ANNEX D
Sediment Transport and Geomorphology

TECHNICAL REVIEW REPORT

on

Prior Consultation for the Proposed Luang Prabang Hydropower Project

Prepared by:
Mekong River Commission Secretariat

23 March 2020

List of Acronyms

ARI	Average Recurrence interval
CIA	Cumulative Impact Assessment
DG	Design Guidance
DSMP	Discharge Sediment Monitoring Project (MRC)
EIA	Environmental Impact Assessment
EMMP	Environmental Management and Monitoring Plan
FS	Feasibility Study
ISH	Initiative for Sustainable Hydropower (MRC)
LLO	Low Level Outlets
LMB	Lower Mekong Basin
LPCL	Luang Prabang Power Company Limited
LPHPP	Luang Prabang Hydropower Project
MRC	Mekong River Commission
PDG	Preliminary Design Guidance
SSC	Suspended sediment concentration
TBIA	Transboundary Environmental and Social Impact Assessment
UMB	Upper Mekong Basin

Contents

1 Background

The Mekong River Commission has commenced the Procedure for Notification, Prior Consultation and Agreement (PNPCA) for the proposed Luang Prabang Hydropower Project (LPHPP) to be constructed by the Luang Prabang Power Company Limited (LPCL). One of the themes that requires evaluation is the potential impact of the project on sediment transport and geomorphic processes in the Lower Mekong Basin (LMB). This report reviews the developer's proposal with respect to these topics, compares the proposed design with the MRC's Preliminary Design Guidance (PDG) 2009, and comments on areas where more action, information or explanation is required to address the criteria in the PDG. Comments and recommendations that align with the recently revised Design Guidance 2018 are also included where they provide additional insights or underpin recommendations.

This review is based on Volumes 1 – 6 of the Luang Prabang Power Company Limited Feasibility Study, Revision 1 dated 7 October 2019. The sections of the Feasibility Study included in this review include: the Executive Summary (Vol 1), Feasibility Report (Vol 2), Drawings (Vol 3), EIA (Vol 4-1), EMMP (Vol 4-3) CIA/TBIA (Vol 5), Hydrology (Vol 6-1), Topography (Vol 6-2), Hydraulic Modelling (Vol 6-5) and EIA Annex (Vol 6-6). Where relevant this report refers to information provided by the developers during meetings in December 2019 and February 2020, but the technical assessment is based on the submitted documents.

This report includes

- A review of the sediment transport and geomorphology data used by the developer as the basis for project design and operations;
- A review of the proposed LPHPP, with respect to the appropriateness of the project infrastructure and proposed operating rules to avoid, minimise and mitigate potential transboundary impacts. This component of the review is based on the potential risks, impacts and mitigation options identified in the MRC Hydropower Guidelines (
- Table 1, MRC, 2017), but limited to those processes and impacts that may have a transboundary impact. The changes most relevant to the Luang Prabang proposal include the loss of river connectivity and trapping of sediments as noted in Table 1;
- A review of the sediment transport modelling used by the developer to investigate sediment trapping and transport through the impoundment, near the infrastructure and downstream of the project;
- A review of the sediment monitoring and management plan proposed by the developer; and,
- A summary of the transboundary impacts identified by the developer, and how these compare with the present understanding of sediment transport processes in the LMB.

In each section of this report the information presented by the developer is briefly summarised, and then comments are provided relevant to the PNPCA process based on that information.

Table 1. Summary of geomorphology & sediment transport key risks impacts and vulnerabilities as identified in the ISH Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries (MRC, 2017)

Change	Key Risks, Impacts & Vulnerabilities
Annual / inter-annual changes to flow – *Not applicable to the LPHPP*	
	Water logging & loss of vegetation leading to increased bank erosion

Change	Key Risks, Impacts & Vulnerabilities
Changes in seasonality & continuous uniform release	Increased erosion due to increased scour (bed incision, bank erosion)
	Winnowing of smaller sediment leading to bed armouring & reduction in downstream sediment supply
	Bank scour focussed over limited range leading to increased bank erosion
Modification of flood intervals: Reduction in occurrence of minor floods & no change in large events	Channel narrowing through encroachment of vegetation Increased risk in upstream of flooding and floodplain stripping during large (>1:10 ARI) flood events
Change in relationship of flow & sediment transport	Decoupling of tributary & mainstream flows Erosion and / or deposition at tributary junctions due to tributary rejuvenation
Daily / short-time period changes in flow – *Unlikely to be applicable to the LPHPP**	
Hydro-peaking	Rapid water level fluctuations and wetting & drying of banks increases susceptibility to bank erosion and seepage erosion (piping) processes
	Increase in shear stress during flow changes increases erosion and bed incision
Loss of river connectivity – *Applicable to the LPHPP in the context of the cascade*	
Disconnect between flow and sediment delivery	Sediment availability not timed with periods of recession leading to decreased deposition and increased erosion
	Loss of seasonal sediment 'pulse'
Creation of impoundments – *Applicable to the LPHPP*	
Trapping of sediments	Reduction in sediment availability downstream of dam leading to increased erosion
	Changes to the grain-size distribution of sediment downstream contributing to channel armouring and alteration of habitat distribution and quality-This will be an issue if a free-flowing reach remains between LPHPP and Xayaburi HPP
Water level changes within impoundment	Lake bank erosion, increased risk of landslips
Diversions or intra basin transfers – *Not applicable to the LPHPP*	
Decreased flow in donor basin	Channel narrowing due to vegetation encroachment
	Armouring of beds and bars due to reduced sediment transport
	Decrease in frequency of high flow events increases impacts of extreme events (upstream flooding, floodplain stripping)
Increased flow in receiving basin	Increased bank erosion and bed incision to accommodate increased flow

**Hydropeaking does not seem to be proposed for the LPHPP, but the impacts may be applicable if Pak Beng operates in a peaking mode.*

2 Data used by the developer

2.1 Overview of data provided

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

- Aerial LiDAR surveys to document the right bank landforms where the dam and power station and other infrastructure are proposed to be constructed;
- A topographic survey including aerial images and LiDAR for the proposed impoundment;

- Bathymetric surveys from approximately 2 km upstream of the proposed dam site to 1 km downstream of the confluence with Nam Ou and 1km of the Nam Ou from the confluence with the Mekong;
- Channel cross-sections collected during the Xayaburi investigations, and 348 channel cross-sections collected during the Luang Prabang investigations;
- Maps of the proposed inundated area delineating the existing distribution of 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;
- The concentration of