have been used for the Flood Frequency Analysis (FFA). The developer has assumed that the flood peaks are not affected by the Lancang cascade, as these peaks are likely to coincide with periods when the reservoirs are full, and the dominating storm events occur downstream of the cascade. However, there is no sound evidence that supports this assumption. Nonetheless, for the purpose of the extreme value analysis it seems acceptable as it seems to provide a conservative estimate of the flood peaks. However, it does not consider the possibility that flood operations of Chinese dams may lead to amplification of floods (e.g., release of extra discharge through spillways during the flood, to lower reservoir levels for flood prevention).

The software tool HQ-Ex by DHI-Wasy has been used for the FFA, which provides fits for several extreme-value distributions (7 commonly used distributions) and generates a final distribution as the mean of the results. Creager curves are used to transform the Chiang Saen and Luang Prabang flood values to those for the dam site.

An overview of the calculated flood flows is provided. However, there is no explanation given as to how the Creager factors are calculated and transferred to the flood values at the dam site. The columns with flood discharges at CS and LPG do not correspond to others used in the documentation, and do not show a consistent rise with return period. The table should be corrected if needed, and it should be explained in the text how these values are calculated from these intermediate values and factors.

The documentation presents the derivation of the Probable Maximum Flood (PMF). The developer defined the PMF (Probable Maximum Flood) using the Probable Maximum Precipitation (PMP) and applying it as input to the water balance model. The most important sources of severe rainfall with several days duration are typhoons and severe tropical low-pressure systems in the Lower Mekong region. Their frequency and intensity are independent of the strength of the SW Monsoon. They can, for example, affect the Basin even when the monsoon is weak. They can form in close succession and it is not uncommon for one such storm to be followed by another in just a matter of a few days.

The source of PMP storm data is a report by the US Corps of Engineers (1970), also presented in WMO (2009). This US-report was prepared for potential dam sites in Luang Prabang, Pakse and Kratie. The PMP is based on several severe storms before 1970 (Tilda, Violet, and Vae). This is appropriate for the determination of the PMF for the Mekong.

Table 4.2 presents peak discharges for different return periods from various studies, and at different locations upstream, at, and downstream of the Luang Prabang HPP.

Table 4-2 The discharges for different return periods produced by different bodies. (The references and acronyms are presented in Annex C)

Return (yr)	10,000	5,000	2,000	1,000	500	200	100	50	20	10	5	2
P (%)	0.01	0.02	0.05	0.1	0.2	0.5	1	2	5	10	20	50
ESTIMATES FOR LPHPP												
Q_Final	33500	32100		28800	27300	25300	23800	22200	20000	18200	16200	12800
AIT CNR	30000	28400	26400	24000		20500	19000	17500	15500	14000	12500	10000
ESTIMATES FOR CHIANG SAEN												
MRC 2009							20000	18000	16000	14500	13000	10000
PB PNPCA			29300	27500	25700	23300	21500	19600	17000	15000	12800	9490
PMFM 2011								21719	20964	13666	12567	10457
ESTIMATES FOR PBHPP												
PB PNPCA	33500	32100	30200	28500	26800	24600	22900	21100	18700	16700	14600	11300
AIT CNR	30000	28400	26400	24000		20500	19000	17500	15500	14000	12500	10000
ESTIMATES FOR LUANG PRABANG GAUGE												
PL PNPCA	37000	35500	33500	31900	30400	28200	26500	24800	22400	20400	18300	
PB PNPCA			31700	30300	28800	26900	25300	23700	21500	19700	17700	14400
MRC 2009							26400	24400	21800	19800	17700	14500
MRC 2006							23500	22000	20500	19500	17500	15000
ESTIMATES FOR THE XAYABURI HPP												
Xayab CNR	38500	36700	34200	32800		28300	26500	24500	21800	19800	17700	14500
Xayab (AIT)	45000			37100	34697		29146	26744	24076	22033	18480	

This shows that:

- The maximum peak floods are not consistent between all the studies, but for the purpose of the feasibility study they can be considered comparable (in the same range). Since the flood peaks for the LPHPP are in the higher part of the range, they can be considered conservative and therefore on the safe side.
- The differences can be partially explained by the different approaches. The MRC has based their flood frequency analyses mostly on the GEV method which should provide better results for the Mekong hydrology. The Chinese developers at Pak Beng and Pak Lay have applied the Log-Pearson Type III method according to the Chinese Design Codes.
- The studies have also used different time frames for the input data. It is important to include the extreme flood of 1966 in the time series used for the statistical analyses.
- There is a large difference between the flood peaks at Xayaburi and those from all the other feasibility studies; and
- There are references as to the shape of the design floods. A more in-depth analysis of the combined statistics of flood volume and flood peaks in the cascade will be beneficial for the design and operation of the LPHPP and it is recommended that the multi-variate approach from Adamson *et al*/(1999) and MRC (2005) is used.

4.3.3. Design and operational recommendations

RECOMMENDATIONS FOR THE HYDROLOGICAL FORECASTS

The following recommendations are made with respect to improving the hydrological forecasts of the inflows to the LPHPP:

- The monitoring of water level and discharge at the dam site has been recently initiated (as seen during the site visit). This should be used to validate the simulated data used in the feasibility study. For review purposes, the data collected at this site and the details of the monitoring methods/procedures and QA/QC should be shared with the MRC.;
- The QA/QC procedures applied to assess and correct inconsistencies in data sets should be presented.
- The manually recorded rainfall should be used to improve the precipitation input in the water-balance model and the simulations re-run if necessary; and
- The potential impacts of climate change on discharge at the dam site should be forecast for the full operating life of the LPHPP.

RECOMMENDATIONS FOR THE TAILWATER CALCULATIONS

The following recommendations are made in respect of improving the tailwater calculations:

- The rating curve at Soupanouvong and at the LPHPP site should be corrected for the impacts of operations at the Xayaburi HPP.
- The sensitivity of the tailwater levels to changes in the alluvial deposits and flows from the Nam Ou River into the Mekong should be shown; and
- The developer should recalibrate the model based on recent/new measurements of levels and discharges near the dam site and between the Soupanouvong station and the dam site.

The developer has indicated that the tailwater rating curve is currently being revised using a bathymetric survey and considering the Nam Ou tributary. Only the flow velocity results of this work have been shared, and it is recommended that the full study results are shared as part of a post prior consultation JAP.

RECOMMENDATIONS FOR THE FLOOD PEAK ANALYSIS

The following recommendations are made with respect to finalising the design standards for the flood peak and volume:

- The impacts of climate change on the flood frequencies should be included in the assessments. For example, the expected increase of the monsoon discharge and a possible increase of storm intensity can lead to higher values for the 10,000-year flood and PMF over the long term; and
- The probability of flood volume and flood discharge should be presented jointly to determine a proper flood hydrograph.

RESERVOIR OPERATING RULES

The Luang Prabang HPP is a Run-of-River (RoR) hydropower plant, i.e. the discharge through the infrastructure equals the inflow, and the Full Supply Level will be maintained within a narrow range most of the time during operation. Although an increase or decrease of in the FSL might be required during spillway operation or other exceptional operating cases - like floods. An “operating range” for the FSL of around 0.50 m will be required, and the developer indicates that the FSL will vary between 312.00 and 312.50 m asl.

The operating rules for the LPHPP that can be derived from the information provided are as follows:

- Up to 5,355 m³/s, all the flow water passes through the turbines, this will be for about 80% of the time.
- At inflows greater than 5,355 m³/s the Low-Level Outlets (LLO) will be brought into operation. This will occur for some 20% of the time, most likely on an annual basis.
- When inflows exceed the capacity of the turbines and the LLO flows the excess flow is passed through the surface spillways.
- The turbines are shut down when they reach their minimum required head, which is expected to be about around 20,000 m³/s. At flows above this, all the flow is passed through the spillways and LLO.

In order to optimise the operating range for the Luang Prabang HPP, the minimum tailwater level is set to 275.50 m asl (discharge of approx. 745 m³/s), and the maximum TWL to 295.50 m asl. (discharge of approx. 24,180 m³/s, higher than the 100-year flood). The resulting head range is between 36.5 m and 16.5 m (see section 14.3.1.3 of the FS). However, the tailwater might be subject to lowering when erosion processes occur in the downstream reach or when the recommendations regarding the tailwater calculations made above are adopted.

No further details of the operating rules have been presented and there are no descriptions of any possible rapid fluctuations caused by opening and closing of the spillways and outlets (and turbines). There are no provisions for environmental flows because of the run-of-river operations and the downstream Xayaburi HPP. This is reasonable, if rapid fluctuations are avoided.

The FS mentions the possibility, and necessity, of joint operations with Pak Beng and Xayaburi HPP's, but does not provide details. It would be important elaborate these joint operations to optimise hydropower output, for sediment management operations, and other environmental purposes. It is also relevant to align releases from the dams (e.g. for water-level lowering), such that the extra discharge can be handled by the downstream schemes, and that the power supply is not compromised. However, addressing these aspects lies beyond the purview of the developer and should be addressed by the Ministry of Energy and Mines (MEM) in the Lao PDR and / or the MRC.

RECOMMENDATIONS FOR THE OPERATING RULES

- The raising of the operating level from 310 m asl to 312 m asl, will impact on power output at the Pak Beng HPP. While there is a net gain in power total output from both HPPs, the concern is rather on the impacts on the economic viability of the PBHPP. The Lao delegation to the JCWG has indicated that this is receiving attention.

- The developer should further elaborate the expected operational rules for the spillways, power generation, and reservoir levels, particularly with respect to ramping rates to avoid rapid fluctuations downstream; and
- The operating rules must be updated to provide for the potential (flood) impacts at Luang Prabang City (see the Dam Safety sub-section). The developer presented more detailed operating rules during the site visit and has provided these in an Addendum to the FS. However, these have not yet been formally shared for review.

The developer has confirmed that operations will follow the “inflow=outflow” concept, and that rapid fluctuations in water levels will not occur. They note that while the turbines will be capable of higher ramping rates, these will not play a role since no peaking is envisaged. Flow changes through the powerhouse will be compensated by the spillway so that total plant outflow remains stable respectively equal to river flow.

It is nevertheless important to clearly elucidate the operating rules in the JAP for the purposes of the PWUM, which will track whether the operations are being implemented as designed.

4.3.4. Project monitoring and adaptive management

COMMENTS ON THE HYDROLOGICAL MONITORING PROPOSED BY THE DEVELOPER

Monitoring for hydrology and hydraulics is part of the normal operations of the mainstream dams in the Mekong. Monitoring should provide the information needed to operate the station in a run-of-river mode (e.g., discharge forecasts, tailwater), but also to manage environmental impacts and for dam safety. It is common practice to set up a monitoring plan that presents the objectives (what is the purpose of monitoring), what variables should be monitored, where should they be monitored, and at what frequency. The Procedures for Data and Information Exchange and Sharing (PDIES) make provision for the sharing of these data with the MRC.

The monitoring for environmental and dam-safety variables at the dam site is presented including water level, seepage, and climate. Automatic recording connected to a warning system has been proposed. The developer also proposes to monitor water levels upstream and downstream of the dam with automatic monitoring devices. A small-scale meteorological station will be installed at a suitable location on the dam abutment for monitoring temperature, rainfall and humidity.

The initial documentation did not provide further information on the hydrological monitoring system that is proposed for the operation of the scheme, and for monitoring the environmental impacts. The developer has subsequently indicated that the intention is to link the hydrology monitoring to the existing telemetric system for the Xayaburi dam, but with additional stations near the dam and further upstream. The documents provided on 11 March 2020 present theXHPP hydrological monitoring and forecasting system, however this document has not yet been reviewed in detail.

Similarly, ramping operations during dispatching, for social and environmental management, requires a system that provides the information for optimized reservoir operation. There are also safety, and economic benefits to such a system. Annex C provides some guidance on the issues that must be addressed in this regard.

The system is needed for the full life cycle of the project, starting from pre-construction and continued during operation. The MRC and WMO guidelines (HYCOS system and JEM

procedures) should be used to determine the specifications for this monitoring system, as a consistent and uniform system over the entire LMB facilitates data exchange, integration into national systems, and a uniform knowledge base. Information on the proposed QA/QC processes should also be provided.

MODELLING TOOLS FOR IMPACT ASSESSMENT

Several modelling tools have been used to provide quantitative estimates for the design conditions in the rivers, reservoir and structures. However, detailed information on the set-up and use of the models has been provided in separate reports that have not been submitted for the prior consultation process. The information that is presented is insufficient for a detailed review. The following bullets summarise some observations in this regard:

1D model

- The calibration of the FLORIS, GSTARS and HEC-RAS models is based on the earlier studies of CNR in 2009, and not on recent measurements.
- The GSTARS model uses the CNR - 2009 cross-sections. But the HEC-RAS model for the hydrodynamic simulations for the same reach has been set-up with the updated cross-sections. It was shown in the backwater simulations that the calibrated water levels in HEC-RAS appear to differ by several meters at some sections, possibly due to a mismatch in cross-sections. The 2009 cross-sections and the new surveys for these sections should be compared to better evaluate the model results.
- The GSTARS model calculates how sedimentation and erosion processes vary along the reach. The impact of the hydrodynamic gradients and slope is essential for these calculations and requires careful judgement of the above-mentioned inconsistencies between models and data; and
- The HEC-RAS model (version 5.0.5) used for the dam-break simulations is based on the HEC-RAS setup developed by CNR in 2016 for the backwater calculations for Xayaburi HPP.

2D Model - Basement

- The choice of hydraulic roughness in the model is not based the calibration against actual measurements but are chosen based on literature and the experience of the developer; and
- The aim of the model is to optimise the hydraulic conditions upstream and downstream of the infrastructure. The model has also been applied to simulate the river diversion during construction phase for the 100-year flood condition.

3D model

- A 3D CFD model has been applied to calculate the hydraulics and for hydraulic optimisation of the water-conduit system, its intakes, diffusers for the navigation locks. However, only the results are presented and there is no further information available in the FS.

Hydrological model – HBV or SWAT or similar

- There are no references for the water balance model (other than the statement that it has been applied often). More information on the capabilities, validation and reliability of this model should be shared; and

- As this is a water-balance model, it cannot capture the full dynamics of HPP operations and the propagation and damping of fluctuations. This requires an unsteady-flow hydrodynamic model. However, in this study the model is only used for calculating monthly flows, hence these dynamics play a minor role.

Physical model

- The performance of the spillways and their optimisation was tested in a physical model in the Asian Institute of Technology (AIT) in Bangkok. Reference is made to two reports from these experiments that have not been shared but seem to contain more detail on the experiments for the LPHPP, and the experiments carried out for Xayaburi dam design which serves as a template for the LPHPP spillways. These reports should be shared as part of the JAP.
- The model tests were carried out in a flume. Although the flume dimensions have not been reported in the documents, it seems that over the width of the dam, two low level outlets and one surface outlet have been inserted, covering a real width of 46 m, and a scaled width of about 0.8 m. A 13 m long flume section is introduced as the forebay for development of the velocity profile (including flow straighteners and energy dissipators), followed by the structure with a real length of about 180 m or 30 m in the flume. The length of the flume section downstream of the model towards the tail gate has not been reported. The total length of the flume is therefore >43 m.
- A scaling factor of 1/60 has been used for the geometry. Proper Froude scaling has been applied and resulting scale factors for different parameters have been presented.
- It is not possible to assess, from the photos, whether additional roughness has been added to the flume bottom to represent the properly scaled bed roughness of the reservoir; and
- The developer verbally indicated (Dec 2019) that a scale model for the structures and the up- and downstream river sections (scale 1/110) is being prepared at AIT and will be used for the detailed design of the outlet structures and stilling basins.

MITIGATION OF WATER-LEVEL FLUCTUATIONS (IMPOUNDMENT AND DOWNSTREAM)

The CIA-TbIA lists the following hydrological impacts due to the LPHPP:

- Increases in the upstream water level and the creation of a reservoir with surface area of about 49 km², reaching to the Pak Beng HPP.
- Decreased flow velocities in the reservoir area. It is assumed that the residence time is some 5 to 9 days.
- Reduced outflow during impounding to reach full-supply level (FSL), which is assumed to take 15 to 20 days; and
- Water level fluctuation of reservoir relative to FSL are in the order of 1 m for minor floods up to 2.2 m for the PMF. It is not clear how these numbers were derived.

The documents indicate that no rapid changes in inflow are expected. However, changes in the outflow from the Pak Beng dam or other projects, may result in rapid fluctuations which must be passed through the structure. This would require an automatic monitoring, transmission and warning system, and a quick response of outflow structures. Alternatively, the peaks can be

absorbed by the LPHPP (in the impoundment) and released with proper ramping of the flows considering the downstream reach. Such an operation has not been addressed in the documents. The approaches to possible rapid changes in inflows should therefore be further elaborated as well-defined operating rules as part of a Joint Cascade Operating study, and these should be included in the PWUM.

The backwater calculations have been obtained from the HEC-RAS software. Calibration of the model was based on the 2009 CNR study “Optimization study of Mekong Mainstream Hydropower”.

- The dam is located at km 2,036, but the figure only shows results above km 2,040. This means that 4 km and the boundary condition is not shown. The boundary value of the low flow condition near the dam seems to be higher in the simulation than the observed water level. This seems erroneous and should be explained.
- Upstream of km 2080, there are water level differences - at all discharges - of several meters between the computed water levels in each model. A closer look at these sections, shows that these are characterised by bed rock outcrops and sand bars, which may lead to different roughness values and possible cross-section changes relative to 2009. The developer has not described, analysed and resolved these differences. This magnitude of error between water levels would typically be regarded as an unsuccessful calibration. Nonetheless, for the purposes of the feasibility level assessment, it can be acceptable if properly explained and motivated. This motivation should be presented in a clearer way; and
- It is useful and illustrative that an estimate has been presented on the potential energy losses at PBHPP due to the tailwater impact of LPHPP. However, it is recommended that the operation levels that have been assumed for PBHPP are added, as this scheme has been designed to operate with seasonal varying levels (to protect the upstream Keng Pha Dai reefs).

Some differences have been found while comparing the results for reservoir levels and backwater levels with the data used for the Pak Beng feasibility study. Pak Beng is located on km 2,184, and the distance between the dams is about 147.5 km. The modelled levels are all several meters below those reported at Pak Beng. These differences must be further investigated and explained.

IMPACTS RELATED TO HYDRAULICS OF THE STRUCTURE

The developers recognise that the crosscurrents from the spillway operation may hinder navigation towards and from the downstream approach channel. The details of these currents have not been assessed. The developers suggest that this may be avoided by leaving a small “island” between the downstream spillway channel and the approach channel. However, it is not clear from the plan drawings whether the downstream separation wall is tied into the island. The developer did nonetheless indicate that this is the case during the site visit. The Navigation Section below also makes some proposals to the realignment of the navigation lock which would eliminate the upstream and downstream islands.

The configuration, with the powerhouse in the middle of the structure, has some hydraulic advantages and disadvantages compared to an arrangement where the powerhouse is directly positioned next to the navigation lock (near the left bank). However, the hydraulic performance has not been studied in detail. It is anticipated (and recommended) that detailed hydraulic modelling will be applied to test and optimise this performance. An alternative layout where

spillways are placed both left and right of the powerhouse has been proposed for further consideration in a later development stage.

During the first construction phase, the coffer dam claims around 75% of the river width at the dam site, starting from the right bank. The river will be diverted, flowing through the remaining narrow section at the left bank. This will cause lower flow velocities immediately upstream and higher flow velocities in the constricted section at the construction site. Both the upstream and downstream cofferdam are designed for a 100-year flood. An additional 3 m freeboard has been included hence the crest of these cofferdams will be built at 302 m asl. During the design-flood conditions the 2D model calculations show maximum flow velocities in the range of 6 m/s, and water levels ranging from 297.8 m at the upstream cofferdam, to 295.3 at the downstream cofferdam.

The design of the spillway section is largely copied from the Xayaburi Dam, but with 6 surface spill ways (instead of the 7 at Xayaburi), and 3 low-level outlets instead of the 4 at Xayaburi, all with radial gates (tainter gates). The performance of the spillways and their optimisation was tested in the physical model. A brief overview of these experiments and some results are presented. However, as the designs are copied from the Xayaburi spillways, it has been decided to only perform flume experiments for detailed simulation of the surface spillways and low-level outlets (LLO).

The stilling-basin design of the spillways is also copied from Xayaburi and the concrete aprons and end sill are identical. However, the performance must be evaluated based on the conditions that prevail in the river during operation, as the tailwater and flood statistics differ. The stilling basin will have to cover the length of the hydraulic jump, and depends on the Froude number of the inflow, and the tail-water depth. During the site visit (Dec 2019) the developer indicated that a scale model has been prepared at AIT to carry out detailed simulations for LPHPP which will be used to improve the structures and their operations.

The 2D model has been used to optimise the spillway and power-house approach flow, creating a rather uniform approach flow while optimising the amount of excavation needed to accommodate this flow. The calculations for the spillways were made for the 10,000 year flood and the PMF. The calculation for the power inlets was made for the rated discharge of 5,355 m³/s. The results are presented graphically, but the figure is missing a legend to assess the velocities.

The following observations are made:

- The flow entering the spillway section from the left during the 10,000-year flood, curves strongly around the 'right pier' with apparent high velocities. However, the documentation does not show any signs of separation of the flow next to the pier. This may occur when the horizontal viscosity in the model is overexaggerated, and these results should be carefully interpreted and tested for such effects. Especially because this could mean that the left surface spillway could behave differently than anticipated from the modelling, and the other outlets must compensate for this.
- Figure 12-21 of the FS also shows a relatively quiescent area in front of the powerhouse and possibly in front of the closing structure. Similarly, it seems worthwhile investigating the influence of the horizontal eddy viscosity, as this may also be a zone where flows can develop a large gyre (whirlpool). The presence of such a gyre may lead to increased sedimentation in front of the powerhouse during the flood conditions for which this simulation was presented; and

- Details are given on the design of the radial gates for the spillways. This section does not provide insight in the actual designs of these gates, including the loads and strengths, prevention of wear and vibrations, etc. The developer has indicated after the site visit, that these calculations and insights have been obtained from the Xayaburi dam. The actual designs will be analysed and calculated in close cooperation with the supplier during the design phase.

The following recommendations are made regarding the hydraulics at the dam site:

- Results of the various laboratory experiments should be presented/shared as part of the JAP, to show that the stilling basin dimensions suffice for the chosen design. This needs to be verified as the conditions for discharge and tailwater are not identical to those in Xayaburi HPP. Also, the design should account for the possible changes/uncertainties in tailwater for instance due to downstream erosion and impacts of Nam Ou inflows to the Mekong River just downstream of the LPHPP.
- The sensitivity of the simulation results of the 2D model for the horizontal eddy viscosity should be tested to investigate the possible development of gyres and eddies that may disturb the hydraulic conditions at the inflow towards the spillways and powerhouse. Preferably the model should be calibrated based on local observations and a planned physical scale model for the entire section (see next bullet).
- Physical model tests for the entire structure and its approach flow and tailwater section should be conducted (instead of just of the flume experiment). The developer has indicated that these are being prepared at AIT. The flow fields from the 2D numerical model do not replace the complex and 3D flow fields that are expected near the scaled structures at different operations in a physical model.

4.3.5. Alignment with the PDG 2009

The original version of the Preliminary Design Guidance (PDG) does not contain clauses for hydrological and hydraulic parameters. It does, however, indicate that it is necessary to consider how much water needs to be released to maintain downstream ecosystems, determined through an Environmental Flow Assessment (EFA) that must be introduced during the EIA stage. However, as the LPHPP is a run-of-river HPP sited between two other cascade HPP, EFAs are not required. However, special measures may be required to maintain aquatic habitats immediately downstream of the LPHPP. These are detailed in the Aquatic Ecology section below.

The new version of the Preliminary Design Guidance (PDG2019) contains a section and various clauses to guide the hydrology and hydraulics aspects of the design process, and this has been used to inform this section of the review. Annex C provides an assessment of the alignment of the design to the PDG 2009 and PDG2019. This analysis suggests that most of the parameters have been considered to some extent, but some actions are still necessary as outlined above.

4.3.6. Considerations for the JC

This review of the hydrology and hydraulics of the proposed LPHPP includes several recommendations and requests for further information. Most of these pertain to improvements in the mathematical and physical modelling which will provide a better basis for determining the financial viability of the LPHPP, and its design. This may in turn affect the willingness of the

operators to consider operations that reduce power output, but which reduce the potential for transboundary harmful effects.

The JC may wish to request the additional information to be provided as part of a post prior consultation JAP process.

The flow data and applied methods from the newly established gauge at the dam site should be shared with the MRC. The hydrological data for 2015 – 2019 forwarded after the 3rd JCWG meeting on 05 March 2020 is however gratefully acknowledged.

4.4. Sediment transport and geomorphology

Key features of the sediment transport facilities and geomorphology review:

- ▶ The developers have provided relevant and consistent data and information related to geomorphology and sediment transport in the region of the development.
- ▶ The report provides a good literature review of the range of sediment data sets available, and the role that land use and upstream hydropower developments have played in sediment transport.
- ▶ The site-specific sediment data provided for review is limited. But additional data are being collected and this will continue throughout the final design, construction and operational phases.
- ▶ The sediment discussion focusses on past changes related to land use and damming, and only briefly mentions the potential impact of existing or future mainstream or tributary hydropower projects situated upstream of Luang Prabang.
- ▶ The loss of exposed sand bars and rocky outcrops over the 160 km river reach to be inundated, and just downstream of the LPHPP has not been discussed in relation to the availability of these habitat types. The assessment of critical habitats that may be lost is ongoing.
- ▶ The sediment management infrastructure consists of 3 Low-level outlets that will be brought into operation as soon as turbine capacity is reached. However, no other management strategies for use of the LLO are presented.
- ▶ The developer has not described sediment routing operations which could increase the through-put of sediments and contribute to reducing transboundary impacts.
- ▶ It is noted that the infrastructure allows for this, and these operations need to be developed and integrated as part of the cascade operations if transboundary impacts are to be minimised.
- ▶ Sediment transport modelling is at an early stage using simple models and is planned to be improved in the upcoming project phases. While broadly consistent with the modelling done by the MRC, the current simulations most likely underestimate the sediment trapping.
- ▶ Options to promote the transport of sediment throughout the impoundment should be included in future phases.
- ▶ The sediment passing infrastructure included in the design is broadly aligned with the PDG 2009.
- ▶ Operations to avoid, minimize or mitigate impacts associated with sediment transport to align with the PDG must be developed as part of Joint Cascade Operations.
- ▶ On most other aspects (e.g. modelling, monitoring, transboundary impacts) there is insufficient information available to make a robust determination.

4.4.1. Objectives

The downstream transport of sediment is important to maintain ecological functioning. Sediment may be deposited in riparian wetlands, bringing nutrients to these areas and providing habitats for the biota. Coarse sediment transport is required for maintaining the structure and stability of the river channel. Sediment transport has over the millennia developed the Mekong Delta into the fertile rice bowl of Viet Nam. Conversely, removing sediment through trapping behind dams increases the erosivity of the released water, which destroys and alters existing habitats and can erode the banks of the river posing a danger to riparian communities and infrastructure. Sediment build up in impoundments and near HPP infrastructure can reduce

its power output and pose a risk to operations, while rapid fluctuations in reservoir water levels can cause the banks to slump.

The objectives for sediment transport and geomorphology measures outlined in the PDG2019 are therefore to:

- i. Maintain the morphological equilibrium of the Mekong River.
- ii. Minimise changes to sediment delivery to the downstream environment with respect to sediment quantity, the seasonality of sediment delivery, and grain-size composition of the sediment load.
- iii. Minimise geomorphic impacts arising from changes in sediment transport, including changes to riverbanks, riverbeds and aquatic and riparian habitats.
- iv. Minimise deposition within the impoundment to prevent upstream river changes and maintain and protect project infrastructure.

4.4.2. Pre-project monitoring and analysis

SEDIMENT DATA USED BY THE DEVELOPER

The developer has provided the following data and information relevant to geomorphology and sediment transport:

- Aerial LiDAR surveys to document the right bank landforms where the dam and power station and other infrastructure will be constructed.
- A topographic survey including aerial images and LiDAR for the proposed impoundment.
- Bathymetric surveys from approximately 2 km upstream to 1 km downstream of the proposed dam site.
- Channel cross-sections from the proposed impoundment and channel cross-sections collected during the Xayaburi investigations.
- Maps of the proposed inundated area showing sand bars, bedrock outcrops, forest, villages and other features.
- Numerical hydraulic model results showing water velocities associated with high flow events near the hydropower infrastructure during the period of river diversion and after the project is completed.
- Numerical model results showing the distribution of deposited sediments in the proposed impoundment after about 20 years of operation.
- The grain-size distribution results from 10 sediment samples collected from riverbank deposits within the proposed impoundment area in April 2019, used in parameterization of the sediment transport model.
- Suspended sediment concentrations in six samples collected from the Supanuvong, Luang Prabang and the Houa Yo stations collected in April 2019; and
- Sediment transport information and data from published papers and reports.

The developers have provided relevant and consistent data and information related to geomorphology and sediment transport in the region of the development. The spatial data adequately covers the dam site and impounded area. However, there is a lack of spatial information for the downstream river reach extending to the Xayaburi backwater and including the Nam Ou confluence.

The report provides a good literature review of the range of sediment data sets available, and the role that land use and upstream hydropower developments have played in affecting sediment transport on a regional scale. The developer does not provide any site-specific sediment transport measurements. This is important as the conditions at the LPHPP are not accurately captured by the Chiang Saen or Luang Prabang monitoring sites. The Chiang Saen data will under-estimate sediment transport relevant to the dam site due to several large tributaries entering in the intervening reach. The data from the Luang Prabang monitoring site, which is located downstream of Nam Ou, will conversely over-estimate sediment transport at the proposed dam site. Despite this, the overview of the available data provides a good general synopsis of sediment issues.

Much of the data underpinning the discussion of sediment transport and potential transboundary impacts associated with sediment trapping were derived from the literature and previous investigations related to the development of the Xayaburi hydropower project. However, the developer did not draw upon available information related to sediment transport modelling including sediment trapping in impoundments under various MRC studies. Several of these studies are directly relevant to the Luang Prabang development and provide a basin-wide context for the potential changes associated with the upper Lao cascade and provide insights into sediment trapping in each of the HPP in the cascade and potential transboundary impacts.

The Feasibility Study (FS) presents a literature review summarising studies documenting the distribution of sediment input in the Lower Mekong Basin (LMB), the suspended sediment loads before and after construction of the Lancang cascade in the Upper Mekong Basin (UMB) in China, and the grain-size distribution of suspended and bedload sediment. This includes studies that clearly show a decrease in sediment concentrations and loads following placement of the dams, as well as studies that suggest little or no change. The FS includes a trend analysis of flow and suspended sediment results from Chiang Saen and suggests that the results show there has already been a major reduction in sediment load concluding:

"For this study, total sediment loads (washload, suspended and bedload) of about 110 Mt/y pre-dam and 20 to 24 Mt/y post-dam [Lancang Cascade] are considered for the Luang Prabang HPP site."

The FS, recognises the need to collect additional site-specific sediment information upon which a comprehensive sediment management strategy for Luang Prabang can be based. Specifically, it recommends additional investigations and modelling related to sediment deposition in the upper reaches of the impoundment and collecting suspended sediment, bedload sediment including mass and grain-size determination to support these investigations. The documentation indicates that this work is underway and that the results will be incorporated in later phases.

COMMENTS ON THE PRE-PROJECT ANALYSES

Using literature reviews to understand sediment transport in the catchment is a sound starting point, and the summary of investigations captures information that is relevant to the LPHPP

development. However, this TRR concurs with the need for the addition studies and monitoring, and it is recommended that these studies and data are shared with the MRCS as part of any post prior consultation process and JEM project. The developer has indicated that this monitoring is underway.

The sediment discussion focusses on past changes related to land use and damming, and only briefly mentions the potential impact of existing or future mainstream or tributary hydropower projects situated upstream of Luang Prabang (e.g. Pak Beng, Nam Tha, Nam Beng, or Nam Pho and Nam Lwe in Myanmar), or how the LPHPP operations will interact with the downstream Xayaburi hydropower project, and the Nam Ou cascade.

More attention needs to be paid to the reach immediately downstream of the LPHPP. Here water and sediment released by the LPHPP will mix with flow and sediment discharged from the Nam Ou, and sediment transport into the backwater of Xayaburi will be governed by the combined inflows. Understanding sediment deposition and transport patterns in the Xayaburi backwater is important as this will affect local flooding and erosion risks and the overall movement of sediment through the cascade. The preservation of as much of the remaining free flowing habitats along this reach as possible is also important. The inter-relationships and inter-dependencies between tributary and mainstream HPPs in the area are not addressed with respect to sediment transport, and are relevant to overall sediment transport, trapping and transboundary impacts.

The provision of site-specific sediment information is limited to the grain-size distribution of 10 riverbank samples used to guide the starting bed material composition for the modelling exercise, and 6 suspended sediment samples collected in April 2019. The revised draft PDG2019 recommends at least one year of site-specific sediment monitoring prior to the PNPCA process. This would have allowed a comparison of the assumed sediment load (22 Mt yr⁻¹) with field results and could have been used to determine the site-specific grain-size distribution in the wet and dry seasons.

The discussion of sediment transport management strategies and mitigation measures at this stage is very limited, and only includes the opening of the Low-Level Outlets (LLO) when flow rates exceed that required by the powerhouse and ancillary services (fish pass facility and navigation) – i.e. 5,355 m³/s. This will produce pressure flushing, which will remove small volumes of sediment from a limited area upstream of the outlets but will not mobilise sediment deposited further upstream. The developers confirmed during discussions in December 2019 that this is currently the only sediment management strategy planned, and sediment routing (drawing down water level during periods of high sediment inflow to maximise sediment throughput) and sediment flushing (drawing down water levels to induce channel erosion and discharge large volumes of deposited sediment) are not planned.

The documentation suggests that eventually a new sediment equilibrium will be established which will increase sediment discharge from the impoundment. Given the length of the inundated area (~150 km), this new equilibrium will require a very long time (decades to centuries) to establish as it requires development of a delta extending from the headwater of the impoundment to the dam wall.

The sediment management strategy currently presented may be adequate for managing sediment deposition for power production provided that the threshold values are exceeded on approximately an annual basis, but it is not the most effective strategy for promoting sediment movement through the LPHPP on an annual or seasonal basis to minimise transboundary impacts as is recommended in the PDG 2009. Sediment routing through the impoundment, e.g.

during periods of high sediment inflow or sediment flushing, involving the drawdown of water levels to erode and mobilise sediments deposited in the impoundment is therefore recommended. However, this can only be done as part of joint operations of the upper Lao cascade. It is therefore recommended that studies are undertaken by the Government of Lao PDR and / or the MRC, with the intention of developing viable sediment management operating rules for the cascade which balance the costs of lost generation capacity with the long and short term benefits to the downstream reaches.

GEOMORPHOLOGICAL DATA USED BY THE DEVELOPER

The documentation presents information relevant to the geomorphology of the area and potential impacts associated with the development in several sections of the reports. The physiographic regions of the Mekong River catchment are presented, along with a detailed description of the topography of the project area. The Geology section of the report links the geomorphology of the project site to the underlying geology, and the EIA Report includes detailed maps of the potential area of inundation showing the distribution of different land types / uses that will be drowned by the project (sand bars, forest, rock outcrops, plantations, gardens, etc.).

However, the geomorphic impacts of the project are only discussed in general terms. For example, The FS notes that during operations some of the riverbanks will be prone to erosion due to the change in surface (within the 0.5m operating range) and groundwater levels and is expected to continue until the slopes are naturally flattened. The risk of landslides associated with the water level changes is, however, considered to be low. The developer has indicated that the critical habitat assessment is currently ongoing and that more information on the habitats that will be lost will be included in updates of the EIA.

Changes to downstream sediment transport, including transboundary impacts, are stated as likely to occur, but not described in detail.

COMMENTS ON THE GEOMORPHOLOGY INFORMATION

The report contains a substantial amount of background information related to the geomorphology of the region, but only provides general comments about how it is likely to change due to the development.

The spatial information provides a good baseline of present conditions in the proposed area of inundation, but this information is not used to predict geomorphic changes in the impounded river reach, or the river reach immediately downstream. The PDG 2009 recommends considering changes to the river thalweg, tributary confluences, the potential for mid-bar formation, and potential impacts associated with deposition at the head of the impoundment. These issues are not addressed.

The link between land use and sediment input is discussed in the sediment transport section with respect to historic land use changes in China, but there is no discussion of how the changing land use patterns within northern Lao PDR in general, and the project area in particular, might affect sediment transport in future. Google Earth images show sediment deltas downstream of tributaries draining cleared or cultivated land in the area of inundation. Changing land use over the life of the project could have an impact on sediment input, the creation of bars or river mouth deltas and overall sediment management. Although immediate impacts associated with land clearing and increased sedimentation will be localised, the bigger picture of how sediment is managed within the overall upper Lao PDR cascade is a critical transboundary issue.

There is no discussion of the impacts of fluctuating water levels within the impoundment on erosion of the shoreline. The documentation indicates that there will not be any hydropeaking at the LPHPP but the potential for hydropeaking at the upstream Pak Beng hydropower project is not addressed. Peaking at Pak Beng would affect water levels within the Luang Prabang impoundment and may increase daily level fluctuations. It should nonetheless be noted that the Pak Beng prior consultation process indicated that hydropeaking was not planned.

The loss of exposed sand bars and rocky outcrops over a 160 km river reach has not been discussed in relation to the availability of these habitat types for biota. The proposed area of inundation contains many deep pools which are recognised as important habitat for fish and are highlighted in the PDG 2009 as being important areas to understand and monitor. The EIA, however, recommends that rapids and deep pools upstream of the Pak Beng reservoir should be protected to maintain some spawning areas.

DESIGN AND OPERATION OF THE SEDIMENT FACILITIES

The attributes of the LPHPP infrastructure relevant to sediment transport and river geomorphology are:

- The project is located between a left and right bend in the Mekong River. The natural flow path will direct water away from the powerhouse, but the project will excavate large volumes of material from the right bank, re-aligning the main channel with the powerhouse and spillway. This will promote the retention of sediments in suspension and maximise bedload movement close to the dam towards the low-level outlets.
- The three Low-Level Outlets (LLOs) are located on the bed of the river and have sill level of 275 m asl, and dimensions of 12 m by 16 m (width / height). A low-level outlet approach channel is shown in drawings but not described. It appears that the channel will direct flow towards the LLO during the second construction stage and may direct bedload toward the LLO during normal operations.
- The infrastructure will create an impoundment with a depth of up to 70 m at the dam wall. The length of the backwater will extend approximately 156 km upstream, to the Pak Beng dam site.
- No sediment management infrastructure is incorporated into the powerhouse, or the left bank closing structure.
- Water level fluctuations within the impoundment will be maintained at less than 0.5 m / day during normal operations which will minimise erosional impacts on the shoreline of the impoundment.
- The low-level outlets will be opened prior to the surface gates during periods of high flow ($> 5,335 \text{ m}^3/\text{s}$) promoting the release of sediments from the base of the impoundment.

SEDIMENT TRANSPORT MODELLING

Sediment transport modelling of the LPHPP impoundment area has been completed using GSTAR 2.1 (*Generalised Sediment Transport model for Alluvial Rivers*), developed by the US Bureau of Reclamation. The model is a 1-D hydraulic model with quasi 3-D sediment transport elements, allowing for different grain-sizes to be modelled. The model can predict sediment mobilisation and deposition, but not geomorphic changes to the channel such as bank erosion. The model setup was based on the cross-sections and water level measurements collected by

CNR in 2009, with the starting grain-size distribution in the bed of the channel based on 10 sediment samples collected from the impoundment area of inundation. Historic sediment data from the MRC was used to guide the input loads and grain size distribution of suspended sediment.

The model results show deposition throughout the impounded area, with higher potential in the area between km 2052 and 2164 (Figure 4.2).

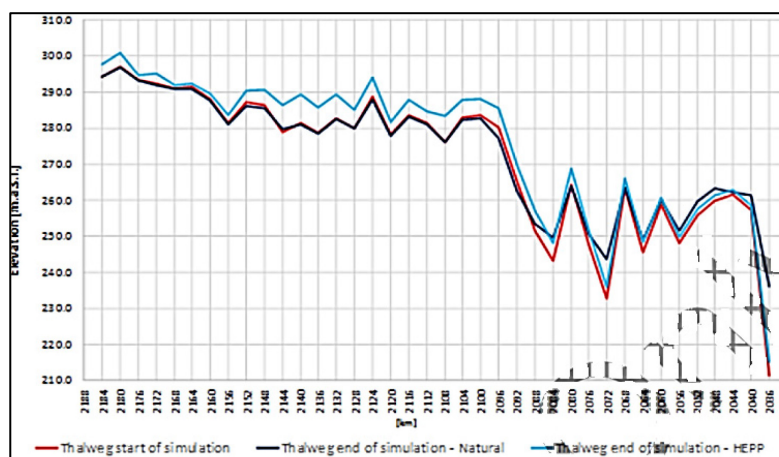


Figure 4-2 Results of the simulation of sediment deposition in the LPHPP reservoir.

Fine silt and clay sized material was generally transported through the impoundment, along with some coarse silt, whereas most of the fine sand material is deposited.

Two-dimensional modelling (BASEMENT software package) was used to examine the hydraulic flow conditions upstream and downstream of the hydropower plant under conditions of high flow, but the results are not interpreted with respect to sediment transport.

The FS states that additional sediment transport modelling will be conducted to verify the currently proposed arrangement of the spillway and lower outlets to support sediment routing or similar sediment management operations.

COMMENTS ON SEDIMENT TRANSPORT MODELLING

The information used is relevant and provides a good initial basis for the ongoing development of the LPHPP, but the work presented is in a relatively early stage making interpretation with respect to the PDG 2009 difficult. The following comments are provided related to the sediment transport modelling in the impoundment:

- The GSTAR model is a basic 1-D model sediment transport model. Flows are averaged across the cross section, which means the model cannot predict deposition across the impoundment profile. The FS recognises this and states that the model should be considered a '*rough estimate of the sediment transport processes*'. Understanding sediment transport is a significant transboundary issue and a more robust modelling approach should be applied to provide the most reliable information possible.
- The longitudinal section used for the sediment transport model is based on 38 cross-sections and parameters used for Xayaburi but has not been calibrated for Luang Prabang. The longitudinal section shows a relatively flat area in the upper section of

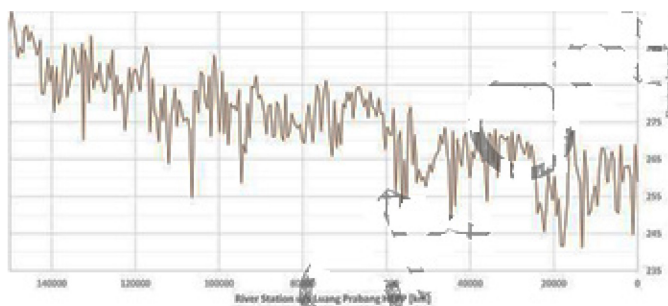


Figure 4-3 The more detailed longitudinal profile of the impounded reach.

the impoundment and a large change in elevation between km 2100 and km 2082 (Figure 4-2). However, the more detailed longitudinal section in Figure 4-3 captures the high number of deep pools within the impoundment and shows a more continuous slope as compared to the model setup. These differences will affect the results, including a likely under estimation of the trapping efficiency by deep pools.

- The starting bed material is set at fine sand, based on sediment samples collected from riverbanks in April 2019 from the impoundment area. Bed materials are generally coarser than bank materials, and it is likely the grain-size present in the deeper channel is considerably coarser. Considering the high sensitivity of the model to the grain-size, incorporating a realistic grain-size for the channel is important and will affect the results.

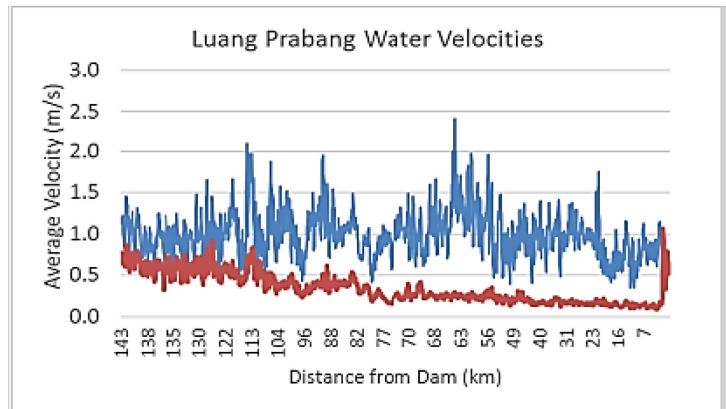


Figure 4-4 Predicted water velocities in the Luang Prabang impoundment based on results of Delft 3D modelling. Blue line indicates water velocity without impoundment, and red line shows decrease in water velocity following impoundment. Average velocities are below the 0.3 m/s threshold for most of the length of the impoundment

- The modelling results show greater deposition in the upstream portion of the impoundment, and the FS states that the loss of material in this area contributes to a lack of deposition in the lower part of the impoundment. These results are not related to the characteristics of the channel.
- In general, the modelling results are consistent with the results from the MRC studies. The velocity results show a reduction in velocity downstream, accounting for the lack of sediment transport downstream. The FS states that it will take a long time to establish a new sediment equilibrium, but there is no consideration of management actions such as sediment flushing and sediment routing that could reduce this time period, leading to a reduction in transboundary impacts in the shorter term.
- The FS does not quantify the model results, only indicating that clay and fine silt is transported through the impoundment and most of the fine sand is deposited. The model input was based on an input of 22 Mt/yr, with 20% to 75% of the load consisting of fine-sand with the proportion linked to the flow rate. The brief description of the results suggests that that up to 75% of the total sediment load will be trapped, corresponding to the percentage of fine sand in the load. This will reduce the concentration of, and alter the grain-size distribution in, the downstream sediment load. This will in turn affect the scouring in the free-flowing reach immediately downstream of the LPHPP. Quantifying these processes and changes is very important for predicting the overall change in sediment transport and transboundary impacts through the cascade. Additional quantification and discussion of the results, and downstream implications of findings is recommended.
- There is no sediment transport modelling associated with sediment discharge from the dam related to the proposed use of the LLO. A greater understanding of how much sediment might be mobilised during high flow events when the gates are open is

required, especially as this is presented as the sole downstream sediment transport strategy. Modelling of sediment routing and flushing, which are not proposed by the developer, is also warranted, to establish whether these approaches would avoid, minimise or mitigate potential transboundary impacts. However, this modelling must be done for the whole upper Lao Cascade by the Government of Lao PDR and / or the MRC. This study would nonetheless benefit from more rigorous modelling for each of the HPPs.

- The impacts in the reach downstream of the LPHPP and the backwater of Xayaburi are not addressed. This area will experience increased deposition if Nam Ou and LPHPP release sediments during lower flow periods. There is also a high risk of erosion in this reach due to sediment hungry water being discharged from both the LPHPP and Nam Ou cascade. Erosion in the confluence reach could induce channel instability and bank erosion. It is recommended that this reach be specifically investigated in future hydraulic and sediment transport modelling exercises, and that conjunctive operating scenarios are developed by the Government of Lao PDR and / or the MRC.
- There is no modelling of sediment behaviour near the hydropower infrastructure, or downstream of the impoundment; and
- The FS draws heavily on existing papers and reports for sediment transport information but does not include reference or comparison to the sediment modelling projects that have been completed as part of the Upper Laos PDR Cascade Case Study for the MRC, or for the Council Study. These investigations have included complex sediment models that should be used to compare the results.

The developer has indicated that a 3D bathymetric survey of the area between the dam site and the Nam Ou confluence has been carried out, that bathymetry of the impoundment at 500m intervals, and a LiDAR survey of the area to be impounded have been undertaken. They indicate that this provides a very detailed investigation which provides a sound and sufficient basis for future modelling. It is recommended that these analyses are shared as part of the JAP process.

4.4.3. Design and operational recommendations

COMMENTS ON INFRASTRUCTURE AND OPERATIONS

The operations of the proposed LPHPP will be affected by, and potentially affect, numerous other hydropower projects. The immediate downstream area has a high population and is designated as a World Heritage Site. The river is heavily used for tourism and navigation, which will be affected by the combined operations of the hydropower projects in the region. The infrastructure and operating regime at LPHPP should therefore provide flexibility such that operations can respond to a range of conditions or needs.

The size and design of the LLO are similar to those for Xayaburi, suggesting that the sediment loads could be passed through both impoundments under coordinated operations. Because of the similarity in design, the physical model results from Xayaburi have been scaled and applied to the LPHPP project, while site-specific hydraulic testing for Luang Prabang was planned. However, the results of these studies have not been shared. It would be useful to include monitoring data from Xayaburi showing the effect of using the LLO during high flow events with respect to sediment transport. This could include channel cross-sections showing sediment

deposition at the dam wall before and after use of the LLO at different flow rates or estimates of sediment discharged from the station at different water levels or estimates of downstream channel scour associated with the operations.

With respect to the operation of the LLO:

- The FS only discusses use of the LLO during periods of high flow when the project is spilling. This only mobilises a small volume of sediment from a cone directly upstream of the LLO, with little or no movement of sediment in the main impoundment. The FS does not discuss sediment management with respect to manipulating water levels to maximise sediment throughout the impoundment. The developer has confirmed that these approaches are not planned in the operating regime, but that this can only be done as part of cascade operations.
- The LLO will operate when the flows exceed 5,335 m³/s. This will only occur for about 5 to 7% of the time, but most likely on at least on a yearly basis. However, additional modelling that simulates how much sediment would be discharged through the LLO on an average, dry and wet year would be useful to provide an estimate of sediment input into the Xayaburi HPP as related to sediment movement through the cascade.
- The combined operation of the surface gates and the LLO will govern how much water is discharged through the latter. More discussion of the interaction between the LLO and surface spillway is therefore required to assess the impacts of sediment transport in floods (> 8,885 m³/s).
- Other aspects of sediment management that require additional information or clarification include:

How sediment discharges released from the LPHPP will interact with the discharge from Nam Ou, or affect the backwater of the Xayaburi HPP are not addressed; and

There is no infrastructure or management actions described related to the potential accumulation of sediment along the left bank closure structure, or to reduce sediment input to the powerhouse. The channel leading to the LLO may be intended to direct bedload away from the powerhouse, but this is not discussed. In discussions the developer has suggested that dredging upstream and downstream of the left bank closure structure is likely to be required.

4.4.4. Project monitoring and adaptive management

The FS briefly describes monitoring during the final design, construction and operations, including the following:

- Measurement of suspended sediment at the dam site, Luang Prabang town, and Chiang Saen, using appropriate techniques and aligning with ongoing monitoring programs such as the DSMP where feasible.
- Measurement of bedload at the dam site and two other sites.
- Determination of grain-size distribution on the collected suspended and bedload samples; and
- Determination of grain-size for additional bed material samples collected from the proposed area of impoundment.

The developer has indicated that sediment monitoring has been initiated, and that the results will be incorporated into the study in subsequent project phases. It is recommended that these data are shared as part of the JAP process.

COMMENTS ON MONITORING

It would have been beneficial for the developer to implement sediment monitoring at an earlier stage to allow inclusion of some site-specific results in the FS and allowed comparison of the assumed sediment load at the dam site.

The proposed monitoring is not described in detail, with the number of proposed sites to be monitored indicated, but no details regarding exact locations, monitoring frequency or field methods to be used, are provided. In general, the proposed approach appears to be aligned with the PDG 2009, but due to a lack of detail it is not possible to evaluate alignment with the Guidance. There is no discussion of proposed monitoring of the impounded area following inundation in the main FS, although monitoring bank erosion is mentioned in the EIA. The developer has suggested that erosion of the banks is not critical as the water level fluctuations are limited to 50 cm and are only to provide a safety buffer for operations and are not daily operational changes.

4.4.5. Alignment with the PDG 2009

Overall, the developer draws on reasonable and consistent information to provide an early basis for assessing the sediment related impacts of the project. However, many of the topics included in the PDG 2009 are only addressed at a general level, with insufficient detail to allow an evaluation of alignment. Important topics that require additional detail include:

- The proposed approach for sediment management and minimising transboundary impacts is limited to opening the LLO during periods of high flow. This approach will not maximise the sediment transport downstream. In December the developer confirmed that sediment flushing, or routing is not planned. This is contrary to the PDG 2009 which recommends sediment routing and flushing as the best approach for minimising downstream and transboundary impacts. However, the developer has indicated that the infrastructure does allow for these sediment management options, but that these must be developed as part of the cascade management system; and
- The LPHPP is in a hydrologically complex area, due to the downstream confluence of the Nam Ou and Mekong Rivers, the backwater of the Xayaburi, and numerous upstream existing and proposed upstream dams. This development, and all subsequent developments, will require a high level of coordination and operation with existing and future projects to minimise transboundary impacts. It would have been useful to describe the range of cooperative actions that could be applicable to the cascade, and to suggest potential ways to develop coordinated operations.

Due to these omissions, and due to the general nature of much of the other information presented, many of the topics contained in the PDG 2009 are rated as 'not aligned' with the PDG 2009 or 'not enough information to assess' in Annex B, and overall the FS level is considered to not align with the PDG 2009. The developer has indicated that work is ongoing, and that additional information will be provided but none has been received by the completion date of this TRR.

4.4.6. *Considerations for the JC*

The JC may wish to take note of the following:

- The data from the sediment monitoring currently underway should be shared as part of the JAP process.
- More attention needs to be paid to potential impacts in the reach immediately downstream of LPHPP extending to the backwater of the Xayaburi project and related to the impacts of the Nam Ou cascade.
- Strategies that promote the rapid movement of material downstream and through the impoundment, such as sediment routing or sediment flushing, are recommended by the PDG 2009 and should be developed as part of cascade operations by the Government of Lao PDR and / or the MRC.
- It would be useful to monitor sediment flushing operations at Xayaburi showing the effect of using the LLO to support the final designs for the LPHPP, and to share this information with the MRC.
- More robust sediment transport modelling should be applied, to support the development of cascade sediment management operations.
- The long-term transboundary impacts of sediment trapping are underestimated, and the short-term impacts must be considered permanent unless substantial measures to minimise these impacts are included.
- Many of the topics included in the PDG 2009 are not addressed or only addressed at a general level, with insufficient detail to allow evaluation of alignment.
- Overall, the FS level design is considered to not align with the PDG 2009.

4.5. Water Quality and Aquatic Ecology

Key features of the water quality and aquatic ecosystems review:

- ▶ The LPHPP documentation provides a good overview of the water quality and aquatic ecology largely based on data obtained from the MRC and two field surveys carried out in February and November 2019.
- ▶ Currently water quality in the upper Lao reach of the Mekong is very good and suitable for protection of aquatic life, human health and for agricultural use.
- ▶ However, there is no discussion of possible changes due to future developments and the LPHPP.
- ▶ The water quality data reported by the developer reflect a risk of eutrophication in the impoundment.
- ▶ The reported monitoring for water quality and aquatic ecosystems is limited and not sufficient to establish a baseline. However, the developer has confirmed that monitoring is ongoing and will follow the requirements specified by the GoL, and that the monitoring programme will be presented for evaluation. This is not yet been provided.
- ▶ Construction will affect water quality, but this can be managed against established management protocols.
- ▶ The ongoing water quality monitoring programme is not elaborated in detail, and the adaptive management and response measures are not described.
- ▶ The loss of most of the free-flowing section of the Mekong between the LPHPP and the Xayaburi headwaters, due to higher operating levels at the latter, is critical.
- ▶ The loss of rapids and riffles by the impoundment upstream of the LPHPP right up to the base of the PBHPP removes the habitat for many of the species that form much of the catch in this zone of the Mekong mainstream.
- ▶ The developer has proposed ongoing monitoring programmes for water quality and aquatic ecosystems, but no indication is provided as to how this will be used to support adaptive management.
- ▶ No budget is specified for the monitoring programmes.
- ▶ It is recommended that the developer applies the methodologies developed under the MRC's Joint Environmental Monitoring programme.
- ▶ The establishment of the baseline and the ongoing monitoring is not fully compliant with what is recommended under the PDG 2009.

4.5.1. Objectives

Water quality and aquatic ecology of rivers are impacted by hydropower development, although the extent of these impacts depends on the infrastructure and operational design of the HPP. The impoundment of water, even behind run-of-river schemes, changes the physical and chemical environment affecting the available habitats for species that are adapted to a flowing water regime. The water quality issues associated with hydropower development differ between the construction, immediate post-impoundment and operational phases and can affect the fitness of the water for use.

The draft PDG2019 outlines the objectives of the guidance for water quality are to:

- i. Reduce the risks that water quality within the impoundment will impact the use of the impoundment for other purposes, such as fisheries, or impact on human health, or cause interference with, and damage to, hydropower infrastructure such as turbines.
- ii. Minimise water quality impacts downstream of the dam on fisheries, aquatic ecosystems and human health and other users.
- iii. Ensure alignment with the Procedures on Water Quality, which seek to maintain the water quality of the Mekong River mainstream.

It outlines the objectives for the aquatic ecology guidance are to:

- i. Protect and conserve aquatic habitats as far as practicable during the development and operation of mainstream dams.
- ii. Minimise the impacts of the construction and operation of hydropower dams on the aquatic ecology and ecosystems of the lower Mekong River system.
- iii. Reduce the risks of the proliferation of pests, parasites or diseases within aquatic ecosystems in hydropower impoundments on the Mekong mainstream.
- iv. Sustain aquatic ecosystems reliant on the flow regimes of the river.

4.5.2. Pre-project monitoring and analysis

WATER QUALITY

Currently water quality in the upper Lao reach of the Mekong is very good and suitable for protection of aquatic life, human health and for agricultural use (Table 4-3).

The LPHPP documentation includes a review of data from the MRC water quality network and a surveys carried out in February and November 2019. This survey included water quality field sampling and analysis at four stations in the Mekong River upstream and downstream of the LPHPP dam site and one site in the Nam Ou. Five surface water samples were taken at each location using standard methods. A wet season sampling was planned for May 2019, but these data have not been provided.

Table 4-3 The water quality classes for the stations in the upper Mekong mainstream in the Lao PDR from the MRC State of the Basin Report.

A: Excellent; B: Good; C: Moderate; D: Poor; E: Very Poor.

Station No.	Name	Country	Class									
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Protection of aquatic life												
1	Houa Khong	Lao PDR	A	A	A	A	B	B	B	B	B	B
2	Chiang Saen	Thailand	A	B	B	A	B	B	A	B	B	B
3	Luang Prabang	Lao PDR	A	A	B	A	A	B	B	B	A	B
4	Vientiane	Lao PDR	A	A	A	A	A	B	B	A	A	A
Protection of human health												
1	Houa Khong	Lao PDR	A	A	B	A	B	B	C	A	A	A
2	Chiang Saen	Thailand	B	B	B	A	B	B	B	B	B	B
3	Luang Prabang	Lao PDR	A	A	B	A	B	A	B	B	B	A
4	Vientiane	Lao PDR	A	A	B	A	B	B	B	B	B	A
Agricultural use												
1	Houa Khong	Lao PDR	A	A	A	A	A	A	A	A	A	A
2	Chiang Saen	Thailand	A	A	A	A	A	A	A	A	A	A
3	Luang Prabang	Lao PDR	A	A	A	A	A	A	A	A	A	A
4	Vientiane	Lao PDR	A	A	A	A	A	A	A	A	A	A

The developer notes that the water quality was mostly in the MRC Classes A and B. Some sites where lower-Class scores were noted had slightly elevated levels of nitrate-nitrogen and

ammonium-nitrogen, high TSS concentration, plus high coliform bacteria counts. This probably reflects the increasing riparian human population in this reach. However, there is no discussion of changes in water quality in the region over time or how future developments, particularly arising from human population growth and urbanisation, might affect the water quality. These changes will affect water quality in the impounded reach and downstream of the dam, which could be exacerbated by the LPHPP. The data reflect a risk of eutrophication in the impoundment, especially during the construction and filling phases.

However, the surveys undertaken to date, even if supplemented by data from the literature, do not yet establish a baseline against which to measure any changes. It is usual to include several years of sampling prior to the development to show diel as well as seasonal variations in water quality. It is, therefore, recommended that the planned water quality monitoring is initiated as soon as possible and is expanded in scope to provide a more comprehensive baseline before construction starts.

AQUATIC ECOLOGY

The documentation notes the objectives with respect to Aquatic Ecology, are as follows:

- Protect and conserve aquatic habitats as far as practicable during the development and operation of mainstream dams.
- Minimise the impacts of the construction and operation of hydropower dams on aquatic ecology and ecosystems of the lower Mekong Rivers system.
- Reduce the risks of proliferation of pests, parasites or diseases within aquatic ecosystems in hydropower impoundments on the Mekong mainstream.
- Sustain aquatic ecosystems reliant on the flow regimes of the river.

The baseline assessment comprises a review of fisheries studies, data from two field surveys carried out in February and November 2019 for plankton and benthos, as well as a review of data collected during previous studies carried out for the Xayaburi (2010) and Pak Beng (2013) prior consultation processes, and surveys by the XHPP developer as part of the concession agreement.

The results of the phytoplankton, zooplankton and benthic macroinvertebrate surveys were variable. Total densities and diversity of phytoplankton and zooplankton were consistent with samples taken at Xayaburi and Pak Beng, but the diversity and abundance of benthic macroinvertebrates were inexplicably low in both surveys and possibly reflect the sampling methodology.

Again, the developer indicated that wet season sampling was planned for May 2019 to further assess the impacts of the project on aquatic biodiversity, but the results have not been provided.

The sampling design and extent of the surveys are also limited and not consistent with international or MRC standards. There is little attempt to relate plankton and benthic invertebrate surveys to previous results from MRC studies. The monitoring programme therefore does not yet establish a baseline status to assess future changes.

The MRC's Aquatic Ecological Report card system defines the following Classes:

- **Class A (Excellent):** 10 - 12 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity to support fish and other freshwater functions are similar to those at reference sites.
- **Class B (Good):** 7 - 9 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity are slightly less than that at the reference sites. Human activities may have caused some disturbance.
- **Class C (Moderate):** 4 - 6 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity are markedly less than at the reference sites. Disturbance resulting from human activities is present.
- **Class D (Poor):** 0 - 3 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity are significantly less than that at the reference sites. Various disturbances from human activities are likely to be present.

Table 4-4 The Aquatic Ecological Health in the northern LMB (from the MRC Report Cards).

Site Code	Location	Year				
		2005	2006	2007	2008	2011
Lao PDR						
LMX	Ban Xiengkok Luangnamtha	B			D	D
LPB	Done Chor, Luang Prabang	A			B	A
LVT	B. Huayhome, Vientiane			B	C	C
Thailand						
TCS	Chiang Saen				B	B
TKO	Nam Kok at Chiang Rai	A			A	B

Table 4-4 shows that as of 2011 the Mekong River in the vicinity of the LBHPP was still relatively unaffected by human activities.

There is some comment on the impacts of the LPHPP on potential changes in aquatic habitats in downstream reaches or in the inundated area of the reservoir. A survey of the geomorphology of the reach has been done but this is not specifically related to the loss of these habitats. The river will be impounded for some 156 km with a total loss of riffle habitats up to the Pak Beng HPP. These are important for benthic macroinvertebrate species. This will likely lead to loss of species from the region. There is no analysis of the value and uniqueness of these aquatic habitats or an assessment of their ecological significance in the context of the whole LMB. There is also no analysis of the impacts of changes in flow regime on in-channel habitats, especially the potential inundated area.

The developer has indicated that the assessment of the habitats that may be lost is ongoing. However, no data have been shared yet. It is recommended that these data are shared as part of the JAP process.

Studies of terrestrial fauna and flora were also undertaken, including forestry products and wildlife in the Luang Prabang HPP area of influence. Species lists of various faunal groups were provided, highlighting their IUCN conservation status. Several tree species, reptiles, amphibians and birds were indicated as threatened but no specific actions to protect them were outlined.

4.5.3. Potential impacts and measures

The developers have provided an assessment of the likely impact of the LPHPP on the physical, chemical and biological components of the river ecosystem. These reflect the intensity, extent and duration of anticipated potential positive and negative impacts. These differ between the pre-construction, construction and operational phases as highlighted in the following sub-sections.

PRE-CONSTRUCTION AND CONSTRUCTION PHASES

The river and adjacent terrestrial ecosystems will be subject to considerable impacts during the construction phase, which will impact water and habitat quality, with corresponding impacts on the aquatic ecology and fisheries. Activities such as excavation, earthworks and transport of construction materials can affect water quality if not managed against established management protocols. They can lead to substantial increases of suspended solids, oils and chemical spills. In addition, improper disposal of waste materials, especially organic and domestic wastes, can cause substantial environmental damage resulting in degraded soil, water and air quality. However, good practice guidelines indicate that with correct monitoring, mitigation and implementation, these impacts are expected to be minimal.

The developer outlines the possible impacts of construction on surface water quality, noting the potential increase in suspended solids due to site clearance and earthworks, increases in BOD due to additional organic matter in sewage water from construction camps, and contamination with oil from operation and maintenance of plants. However, the developer indicates that measures will be put in place to minimise impacts. These include:

- Site preparation activities to be carried out in the dry season to avoid run-off of sediments.
- Surrounding the construction site by temporary ditches to trap sediment runoff.
- Roofing of potential contamination areas to prevent contaminated run-off.
- Installation of a wastewater treatment plant for worker camps.
- Installation of toilets for workers away from the watercourses.
- Install contaminant treatment facilities to meet water quality standards before discharge.
- Install oil traps and settling ponds before release to the environment; and
- Monitoring and maintenance.

While these measures will limit the sediments and contaminants reaching the watercourses, they should be supplemented by measures to reduce the risk of contamination at the source. Despite these measures, soil erosion, bank side collapses, spillages and accidents and malfunction of wastewater treatment plants will most likely occur. This will have a temporary impact on water quality downstream, particularly in the low flow seasons.

The developer has proposed a water quality monitoring programme during the construction phase, but this is highly descriptive, and it is unclear how the contractor will respond to any problem encountered. A more proactive plan for monitoring and managing potential impacts during construction should be presented, including monitoring key variables continuously and warnings linked to rapid response protocols. The developer has indicated that the relevant GoL legislation regarding water quality monitoring will be implemented. However, this needs to be elaborated for review in the transboundary context.

The flooding of terrestrial vegetation causes elevated high BOD and lowering of dissolved oxygen in the impoundment and in the immediate downstream reach if the water is released. This typically occurs in the first 5-7 years after flooding and is a major problem that should be mitigated. The developer proposes dealing with this by removing surplus vegetation in the reservoir area prior to impoundment. However, removal of vegetation can result in reduced

productivity of the reservoir and poor fish production. It is therefore recommended hard wood vegetation is removed selectively and areas left to enhance protection of the fish stocks by creating zones that are difficult to fish, and to enhance food resources for the fish through epiphyton on the woody debris.

OPERATIONAL PHASE

The EIA highlights water quality problems that may arise during the lifetime of the project. These are typical of HPPs on the Mekong mainstream, and the following, drawn from the Pak Beng TRR, apply:

- *Impacts due to erosion/sedimentation:* Erosion and sedimentation can take place in the reservoir where degraded forests exist. Sedimentation in the reservoir reduces the downstream transport of sediments. The 'sediment hungry' outflows from the reservoir may induce erosion and a scouring downstream.
- *Impacts due to wastewater discharge* due to increased human activities around the reservoir and along the riverbank. The development will possibly stimulate the expansion of communities, industries, agriculture, aquaculture and tourism along the Mekong. If the management of wastewater and solid waste is inadequate, new sources of pollution would negatively impact water quality. These water quality changes could have an impact on aquatic organisms, resulting in loss of biodiversity and potential fish production. Appropriate urban and land-use planning, and control measures are required to minimise these impacts.
- *Impacts due to agriculture and aquaculture:* Following inundation, agriculture and aquaculture activities are likely to expand. These can have direct impacts on water quality from fertilizers and pesticides, which introduce nutrients and toxic substances that contaminate the river. Aquaculture could also cause high organic loads in the river due to feeding the fish. This can cause algal blooms, although this may only be a problem at lower flows. Good practice in agriculture and aquaculture is necessary to prevent eutrophication as well as safeguard the ecosystem.
- *Impacts due to navigation and oil spills:* Impacts on water quality from navigation can stem from wastewater, grease and oil being discharged directly into the river from vessels. Oil spills might result from accidental leakages. Waste treatment and anti-oil spill measures should therefore be provided at the navigation facilities.

Sediment flushing can have serious impacts on the downstream habitats and biota caused by smothering of habitat and loss of aquatic invertebrate fauna, which acts as food for fishes. Fishes are also vulnerable to smothering of eggs and spawning habitat of the many rhithron/rheophilic fish species that inhabit this region of the Mekong. These species, which contribute significantly to the fisheries, will likely be lost due to inundation of their preferred habitat (see the Fisheries section). None of these issues have been addressed in detail in documentation, and there is little emphasis on the impact of the LPHPP on aquatic ecology. The developer suggests that the long-term impacts will be local and like those described for the construction phase.

The water monitoring programme proposed for during the construction phase is presumed to be carried on through the operational phase, although it is unclear if modifications will be made as the new data allow better understanding of potential changes. It is therefore important that robust water quality monitoring protocols, that are responsive to the likely impacts, are

presented. The institutional arrangements for environmental management are outlined, but it is unclear how the plan will be implemented and enforced.

MODIFIED FLOWS AND HABITAT

The ecological integrity of a river depends to a high degree on the hydrological regime. The LPHPP will change some 156 km of river from a flowing to largely impounded, slower-flowing water body. The loss of rapids and riffles removes the habitat for many of the species that form much of the catch in this zone of the Mekong mainstream. This includes many locally endemic and nationally/globally threatened species. Many drifting of aquatic organisms, especially the egg and larval stages of fish, use flows to disperse downstream to nursery and feeding habitats. Generally, velocities greater than 0.3 m/s are required to maintain this drift of fish larvae. As the hydrology section has noted, velocities will, post closure of the dam, rarely go above this threshold for the full length of the impounded reach. Recent hydrodynamic modelling data received (March 2020) indicate that for a discharge of 2,620 m³/s, maximum cross sectional velocities through the last 40 km of the impoundment upstream of the dam will be below 0.3 m/s. Flows will be lower than 2,620 m³/s for some 70% of the time. Notwithstanding the comments on the modelling of velocities outlined in the hydrology section, it is unlikely that enough downstream drifting larvae will make it through the impoundment to maintain viable populations. Minimising this problem requires reducing operating levels in the reservoir at certain times, compromising hydropower output. The implications of this are addressed elsewhere in this TRR. Mitigation measures to address lost fish and other aquatic animal production need to consider wider options beyond stocking and fish farming in the impoundment, e.g. to explore use of off-setting and creation of artificial wetlands and lagoons to increase productivity.

The free-flowing stretch of river between the LPHPP and the Xayaburi HPP backwater will be the last remaining habitat for many important Mekong fish. The developer has indicated that this is likely to be only some 12 km long. This, while negligible compared to the length of flowing river that will be lost, would still be important as a last refuge for critical species, including the iconic Mekong giant catfish that is thought to spawn around the confluence with the Kham River.

The hydrology section above has noted that the tailwater rating curve for the LPHPP is currently being updated based on improved bathymetry data and considering the Nam Ou tributary. The sediment section has noted that scouring of the reach immediately downstream of the LPHPP is likely to occur due to the discharge of sediment hungry water. It is therefore important that the updated tailwater rating curve study is shared, that the potential impacts on the habitats in the free-flowing section be quantified, and that special measures to preserve any remaining critical habitats are developed.

4.5.4. Project monitoring and adaptive management

THREATENED SPECIES

The LPHPP EIA provides an overview of the most important biological resources in the upper zone of the LMB in the proximity of the LPHPP development. The region supports a rich fauna and flora, with many endemic species (only found in this region and nowhere else globally). Many are also reported to be threatened, including some iconic Mekong species. However, while the EIA lists endangered and vulnerable aquatic organisms and suggests potential impacts, it does not recommend specific monitoring or management plans for these species.

Less attention is paid to the aquatic habitats and their ecological importance, particularly the loss of flowing water habitat behind the dam structure, and the documentation focusses on the fish migration aspects. The documentation indicates that the stretch of river upstream of the PBHPP should be maintained to preserve this habitat. This will require the migrating species to pass through all 5 of the cascade dams. This is of growing importance within the upper Laos cascade of dams where habitat is being lost by the series of impoundments. (This is dealt with in more detail in the Chapter on Cumulative and Transboundary Harmful Effects.) It is, therefore, likely that some of the threatened species could become extirpated (locally extinct) should the full cascade of dams be developed. There is consequently a need for a robust, appropriately designed and long-term biodiversity monitoring and evaluation programme.

WATER QUALITY AND AQUATIC ECOSYSTEM HEALTH

The developer proposes that post-construction monitoring is based on the results of the pre-construction monitoring. This is normal protocol but requires sufficiently robust pre-construction monitoring. The current proposal for water quality and aquatic ecology monitoring includes the same parameters and methods as well as frequency of sampling as the preliminary monitoring described above. However, the EIA notes that iron and manganese analysis should be included to assess the risk of downstream release and deposition, as well as monitoring water transparency and turbidity in the impoundment. The sampling locations proposed are also different from the two upstream and three downstream stations sampled during the February 2019 surveys. It is not clear from the documentation provided whether the sampling frequency is quarterly or bi-monthly. The latter could mean either twice a month or once every two months. Monitoring for aquatic ecology parameters (plankton and benthos) is proposed at 5 sites, four times per year following standard techniques. This could use the MRC's Aquatic Ecosystem Report Card format for reporting.

However, there is no indication provided as to how the monitoring system will flag up water quality and ecological health issues, and how the operators will respond to problems encountered. No budget has been described for the environmental monitoring. The ability to identify and react to impacts through adaptive management will therefore be limited.

4.5.5. Alignment with the PDG 2009

The LPHPP documentation provides a good overview of the water quality and aquatic ecology largely based on data obtained from the MRC and field surveys carried out in February and November 2019. However, the PDG 2009 requires longer periods of monitoring covering the full hydrological cycle. This baseline monitoring should therefore be expanded prior to construction.

There is also no evidence of the establishment of a core group of independent experts to assist with the design of the monitoring programmes as is required under clause 88 of the PDG 2009. The developer has however indicated that they use internationally recognised companies and experts to design, perform and supervise the monitoring. It is recommended that the methodologies outlined in the MRC's Joint Environmental Monitoring are adopted.

Annex B provides a more complete evaluation against the requirements of the PDG 2009.

4.5.6. Considerations for the JC

As with in the sediment section, the developer has made better use of the data available through the MRC. However, the monitoring should be expanded to provide a firmer baseline against which impacts can be measured. It is recommended that:

- The monitoring programmes align with the JEM protocols, and that the data be shared as part of the JAP process.
- This monitoring should continue throughout the construction and operational phases and be supported by dedicated and specified budgets.

The lost habitat, particularly for species that require flowing water, needs to be quantified. Given that this is due to the cumulative impacts of the full cascade, lost habitat should be identified all the way upstream from the future Sanakham HPP to Chiang Saen. This lies beyond the remit of the developer and should be done by the GoL and / or the MRC.

4.6. Fisheries and fish passage

Key features of the fisheries and fish passage review:

- ▶ The Mekong River System is home to the world's second largest fish diversity and the largest inland fishery valued at some \$11 billion / yr.
- ▶ Considerable fishing activity takes place in the area of the LPHPP, mainly based on the migratory fish species. The catch is estimated at some 40,000-60,000 t/yr of fish in the zone upstream of Vientiane. These fisheries are important as a source of protein and income for many of the riparian communities in this upper zone.
- ▶ The documentation provides an extensive review of the fisheries in the LMB but does not make use of information and data from the most recent studies.
- ▶ The monitoring of fish abundance and diversity and fisheries in the initial documentation is limited. Additional data from surveys at LPHPP have been provided after the 3rd JCWG meeting on 05 March 2020, but this monitoring remains limited. A robust monitoring programme should be established to provide a comprehensive baseline against which to measure change.
- ▶ It is recommended that the LPHPP monitoring is based on the procedures outlined in the Joint Environmental Monitoring programme.
- ▶ There is limited information on the socio-economic importance of the fisheries to food security and rural livelihoods, and number of people affected.
- ▶ The current feasibility level design of the fishpass facilities is not likely to function as intended.
- ▶ This section of the TRR makes recommendations for the redesign of fish pass facilities (Table 4-5). If implemented these design changes are likely to yield substantial benefits.
- ▶ The LPHPP will affect both upstream and downstream migration. Minimising this problem is possible but will compromise hydropower output and / or entail additional construction costs.
- ▶ Mitigation measures to address lost fisheries need to consider wider options beyond stocking and fish farming in the impoundment.

Note: *The developer has indicated that the fish pass design is at the feasibility stage, and that the comments provided in the TRR are noted and will be considered in an optimization of the current concept. They have nonetheless indicated that they disagree that the fishpass facilities will not function as intended.*

4.6.1 Objectives

The Mekong River System is home to the world's second largest fish diversity (after the Amazon) and the largest inland fishery with a value of some \$7 billion. Fisheries are vital to sustaining the livelihoods and food security of many of the rural poor in the basin. Artisanal fisheries are also vital to the economies of the Member States. However, many species are migratory, some migrating along the full length of the Mekong in the Lower Mekong Basin. Generally, the total fish biomass and diversity increases downstream, but fisheries are still an important component of food security and economies in the Luang Prabang region. It is therefore important to enable upstream and downstream migration as much as is viable, and the inclusion of fishpass facilities at mainstream HPPs has become standard practice.

The draft PDG2019 indicates that the objectives in this regard are to:

- i. Maintain fisheries and other aquatic animal (OAA) yields and fish diversity sufficient to sustain the food, livelihoods and ecological integrity of the Lower Mekong Basin.
- ii. Minimise the impact of dam construction and operation on upstream migration of fish species through design of appropriate fish passage facilities, where necessary.
- iii. Minimise the impact of dam construction and operation on downstream movement of fish species through design of appropriate operational regimes, fish passage facilities, fish guidance systems and appropriate turbine designs.
- iv. Minimise fish and fisheries impacts arising from changes in the flow regime downstream of the dam, in the impoundment, and upstream.
- v. Mitigate impacts of individual and multiple mainstream dams on local and transboundary fish and fisheries, and OAAs.

This section firstly provides comment on the fishpass facilities proposed for the LPHPP, and then highlights issues relevant to fisheries impacts.

4.6.2 Potential impacts

FISH MIGRATION

Given the high diversity of species and complexity of their life cycles, Mekong fish species are nominally categorised into 10 guilds based on their main habitat requirements and migratory traits, plus an additional category (G11) for non-native invasive species (Table 4-5). These include a number of migratory 'guilds' that move up and downstream along the mainstem of the river and/or into tributaries to complete their life cycles. The main migratory guilds present in the LPHPP area are long (G2) and short (G3) distance migratory white fishes, grey fishes (G4) and anadromous species (G8). In addition, rhithron species (G1), are resident in the local area (Ecological Zone FA1) and inhabit shallower riffle zones and are important in terms of diversity and their contribution to the catches.

Table 4-5 Contribution of different fish species guilds to diversity in different zones of the upper Mekong in Laos. The Guilds highlighted in red are likely to be affected by the upper Lao Cascade. (after MRC Council Study, MRC 2017)

Ecological zone	Guild categories											Total
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	
FA1	67 (44)	9	41	29	19	20	2	1	1	0	20	209
FA2	83 (38)	11	68	58	28	32	2	1	1	0	12	296
FA3	77 (31)	11	73	57	30	32	5	1	1	0	13	300

The general understanding of fish migration patterns in the Mekong is that there are three main systems, the lower zone below Khone Falls, the zone upstream from the falls to Vientiane and the third zone upstream of Vientiane (Figure 4-5), and this is acknowledged in the LPHPP EIA report. However, there are also many species that migrate between these zones, and some species (possibly as many as 30 and mostly commercially valuable white fishes) that migrate longer distances between zones. Migratory species require unobstructed passage upstream, as well as the capacity for adults, larvae and juveniles to migrate or drift downstream.

The timing of these upstream and downstream migrations is variable depending on fish life cycles and appears to mostly driven by the flood cycle, but importantly, there appears to be continuous spawning in the river with peaks during the spring (February-March) as the most important, followed by the onset of the flood (June-July) and then when the water is receding (November).

The LPHPP site and impoundment are in Zone 1 of the Mekong's Ecological Reach (MRC 2010), which is associated with the spawning habitat of several important species, including the endangered Mekong giant catfish. Although the precise number of species in the region is unknown, 209 species are indicated in the MRC's fish species database as having been found in the upper Zone (Table 4-5). However, many species, especially the rhithron guild (Guild 1), are exclusively found in the headwaters of tributaries and are not found in the impact area. Fish catch monitoring carried out by LARReC between 2007 and 2013 found about 70 species caught in gill nets alone. These records are consistent with the number of fish species (81 fish species from 18 families) recorded in the LPHPP EIA in February 2019 and the cumulative number of species (107) found in four surveys conducted in 2019.

Of concern, are the potential impacts on rhithron and long and short distance migrating whitefish species (Guilds G1, G2 and G3), which make up most of the catch in the upper zone. The MRC Council Study shows that disruption of the migration pathways, using the DRIFT

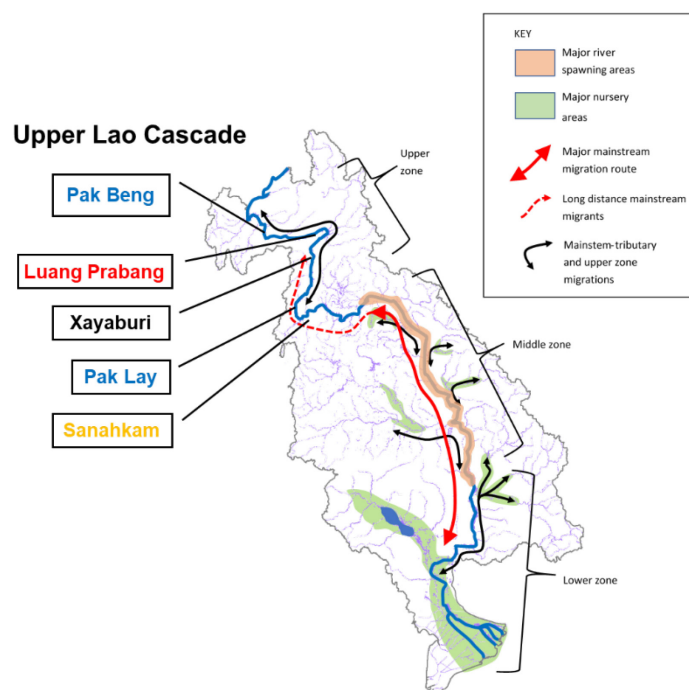


Figure 4-5 Map of migration systems in the Lower Mekong Basin (Source: DG2018). Showing the location of the HPP in the upper Lao Cascade.

model, is likely to have significant impacts on these species. The dam itself will block migratory species and inundate the spawning habitats while drifting larvae are likely to be lost. Rhithron species will be lost from the impounded area as these species require flowing water habitats. There is likely to be a proliferation of non-native species, particularly common carp and Nile tilapia, which already comprise a high proportion of the catch in the impact area, and it is likely these will benefit from the changed environment and expand further, possibly eliminating native species. The dam will also likely inundate many deep pools that act as refuge areas for fish during the dry season. How these deep pools will respond to the altered flow and sediment dynamics is unknown. Several fish species found in the area are listed on the IUCN Red List of threatened species, but not all are listed in the EIA.

FISHERIES

Considerable fishing activity takes place in the area, mainly based on the migratory fish species. It is estimated that some 40,000-60,000 t/yr of fish are caught in the river system in the upper zone. In terms of the Basin fisheries, the upper part of the Mekong is not as productive as the middle and lower Mekong zones, which together produce approximately 2 million tonnes of fish per year. This production in the upper Zone is, however, highly likely to be compromised by the Luang Prabang HPP, as well as the rest of the upper Lao cascade. There is a proliferation of non-native common carp and tilapia from fish farms in the markets, which could potentially substitute for any loss of the capture fishery. However, it is unlikely this source of fish will benefit rural communities in terms of loss of fishing activity or food security. This is especially true for rural communities that will not have the capital to establish aquaculture production units.

Fishing generally occurs during the period of upstream migration of many species and is associated with increasing water levels. However, these species are not the only ones captured; a wide diversity of finfish species is found in the markets, including the non-native species, plus a range of amphibians, snails and Crustacea (OAA). OAAs are discussed in the CIA-TBIA as an important source of food, but the scale and value of this contribution is poorly defined.

In addition, considerable fishing activity takes place in the tributaries associated with this region and isolation of these tributaries or flooding out of the habitat also will likely compromise these fisheries.

4.6.3. Monitoring and impact assessment

Fisheries surveys were carried out at the same time and locations as the water quality monitoring - in the dry season. There is no indication of the sampling methods, but it is assumed to be either gillnetting or seine netting, both of which are highly selective. A total of 534 individuals, (dominated by a single species - *Sikukia gudgeri*) from 81 species, representing 18 families were caught in February 2019. 2206 individuals representing 107 species (again dominated by *Sikukia gudgeri*) were identified from 4 surveys carried during 2019 (February, June, September and November). This diversity reflects what is expected from the region, but the number of individuals caught was low and ongoing monitoring is recommended to establish the baseline for the fish community and population structures. This monitoring was supported by fish species surveys at local markets and interviews of 10 fishermen from five villages, the latter largely indicated the best time for fishing, gears used and how they disposed of their catch, but they were not consulted on recent trends in catches, especially since the construction of Xayaburi HPP.

In March 2020, additional information was received based on ARIS underwater acoustic camera surveys at LPHPP. These results are from four monthly surveys (Feb-May 2019). They provide counts of fish of different sizes moving up and downstream broken down into day and night for 8 days each month. No information is given of the proportion of images captured in different ranges of the ARIS equipment. Similarly, no information is given of the species imaged, just the size of individuals, which were mainly in the 10-20 cm size range. No interpretation of the information is given, nor are more recent data provided to show annual trends.

The EIA provides a review of endangered and vulnerable aquatic organisms, mostly fish species, in the area and suggests potential impacts could arise from the obstruction to migration and change in environmental conditions. It does not, however, suggest that these species will require special studies and management plans. There are also inaccuracies in the reported IUCN threatened status. One of the biggest impacts recognised, in addition to the major barrier created by the dam, was the change in hydraulic conditions upstream of the dam and the potential loss of deep pools in the impounded section. The EIA suggests the impoundment will, however, provide more deep-water areas, but does not recognise the impoundment will be very different habitat with a different functional role.

The SIA suggests that fishing is not the main occupation among local villagers in the project area, yet between 24 and 50% of households are engaged in fishing. No indication of the contribution of fishing to income or food security is provided. A few households have fishponds / tanks, presumably as some part of a fish farming activity, but the income generated is minimal. This suggests that that some households may have the skills, but not necessarily the resources or infrastructure, to farm fish should the need arise.

An extensive review of the fisheries in the LMB is provided but does not make use of the information provided in the MRC Council Study or the MRC fisheries database. The Council Study estimated a 40% reduction in short distance migrating whitefish in the upper zone and should be used to guide the ongoing design.

The developer notes that fisheries will be adversely affected by the disruption to migration and potential loss of endangered and threatened species both during the construction and operational phases, but little attempt has made to relate the fisheries stock dynamics to environmental changes brought about by the development and operation of the scheme. Modelling of the likely changes in structure and functioning of the in-channel habitat features should be undertaken to predict likely changes in the fish population and community structures and overall impact on the fisheries.

The baseline monitoring undertaken is considered inadequate, and a comprehensive monitoring programme should be established to provide a robust baseline against which to measure change during the final design phase. It is important that a fishery monitoring programme be set up and reviewed for robustness as soon as possible. This must be designed to assess any potential impacts, and to propose effective measures to minimise these impacts, or perhaps propose alternative mitigation measures to maintain people's livelihoods through offsetting should the potential cascade of dams cause irreversible damage.

SOCIO-ECONOMIC IMPORTANCE OF FISHERIES RESOURCES

The EIA, CIA-TBIA and SIA describe the importance of the fisheries to the livelihoods both in the LPHPP impact area and elsewhere in the LMB. However, it was concluded that fisheries are not important to the region where the LPHPP is planned, and that the effect of the dam on the fishing communities would be limited to the immediate dam area. These two conclusions are

incongruous and the importance of fish to food and nutritional security in the LPHPP area seems to be underestimated.

The CIA-TBIA gives some indication of the importance of fish as a source of food in Lao PDR. However, the data used are outdated and more recent MRC data provide a better reflection of the importance of fish to diets in the LPHPP impact area. The CIA-TBIA also attempts to estimate the fish production in the impoundment to compensate for the lost river fisheries. The crude calculation based on the surface area of the impoundment and production per unit is likely to overestimate the potential production and underestimate the consumption of fish.

Unfortunately, there is limited information on the socio-economic importance of the fisheries to; food security and rural livelihoods, the number of people affected and the loss of ecosystem services to rural communities. What information is available appears contradictory and fragmented, and it is recommended that a more comprehensive baseline on the socio-economic importance of fisheries to the potentially affected people is established. This should include non-timber forest products and OAA. To this end it is suggested that more extensive surveys, at least monthly, are initiated.

The developer has indicated that regular fish monitoring is ongoing and is based on the Xayaburi experiences. It is recommended that these data are shared as part of the JAP process.

4.6.4. *Fish pass facilities*

PRINCIPLES OF FISH PASSAGE DESIGN

Attraction and Passage

Fishways, whether technical or nature-like, require consideration of two criteria:

- i. *attraction* (i.e. to the fishway entrance), and
- ii. *passage*

These are interdependent: if fish are not *attracted* to the fishway or cannot locate it, they cannot use it; equally, if they can locate the fishway but passage conditions are poor fish cannot use it.

Effective *attraction* is dependent on three characteristics:

- i. *Proportion of flow*

The higher proportion of river flow in the fishway the greater the attraction for fish.

- ii. *Upstream limit of migration*

Migrating fish swim upstream, attracted by the flow, to the limit of migration; this is where a fishway entrance needs to be located. A good example of using this aspect of fish behaviour in the Mekong River, is the location of lee traps by fishers at Khone Falls, which are adjacent to natural migration barriers.

- iii. *Discrete flow for fish to locate*

The flow from a fishway needs to be readily distinguishable to migrating fish and not masked by turbulence or competing flows.

Effective *passage* is dependent on:

i. Fish behaviour

Fish behaviour relates to attraction and passage. In attraction, it includes search patterns below a structure, response to turbulence, and response to different channel morphologies. In relation to passage an important aspect is the minimum water depth that fish require. This is not a single figure but interacts with width (e.g. channel width) and longitudinal spacing of different depths (e.g. resting pools may need to be deeper). Other behavioural aspects that can be important include the response of fish to light and tunnels, and diel movement patterns.

ii. Swimming ability

In rivers, channels and fishways, fish negotiate water velocity and turbulence. In fish passage design these characteristics need to be within the burst, prolonged and sustained swimming ability of fish. These swimming modes utilise anaerobic and aerobic metabolism and they vary between sizes and species. There is also a behavioural element to consider where some species use boundary layers (layers of low water velocities adjacent to surfaces) more effectively than others.

EVALUATION OF PROPOSED MEASURES

The principle of the weakest link is central to fish passage design. Each component of the fish passage solution (upstream and downstream) needs to be effective; otherwise the weakest link will set the standard, and effectiveness, of the entire system. Thus, even if there are significant investments in infrastructural measures, if these are not matched by operational measures to promote downstream larval drift and the availability of upstream habitat for spawning, populations of migrating fish will decline.

The LPHPP developer has chosen to follow the MRC draft Preliminary Design Guidance (PDG2019) with the objective of designing the fish passage facility to operate all year. The most recent data from the Xayaburi HPP show high levels of upstream migration during the dry season and during the onset of the rainy season. Those data suggest a key season of upstream migration and can be used to identify periods of low migration when maintenance of the fish passage facilities would have minimal impact.

There are few data on downstream fish migration in the upper Mekong. For adult and sub-adult fish, it is more likely to occur at any time after the peak upstream migration in the dry and early rainy season and extend to the end of the rainy season. Hence the period of downstream migration could be from June to December, however, larvae have been found to drift downstream all year.

The fish passage facility has been designed according to the draft PDG2019 to operate from minimum flows to 10,650 m³/s. The minimum flow in the LPHPP hydrology report is 793 m³/s, although 1,170 m³/s has been used in the design. As fish are migrating upstream in low flows during the dry season, the water levels associated with the minimum flow of 793 m³/s, or as determined after the recommendations in the hydrology section are addressed, needs to be adopted for the design. This is particularly important as evidence suggests that flow regulation in China, while increasing flows in the dry season in general, can result in protracted periods of very low flows. The developer has however indicated that overall, the effect of the Lancang

Cascade is to increase dry season flows, and consequently that the 1,170 m³/s design flow is appropriate.

The upper flow range of 10,650 m³/s is almost the same as the Xayaburi HPP fish passage facility; hence these two projects have the potential to operate in unison for fish migration. Given the upper flow range, the fish passage facility at LPHPP needs to accommodate three major hydraulic conditions:

- i) Up to 5,355 m³/s, when all water passes through the turbines. At these times upstream migratory fish will be attracted to the powerhouse. Almost all downstream migrating fish will pass through the dedicated fish bypass or turbines.
- ii) Between 5,355 m³/s and 10,650 m³/s when both the spillway and powerhouse are operational. At these times upstream-migrating fish will be attracted to the powerhouse and spillway. Downstream-migrating fish will pass through the dedicated fish bypass, or turbines, or spillway.
- iii) At flows greater than 10,650 m³/s when increasing flow passes the spillway. At these times the upstream fish passage facility would be operating sub-optimally, as per the draft PDG2019, and most downstream-migrating fish would be using the spillway.

SUMMARY

Issue: The fish passage design provides for flows from 1,170 m³/s to 10,650 m³/s, which covers the anticipated migration period and matches the operating range of the Xayaburi HPP. However, the minimum flow may have to be revised downward once the recommendations in the hydrology section are addressed.

Recommendation: Change minimum design flow to match the revised minimum flows as per the hydrology recommendations.

Risk if not addressed: Moderate

The developer has suggested that the minimum flows have not been noted since the development of the Lancang cascade and are not likely in future. However, the recent very low flows due to the operations of the Lancang Cascade suggests that protracted periods of very low flow are still possible. In any event, it is prudent to design for a level below the minimum tailwater because the river can, and often does, erode downstream of the dam after construction. If this occurs, it is extremely expensive to modify the fishway after it is built to accommodate a lower level. It is not, however, cost-sensitive to accommodate the minimum tailwater level in the design.

Headwater levels

Under the current design the LPHPP will operate with a 0.5 m headwater range. This is very narrow and further consideration should be given to a wider range to allow for future changes to dam operation, particularly if consideration is given to draw down the impoundment at lower flows to promote downstream drift of eggs and larvae, and sediment flushing. This may be recommended as part of Joint Cascade Operations.

The headwater range will set the floor level of the fishway. If the reservoir is operated at 310 m to accommodate the concerns expressed by the Pak Beng operator, the floor level of the fishway would have to be adjusted.

SUMMARY

Issue: If the operating levels of the reservoir are adjusted, the fishpass design will have to be adjusted.

Recommendations: Review future dam operation to ensure floor level of fishway exit is sufficiently low to accommodate future changes.

Risk if not addressed: Insignificant (if reservoir operated as planned).

Tailwater levels

The minimum tailwater for the LPHPP fishway is set at 276.70 m asl, for the minimum flow of 1,170 m³/s. If the minimum flow is adjusted, as discussed in the hydrology section, the minimum tailwater level for the fishway design needs to be adjusted accordingly.

The tailwater range for flows of 793 m³/s to 10,650 m³/s is approximately 12.43 m, from the 277.0 m to 287.43 m elevation. For comparison, the Xayaburi HPP fishway is designed for 14 m of tailwater variation.

SUMMARY

Issue: The proposed minimum tailwater for the LPHPP fishway needs to be adjusted in line with any new operating rules, minimum flows and the outcomes of the study on the tailwater rating curve.

Recommendations: Lower the minimum tailwater for the LPHPP fishway accordingly.

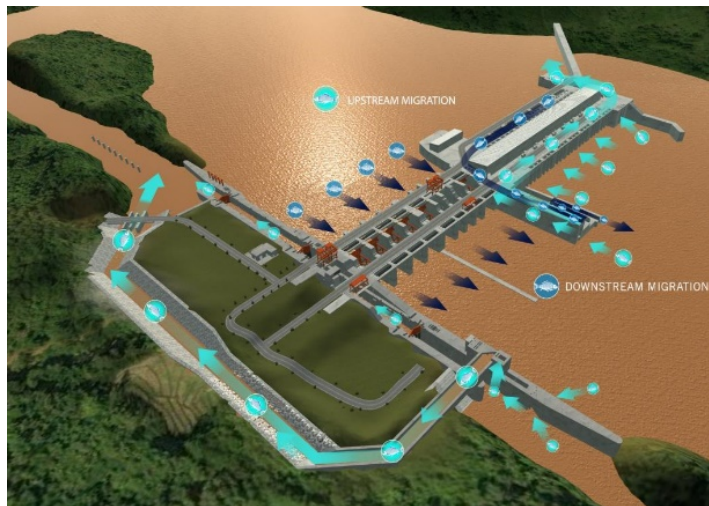
Risk if not addressed: Moderate

UPSTREAM FISH PASSAGE

Attraction - entrance location

The LPHPP fish passage facility has several entrances (Figure 4-6):

- i) along the top of the draft tubes of the powerhouse.
- ii) at each side of the powerhouse.
- iii) at the left-hand side of the spillway; and
- iv) on the right-hand side of the spillway (which is an addition to the Xayaburi design).



At the concept level, these are all the key locations where fish would migrate to. At a more detailed level, as per the plans supplied, most of these locations need refinement or major modification.

Figure 4-6 Upstream fish pass facilities – in light blue.

The entrances on top of the draft tubes and to the sides of the powerhouse are well located for surface and midwater species. However, benthic species and thalweg-oriented species (which use the deepest channel in the river), do not have adequate entrances. Some of these may ascend to the proposed draft tube entrances but some are unlikely to do so. Hence, it is recommended that additional entrances for these bottom-dwelling fish be considered. The developer has, however, indicated that the riverbed will be shaped to lead benthic fish to the entrances left and right of the powerhouse.

When the low-level spillway outlets are used, the adjacent gates are closed, and fish will swim to either side of the low-level gates. At moderate flows fish will be forced further down the stilling basin by the high turbulence and at high flows fish are likely to be unable to access the stilling basin and will collect at the end of the surface spillways. It is therefore important to investigate the operating phases through physical modelling to develop appropriate fishway entrances for different flows. Suitable scales for physical modelling are 1:100 for broad patterns and 1:20 for detailed flows and fishway entrances.

The spillway abutments will likely need to be shaped. Offsets in the abutment wall can create effective conditions for fishway entrance at different flows and these should be tested up to spillway flows of 10,000 m³/s, in increments of 500 m³/s. In the present design the left-hand spillway entrance is well positioned for high flows, while the entrance of the fish lock at the navigation lock may need to be repositioned. This latter fish lock also has an entrance on the navigation lock side, which is presently not integrated with flows from the lock valves. The developer, however, notes that this will be refined at the Tender Stage.

SUMMARY

Issue: Powerhouse entrances favour surface-dwelling species and are poor for benthic species, while the spillway entrances do not accommodate different flow patterns and zones of fish attraction. Some species of migrating fish will very likely not locate the proposed fishway entrances.

Recommendations: Benthic fishway entrances are needed at the powerhouse, while the thalweg needs to be shaped to guide benthic fish. The developer has indicated that this will be done. Multiple fishway entrances are required on both sides of the spillway and physical modelling is required to optimise these. The entrance for the fish lock at the navigation lock needs optimisation.

Risk if issue not addressed: Major for benthic species and for species migrating at high flows when the spillway is in use. Minor for surface/midwater species migrating up to 5,000 m³/s.

Selection of Fish Passage Options

The LPHPP uses dual fish locks on the left abutment and a single fish lock on the right abutment. At the concept level these options may be suitable, but the documentation does not have a comparison with other fishway options, so it is difficult to assess the suitability of the design.

Fish locks have been generally not worked well in large tropical rivers and have been abandoned in the USA and France. There are, however, three other options that could be assessed: fish lifts, large bypass channel fishways, or large pool-type (e.g. vertical-slot) fishways. Given the general arrangement of the dam, a large bypass channel is unlikely to be suitable as the left-hand abutment is not against the bank.

A large pool-type fishway, such as a vertical-slot, with low velocities, low turbulence and large resting pools is a viable option and needs to be evaluated. Importantly, a pool-type fishway operates continuously and has no moving parts for maintenance. Fish lifts are widely used at high dams and need to be evaluated. They have the advantage of a quick cycle time and overcoming some of the fish behaviour issues of fish locks.

There is a fish lock on the right bank alongside the navigation facilities, which enables fish passage on the right bank. The navigation lock, however, should also be considered for fish passage during construction when there is low headwater and the fish lock would not be operational. The navigation lock may potentially be useful for fish passage at high tailwater levels, by using the overflow section in the abutment.

SUMMARY:

Issue: In the supplied documentation other fishway options have not been considered. The developer has indicated that a Discussion Paper on the various options has been submitted on 19 December 2019. However, this has not been made available for review.

Recommendation: Review other fish passage options using functional criteria. Consider the navigation lock for fish passage during construction.

Risk: Major.

Fishway Discharge

The LPHPP design complies with the PDG 2019, providing 10% of the 95%^{ile} flow and 1 % of the 1-in-1 Year Annual Recurrence Flow. It is likely that the right-hand fish lock, at the navigation lock, may have low attraction, so opportunities to improve attraction flow at this side of the spillway should be investigated during the detailed design stage. It should be noted that any flow that the fishway uses, once the spillway is operational, is not lost hydropower generation.

SUMMARY

Issue: The fishway discharge meets the MRC Design Guidance.

Recommendations: No change. Utilise opportunities in detailed design to increase attraction flow of right-hand side fish lock.

Risk if not addressed: Insignificant

Water velocity and turbulence

Water velocity criteria meet the recommendations in the draft PDG2019. Turbulence is not discussed in the documentation concerning the fish locks or connecting channels and further details are needed. Turbulence is more critical in pool-type fishways; in fish locks, turbulence and water velocity are potentially adjustable.

SUMMARY:

Issue: No information on turbulence.

Recommendations: Provide further data on turbulence.

Risk if not addressed: Minor

Fishway Depth

The draft PDG2019 recommendation for the minimum depth of 3 m has been adopted. However, the minimum tailwater for the fishway, and the floor levels of the fishway entrances, need to be 1.7 m lower to provide sufficient minimum depth. As flow and tailwater increases, the impact of shallow depth would be reduced.

SUMMARY:

Issue: Water depth is too shallow for large fish and is overestimated in the present design.

Recommendations: Increase design depth to 3 m and calculate using the lowest operational headwater and tailwater levels.

Risk if not addressed: Minor

Lock chamber size and number

The size and number of fish lock chambers are determined by migratory biomass and fish behaviour. Migratory biomass is difficult to estimate in large rivers. It has been found that at the Xayaburi HPP up to 5 t of fish pass per hour at certain times, but as it is unsafe to sample in highly turbulent flow this may be an underestimate, if most fish migrate in under higher flow conditions.

Fish behaviour is important because fish locks are cyclic, so that fish need to wait in the lock chamber. Fish will swim in and out of the lock, even with a V-trap. The LPHPP lock chambers are 6 m long by 6 m wide on the left abutment and 6 m long by 4 m wide on the right abutment (navigation lock). The length of these is too short because large fish in the Mekong can be 2 to 3 m long. Lock chambers of 9 to 12 m need to be considered to accommodate these fish. The developer has indicated that they believe that size of the lock chambers is adequate. However, this has not been motivated through an analysis and presentation of the data.

In large rivers with potentially high biomass, fish lifts and fish locks have a long entrance channel of up to 60 m with a “crowder”. This ensures a high biomass can be collected and large fish will remain in the channel. On the left abutment the LPHPP fish locks have entrance channels with crowdors that are 20 m. Longer entrance channels need to be evaluated in the ongoing design. The right-hand abutment fish lock appears not to have a crowder, and one should be included.

SUMMARY:

Issue: Lock chambers and entrance channel are too short. (This is disputed by the developer).

Recommendations: Increase lock chamber and entrance channel length. Add crowder to fish at right abutment

Risk if not addressed: Major

DOWNSTREAM FISH PASSAGE

Background

The following section is structured by the potential downstream migration paths for fish in the LPHPP, which are through the: reservoir, turbine debris screens, dedicated fish bypass, turbines and spillway (Figure 4-7). For flows below 5,355 m³/s, which will be the case for most of the time, flow passes through the powerhouse, which will guide downstream-migrating fish to the debris screens and turbines. At flows over 5,355 m³/s both the powerhouse and spillway are used.

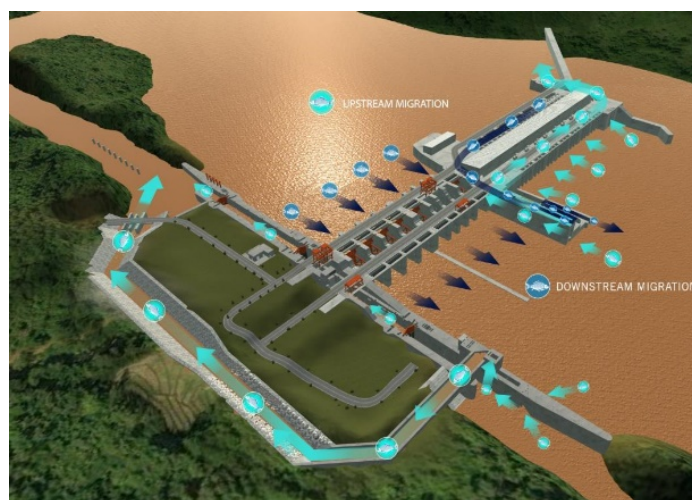


Figure 4-7 The downstream fish pass paths in dark blue.

Passage through the reservoir

Downstream drifting larvae typically require a minimum mean channel velocity of 0.3 m/s to be maintained in the water column²³.

The velocity modelling done suggests that this threshold will rarely be reached, especially in the length of reservoir close to the dam. However, impacts on drifting larvae can be minimised by lowering the reservoir level to maintain water velocity throughout the reservoir; as river discharge increases, the reservoir level can be raised and water velocities can be maintained. It is therefore recommended that the hydraulic modelling of the reservoir be reviewed to assess the potential to maintain water velocities for larval drift.

This may require reservoir water levels to be reduced for periods of time and would impact energy production and would have to be considered as part of joint cascade operations. This means that a balance between the financial viability of the LPHPP, Internal Rate of Return, Concession Period and Fisheries (and hence ecological and socio-economic) impacts should be found (see Chapter 7). The developer has indicated that these studies are underway, and it is recommended that these results are shared as part of the JAP process.

SUMMARY

Issue: The reservoir creates a still-water habitat at low flows that can prevent larval drift and causes mortality of this life stage. The discharge that is sufficient to maintain larval drift throughout the reservoir is unknown but is likely to be rare.

Recommendations: Conduct further hydraulic modelling. Review reservoir management as part of Joint Cascade Operations to mitigate the impact.

Risk if not addressed: Major (until further analysis is done).

Passage through the debris screens

Fish approaching the turbines first encounter a debris screen. The details of the proposed debris screens are not shown but they are typically vertical bars with gaps of 12 to 20 cm. The gaps allow eggs, larvae, juveniles and adult fish up to approximately 75 cm long to pass through to the turbines. However, because of high water velocities at the screens, larger fish can be impinged and die. Hydraulic modelling of water velocities in front of the screens is needed to assess this risk.

However, the present screen design is relatively perpendicular to the flow and does not direct fish to the bypass entrance. A screen angled as outlined may direct fish towards the entrances (Figure 4-8). Similar designs have been applied widely over the last few decades.

²³ In the upper Mekong River this threshold may be higher

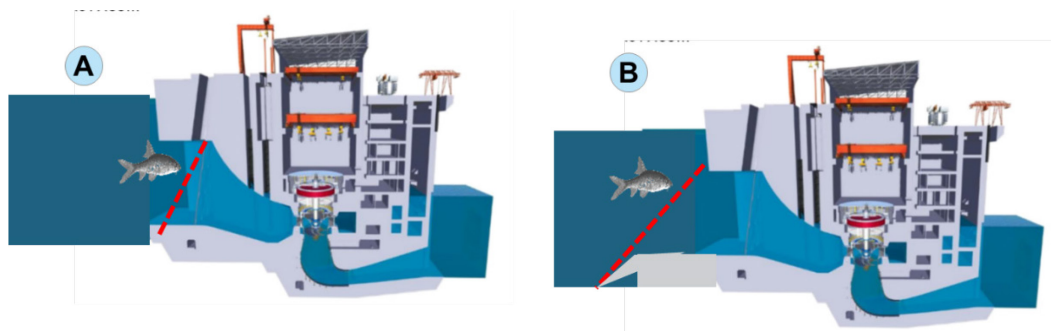


Figure 4-8 The existing debris screens (A), and a proposed new configuration (B).

However, the developer has commented that tilting the trash rack is not possible as the trash rack cleaning machines require near vertical screens and the shape of the steel profiles will be optimised to reduce fish injury. However, as the design is still at the feasibility level, they have indicated that other design options will be explored. It is recommended that this is shared as part of the JAP process.

SUMMARY

Issue: In the present design of the LPHPP the debris screen in front of the turbines has an extremely high risk of impingement and mortality of large fish.

Recommendations: The screen needs to be redesigned, with an acute angle and low water velocities

Risk if not addressed: **Critical** (one of the most critical aspects of the project)

Passage through the dedicated fish bypass

Dedicated fish bypasses have been used successfully elsewhere but they are untested for tropical species. A turbulence of 500 W/m³ is quoted for the bypass; this may be satisfactory but no data on the impacts on fish are provided. Further information is required before an evaluation of the fish bypass can be made.

Summary

In the present design the dedicated fish bypass appears to provide negligible downstream passage of fish.

The developer disputes this statement, indicating that the monitoring at Xayaburi has shown that most of the downstream migrating fish are less than 30 cm long and swim close to the surface. They also note that the turbine inlets are several meters below the surface, and that the fish would therefore be drawn to the downstream passage facilities.

Passage through the turbines

The developer plans to use “fish friendly” turbines, including oil-free hubs, reduced runner blades and rotational speed and minimising gaps. However, there are no quantitative data on pressure impacts (barotrauma), shear and blade strike. The extent of injuries and mortality from these impacts depends on the size, swim bladder (gas bladder) morphology and the fragility of the species. The turbine design is also important; the number of blades (less blades – less injury), blade speed (lower speed - less injury), blade thickness (thicker blades - less injury),

number and location of wicket gates (less gates – less injury), and depth of turbine (deeper – less barotrauma).

The physical attributes of the turbines are described but there are no specific data on the impacts of strike, barotrauma and shear on Mekong fishes. There is also no comparison between the three main turbine choices: Alden, Bulb and Kaplan.

SUMMARY

Issue: Insufficient information on the size of fish that would pass through debris screens, pressure and shear profiles of turbines, and a quantitative assessment of mortality/survival.

Recommendations: Provide information on the size of fish that would pass through debris screens, pressure and shear profiles of turbines (CFD), and quantitative assessment of mortality/survival (CFD). Assess inclusion of a simple pressure acclimation weir in front of the turbines.

Risk if not addressed: Critical

The developer has indicated that the manufacturer of the turbines at Xayaburi will prepare an assessment of the fish survival rates through the turbine. The assessment for the most common Mekong fish was provided during the site visit.

Passage through the spillway

The design objective for LPHPP is to provide fish passage from minimum flows to 10,650 m³/s. The spillway would be used when river flows exceed the powerhouse and LLO flows, although it could be used at other periods for small discharge to balance flow through the turbines. Larvae, sub-adult and adult fish are likely to be migrating downstream when the spillway is in use.

The spillway uses undershot radial gates, with overshot flap gates to pass debris. These gates have a high risk of injuring fish if they partly open, providing undershot flow. Injuries occur from pressure changes passing through the gates and shear forces. If the gates are operated fully open there is little risk for fish. The spillway has a relatively smooth profile with no dissipators, so there is no sudden deceleration or direct impacts. It is therefore preferable to operate with fewer gates fully open than more gates partly open. This should be specified in operating rules.

If the gates are used in the partly open position it is recommended that the gates are replaced with an overshot design or use overshot gates within all the radial gates. These small overshot gates can then pass low flows until a radial gate can be fully lifted. The path of fish after they pass through these overshot gates needs to be smooth, not impacted by support beams of the radial gate, with a gradual transition onto the spillway.

The flows through the LLO could have significant pressure and shear impacts on fish which needs to be investigated.

Gate operation has a significant influence on flow patterns downstream and the effectiveness of fishway entrances. Various configurations of gate operation need to be tested in physical modelling to integrate flow patterns with the spillway entrances for the fishways.

SUMMARY

Issue: Undershot radial gates and the low-level outlet gates can injure fish and cause mortalities.

Recommendations: Replace the gates with an overshot design or utilise overshot gates within all the radial gates. Assess pressure/shear impacts of the low-level outlets and mitigate, if necessary.

Risk if not addressed: Moderate

The developer has noted that the recommendations for gate opening will be considered, but that the type of gate selected was best in terms of dam safety.

FISH PASSAGE DURING CONSTRUCTION

There are two stages to fish passage during construction: i) when the river is partially blocked by a coffer dam, and the river flows freely on the unblocked side, and ii) when the second coffer dam is installed, and flow passes through the completed spillway section. In the first stage of construction the cross-section of the river is reduced which would increase water velocity and could impede or block fish passage. The modelling that has been done suggests that flows in the open stretch of the river will be up to 6 m/s for the 100 year flood (23,800 m³/s), with a 2.5 m upstream to downstream water level change. However, this has only a 1% risk of occurrence.

In the second stage, fish cannot pass upstream through the spillway because water velocities are too high, due to the reduction in cross-sectional waterway area, and the laminar nature of the flows. In this stage a dedicated fish passage solution is required. This could be through the navigation lock or the right bank fish locks.

SUMMARY

Issue: Fish passage during construction needs to be addressed in more detail.

Recommendations: Do detailed hydrodynamic or physical modelling for the Stage 1 coffer dam and provide a dedicated fish passage solution for Stage 2, and Stage 1 if required. Investigate using the navigation lock for fish passage.

Risk if not addressed: Moderate

The developer indicated during the site visit that fish migration during construction would continue along the left bank during the stage 1 construction, and that modelling of the water velocities and water depths in this portion of the river had demonstrated that these were close to natural. During the 2nd stage construction, the fish migration facilities in the right bank infrastructure would be operational.

4.6.5. Key Recommendations

The key recommendations for the redesign of the fish passage as presented in the documentation provided are summarised in Table 4-6.

Table 4-6 Key recommendations for the revision of the fish passage design.

UPSTREAM PASSAGE

- Change minimum design flow from 1,170 to 793 m³/s; lower tailwater level and floor levels of fishways to match. Or, if the lower operating level of 310 m is selected lower the levels if the fishways accordingly
- Add benthic fishway entrances and shape thalweg to guide migratory fish.
- Add spillway entrances for fishways and optimise in physical modelling.
- Review fishway design options comprehensively.
- If fish lock design is pursued, increase lock chamber length and entrance chamber length.

DOWNSTREAM PASSAGE

- Assess larval drift at various flows with hydraulic modelling and review reservoir management, if necessary.
- Change debris screen design to have a more acute angle to guide fish to the bypass; and design screen to ensure there are low water velocities to prevent impingement.
- Investigate a simple pressure acclimation weir in front of the turbines.
- Provide data on blade strike, shear and pressure of the turbines; and the size of fish passing through the debris screens.
- Spillway: Use radial gates fully open to reduce impacts on fish, or replace radial gate with an overshoot design, or use overshoot gates within all the radial gates. Ensure design of radial gates and spillway has a smooth path for fish.

PASSAGE DURING CONSTRUCTION

- Do detailed hydrodynamic or physical modelling for the Stage 1 coffer dam and provide a dedicated fish passage solution for Stage 2, and Stage 1 if required.
- Investigate using the navigation lock for fish passage.

4.6.6. Risk assessment

BACKGROUND

Risk assessment is a qualitative analysis of the consequence or scale of risk and the likelihood or probability of the risk occurring (Table 4-7). These two values are combined to produce an overall risk score (Table 4-8). A risk management framework operates by establishing the context (i.e. proposed hydropower development); identifying the risks on the existing situation (consequences and likelihood); assessing the risks; and treating the risks. Consequently, it is a useful tool to prioritise actions and resources, and to identify knowledge gaps, which then inform the monitoring programme.

Table 4-7 Consequence and Likelihood scores.

Consequence	Likelihood
Critical	Almost certain
Major	Likely
Moderate	Possible
Minor	Unlikely
Insignificant	Rare

Key: Low Moderate High Very High

Table 4-8 The risk matrix.

		Consequence				
		Insignificant	Minor	Moderate	Major	Critical
Likelihood	Very likely	M	M	H	VH	VH
	Likely	M	M	H	H	VH
	Possible	L	M	M	H	VH
	Unlikely	L	L	M	M	H
	Rare	L	L	M	M	H

In the present risk analysis the following risks are assessed: i) the Proposed Design as presented and ii) the Proposed Design after applying recommendations and mitigations outlined in this TRR; the latter assesses the *probability that the risk can be mitigated*, which not only reflects the recommendations but also assumes ongoing discussion between the developer and the MRC, which the JC may wish to propose as conditions, that would result in the optimal design being presented.

Only the most important risks have been examined so the *consequence* of these is either *major* or *extreme* and hence, the risk scores, based on differing likelihoods are *Moderate*, *High* or *Very High*. The risk assessment of the Proposed Design reflects the issues raised in this review, but importantly it prioritizes where the design needs to be improved. Those risks that are *Very High* or *High* are the highest priorities to address in the design.

DISCUSSION

The risk assessment of the proposed fish passage facilities highlights that for upstream passage large and benthic fish are disadvantaged in the design presented in the documentation, and the design is more effective at low flows than at higher flows (Table 4-9). The developer has indicated that ramps will be provided to guide benthic fish to the fish pass intakes on the left and right sides of the powerhouse. Downstream passage has greater risks overall, again with larger and benthic fish more disadvantaged. The developer has indicated that additional hydraulic studies on the velocities in the impoundment will be undertaken to provide a better idea of where the velocities may decrease below 0.3 m/s.

Applying all the recommendations reduces most of the risks but leaves two that are *very high*. These are: i) maintaining drift of larvae through the impoundment and ii) passing large-bodied fish downstream the dam, particularly at the debris screens. These two risks can be mitigated in theory, but both would potentially require a major change in the operations the LPHPP, and an innovative approach to hydropower and fish passage. If these risks eventuate, they would severely impact the sustainability of the species impacted, affecting populations upstream and transboundary downstream.

The developer has indicated that a separate document has been provided on 19 December 2019, however this has not yet been provided through the LNMC. It is recommended that this document is reviewed as part of the JAP process.

Table 4-9 Risk Assessment of Proposed Design based on criteria in Table 4-8, for each size class, behaviour category, migration flow and biomass.

RISKS BEFORE ADDITIONAL MEASURES

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fishway	Ineffective exit – risk of fallback	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Mortality passing <u>Luang Prabang</u> site – including spillway and turbines	Poor exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very High	Very High	Moderate	Moderate
Small-bodied species (5 -30 cm)	High	Low	Low	Moderate	Very High	High	Moderate
Medium-bodied (30-150 cm)	Very High	High	Low	Low	Very High	High	Moderate
Large-bodied (150-300 cm)	Very High	Very high	Low	Low	Very High	Very High	Low
Behaviour							
Surface	Low	Low	Low	Low	Very High	High	Moderate
Mid-water	Moderate	Low	Low	Low	Very High	Very High	Moderate
Benthic (including <u>thalweg</u>)	Very High	High	Low	Low	Very High	Very High	Moderate
Migration Flow							
Low (dry season)	Moderate	Moderate	Low	Very High	Very High	Very High	Moderate
Moderate (early wet, late wet)	High	Moderate	Low	Moderate	High	High	Moderate
High (wet season)	Very High	High	Low	Low	Low	Low	Low
High Biomass	High	High	Low	Low	Very High	Very High	High

Key: Low Moderate High Very High

RISKS AFTER RECOMMENDED MEASURES ARE APPLIED

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fishway	Ineffective exit – risk of fallback	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Mortality passing <u>Luang Prabang</u> site – including dam turbines	Poor exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very high	Moderate	Moderate	Moderate
Small-bodied species (5 -30 cm)	Moderate	Moderate	Low	Low	Moderate	Moderate	Low
Medium-bodied (30-150 cm)	Moderate	Moderate	Low	Low	Moderate	High	Low
Large-bodied (150-300 cm)	High	High	Low	Low	Moderate	Very high	Low
Behaviour							
Surface	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Mid-water	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Benthic (including <u>thalweg</u>)	High	Moderate	Low	Low	Moderate	High	Moderate
Migration Flow							
Low (dry season)	Low	Low	Low	High	Moderate	High	Moderate
Moderate (early wet, late wet)	Moderate	Low	Low	Low	Moderate	Moderate	Low
High (wet season)	High	Low	Low	Low	Low	Low	Low
High Biomass	High	High	Low	Low	Moderate	Moderate	Moderate

Key: Low Moderate High Very High

4.6.7. Compliance with preliminary design guidance (PDG 2009)

The LPHPP does not align with the PDG (see Annex B for crosscheck list). Specific issues are highlighted below. When doing this evaluation, due consideration was given to the LPHPP being immediately upstream of Xayaburi HPP.

- The fish passage facilities are extensive and cater for fish approaching the dam in different places. However, no other fishway options have been considered in the original documentation provided. The design favours surface-dwelling species and is poor for benthic species. The spillway entrances do not accommodate different flow patterns and zones of fish attraction on the spillway.
- The proposals for downstream passage do not include options for the drift of larvae through the reservoir and mortality of fish passing through the trash screens, turbines and spillway. Currently, there is no possibility of assessing whether the fish passage facilities will function as expected.
- Weaknesses in the planning and design of the fishways are recognised such as the size of the lock chambers and the relationship to downstream dams has not been fully explored in the documentation provided.
- The limited baseline surveys preclude any assessment of whether the fish passage facilities will cater for the diversity of species in this region, the variability in timing of migration (all year round), and the volume of fish that will utilise the fish passage facilities in both the upstream and downstream direction.
- Little information is provided on the hydrological and hydraulic conditions in and around the dam site and proposed fish passage facilities. Although some modelling has been undertaken.
- Information on monitoring and evaluation is superficial and needs more information on methods, sites and frequencies. No adaptative management programme is envisaged and no contingency funds indicated should adaptation of the fish passage facilities be required.

4.6.8. Considerations for the JC

The LPHPP documentation provides a reasonable overview of the fish species diversity in the upper Lao reach but less so for the linkages with elsewhere in the LMB. This was based on MRC reports, data gathered during prior consultations for Xayaburi and Pak Beng and as part of the concession agreement during the development of Xayaburi HPP and 5 surveys during 2019. The documentation describes the proposed fish passage facilities to move fish both up and downstream around LPHPP dam and infrastructure and measures to mitigate potential problems.

It is recommended that:

- The comprehensive baseline monitoring programme is made available for assessment and is initiated as soon as possible: this should follow the methodologies outlined in the Joint Environmental Monitoring programme.
- Greater consideration is given to the importance of fish of high conservation value and the overall importance of fisheries to livelihoods and food security.
- The developers recommendations to further develop the fish passage design in a workshop should be included in the post prior consultation Joint Action Plan.

4.7. Dam Safety

Key features of the review of the dam safety:

- ▶ The LPHPP is classified as an Extreme Risk Dam according to the Lao Electric Power Technical Standards (2018) and must meet stringent flood safety standards. This is due to the impounded volume, dam height and proximity of Luang Prabang City.
- ▶ The LPHPP has been designed to the same flood safety standards as the Xayaburi HPP as recommended in the PDG 2009. These standards are lower than the LEPTS 2018 with respect to several aspects including the design floods and dam stability, and the developer has confirmed that the design will be checked and revised to comply with LEPTS 2018.
- ▶ The Feasibility Study presents a sound basis for the formulation of the project but lacks some of the detail that would be expected at this stage for a major hydroelectric development.
- ▶ An initial site investigation has been undertaken, which provides a good understanding of the structural geology of the site but has identified issues that require further investigation, as well as further coverage of the site and quarries. An additional programme of site investigation is now in progress.
- ▶ In the PNPCA submission there was no interpretation of geology to derive preliminary foundation parameters for design and no description of stability loading cases and results. Additional documents have now been submitted and reviewed.
- ▶ A Seismic Hazard Assessment has been undertaken that provides a suitable basis for project design.
- ▶ The hydraulic model study has recently commenced. Therefore, the spillway capacity and erosion protection requirements for the project have not yet been adequately demonstrated.
- ▶ There is no reference to the appointment of a Dam Safety Review Panel. This Panel should be appointed as soon as possible.

The developer has indicated that they will take up the design standards discussion with the GoL. They have also indicated that the LPHPP physical model at AIT has been completed and that testing is underway.

4.7.1. Objectives

Large dams pose significant risks to downstream communities if they fail, causing both economic damage and loss of life. These risks may be transboundary in nature. Dams must therefore be built to agreed design standards. Generally, these standards are more stringent for larger dams that pose significant dangers should they fail. The standards are also site specific, requiring higher standards of design and construction where the flood peaks are higher, or where there are specific risks posed by the geology at the dam site or active faults near the site.

The draft PDG2019 outlines the objectives of the dam safety guidance as follows:

- i. Ensure that a dam does not contradict Article 7 of the Mekong Agreement by causing harmful damage to the environment (upstream or downstream) through its operation or in the event of a failure of the dam.
- ii. Protect life, property and the environment from the consequences of dam operation or failure, based on an understanding of the risk imposed by the dam and the consequence of failure.
- iii. Ensure a consistent approach to design criteria for mainstream dams, specifically for the safe passage of extreme floods and seismic stability.
- iv. Ensure that design, construction, operation and maintenance regimes, as well as institutional arrangements, are consistent with national requirements and international good practice for the safety of dams and related emergency response planning.

This section considers the extent to which these objectives are met by the LPHPP design and operations.

4.7.2. Design standards used

Apart from the guidance provided in the PDG 2009, the following design standards were consulted:

World Bank Operational Policy 4-37: The PDG 2009 recommends that this OP is used to guide the design of mainstream dams. The requirements of OP 4-37 are:

- Independent panel of at least three experts must review the investigation, design, construction and start of operations.
- Detailed plans for:
 - Construction supervision and quality assurance.
 - Instrumentation.
 - Operation & Maintenance.
 - Emergency Preparedness.
- Periodic safety inspections of the dam after completion.

There is no mention of OP 4-37 in the engineering sections of the Feasibility Study report. Compliance with the relevant provisions is assessed in the subsequent sections of this report.

ICOLD Bulletins: The following ICOLD Bulletins have been referenced in the Feasibility Study report, but in some cases, it is not clear how their recommendations have been incorporated in the formulation of the project:

- B148 Selecting seismic design parameters for large dams (2016)
- B99 Dam Failures - Statistical Analysis (1995)
- B111 Dam Break flood analysis - Review and recommendations (1998)

- B72 Selecting Seismic parameters for large dams ²⁴
- B126 Roller-compacted concrete dams. State of the art and case histories (2003)

In some cases, the dam safety recommendations of ICOLD Bulletins are either repeated or revised in the draft PDG 2019. In the context of the Mekong mainstream projects it is assumed that the PDG requirements take precedence. Draft PDG 2019 additionally refers to the following ICOLD Bulletins:

- B120 Design features of dams to resist ground motions (2001)
- B59 Dam Safety Guidelines (1987)
- B130 Risk assessment in dam safety management. A reconnaissance of benefits, methods and current applications. (2005)

Lao Electric Power Technical Standards (LEPTS 2018)

Compliance with the Lao Electric Power Technical Standards (LEPTS) is a requirement of Paragraph 267 of PDG 2019. LEPTS was first published in 2004 and was substantially revised in 2018. A set of supporting Dam Safety Guidelines was also produced by the Ministry of Energy and Mines. These guidelines form part of the revised LEPTS, which was approved for implementation from 27 June 2019. The developer has indicated that these will be used for the final design of the LPHPP.

4.7.3. Geological analysis

GEOLOGY

The developer has undertaken an investigation of the geology of the dam site, and the documentation provided presents a detailed description of the initial ground investigation and geological mapping of the project area.

The feasibility level ground investigation comprised:

- Exploratory Boreholes – 9 no.
- Exploratory Trenches – 7 no.
- Trial Pits
- Geophysical Survey – seismic refraction and resistivity
- In situ testing in boreholes – permeability tests
- Laboratory Testing – rock and soil samples.

Most of the investigation has been carried out on the right bank where the major structures are to be founded. A single borehole and two seismic lines have been carried out on the right bank. No investigation of the deeper main river channel section has been carried out. The principal structure in this location will be the closure structure, proposed to be a 50 m high, 280 m long RCC Dam.

²⁴ Bulletin 72 was published in 1989 and is now replaced by Bulletin 148.

Based on borehole findings, the anticipated excavation depths for the powerhouse and spillway structures vary between 5 to 24 m. Notes for each of the boreholes identify exceptions where the geology was not as expected. The geophysical survey found anomalies with either possible crushed or shear zones being identified. The most important line referenced in the report was orientated parallel to the river on the right bank. The anomaly was coincident with the valley bottom of a small tributary – the Houy Yor. A borehole was drilled at this site to investigate this feature and found a meta-sedimentary rock wedge between volcanic rocks. The report notes possible continuity with adjacent boreholes. The report states that the recovered core does not indicate an active fault zone and that boundaries between the different rock types are stratigraphic.

Geological maps will need to be updated to include this detail and any other similar potential features that may need investigation. The orientation and inclination of the feature may introduce a weakness zone within the foundation which may not be significant for stability but should be investigated further and mapped onto foundation excavation plans together with any other similar features.

Water pressure testing in boreholes found varying values but incidences of high permeability were noted at 30 to 60 m in 4 of the boreholes. The report notes that the high permeabilities may be a result of open joints of some persistence or possible short circuit around the packer during the test. If this is not known, it should be assumed that the results imply open joints and consideration should be given to potential persistence and interconnectivity of joints within the foundation areas. Further testing should be considered in this regard.

Construction materials will primarily be from the quarrying of limestone of which five possible outcrop locations were identified. However, only one location was investigated. Karstic features were found within some limestone outcrops. Due to the geological formation at this location, it was concluded that high wastage would be expected therefore other potential quarry locations would be investigated further. A range of laboratory tests were carried out on rock and soil samples, to assess suitability for construction as aggregate for concrete.

The geological investigation therefore provides a good basis for assessing the foundation conditions for each of the major structures at the feasibility stage. The information is well presented within each of the volumes. However, additional investigation will be required to provide further details and understanding of the anomalies found, together with a more intensive laboratory testing and field mapping of outcrops. The main structure for which there is the least direct information is the closure dam. Interpretation of the available information, including the results of field mapping of outcrops can be used to develop assumed foundation design parameters, but these must be verified by further investigation.

A further detailed round of ground investigation is required and should be based on the results of preliminary design of the major structures, and the need to further understand anomalies found in the initial investigation. An initial failure modes assessment for each structure may also indicate the requirement for further investigation.

A further programme of investigation was in progress on both banks at the time of the site visit on 4 December 2019. The details of the programme and the results were not available but selected core boxes were inspected and outcrops of the andesite and shales were noted in the proposed powerhouse area. It was noteworthy that the river had eroded both rock types to a similar extent and no step was evident at the contact.

The developer advised that this additional investigation was intended to improve the understanding of foundation conditions at the dam site. It was stated that the results of the investigation to date largely confirmed the findings of the Feasibility Study investigation and no new issues of significance had been identified.

The developer also advised that a LIDAR survey and geological inspection of the reservoir perimeter had been undertaken. This had indicated the presence of karstic limestone formations, but these were not considered to create a risk of reservoir leakage.

SEISMICITY

The seismo-tectonic situation provides a description of the nearest active faults to the project site together with seismic parameters. The report advises that lineaments observed within the construction site area are thought to be seismically inactive but will still be investigated. The nearest active fault is 8.6 km from the project site.

The seismic hazard assessment indicates that Luang Prabang is within a moderate to high seismicity region. The Feasibility Study report describes the site-specific assessment of seismicity carried out focusing on the fault system that bounds the project area. Both probabilistic and deterministic analyses have been carried out. Design earthquakes have been determined for a range of load cases.

The report describes attenuation relationships used in analysis and then describes each of the analysis methods in detail. For the Safety Evaluation Earthquake (SEE), both the probabilistic and deterministic analyses predicted the peak ground accelerations as 0.49 g (horiz) and 0.4 g (vert). These values are substantially higher than the guidance values proposed for the Maximum Credible Earthquake in LEPTS 2018. The PDG requirements are therefore met.

THE NOVEMBER 2019 SEISMIC EVENT

Two seismic events occurred on 20 November 2019 approximately 31 km ESE of Chaloem Phra Kiat near the border between Thailand and Lao PDR. The larger 6.1 magnitude event was noted throughout the region. The source appears to be the active Mae Ing fault. The reported Peak Ground Acceleration (PGA) at the epicentre was significantly below the design limit proposed in the Feasibility Study. However, during the site visit the developer undertook to consult their specialist to establish if this event necessitated any revision to the proposed PGA design values. This has been done and their written responses include comment from their seismicity expert. It was confirmed that the LPHPP design standards are adequate.

4.7.4. Design and operational parameters

FLOOD PARAMETERS

The Feasibility Study report proposes that the spillway should be designed for the following two events:

Design Flood	10,000 year	33,500 m ³ /s	one gate out of operation
Check flood	PMF	41,400 m ³ /s	all gates in operation

The developer presented lower values for the Design and Check Floods at the meeting on 4 December 2019 but confirmed that the differences were an error and the Feasibility Study values should stand.

It is current good practice to consider the potential impacts of climate change in extreme flood assessment. There is no reference to climate change in the Feasibility Study with respect to extreme flood estimation. This should be considered (as is also recommended in the hydrology section).

The FS does not offer a definition of the required performance of the dam and spillway under the Design of Check flood events.

The PDG 2009 requires compliance with National Standards, in this case the LEPTS 2018. LEPTS 2018 defines Inflow Design Flood as:

“Inflow design flood (IDF)” means the flood that a dam body is capable of safely passing through spillway and withstanding loading condition under normal operation without any damage to the dam.

The developer verbally indicated at the site visit that they did not consider examination of spillway capacities for the upstream HPPs to be a valid design consideration. However, the LEPTS requires that the discharge capacity of upstream dams is considered when assessing the design flood for the project, and the developer has indicated that they will comply with the LEPTS 2018.

DISCHARGE CAPACITY

The proposed geometry of the surface and low-level outlet spillways and stilling basins is the same as adopted at Xayaburi, although the number of gates is different. Xayaburi has seven surface spillway gates and four low level outlet gates, whereas Luang Prabang has six surface spillway gates and three low level outlet gates. The head differences across the two projects are also slightly different depending on discharge.

The Feasibility Study assessment of spillway capacity for Luang Prabang has been based on the Xayaburi model tests. Flume tests for the Xayaburi gates were conducted at AIT at a physical scale of 1:60 and Froude scale discharge. This is useful as a first approximation for the Luang Prabang spillway capacity, but more work is required for the final design. The developer has verbally indicated that a 1:110 scale physical model of the entire dam and spillway, including upstream and downstream sections of the river, had been constructed at AIT, and that tests were underway. These results should be shared as part of the JAP process.

There is no reference in the Feasibility Study report to the determination of freeboard between reservoir level and crest level under various combinations of events. The proposed dam crest level is EL 317 m and the reported reservoir level under PMF conditions is EL 314.2 m, providing a freeboard of 2.8 m. The LEPTS 2018 provides detailed freeboard requirements based on dam type, spillway type and combinations of seismic, flood surcharge and wave run up conditions. The developer should demonstrate that the proposed freeboard complies with these requirements.

GATE RELIABILITY

Reliability of gate operation is a key consideration for dam safety. Some authorities require the Design Flood to be safely discharged with one gate out of operation (n-1). ICOLD Bulletin 172 recommends this approach for small reservoirs where a rapid rise in water level might occur. The Feasibility Study report adopts an (n-1) approach for the Design Flood. This is a prudent provision but a re-examination of freeboard under the revised PMF Inflow Design Flood is required.

A broader consideration of gate reliability is also required. Loss of grid connection and power supply under extreme weather conditions is possible and must be considered. The Feasibility Study report states that an emergency power supply is available from a standby diesel generator at the powerhouse. This supply will operate the spillway gates and essential services in the event of a grid outage. Consideration should also be given to configuring the hydraulic pumping sets for the gates such that there is some interconnection and redundancy between gate systems and gates can be opened by adjacent hydraulic units.

In view of the extreme consequences of gate operation failure, consideration should also be given to incorporating an additional backup system. An effective solution that has been adopted on some fully gated spillways are mobile hydraulic pumps. These can be driven by a small pull start petrol engine and the hydraulic pump can be coupled directly to the gate hoists to open a gate in an emergency.

A robust design for the gates, supporting structures and operating system is required so that the system remains completely undamaged following the Operating Basis Earthquake and fully operational after the Safety Evaluation Earthquake. The developer has indicated that this will be taken up.

Careful consideration should be given to the rate of gate opening, since failure to respond quickly may cause unacceptable and unsafe water level changes both upstream and downstream. For example, a grid outage at full station load would result in an instant requirement to replace a downstream discharge of 5,355 m³/s. It is not clear how long the current arrangement of radial gates would take to respond to this event, particularly if the primary source of power was not available. The possibility of providing a rapid response facility in the spillway arrangements for forced grid outages should therefore be examined. Annex G outlines several options that could be considered in this regard.

The requirements for opening times, redundancy and security of spillway gate operation are not considered in the Feasibility Study report.

ENERGY DISSIPATION

The physical model test report does not provide any information on the effectiveness of energy dissipation or the potential for erosion in the riverbed downstream. This should be considered since erosion propagating upstream could undermine the stilling basin structure and result in progressive failure of the structure. It is noteworthy that the Design Criteria Annex to the Feasibility Study Addendum proposes that the design for the spillway stilling basin is based on the 50 year flood. A much higher return period design condition should be adopted to ensure that regressive erosion does not occur that could place the spillway structure at risk.

The geological model currently indicates that part of the powerhouse is to be founded on meta-sedimentary rocks and therefore consideration should also be given to the potential for bed erosion downstream of the turbine outlets particularly where the strike of joints in the rock are parallel to flow direction.

The AIT model study covering the full Luang Prabang dam and spillway will provide an opportunity to measure velocity fields and determine potential zones of erosion and deposition.

4.7.5. Flood Management

Effective flood management will require an understanding of inflow conditions and cannot be undertaken based simply on reservoir level monitoring at the dam.

There will be a requirement for an upstream hydrometric network and effective communication with upstream projects. The most efficient spillway release strategy can then be devised and implemented. This may take several years of real operating experience to develop and will require all schemes on the mainstream cascade to share information and agree a flood management plan with the Government of Lao PDR as part of the cascade operations. This plan will also permit the provision of timely warnings to downstream communities before spillway releases are made.

There is no reference to a cascade flood management strategy in the Feasibility Study report. This is beyond the scope and responsibility of a single developer on a cascade with multiple owners. A co-ordinated approach by the Government of Laos and / or the MRC is therefore recommended.

The developer has advised that the hydrometric network for the Xayaburi project will also be used for the Luang Prabang project. They also advised that they had examined various flood management strategies and found that advance lowering of the reservoir level was not beneficial overall. The increased impact of the drawdown on Luang Prabang city was judged to be greater than the mitigation achieved at Ban Pak Beng.

RIVER DIVERSION

River diversion is achieved by constructing the right bank structures (navigation locks, spillways and powerhouse) first in a single coffer dam and confining the river to the left channel. The cofferdam around the right bank works will be designed for the 100-year flood with a freeboard. The developer has verbally indicated that the flow conditions around the stage 1 coffer dam are currently being investigated at AIT. Whilst this is a typical figure for flood security during river diversion the probability of cofferdam overtopping is considerably greater than a failure during the operating phase. Some form of upstream flood forecasting system would therefore be advisable so that the works can be safely evacuated if there is a risk of overtopping.

4.7.6. Stability

DESIGN STANDARD

The design standard specified for stability in the Feasibility Study report is:

USACE EM 1110-2-2200 Gravity Dam Design. US Army Corps of Engineers, Engineering and Design, 1995.

This is a standard reference in the industry for gravity dam stability. LEPTS 2004 and 2018 provide specific requirements for the stability of concrete dams. A safety factor of three against sliding is required for the usual loading case on dams higher than 15 m. This requirement is more stringent than the factor of safety of two required by USACE EM 1110-2-2200, and the reason for this difference needs to be understood and considered in any discussion with the GoL regarding the use of the LEPTS 2018.

The requirements for overturning stability in the two publications are similar. However, the draft PDG 2019 does not offer any specific guidance on dam stability.

LOAD CASES

The loading cases that have been considered are described in the Addendum to the Feasibility Study. The quoted design standard is USACE EM-2-1110-2100 but reference is also made to LEPTS 2018 which requires higher factors of safety for sliding stability. The initial range of proposed load cases is appropriate. A reduction in uplift pressure of 35% is assumed due to the drainage curtain. This is consistent with the proposed USACE design standard which recommends a drainage efficiency in the range 25 – 50%. Additional load cases are included where the foundation drainage system has failed and there is no corresponding reduction in uplift pressure.

Results are presented in the Addendum for the navigation lock, surface spillway, low level outlet, power house and RCC closure dam. Powerhouse results are sub divided into sections on the siltstone + shale and the basaltic andesite. It is noteworthy that the permissible bearing pressure quoted for the two rock types under the powerhouse is the same (9,000 kPa) whereas a lower permissible bearing pressure (6,250 kPa) is quoted for the adjacent spillway structures on the basaltic andesite. The reason for this is unclear and does not appear to be consistent with the allowable bearing pressure values proposed in the Geotechnical Analysis Report. However the predicted bearing pressures are in most cases substantially lower than the allowable values.

It will be essential when the stability of the proposed spillway, powerhouse and RCC dam sections are considered further that careful consideration is given to the identification and analysis of any sub horizontal joints, bedding planes or other discontinuities in the foundation rock mass that might be potential failure planes.

The stability of all sections will need to be checked and verified by Dam Safety Review Panel (DSRP) once the site investigation programme is completed.

4.7.7. Reservoir operations

Indicative reservoir operating rules are outlined in elsewhere in this TRR. Daily peaking operation is not envisaged, but a more important practical constraint will be to consider imposing limits on the rate of change (ramping rates) of tailwater level which will be much more sensitive to changes in discharge through the dam. Rapid changes in tailwater level are potentially unsafe for river traffic, riverbank users and riverbank property, and can have negative environmental impacts in the free-flowing reach of the Mekong mainstream up to the Xayaburi backwater.

The operating level range of 312 to 312.5 m is higher than the value of 310 m proposed by the Optimisation Study of Mekong Mainstream Hydropower – 2009 undertaken for the Lao PDR Ministry of Energy and Mines. There are no apparent dam safety consequences for the adoption of this higher operating level. The concerns raised by Pak Beng HPP developer, and the response by the Lao delegation to the JCWG have been addressed elsewhere in this TRR.

During the passage of floods, a reservoir level surcharge will occur. This is reasonable. Under the Design (10,000 year) event the reservoir level at the dam will rise to 313.6 m if one gate is out of operation. Under PMF conditions the reservoir level will rise to 314.2 m. The impact of floods on the reservoir level will extend upstream as a backwater effect. However, very substantial changes in tailwater level will occur during major floods and will be influenced by the operation of the Xayaburi project downstream. Operating rules are required to limit the rate of change of water level downstream of the Luang Prabang dam to a safe rate and these should ideally be considered as part of the cascade operations.

4.7.8. Dam safety management

PANEL OF EXPERTS

The Feasibility Study report does not refer to the appointment of a Dam Safety Review Panel as is required by the ICOLD and World Bank Operating Policies for the investigation phase of dam design, which is currently underway. The Policy advises that the Panel should be appointed as early as possible in the project development when investigations are in progress and layout decisions are being made. The Terms of Reference for the Panel are often extended beyond dam safety to cover broader issues of project formulation such as construction procedures, river diversion and power generation facilities. It would be beneficial if these broader Terms of Reference were adopted for the Luang Prabang Hydropower Project. The DSRP is typically appointed by the Government but is funded by the developer. LEPTS 2018 does not make any specific reference to the appointment of a Dam Safety Review Panel (DSRP). However, this is recommended in the PDG 2009.

The developer has indicated that the DSRP is not required during the Feasibility Study. While the PDG 2009 do not expressly recommend the establishment of the Panel during the Feasibility Study, such appointments are often made for large projects and can be useful. Furthermore, World Bank OP 4.37 requires the appointment of a DSRP as early as possible during the investigation phase, and compliance with OP 4.37 is a requirement of PDG 2009. It is therefore recommended that this Panel is established as soon as possible. The developer has indicated that this will be taken up with the Government of Lao PDR.

EMERGENCY PREPAREDNESS PLANNING

An Emergency Preparedness Plan (EPP) should be developed for first impounding when structures are loaded for the first time and much higher levels of monitoring and rapid response are required.

The Feasibility Study report provides a general discussion of the requirements for an EPP, which is appropriate at this stage of the project development. Dam break studies have been undertaken that will form the basis of the EPP. The inundation maps show that the flooded areas downstream are very similar for the 10,000 year flood, the PMF and the dam break event. The city of Luang Prabang will be largely flooded under any of these events. Dam safety, flood management and notifications to downstream communities are matters of extreme importance for any major dam development. The potential to impact a UNESCO World Heritage site further emphasises the need to adopt the very highest standards of dam safety for this project.

INSTRUMENTATION

The Feasibility Study provides an initial indication of the instrumentation that will be provided. The final requirements can be determined later in the development of the project when foundation conditions have been fully exposed, and a detailed failure modes assessment has been undertaken. A detailed instrumentation plan is required by World Bank OP 4-37, but not at the feasibility study stage.

The instrumentation system must cover the left channel closure dam. Sections of this dam are over 50 m high. The list of instrumentation in the Feasibility Study report should additionally include at least one, and preferably two, planes comprising a normal and reverse pendulum. This arrangement will provide precise and unambiguous data on foundation and dam crest deflection, and the developer verbally indicated that these would be considered.

DAM SAFETY MANAGEMENT SYSTEM

The PDG requires the development of a Dam Safety Management System (DSMS). The basic scope of the DSMS should comprise:

- Comprehensive independent dam safety reviews at a maximum time interval of 5 years.
- Annual dam safety reviews to check for damage and functionality, and rectification of issues identified in previous reviews.
- Details on how to identify and report dam safety issues.
- A surveillance system to identify the initiation of potential failure modes; and
- Dam safety relevant design criteria, monitoring & assessments and management plans.

The DSMS is a formalisation of procedures that are generally adopted as part of good practice in dam safety and builds on the issues raised in ICOLD Bulletin - Dam Safety Management (2005). The draft PDG2019 provides additional guidance on the structure and content of DSMS in Paragraphs 275 to 284.

These paragraphs refer to requirements noted elsewhere in draft PDG 2019 and other guideline documents including:

- Instrumentation Plan.
- Construction supervision and quality assurance.
- Emergency Preparedness Plan.
- Temporary works and implications for dam safety.
- Procedures for first filling.
- Operation & Maintenance Manual.

Reference should also be made to the Dam Safety Guidelines in the LEPTS 2018.

The Feasibility Study report refers to many of these issues, but it is too early in the development of the project for the DSMS to have been developed in any detail. However, it is recommended that the detailed DSMS is shared as part of the JAP process.

4.7.9. Failure Modes Assessment

The PDG requires the development of a detailed Failure Modes Assessment. The Feasibility Study refers to consideration of a “Potential Failure Modes Assessment (PFMA)” but does not present a formal failure modes assessment. This is reasonable at this stage, but a failure modes assessment should be undertaken at the commencement of the detailed design stage and should be shared as part of the JAP process. The output of the assessment will inform the scope of further ground investigation, the development of the DSMS, the Emergency Preparedness Plan and the Instrumentation Plan.

Identified failure modes may include:

- Piping failure through weak zones in the foundations or abutments.
- Erosion of weak areas at the downstream toe causing instability of the main structure.
- Structural collapse of one or more spillway gates.
- Failure of flood gates to open causing increased flood levels.
- Structural instability of the key structures, particularly the gravity dam section; and
- Seismic failure of key structures.

The downstream impacts of failure have been examined by the inundation studies undertaken in the Feasibility Study. The events that have been investigated are consistent with the requirements set out in the PDG. However, for completeness this study should consider the implications of successive failure of more than one cascade dam, and the implications of flooding in Thailand downstream of the proposed Sanakham HPP. These investigations should be done by the GoL and / or the MRC as part of a cascade management plan.

4.7.10. Alignment with the PDG 2009

The Dam Safety considerations are broadly in line with the requirements of the PDG 2009 for this stage of the project development. However, the lack of a Panel of Experts is a concern even at this early stage of the project design. The more detailed requirements under the PDG for the final design should be shared as part of a post prior consultation JAP.

4.7.11. Considerations for the JC

The key dam safety considerations for the JC are as follows:

- The Feasibility Study presents a sound basis for the formulation of the project but lacks some of the detail that would be expected at this stage for a major hydroelectric development. The subsequently submitted Addendum to the Feasibility Study provides some of the required additional detail.
- An initial site investigation programme has been undertaken. This programme has provided a good understanding of the structural geology of the site and has identified issues that require further investigation. A further programme of investigation is in progress but no results are yet available.
- A Seismic Hazard Assessment has been undertaken that provides a suitable basis for project design. Analyses indicate that displacement of powerhouse and closure dam blocks will occur under the SEE event. More analysis is required to determine if the relative displacement between blocks could be of a magnitude that results in rupture of water stops and safety critical pipework. Consideration by the Dam Safety Review Panel is required.
- Interpretation of geology to derive preliminary foundation design parameters and results of stability analyses are provided in the Addendum to the Feasibility Study. There is some inconsistency in the selection of allowable bearing pressures that needs to be further checked and verified by the Dam Safety Review Panel.
- The hydraulic model study has not yet been undertaken and therefore the spillway capacity and erosion protection requirements for the project have not

been adequately demonstrated. It is reported that the model study has commenced but no details are available.

- The proposed design standards in the Feasibility Study for stability and flood management do not meet the dam stability and design flood requirements of the revised 2018 LEPTS. In a conference call on 14 February LPCL confirmed that the project design would be revised as necessary to comply with the requirements of LEPTS 2018. It will be important to check compliance in subsequent design reviews.
- The Addendum to the Feasibility Study confirms that the proposed gated spillway does not have sufficient capacity to discharge the design flood required by LEPTS 2018. An enhanced spillway capacity is required.
- There is no reference to the appointment of a Dam Safety Review Panel (DSRP). This Panel should be appointed as soon as possible. It is a requirement of PDG 2019 that the Panel is appointed prior to the PNPCA stage. In a conference call on 14 February 2020 LPCL confirmed that they would discuss the appointment of a DSRP with GoL.

4.8. Navigation

Key features of the review of the navigation facilities:

- ▶ There is little detailed information provided for the ship lock structure and equipment and only a summary explanation of the layout and the ship-lock facilities has been provided.
- ▶ The navigation lock will be located at the right riverbank and will require extensive excavation works. The developer indicates that this option provides for safer navigation, but that this has the drawback that the navigation facilities lie alongside the spillways potentially posing a danger to navigation when the spillways are in operation.
- ▶ The Feasibility Study only provides a brief summary description of the lock fittings and appliances without further explanation. However, some additional clarifications have been verbally provided.
- ▶ Single culverts filling systems have been provided, which poses a safety risk. It is recommended that these are doubled up.
- ▶ The navigation structure is a two-step navigation lock system for 2x500 DWT vessels and is consistent with the PDG 2009. The maximum chamber length is more than what is recommended in the PDG 2009.
- ▶ The air clearance in the navigation locks is acceptable for all flows where navigation is likely to occur.
- ▶ It is recommended that baffle beams are included in the design of the lock filling infrastructure to prevent mushroom shaped upward currents that will shake the vessels and the boats inside the lock chamber.
- ▶ The upstream island may obstruct the view of the locks and shipping in the resting areas, potentially posing a safety risk.
- ▶ The up- and downstream approach channels could potentially be improved by adopting a new alignment for the entire ship lock.
- ▶ No information has been provided for safety and maintenance of the lock, and there is no indication of a list of spare parts.
- ▶ While there is space left for an additional lock structure this may entail significant costs for the notifying country should this be done after the concession period.

4.8.1. Objectives

Article 9 of the 1995 Mekong Agreement indicates that:

“The Mekong River shall be kept free from obstructions, measures, conduct and actions that might directly or indirectly impair navigability, interfere with this right or permanently make it more difficult. Navigational uses are not assured any priority over other uses, but will be incorporated into any mainstream project.”

It is acknowledged that the impoundment of sections of the river behind hydropower dams can facilitate navigation making it safer, if navigation locks are incorporated into the design of the HPP.

The PDG2019 lists the objectives of the guidance on navigation as:

- i. Guarantee continuation of navigation on the Mekong mainstream consistent with Article 9 of the Mekong Agreement, through provision and management of ship locks at all mainstream dams.
- ii. Ensure consistent design and operation of ship locks at all mainstream dams.
- iii. Make sure that dam infrastructure does not impede the potential future development of mainstream navigation in terms of cargo transport capacity, passengers transport capacity and convoy transport development.
- iv. Ensure safe and efficient lock operations.

This sub-section presents the review of the Feasibility Study against these objectives.

4.8.2. Design

MAIN FEATURES

The navigation lock will be located at the right riverbank and will require extensive excavation works. The developer indicates that this option provides for safer navigation, but that this has the drawback that the navigation facilities lie alongside the spillways potentially posing a danger to navigation when the spillways are in operation. The navigation facilities are designed to be operated for 95% of the time and will only be shut down in large floods. The navigation structure is a two-step navigation lock system for 2x500 DWT vessels. The locks are designed to divide the maximum lifting height of 35.5m into two equal parts, as is recommended by the PDG 2009, with a design similar to the tandem ship lock at the Xayaburi HPP.

The locks include three miter gates, an upstream, middle and downstream miter gate. The filling of the chambers of the Navigation Lock is done via a gravity- based feeding system from the headwaters of the plant controlled by bonneted gates. The lockage time for the two-step ship lock is expected to be shorter than 50 minutes.

There is no evidence in the designs submitted that a grouting screen perpendicular to the ship lock axis has been included in the design to avoid seepage. Grout injections have been included under the upper ship lock, probably to improve the subsoil conditions. But there is no explanation as to why the design only includes treating the subsoil under the upper lock. The developer has verbally confirmed that the intention is to provide a grout screen along the entire front of the infrastructure.

The drawings indicate the maximum chamber length is in the order of 125 m, which is more than what is recommended in both the PDG 2009 and PDG 2019. The lower lock chamber dimensions presented in some design drawings appear to be incorrect.

While there is space for a second lock system, and the documentation provided in March 2020 presented the proposed layout for the 2nd locking system. However, its construction may entail significant costs and the removal of the right bank fish passage.

AIR CLEARANCE

The bridge over the upper ship lock has an air clearance of 20.78 m during normal high-water levels. The air clearance for the 10,000-year flood is 16.63 m and is 14.53 m for the PMF. For the downstream bridge, the air clearance during normal high-water levels in the ship lock is 13.95 m, during the 10,000- year flood it is 9.80 m and during the PMF it is 7.7 m. The MRCS Navigation Master Plan recommends an air clearance of 10 m. However, navigation would not continue during extreme flood events and the air clearances are considered adequate.

FILLING AND EMPTYING SYSTEMS

The filling of the chambers of the Navigation Lock is done via a gravity- based feeding system from the headwaters controlled by bonneted gates through a single culvert. Computational fluid dynamics (CFD) modelling of the water conduit system was undertaken to assess the hydraulic performance of the water feeding system. The bottom filling system consists of 7 diffusers with 5 openings each. However, the drawings do not indicate baffle beams to avoid strong vertical flows during filling. This may create mushroom shaped upward currents that will shake the vessels and the boats inside the lock chamber. It is consequently recommended that baffle beams are included in the design (Figure 4-9).

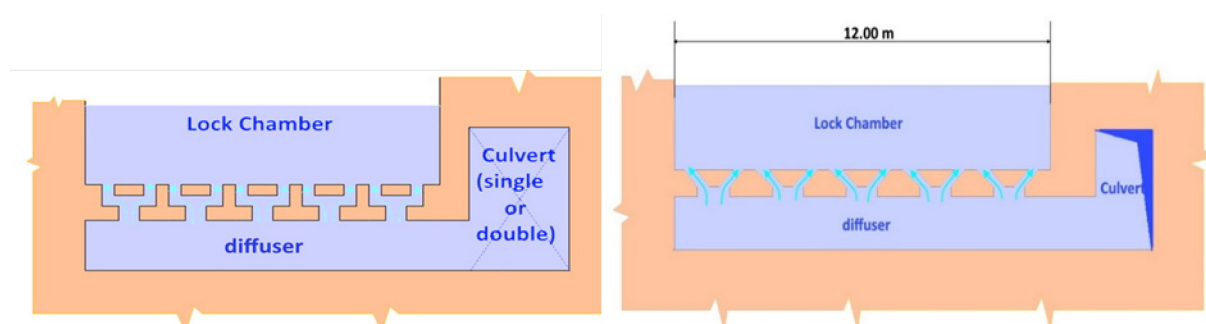


Figure 4-9 Options for baffle beams to reduce the risks of strong up-currents in the navigation locks.

The developer suggests a single culvert filling system with three gates. The intake comprises three bays with a reported capacity of 100 m³/sec. However, the outlet comprises three bays with approximately 75% of the intake capacity, but the reported filling and emptying times are very similar. This discrepancy needs further explanation. The reported metrics are nonetheless consistent with good practice. Nonetheless, it is recommended that the culverts in the chamber walls are doubled. This can reduce the current velocity limiting the risk of cavitation and increasing reliability and substantially increases the operational capacity of the ship lock.

LOCK EQUIPMENT

The Feasibility Study only provides a brief description of the lock equipment (ladders, floating bits, wall armours, line hooks, etc.). The drawings suggest that these are appropriately located, although there is no information on the numbers or exact location of this equipment. However, if this is also similar to the Xayaburi HPP, the design would be considered acceptable. This should nonetheless be confirmed as part of the JAP process.

Both lock chambers are long enough to accommodate the stoppage equipment, even though the stoppage equipment just downstream of the middle gate is not needed. Ships entering the lock cannot hit the miter gates because of the concrete wall which separates the two locks. The third stoppage system, just downstream of the upper miter gate, is therefore not required.

Moreover, there is no detail of the stoppage-system that will be used, although the text mentions a cable stoppage. However, these details can be decided in a later stage if there is enough leeway to keep the vessel away from the miter gate.

APPROACH CHANNELS

The approach channels are depicted in Figure 4-10. The two islands will be left over from the excavation works. The upstream island may obstruct the view of the entry to the locks and shipping in possible resting areas (if these are constructed as recommended), potentially posing a safety risk.

While reference is made to the PIANC recommendations for the access channels and the three areas in front of the ship lock, the documentation only mentions a single lay-by area, whereas the PIANC guidelines recommend 3 areas. At least two of these areas must be linked to the mainland and must include provision of fresh water, waste collection and power supply. The developer has verbally indicated that this is their intention.

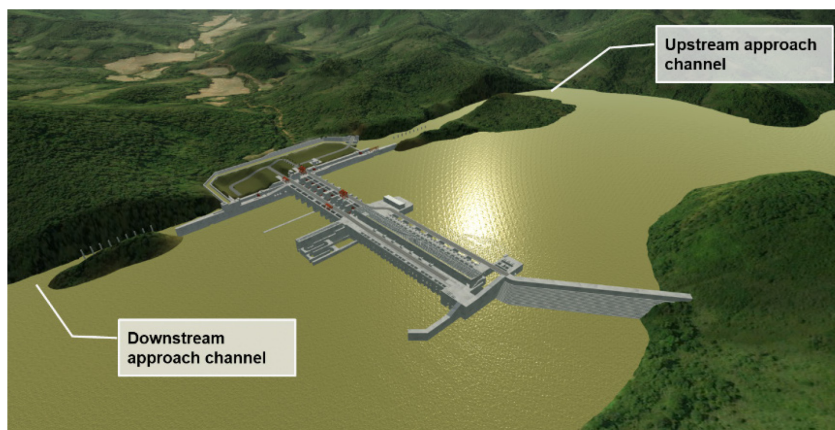


Figure 4-10. Diagram of the proposed LPHPP, showing the upstream and downstream approach channels to the navigation locks, and the islands that will be left after the excavations.

DESIGN STANDARDS

Confusion is created by referring to the CEMT ship classification. This classification is made for European waterways and is not applicable to the Mekong. Existing agreements on the Mekong use the Chinese ship classification. The Chinese ship classification indicates that the navigation facilities should accommodate the 500 ton Chinese self-propelled barge and a push convoy of 2 barges with a pusher. The dimensions of these vessels are as follows:

- Self-propelled barge: overall length $L = 67.50$ m, beam $B = 10.80$ m and draught $D = 1.60$ m.
- Push convoy of 2 barges and one pusher: overall length = 111.00 m, beam $B = 10.80$ m and draught $D = 1.60$ m.

The ship lock chamber dimensions are consistent with these requirements.

The Chinese Classification also defines the requirements of the approach channels. The report “*Condition Survey of dangerous areas for navigation between Luang Prabang and Pakse in the Lao PDR and Thailand*” has defined the two-way channel width in the Mekong for the chosen design vessel, in accordance with the then prevailing PIANC recommendations. These recommend a width of 40.00 m, increasing in the bends in the mainstream. The common bend radius was taken at 430 meters, but 600 m was chosen wherever possible. In critical circumstances (e.g. needing excessive rock removal and consequent environmental impacts) a bend radius of 200 meters was considered acceptable. The developer suggests a bend radius of 330 m, although a radius of 430 m is possible.

PIANC has recently issued a new guideline for navigation channel dimensions: “*PIANC – InCom WG Report nr.141 – 2019 – Design guidelines for Inland Waterway Dimensions*”. The recommendations formulated this new guideline are very useful and shed, *inter alia*, new light on the method for defining the width of access channels to ship locks. It is recommended that these updated guidelines are consulted at the final design stage.



Figure 4-11 A plan view of the LPHPP showing the current alignment of the navigation locks in green, and a proposed revised alignment in orange.

The downstream channel is separated from the spillway by a short separation wall which ties into the downstream island.

The up- and downstream approach channels could potentially be improved by adopting a new alignment for the entire ship lock. The actual ship lock is 90° to the axis of the barrage. Decreasing this angle to 85° or 80°²⁵ could possibly improve the layout of both access channels and substantially reduce the

earthworks in the upstream section, thereby improving the visibility inside the channel. The current design is likely to be confusing for downstream-bound navigation as the entrance will only be visible from relatively short distance upstream. If shipping misses the channel entrance to the right of the island, vessels may be pushed towards the spillway.

An advantage of the proposed new design is that the upstream island will be removed completely whilst downstream the channel will be more sheltered over a longer distance by the island connecting the downstream guidance wall. This would also provide more space for the three mooring zones required under the PIANC guidelines. It is recommended that the pros and cons of the different alignments be explored in more detail in the final design stage, and that these are discussed as part of the JAP process.

4.8.3. Operation safety and maintenance

Chapter 13.2.10. of the Feasibility Report deals with the operation of the navigation lock system. This proposes keeping the tandem ship lock open on both sides (upstream and downstream) when no navigation is occurring. This will potentially improve fish migration but the continuous attraction flow will reduce the volume of water available for power production.

A “*River Information System*” (RIS) may be applied over the full length of the Mekong River in the future. This will require coordination with all other HPP projects in the upper Lao cascade in order to provide as much information as possible to the shipping industry. PIANC guidelines Nr. 125/I of 2019 “*Guidelines and recommendations for River Information Services*” are very useful in this regard. A RIS should comprise:

²⁵ Offsetting the alignment of the navigation locks from the dam structure has been applied elsewhere.

- Fairway information services.
- Traffic information services.
- Traffic Management information.
- Information to support disaster risk reduction.
- Information for Transport Logistics.
- Information for compliance to legislation.
- Information for statistics; and
- Information for water charges and harbour duties

It is recommended that consideration be given to the inclusion of a RIS in the cascade operations investigation by the Government of Lao PDR and / or the MRC.

No information on safety and maintenance of the navigation facilities has been provided. It is recommended that a list of mechanical ship lock spare parts is prepared, and spares are kept in stock in order to reduce the outage times for repair and maintenance. The electromechanical equipment of the ship lock should be simple, straightforward, easy to maintain and reliable. Good communication is needed between the ship lock master and the skipper. This may be vocal from loudspeakers, intercom communication and visual from light signals (red-orange-green) or led-signboard announcements. An overhead crane over the full length of both lock chambers and ship lock heads, is needed for bringing in spare parts, stop-logs, lifting sunken debris in the chamber, rescue operations, or other emergencies. It is recommended that these aspects are addressed as part of the JAP process.

4.8.4. Navigation during construction

The Mekong from Luang Prabang City up to the LPHPP dam site and beyond is heavily used by tourist boats. Construction activities may affect the attractiveness of this stretch river for tourist boats, and this may continue into the operational phase. It is therefore recommended that the developer engages with the boat operators to gauge their perceptions of the proposed HPP, and the use of the navigation lock. Any lockage fee that may be applicable would also have to be discussed with the operators. It is also recommended that the average number of boats travelling up past the dam site is determined before the main construction activities are started to establish a baseline against any claims for compensation can be measured – should the operators choose to lay a claim.

The right bank coffer dam will be in place for some 5 years. During this time the water in the remaining constricted section of the river will be flowing much faster than normal, and special arrangements for navigation will have to be made during this period. The developer has verbally indicated that the smaller boats will be put on a trailer and transported around the construction, following the success of the practice at Xayaburi. However, they are still exploring options for the larger tourist vessels, perhaps including pulling boats.

4.8.5. Construction of the second lock system

The developer has indicated that they are only required to demonstrate that there is space for a second lock system, and the documentation provided after the 3rd JCWG meeting on 05 March 2020 presents a layout of the 2nd locking system. This confirms that there is sufficient

space on the left bank to construct the 2nd lock without the need to demolish the left bank fish pass facilities.

4.8.6. Alignment with the PDG 2009

The proposed navigation infrastructure is mostly aligned with the PDG 2009. However, there are several areas where insufficient information has been provided to confirm alignment. These are mostly related to the safety and reliability aspects of the facilities, including the need for spares, emergency access, fire control, overhead cranes etc. (see Annex B).

4.8.7. Recommendations for the JC

The JC may wish to take note of the following recommendations regarding the navigation facilities:

- The design of the navigation facilities is broadly aligned with the PDG2009, although some details are lacking in the documentation submitted for a full assessment.
- Baffle beams should be included in the design of the lock filling facilities to reduce the risks of strong up currents which could damage vessels by knocking them against the side walls.
- Double culverts should be included in the chamber walls. This can reduce the current velocity limiting the risk of cavitation and increasing reliability dramatically.
- The pros and cons of offsetting the alignment of the navigation locks to 80° to 85° from the perpendicular should be explored.
- A list of mechanical ship lock spare parts should be prepared, and spares are kept in stock in order to reduce the outage times for repair and maintenance; and
- Clarity should be provided regarding the placement and design of the second lock system

The developer has noted in written comments that:

- The navigation facilities are at the feasibility level design, and that these will be updated in the final design stage.
- A full set of spare parts will be provided for to ensure availability as required by the PDG 2009.
- The comments on the filling system are noted and will be considered in the detailed design.
- Boat operators have become accustomed to the locks at Xayaburi, and that the same systems should be employed at the LPHPP.
- The alignment proposed by the MRC expert is noted. However, developer considers the current alignment in compliance with PDG 2009 and international standards regarding visibility. Change of the alignment would considerably increase amount of excavation of the d/s lock chamber.

4.9. Socio-economic impacts

Key features of the socio-economic review:

- ▶ The developer's methodology to determine a baseline involved desk studies, field surveys including household census, and village interviews and meetings, but makes little use of existing, often more recent information at member country and MRC level.
- ▶ Baseline information for the population living close to and potentially affected by the project is provided for four different groups of Project Affected People (PAP) totaling 9,974 people in 26 villages.
- ▶ Baseline information on health and nutrition for the PAPs is limited. There is no baseline information on potentially affected people along access roads, in resettlement areas (future host communities), in transmission line corridors, or upstream or downstream along the Mekong River.
- ▶ Impacts are generally described qualitatively, not quantitatively. Some are differentiated by pre-construction/construction vs. operation phase, and their significance (very high to very low) is determined using the concepts of intensity, extent, and duration.
- ▶ The impacts on PAPs are comprehensively described but the impacts on potentially affected people along access roads, in resettlement areas (future host communities), or upstream or downstream are described briefly or not at all.
- ▶ There are, consequently, no specific mitigation measures identified for these impacts.
- ▶ There are no budgets provided for mitigation measures.
- ▶ Residual impacts that will remain after mitigation are not addressed in the SIA package.

4.9.1. Objectives

The ultimate objective of the prior consultation process should be to ensure that there is adequate protection for all those communities that may be affected by the proposed development. These protections not only cover the dam safety issues outlined in the previous section, but also protection or restoration of livelihoods that may be affected by the project.

The draft PDG2019 lists the objectives for riparian communities and river-based livelihoods as follows:

- i. Engage directly affected riparian communities in all phases of the project's development and operation in a participatory manner.
- ii. Ensure that directly affected riparian community livelihoods are better than, or at least restored to, pre-project levels.
- iii. Implement these support measures, where feasible, within existing institutional frameworks (e.g. MRC, government at various levels, civil society organisations).
- iv. Enhance existing, or create new, transboundary cooperative mechanisms as needed (e.g. to implement support mechanisms for transboundary riparian communities), such as through national, bilateral, regional and MRC-related frameworks.

4.9.2. *Analysis of Documents Submitted*

OVERVIEW

The Luang Prabang Social Impact Assessment has no stated objective, but generally the objectives of SIAs are:

- To identify and assess the regulatory framework, development plans, social situation and potential social impacts on project affected persons (PAPs).
- To identify targeted measures to avoid, minimise and mitigate adverse impacts or measures to improve outcomes for PAPs; and
- To formulate a program including responsibilities and budgets for implementation of the selected measures.

To this end, a systematic SIA would describe the **baseline** situation (pre-project or without project), predict the **impacts** of the project (before mitigation measures are applied), define mitigation measures (following the hierarchy of avoid, minimise, and mitigate) and evaluate the **residual impacts after these measures are applied**.

At the core of this analysis are the predicted impacts before mitigation. These must be based on changes to the bio-physical environment, which are addressed in the previous sections. These changes determine who is potentially affected by the project, which aspects of the baseline situation need to be described, and how – for each of the subgroups affected – the impacts will be addressed to achieve the objective, improvement of quality of life.

The following review covers each of these steps. Examples are provided from the different documents, in order to illustrate the approach and level of detail provided.

4.9.3. *The socio-economic baseline*

The developer's methodology to determine a baseline involved desk studies, field surveys including household census, and village interviews and meetings.

Baseline information for the population living close to and potentially affected by the project is provided for four different groups of PAP:

- PAP-1 – fully submerged – 6 villages, 581 HH, 2,885 persons
- PAP-2 – partially submerged – 9 villages, 692 HH, 3,855 persons
- PAP-3 – lose farmland – 8 villages, 671 HH, 2,330 persons
- PAP-4 – downstream affected by construction – 3 villages, 189 HH, 904 persons

The total number of PAPs included in the SIA is therefore 9,974 (not all of whom will be directly affected, but who live in villages which will experience different levels of impacts). The main livelihoods for these people are cultivation of rice, complemented by vegetables, fishing, livestock raising, harvesting of timber and non-timber forest products (NTFP), manual labour outside the villages, and activities related to trading, boating and tourism along the river. Average annual household incomes are estimated at LAK 40 million / year, equivalent to approximately USD 4,600 / year or USD 1,000 per capita per year. This is plausible, compared to Laos' 2018 GDP per capita of USD 2,600 / year. Average land holding is estimated at 3.3 ha per household.

Baseline information on health and nutrition is very limited (one paragraph each). There is no baseline information on potentially affected people along access roads, in resettlement areas (future host communities), in transmission line corridors²⁶, or upstream or downstream along the Mekong River. By comparison, the Pak Lay transboundary/cumulative impact assessments had baseline information on fisheries, navigation, and other social issues in 5 zones along the Lower Mekong Basin, including an ‘index of dependence’ on river resources.

4.9.4. Expected impacts and mitigation measures

The adverse impacts mentioned in the documentation are summarized in Table 4-10. They are generally described qualitatively, not quantitatively. In the SIA, some of them are differentiated by pre-construction/construction vs. operation phase, and their significance (very high to very low) is determined using the concepts of intensity, extent, and duration. However, because the SIA summarizes impacts by broad categories and does not provide the significance for all impacts, Table 4-11 simply lists the potential impacts.

Table 4-10 Social Impacts, Affected Groups and Proposed Mitigation Measures outlined by the developer

Impact	Affected Groups	Mitigation
Villages fully submerged/affected by land acquisition for construction, loss of all land and assets	PAP-1	Relocation; compensation for land and assets; livelihood restoration or where not feasible, alternative livelihoods options; community properties and cultural resources replacement to meet standard level of services; community/social development programs (including institutions, public health, education, cultural, gender, vulnerable groups, environmental education); and employment/training.
Villages partially submerged, loss of some or all land and assets for some HH	PAP-2	Relocation (where possible moving homes to higher ground within the village); compensation for land and assets; livelihood restoration or where not feasible, alternative livelihoods options; community/social development program; and employment/training.
Villages losing farmland	PAP-3	Compensation for land and assets; livelihood restoration or where not feasible, alternative livelihoods options; and employment/training.
Villages affected by construction dust, noise etc.	PAP-4	Maintenance of vehicles and machines, traffic controls

²⁶ The power purchase arrangements, and hence the transmission lines, still must be finalised.

Impact	Affected Groups	Mitigation
Land loss	Households losing land	Delay of land acquisition until crops harvested; if not feasible compensate at expected yield and market price (e.g. teak) Rehabilitation of temporarily used land Provision of community forests to compensate loss of NTFP
Construction traffic impacts on noise and air quality	Population along access roads	Maintenance of vehicles and machines, traffic controls
Vulnerable groups in 26 affected villages	31% of HH (disability, aging head, widow head – but no poverty data)	Vulnerable Groups Plan to be established based on more detailed assessments.
Ethnic groups in 26 affected villages	Lao Loum (majority group), Khmu, Hmong	Ethnic Development Plan to be developed, preservation of cultural identity, avoidance of conflicts.
Negative impacts on various livelihoods such as fishing, boat traffic, catering for tourists/cargo boats, collection of NTFP, sand and pebble extraction	‘Some villages’, probably among PAP-1, PAP-2, and PAP-3	Compensation and/or inclusion in Livelihoods Restoration Program for the loss of any other form of income. For some impacts, specific measures such as ship locks, community forests.
Positive impact on employment and economic activity during construction, better road connectivity	PAPs	General recommendation for local employment preferences and training (only for the 15 villages affected by resettlement)
Pressure on Luang Prabang World Heritage Site by labor influx; potential impacts on tourist boat travel	Luang Prabang tourism sector	Management of camps. Facilitation of navigation.
Loss of Buddhist stupa and temples, cemeteries, spirit houses	Ban Khokpho and other villages	Relocation/replacement, chance find procedures.
Nutrient intake, e.g. from riverbank gardens and fishing (barriers to fish migration could reduce livelihoods derived from fishing by 30% or more; needs to be further assessed)	PAPs and possibly up-/downstream communities *	Cumulative impact. Developer expected to be responsible for PAPs during transition period and for longer period for the most vulnerable HH.
Changes in prices/costs as a result of cash infusions into local economy (cumulative with other projects such as railway)	Not specified	Not specified
Water use and fish rearing in cages affected by increased turbidity during construction	Villagers living downstream (PAP-4?)	Water quality protection

Impact	Affected Groups	Mitigation
		Provide affected villages with water supply systems where required
Communicable diseases, contamination, accidents, conflicts between locals and outsiders	All PAPs	Management of construction sites and camps Public health programs for PAPs UXO clearance.
Minor changes in gender roles	Women	Training, promotion of gender equality

** The developer expects that the cumulative impact of the project may not be that significant outside the project area and suggest that most of the impacts will be localised within the project area and the resettlement area to be specific. Fish migration is also said to be primarily within northern system, therefore affecting the upstream region more than the downstream region. However, as noted in the fisheries section there are some long-distance migrating fish.*

While the impacts on PAPs in the 26 villages are described quite comprehensively, the impacts on potentially affected people along access roads, in resettlement areas (future host communities), or upstream or downstream along the Mekong River are only described briefly or not at all. There are, consequently, no specific mitigation measures identified for these impacts. By comparison, the Pak Lay transboundary/cumulative impact assessments had impact predictions (some of them quantitative, for example cumulative physical displacement and loss of farmland) for a number of impacts, including those related to bio-physical changes to the river system and the dependence of people on river resources.

While the impacts of access roads are apparently mostly limited to increased traffic, the impacts of transmission lines which could be more than 700 km long, through mountainous terrain, could be large. The total affected area that would need to be acquired or subjected to land use restrictions could be of the same order of magnitude as the Luang Prabang reservoir but have not yet been not addressed in the SIA.

In other chapters, the documentation describes several mitigation measures for impacts on fisheries, sediment, water quality, dam safety, and navigation. These mitigation measures will have indirect social benefits but are reviewed separately in this TRR.

Based on the identification of potential impacts, the SIA provides brief principles, recommendations or statements of intent, for several social mitigation approaches. The SMMP contains descriptions of mitigation measures with different levels of detail. For some, there is only a statement of intent (for example *“The operation pattern of the ship lock will have to be formulated with the aim of satisfying the needs.”*) Other measures are described in more detail.

The SMMP also includes institutional responsibilities, implementation schedules, and internal and external monitoring plans. It essentially covers the same measures as the Resettlement Action Plan (RAP), divided into the following major programs:

- Compensation.
- Resettlement.
- Livelihood Restoration.
- Community/Social Development.

- Public Health.
- Transportation; and
- Chance Finds (i.e. archaeological or historical features that may be exposed by the construction process).

While the RAP contains more detailed mitigation commitments than the SMMP, specifically for the resettlement-related measures, neither of them contains a budget.

4.9.5. Residual impacts after mitigation

Residual impacts that will remain after mitigation are not addressed in the SIA package.

4.9.6. Limitations

OVERVIEW

The information presented in the different steps of an SIA (baseline, impacts, mitigation, residual impacts) needs to progress logically. If an impact is predicted, baseline data and mitigation measures related to that specific impact need to be presented. The objectives of social impact management need to be clearly spelled out, following regulatory requirements. The recent Lao PDR Decree No 31 on Environmental Impact Assessment (January 2019) indicates that the objective should be the improvement of the living standard of PAPs. Measures need to be designed to achieve this objective. Baseline information needs to be sufficiently precise to allow monitoring of social conditions over time, and if objectives are not achieved, to adjust and improve the effectiveness of the mitigation programs as needed.

BASELINE INFORMATION AND DATA

The documentation makes very little use of existing, often more recent information at member country and MRC level. The baseline information on the locally affected PAPs is up to date with surveys from 2019. However, it has some gaps, especially regarding river-related livelihoods (fishing, different categories of boating, gravel extraction etc.)

There is no baseline information on populations in the downstream or upstream zones, although it is acknowledged that there could be impacts, for example, on fish migration and therefore nutrition.

IMPACTS AND MITIGATION

Most of the typical direct impacts on local populations are covered in the SIA documentation, although they are spread across different documents and are described at different levels of detail, and mostly not quantified.

The social impacts could be described more consistently. Some documents use a standard categorization approach (such as Significance of Impacts), while others use verbal descriptions only. Even where the Significance categories are used, the logic behind assigning categories such as 'low' or 'high' is not explained. Impacts should generally be differentiated by gender, ethnicity, poverty or other categories, as vulnerable groups might require different approaches to mitigation.

Mitigation measures related to the physical and economic displacement of people in the immediate project area are relatively well defined. The RAP describes some objectives,

principles and overall outlines of mitigation measures, although there are no budget estimates at this stage.

Mitigation measures for households, businesses and villages which are not directly displaced, but are upstream or downstream from the project or will function as host communities are less well defined. It is uncertain whether the same objectives with regards to livelihoods and living standards apply to these groups, and in which mitigation or compensation measures they can participate. Impacts on different livelihoods based on the river are not likely to be limited to the 26 PAP villages. For example, the attractiveness of the river for tourist trips from Luang Prabang town might change, affecting tour operators in the town. Accessibility of sand and gravel for construction purposes might change along the reservoir, with most sandbanks and riverbanks inundated and sediment settling out at the upper end of the reservoir. Fishing and aquaculture may be affected in various ways.

There is no clear explanation for the definition of cumulative impacts, which only cover hydropower and infrastructure projects within Laos. Potential cumulative impacts with hydropower projects in other parts of Laos (on tributaries, such as the Nam Ou) and in other parts of the Mekong basin are not considered. It is also unclear how cumulative impacts have been considered in the analysis of the transboundary impacts.

Despite a strong dependence of livelihoods along the Lower Mekong Basin on the river and its eco-systems, potential social transboundary impacts which have been the subject of much discussion in the Mekong region over the past years are not covered. It would be advisable to remain consistent with the approach taken in the MRC Council Study and other assessment tools developed by the MRC, which are based on the best available science. A comparison between the scenarios used in the Council Study can inform the assessment of the incremental impacts from LPHPP, against the background of other developments in the basin.

Mitigation options for long distance transboundary impacts are summarized in the final draft of the MRCs revised Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin (2019), which could be used to guide the ongoing design, construction, operation and mitigation of the LPHPP. Where attribution of impacts to particular projects such as Luang Prabang appears difficult, joint initiatives by developers and governments (such as a 'Mekong Fund') might be considered.

RESIDUAL IMPACTS

While it is possible to achieve objectives such as improvements in the standard of living with a well-designed social management program, there is no discussion of the anticipated effectiveness of the mitigation measures and any risks that might impact these.

The conclusions on residual downstream impacts are vague. On the one hand, general concerns are quoted about the impacts of mainstream dams on nutrition. On the other hand, the impacts are downplayed as "not that significant". The downstream residual impacts should be predicted more consistently, based on the best available science, and the actual impacts verified through monitoring, to serve as the basis for mitigation interventions where necessary.

4.9.7. Considerations for the JC

It is recommended that the following additional information is shared as part of a post prior consultation Joint Action Plan:

- Information on methods and data sources for the socio-economic baseline, impacts and mitigation measures.
- Up-to-date information on downstream/transboundary affected populations, consistent with MRC social monitoring protocols, including baseline data on all aspects of livelihoods and living conditions that could be affected.
- Quantitative impact predictions where possible, consistent with relevant MRC studies such as the Council Study.
- Targeted mitigation measures for all predicted impacts, designed to at least retain, if not improve, the livelihoods and living conditions of all affected groups.
- Where practical, joint mitigation and monitoring actions with other developers, government agencies, and the MRC to address cumulative impacts.
- Clear commitments in terms of budgetary, implementation, monitoring and adaptive monitoring responsibilities.

5. TRANSBOUNDARY AND CUMULATIVE IMPACTS

5.1. Introduction

While it is clear that the focus of this TRR is the infrastructural and operational measures that can be put in place at the LPHPP to avoid, minimise and mitigate and potential impacts, the evaluation of the documentation provided must be put in the context of its potential additive impacts. The LPHPP is the 4th HPP in the upper Lao Cascade to undergo prior consultation and will have impacts over and above the impacts of the other mainstream dams, as well as the existing tributary developments and the Lancang Cascade. In isolation the potential transboundary harmful effects due to the LPHPP may not be substantial, but on top of the other existing and planned development it may have considerable impact on the other riparian States. Indeed, much of the impact on the lower reaches of the mainstream and Tonle Sap reported in the Council Study was related to the cumulative impacts of all the planned development.

Moreover, one of the biggest concerns expressed by the review teams related to the extent to which the LPHPP developer had addressed the transboundary cumulative impacts. This Chapter provides commentary on these aspects of the submitted documents.

5.2. Elements and principles of a transboundary impact assessment

The MRC has not yet finalised a guideline for transboundary impacts assessments. However, the EU's - Guidance on the Application of the Environmental Impact Assessment Procedure for Large-scale Transboundary Projects²⁷ lists 7 key steps in large scale transboundary project ESIAs. These have parallels with the MRC approaches to prior consultation. These, modified for the MRC context, are:

- Notification and transmission of information (PNPCA Clauses 5.2 and 5.3), which imply notification after the Feasibility Studies.
- Determination of the content and extent of the matters of the EIA information – scoping (PNPCA Clause 5.2.1 and the PDG).
- Preparation of the EIA information/report by the developer. In the MRC case this is done before notification and is part of the documentation shared. However, in practice the prior consultation process aims to support ongoing infrastructure and operational design, which is tracked through a post prior consultation Joint Action Plan.
- Public participation, dissemination of information and consultation. (This is done on a regional basis by the MRCS, and on a nation basis by each of the member States).
- Consultation between concerned Parties. (This underpins the process of developing the TRR as outlined in Annex A1).
- Examination of the information gathered and final decision (PNPCA Clause 5.4.3 – through the Special Session of the Joint Committee); and
- Dissemination of information on the final decision. (This is done by uploading the Final TRR to the MRC website, press releases and the Regional Stakeholder Forum).

In this context, the prior consultation process is part of the finalisation of the transboundary ESIA, and perhaps particularly for the cumulative and transboundary impacts, where the

²⁷ Available at: <https://ec.europa.eu/environment/eia/pdf/Transboundry%20EIA%20Guide.pdf>

developers may be hesitant to admit liability for transboundary impacts not of their making. This section is presented in this light.

It is standard practice for developers to identify *all* potential impacts of the development, and to propose measures to avoid, minimise or mitigate these. This has the following generic steps:

- Identify the current condition of the natural and socio-economic environment.
- Identify those elements of the natural and socio-economic environment that may be impacted by the project, and the likely post-project condition.
- Identify the measures that can be put in place to avoid, minimise and mitigate potential adverse impacts.
- Outline the 'no-project' scenario. This may include positive and negative aspects. The do-nothing scenario means that the benefits of the project in terms of regional economic growth must be set against lost livelihoods due to other impacts, as well as climate and demographic change.

Undertaking these studies is an inherent part of the costs of the project, and the larger the project the greater the investment needed in this regard. The purpose of including an assessment of any potential transboundary impacts as part of the prior consultation process is to use the resources attached to the HPP development to clarify what impacts may be transboundary in nature and to quantify these as far as possible. This will enable a more in depth look at the impacts of the proposed development and may determine the effort or investments that are required to limit transboundary impacts. This must also recognise that these impacts occur on top of all the impacts from existing developments and raise the potential for unacceptable cumulative impacts from future developments.

It is therefore important for the developer to identify what transboundary impacts *may* occur due to the specific notified proposed use, but also to assess this as part of a cumulative impact assessment that considers the *additional* transboundary impacts that may occur due to the development, and the impacts on existing, planned or foreseeable future developments. This is also central to any determination of whether the proposed water use is a reasonable and equitable use of the shared watercourse (see Section 1.2.2) and is necessary for the notified Countries to evaluate the potential impacts of the proposed use on their existing and proposed future use of the shared watercourse.

Cumulative impacts are multiplicative in nature. Because no fishpass is 100% effective, some fish will be lost in both the upstream and downstream direction at each HPP. To illustrate, assuming that of all the fish arriving at the proposed Sanakham HPP, only 80% pass successfully, then at Pak Lay 80% of the remaining fish pass i.e. 64%, then at Xayaburi again 80% of the remaining fish, i.e. 51% and so on. The same applies in reverse for the downstream migration. This is illustrated for the previously notified HPP for different fishpass efficiencies (assuming the same for each HPP), in Table 5-1 A. Table 5-1B shows the same but including the LPHPP, and Table 5-1C for the full upper Lao Cascade.

Table 5-1 A, B, C An illustration of the multiplicative effect of fish pass efficiency along the upper Lao Cascade, showing the effect of different efficiencies at each of the HPP. This is for upstream migration. The reverse would hold for downstream migration.

A HPP Fishpass infrastructure				B HPP Fishpass infrastructure					C Fishpass infrastructure					
Efficiency	Pak Lay	Xayaburi	Pak Beng	Efficiency	Pak Lay	Xayaburi	Luang Prabang	Pak Beng	Efficiency	Sanahkam	Pak Lay	Xayaburi	Luang Prabang	Pak Beng
80%	80%	64%	51%	80%	80%	64%	51%	41%	80%	80%	64%	51%	41%	33%
70%	70%	49%	34%	70%	70%	49%	34%	27%	70%	70%	49%	34%	24%	17%
60%	60%	36%	22%	60%	60%	36%	22%	17%	60%	60%	36%	22%	13%	8%
50%	50%	25%	13%	50%	50%	25%	13%	10%	50%	50%	25%	13%	6%	3%
40%	40%	16%	6%	40%	40%	16%	6%	5%	40%	40%	16%	6%	3%	1%
30%	30%	9%	3%	30%	30%	9%	3%	2%	30%	30%	9%	3%	1%	0%

This shows that, for example if all the fish pass facilities had a 50% efficiency, then 13% of the fish reaching Pak Lay would make it to spawning grounds upstream of Pak Beng. Including Luang Prabang drops this to 10%, and for the full cascade it is 3%. The opposite happens for the downstream migration and these two products should be combined to give the overall impact. Note, these two elements of impact are not additive but multiplicative. Moreover, if upstream migration to the spawning grounds (which will in effect only exist upstream of the Pak Beng backwaters, i.e. Keng Pha Dai reef and upstream) is unsuccessful, then there would be fewer larvae drifting downstream. If all the HPP are constructed almost all of the flowing water habitat between Sanakham and Keng Pha Dai will be lost.

While Table 5-1 is an oversimplification it does illustrate several key issues highlighted in the fishpass review in the previous chapter and in Annex F:

- The efficiency of the cascade is only as good as its weakest link, and so information on the efficiencies of existing HPP, in this case – Xayaburi, should be shared with view to adaptive management.
- Unless relatively good efficiencies are achieved, there is little potential benefit to additional investments in the fishpass facilities, and investment in mitigation measures may hold greater benefits.
- Increasing the number of HPP has a dramatic effect on the efficiency of the whole cascade (this does not account for the additional loss of habitat).
- The impacts of any HPP are determined by the efficiency of others in the cascade; and
- If the full cascade is developed upstream and downstream fish passage efficiencies would have to be very high.

A similar effect would be evident with the downstream transport of sediment, where lower efficiencies in any of the cascade dams negate much of the investments in sediment management at the other dams. This also underlines the importance of making efforts to comply with the PDG.

These cumulative impacts have been demonstrated by the Council Study, which has provided a more robust, scientific basis for estimating the impacts. The estimate of a 40% loss of fisheries in the upper Zone reported in the Council Study assumed a fish passage success of 20% for Pak Lay, Xayaburi and Pak Beng.

The purpose of the site specific cumulative and transboundary environmental and social impact assessment would be to refine these results, learning from previous cases and improving on the estimates of the efficiencies at the LPHPP.

5.3. A review of cumulative and transboundary impacts

5.3.1. Transboundary hydrological impacts

Transboundary hydrological impacts refer to changes to the annual hydrograph, i.e. reducing and delaying wet season flows, and increasing dry season flows. As a Run-of-River scheme the LPHPP will have minimal impact on seasonal flows, and any shorter-term changes will be buffered by the downstream HPPs.

5.3.2. Sediment impacts

The CIA-TBIA highlights the role of the Lancang cascade in reducing sediment input to the LMB. However, the documentation implies that the trapping of sediment in the upper Lao cascade is minor compared with the Lancang cascade or the hydropower projects on the Lao PDR tributaries. The MRC Council Study, however, showed that the upper Lao PDR cascade has a substantial impact on sediment transport, accounting for 15% of the overall sediment trapping in the basin (including China), or 24% of the total sediment trapped (excluding China). These findings are consistent with the sediment transport investigations presented, which show that fine sand and coarser material (that account for up to 75% of the sediment load) are trapped within the impoundment. A similar finding was provided by the modelling exercise in the upper Lao PDR, and by the Delta Study, with bedload transport reduced from over 20 MT/yr to <5MT/yr due to trapping in the upper Lao Cascade and tributary projects.

The EIA also suggests that sediment transport will again increase when the impoundments reach a new equilibrium but does not provide a time estimate for this process. Given the number of hydropower projects in the cascade (up to 5), the lengths of the impoundments (a combined length of about 600 km), and the reduction in sediment input from China and tributaries, the time-frame for sedimentation to reach a new equilibrium will be decades to centuries. In effect, the impacts from sediment reduction must be considered permanent unless measures to minimise these impacts are included. This issue is not discussed in the CIA-TBIA Report, but they can only be comprehensively addressed through the development of cascade operating rules.

The CIA-TBIA recognises there are delays in impacts progressing downstream and indicates that transboundary impacts will likely reach Thailand within a 'short' period. But suggests that the potential impact on Cambodia, and Vietnam would be minor and that additional sediment input, and the availability of sediments in the river channel for transport will buffer the impact. This is likely correct for a period of time, but over decades to century timescales this cannot be assumed to be true. A greater discussion of the very long-term impacts of sediment trapping in the cascade and tributary projects is needed. This must be set against the potential impacts that are expected, will considering other external drivers for example demographic and climate change. The latter could render some of the longer-term impacts due to sediment trapping moot.

The CIA-TBIA describes potential downstream impacts on geomorphology (habitats) in a general sense (riverbed degradation and channel incision) but does not identify specific transboundary areas that will be susceptible to change, such as the large alluvial reach upstream of Vientiane / Nong Khai. There is no discussion of potential mitigation measures,

such as sediment flushing, to reduce these transboundary impacts. There is mention of using physical measures, such as gabions, to minimise erosion if necessary, but what criteria or thresholds would be used to determine when intervention was warranted is not discussed.

5.3.3. Fisheries and aquatic ecology

The LPHPP developer has not undertaken a rigorous transboundary and cumulative impact assessment, instead relying largely on literature. The assessment of the transboundary impacts in the documentation is largely restricted to descriptions of the fisheries in the LMB and concludes that, *“The upper migration system appears to be relatively isolated, with little exchange to the further downstream migration systems”*. This is not accurate as considerable exchange occurs with downstream reaches of the Mekong. The documentation also reflects on the cumulative impact of the upper Lao cascade but incorrectly interprets that *“... fishes mainly migrate into areas further upstream of Pak Beng for spawning”*.

There is likely to be insufficient free-flowing water upstream of Pak Beng to support the whole of the fishery in the upper migration zone. Moreover, the CIA-TBIA documentation seems to neglect the long-distance migratory fish, and the exchange between the upper and middle and lower migration zones. The conclusion that *“It is therefore expected that the transboundary impact concerning the fish migration is mainly affecting the upper migration system with migration towards China and can hardly be measured in the south towards Thailand, Cambodia and Vietnam”* does not consider the literature on the exchange between the zones.

It is therefore recommended that a more robust transboundary impact assessment is carried out, with special emphasis on migratory main channel resident guilds and migratory main channel spawning guilds, including impacts both upstream in Lao PDR and Thailand and downstream in Lao PDR, Thailand, Cambodia, and Viet Nam. This should include assessments of the social and economic impacts of disrupted migration, and assessment of the “no mitigation” scenario.

5.3.4. Dam safety

The LPHPP lies 25 km upstream of Luang Prabang City, which has been designated as a World Heritage Site. Any impacts of a dam break, or the flood operations may also lead to the loss of life for citizens from many countries. For the purposes of this TRR, impacts on Luang Prabang will therefore be considered as ‘transboundary in nature’, as this will be of concern to the global community. Figure 5-1 shows the likely inundation of the City under different flood operations. The dam break scenario shows similar levels of inundation. Because of the significant consequences of a dam break, the LPHPP should be designed using more stringent standards to those typical of the other HPPs in the cascade. The Emergency Procedures Plan has not yet been fully elaborated, but this is usually not expected at the feasibility level design.

The impacts of a dam break are therefore not considered to be substantially different from the very high flow conditions. However, as the dam break may be more likely when the head difference across the dam is greatest, the likelihood of a dam break may be higher than the extreme flood event, if adequate design parameters are not applied.

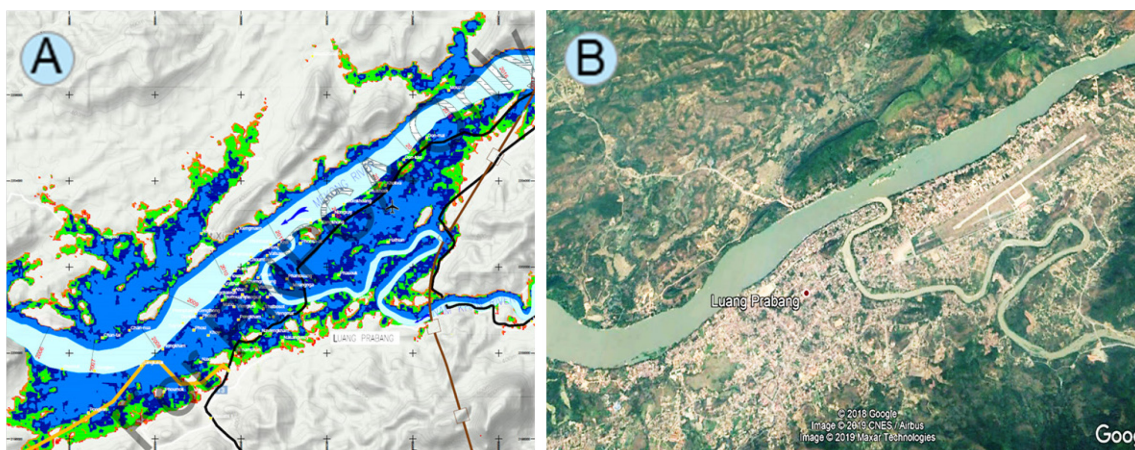


Figure 5-1 The potential inundation of Luang Prabang City under a dam break or severe flood operations. A) shows the extent of inundation under the 100 yr, 1,000 yr, 10,000 yr and PMF as different colours. B) is a Google Earth image of the same area showing the infrastructure that would be affected.

5.3.5. Transboundary socio-economic impacts

The documentation provided does not address the potential transboundary socio-economic impacts, possibly because these were expected to be minor. The potential mitigation of these long-distance transboundary impacts is therefore also not addressed. However, potential transboundary mitigation options are summarized in the draft PDG 2019, and this could be used to guide the any further CIA-TBIA efforts, and the prioritisation of transboundary mitigation options.

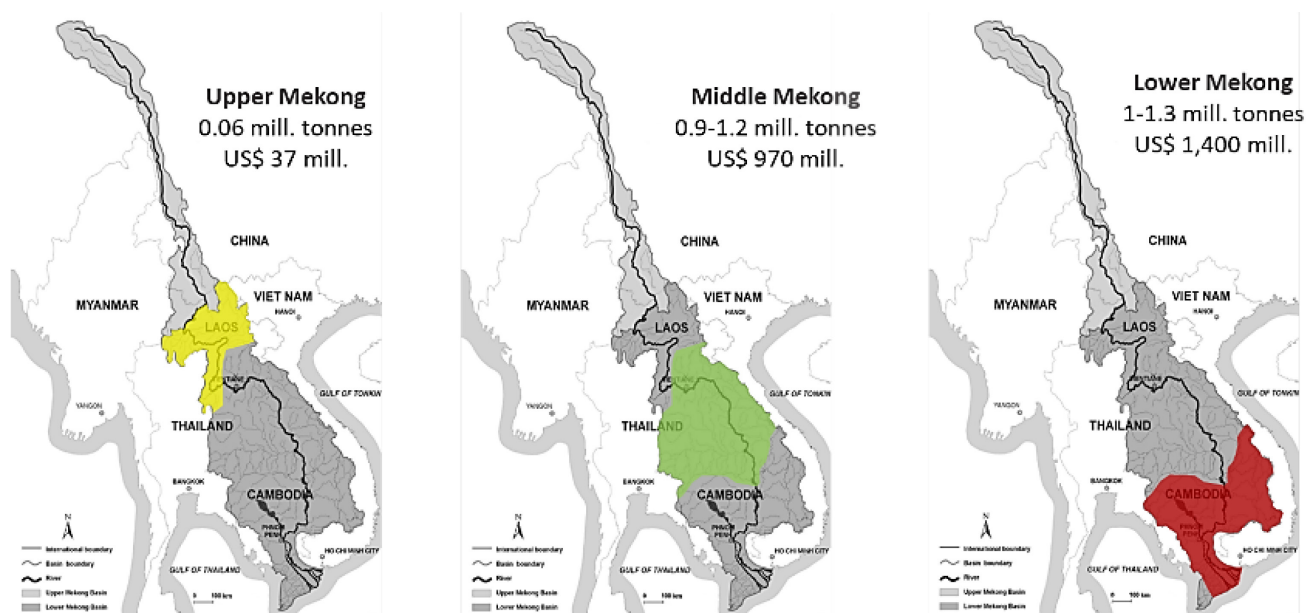


Figure 5-2 The estimated total fisheries and economic value in the 3 zones of the LMB (from MRC 2007).

As per the Council Study, 40% of the fisheries may be lost due to the upper Lao Cascade and assuming a 20% fishpass success rate²⁸. Therefore the 40,000 – 60,000 tonnes / year catch

²⁸ This was based on the experience of the modelers. The Lao PDR has suggested that this is unrealistically low, but without monitoring the efficacy of the fishpass it is not possible to make a definitive assessment of efficacy.

in this zone will drop to 16,000 to 24,000 tonnes. This could have a significant impact on the local capture fisheries and the communities dependent on them.

However, as the total capture fisheries in the LMB is estimated at 2,560,000 tonnes per year (Figure 5-2), these losses in the upper zone may therefore amount to a fraction of the total, should only the upper Lao cascade be constructed. Nonetheless, the impact of the upper Lao cascade will be felt downstream in the middle and potentially lower fisheries zones through disruption of whitefish migration and loss of spawning habitat. These figures also do not account for any potential impacts of the reduced sediment transport on downstream ecosystems.

The loss of transboundary fisheries potential will not be the case should the HPP downstream of Vientiane be constructed, where the amount and value of the capture fisheries is several orders of magnitude higher (Figure 5-2). It is therefore recommended that as a better picture of the fishpass efficacy at Xayaburi emerges, additional investigations using the Council Study models should be undertaken.

5.4. Conclusions and Recommendations

There are several measures that could be applied to further limit the potential cumulative and transboundary impacts of the upper Lao cascade. However, these measures require balancing the costs of reduced power output with the environmental and social benefits that may accrue. Some of these measures may also compromise the financial viability of the individual HPPs without a commensurate increase in the price of the power or extension of the concession period. Some of these measures have already been tested in the Council Study and the work undertaken by the Sustainable Hydropower Strategy, and it is recommended that these studies are expanded to explore different combinations of options that may result in a more appropriate balance between avoiding or minimising transboundary harm and the viability of the HPPs.

This study can only be driven by the Government of Lao PDR. However, the expertise and modelling systems already developed for the Council Study and used in the MRC would facilitate the optimisation of these options. While the Council Study has already done considerable work in this regard, there would be significant benefit to bringing the developers on board to provide more details to support the modelling efforts and the consequent financial impacts. Moreover, now that all the HPPs in the upper Lao cascade have been notified, the existing models can be optimised based on the actual infrastructure to be put in place. If the efficacy of the fish pass facilities at the Xayaburi HPP is monitored the model inputs can also be refined.

This study would also require baseline information on the habitats and geomorphology along the full reach from the proposed Sanakham HPP to the Khe Pha Dai reef, and better information on sediment fractions and fish larval drift. It is recommended that the MRC enters into discussion with the Ministry of Energy and Mines in the Lao PDR in this regard to the optimisation of the operations in the upper Lao cascade.

6. COMMENTS, RECOMMENDATIONS AND WAY FORWARD

6.1. Background

This chapter highlights the broad conclusions of the review and draws out some of the key findings of the review process as recommendations for the Joint Committee.

These recommendations include those that may:

- Place the developer in a better position to assess the potential impacts of the LPHPP using improved hydrological, sediment and ecological data.
- Support the redesign of elements of the infrastructure and operating rules to avoid, minimise and mitigate potential impacts.
- Assist the assessment of the technical and economic feasibility of the revised designs and operating rules.
- Improve the safety of the dam structure and navigation facilities.
- Further minimise the potential for transboundary impacts; and
- Place the Member States in a better position to address the cumulative impacts of the upper Lao cascade, and other HPP developments throughout the Basin.

Comments throughout this TRR consist of those aimed at:

- The quality of the Feasibility Study and submitted reports. These are provided primarily for the Lao PDR's information. They are not included in this chapter, except where they can lead to the better project moving forward.
- Alignment with the PDG 2009 and draft PDG2019. These are offered to help guide the Lao PDR when requesting the developer to undertake additional studies; and
- Proposing measures for the Lao PDR and the developer to consider, leading to a project with lower risks of transboundary impacts. These will ultimately be taken up in the Statement to be tabled at the Special Session of the Joint Committee.

6.2. General Comments

The following general comments are relevant:

- The developer has made better use of the MRC data and Reports, as well as other literature on the flows, sediment dynamics and water quality. However, the more recent work undertaken for the Council Study has not been considered.
- The design drawings are provided in .pdf format, but the watermark obscures some of the details, which has made it difficult to assess the details of the designs.
- Generally, more information on the design and operating rules is required to adequately review the proposed solutions and their alignment with the PDG 2009.
- The developer's previous experience with Xayaburi has contributed considerably to proposals to limit potential impacts even at the Feasibility Stage.

- A post prior consultation JAP will provide the opportunity to joint refine the proposals and bring a broader range of experience to bear on the final design of the project.
- The developer is already addressing many of the issues raised in this TRR.

6.3. Hydrology

6.3.1. Comments

The following general comments on the hydrology and hydraulics covered in the submitted documents are offered:

- The length of the inflow data time series is acceptable. However, no data from the upstream tributaries and hydropower projects, or manual records of rainfall have been used. The effect of climate change and upstream tributary development has been ignored.
- There is insufficient information on the QA/QC procedures already applied, or that will be applied to the new data emerging from the ongoing work.
- The impacts of the Pak Beng HPP have been ignored as it is a RoR scheme. However, the operation of the Pak Beng HPP will provide additional short-duration hydrological signals which should be considered and coped with.
- The operations at the Xayaburi HPP have not been considered when developing the tailwater curves.
- The flood peaks calculated by the developer are comparable with other studies on the upper Lao Cascade. As the values presented for the LPHPP are in the higher part of the range, they can be considered conservative and therefore on the safe side.
- Detailed information on the set-up and use of the physical and mathematical models is in separate reports that have not been submitted for review. The information provided is considered insufficient for a detailed review.
- The results of the physical model tests have not been shared.
- More detail on the operating rules is required for a comprehensive review, and to provide the basis for the eventual inclusion in the PWUM.
- The FS does not explicitly indicate that the real time telemetry network for rainfall and flows for the Xayaburi HPP will be used. However, the developer has indicated that this is the case.
- Data sets that have been sourced, and which are not held by the MRC, should be shared.

6.3.2. Recommendations

- A decision, consequences and motivation for/of the choice of an operating level (of 310 m or 312 m) should be provided.
- The impacts of both climate change (increased incidence of high rainfall events) and upstream hydropower development on future hydrology and flood peaks should be more addressed more comprehensively.

- The probability of flood volume and flood discharge should be presented jointly to determine the flood hydrograph.
- The rating curve at Soupanouvong should be corrected for the impacts of operation of the Xayaburi HPP.
- The sensitivity of the tailwater levels to inflows and changes in the alluvial deposits due to the Nam Ou and LPHPP developments, should be assessed. The impacts of any possible changes in operating levels on tailwater levels should be determined. The quantitative modelling results should be used to determine a baseline for the hydrological and morphological characteristics of the remaining free-flowing river section downstream of the dam.
- The planned additional hydraulic modelling for the full length of the impoundment should be initiated as soon as possible, and the results shared. The developer should indicate what length of the impoundment will have velocities less than 0.3 m/s for different inflows.

6.4. Sediment

6.4.1. Comments

- The developer has provided relevant and consistent data and information related to geomorphology and sediment transport in the region of the development. The spatial data adequately covers the dam site and impounded area.
- The developer did not draw upon the available information related to sediment transport modelling including sediment trapping in impoundments that has been completed under various MRC projects.
- The discussion of sediment management strategies and mitigation measures is very limited.
- The developer suggests that a new sediment equilibrium will be established which will increase sediment discharge from the impoundment. However, this is likely to take a very long time and sediment flushing and routing operations are recommended.
- Including channel cross-sections showing sediment deposition at the dam wall will enhance the understanding of the effectiveness of the gates with respect to sediment transport. Information related to gate operation at different water levels would also be useful.

6.4.2. Recommendation

The following recommendation is offered to support the ongoing design of the infrastructure and operating rules:

- The planned hydraulic modelling of the impounded reach must be completed and used to support the formulation of options for sediment management including flushing and routing operations for the cascade. This should be a joint effort by the Lao PDR and the MRC.

6.5. Water quality and Aquatic Ecology

6.5.1. Comments

The following general comments on the water quality and aquatic ecology are offered:

- The water quality and aquatic ecosystem monitoring carried out to date does not yet provide enough of a baseline against which to measure any change.
- There is no in-depth analysis of the value of any habitats that will be lost, or the potential impacts on the wider LMB ecosystem in terms of lost biodiversity of aquatic productivity. This is also required to establish a baseline. However, the developer has indicated that is currently being done and will be provided for evaluation.
- There is limited discussion on the implications of multiple dams on water quality, aquatic ecology and fisheries.

6.5.2. Recommendations

The following recommendations are offered to support the establishment of a comprehensive baseline, and management of water quality during construction and operations the ongoing design of the infrastructure and operating rules:

- A more proactive plan based on continuous monitoring is required to manage impacts during construction.
- The water quality and aquatic ecological monitoring needs to be expanded and continued. It is recommended that the methods developed for the Joint Environmental Monitoring programme are used.
- The lost habitat, particularly for species that require flowing water, needs to be quantified. This should extend beyond the impounded reach of the LPHPP and should identify lost habitat all the way upstream from the future Sanakham HPP to Chiang Saen. (This could potentially be done by the MRC.)

6.6. Fisheries and fish passage

6.6.1. Comments

The following general comments on fisheries and fish passage are offered:

- There is likely to be a reduction in capture fisheries in the upper zone. This is unlikely to be fully compensated by the productivity of the impoundment.
- The developer has done extensive design work on fish passage, but it is still in a preliminary stage with insufficient information to make a complete assessment.
- The present design of the LPHPP fishway provides negligible downstream passage of fish.

6.6.2. Recommendations

- The baseline monitoring programme should be and independently reviewed for robustness as soon as possible, and should follow the methodologies outlined in the Joint Environmental Monitoring programme.
- Greater consideration should be given to the importance of fish of high conservation value and the overall importance of fisheries to livelihoods and food security.
-

The following recommendations are offered to support the redesign of the fish pass facilities:

Upstream Passage

- Change minimum design flow based on the updated hydrology and potential operations of the upstream storage and lower tailwater level and floor levels of fishways to match.
- Add benthic fishway entrances and shape the thalweg to guide migratory fish to these entrances. The developer has indicated that they are considering options to address this.
- Add spillway entrances for the fishways and optimise these designs through physical modelling.
- Review fishway design options comprehensively, as suggested in Annex F.
- If fish lock design is pursued, increase the lock chamber length and entrance chamber length.

Downstream Passage

- Assess larval drift at various flows with hydraulic modelling and review impoundment management, if necessary.
- Explore different options for the debris screen design to minimise the impingement of larger fish.
- Investigate a pressure acclimation weir in front of the turbines.
- Provide data on blade strike, shear and pressure of the turbines; and the size of fish passing through the debris screens.
- Use the radial gates fully open to reduce impacts on fish, or replace the radial gates with an overshoot design, or use overshoot gates within all the radial gates. Ensure that the design of radial gates and spillway has a smooth path for fish.

Passage during Construction

- Do detailed hydrodynamic or physical modelling for the Stage 1 coffer dam and provide a dedicated fish passage solution for Stage 2, and Stage 1 if required.
- Undertake a full review of the impact of the upper cascade of HPP and tributary dams on fish population and community dynamics to determine the practicality of constructing fish passage facilities at future HPP dams in the Mekong downstream of Sanakham. The review should include environmental, ecological and social and

economic attributes and not be restricted to fisheries. This should be done by the GoL and / or the MRC in collaboration with the HPP developers.

6.7. Dam Safety

6.7.1. Comments

The following general comments on the dam safety aspects are offered:

- The LPHPP is classified as an “extreme risk” dam based on the Lao Electric Power Technical Standards (LEPTS 2018). These are more stringent than the standards that have been applied to previous mainstream projects. The developer has confirmed that the final design will comply with the requirements of LEPTS 2018.
- The Feasibility Study presents a sound basis for the formulation of the project but lacks some of the detail that would be expected at this stage for a major hydroelectric development. In particular, the Dam Safety Review Panel has not yet been appointed.

6.7.2. Recommendations

The following recommendations are offered to support the ongoing design of the LPHPP:

- The results of the current physical modelling of the LPHPP should be shared to ensure that the spillway capacity and erosion protection requirements for the project have been adequately demonstrated.
- The review of the new site investigation, foundation strength parameters and stability assessments should also be made.
- Dam Safety Review Panel should be appointed as soon as possible.

6.8. Navigation

6.8.1. Comments

The following general comments on the navigation facilities are offered:

- There is little detailed information available from the ship lock structure and equipment, and only a summary explanation of the layout and the ship-lock facilities has been provided. This has limited the extent of the review at this stage.
- There is only a summary description of the lock equipment available in the feasibility study. While the drawings suggest that the location of the equipment is adequate, this should be explicit.
- The Chinese ship classification has been used for other treaties on the Mekong and should be applied here.
- The islands left after the excavation of the right bank may obstruct view of locks for vessels approaching from upstream.
- A River Information Service which will provide information to vessels on all the navigation lock facilities in the cascade may be installed in future and could be investigated as part of the cascade operations.

6.8.2. Recommendations

The following recommendations are offered to support the redesign of the navigation facilities:

- Baffler beams should be included in the design of the lock facilities to reduce the risks of strong up currents which could damage vessels by knocking them against the side walls.
- Double the culverts should be included in the chamber walls. This can reduce the current velocity limiting the risk of cavitation and increasing reliability dramatically.
- The pros and cons of offsetting the alignment of the navigation locks to 80 to 85 degrees from the perpendicular should be explored in more detail.
- A list of mechanical ship lock spare parts should be prepared, and spares are kept in stock in order to reduce the outage times for repair and maintenance.
- The plans to ensure navigation during the stage 1 coffer dam should be finalised and shared as part of the post prior consultation JAP process.

6.9. Socio-economic

6.9.1. Comments

A systematic SIA must describe the baseline situation (pre-project), predict the impacts of the project (before mitigation), define mitigation measures (following the mitigation hierarchy of avoidance, minimization, mitigation and compensation/enhancement), and evaluation of the residual impacts after mitigation. In this regard:

- Baseline information on health and nutrition is limited. There is no baseline information on potentially affected people along access roads, in resettlement areas, in transmission line corridors, or upstream or downstream along the Mekong River.
- Residual impacts that will remain after mitigation are not addressed in the SIA package.
- Potential cumulative impacts with hydropower projects in other parts of Laos (on tributaries, such as the Nam Ou) and in other parts of the Mekong basin are not considered.
- The documentation makes little use of existing, often more recent information at member country and MRC level.

6.9.2. Recommendations

It is recommended that the following additional information should be provided as part of the JAP process:

- Methods and data sources for the socio-economic baseline, impacts and mitigation measures.
- Up-to-date information on downstream/transboundary affected populations, consistent with MRC social monitoring protocols, including baseline data on all aspects of livelihoods and living conditions that could be affected.

- Quantitative impact predictions where possible, consistent with relevant MRC studies such as the Council Study.
- Targeted mitigation measures for all predicted impacts, designed to at least retain, if not improve, the livelihoods and living conditions of all affected groups.
- Where practical, joint mitigation and monitoring actions with other developers, government agencies, and the MRC should be considered to address cumulative impacts.
- Clear commitments in terms of budgetary, implementation, monitoring and responsibilities are required for the monitoring of residual impacts.

6.10. The way forward

This Final TRR will be submitted to the Joint Committee who will use it to support their deliberations on 8 April 2020. Any changes required by the JC will be taken up in a Version 4.0

The final TRR, Statement and Joint Action Plan will emerge from the SSJC and will be published on the MRC website.



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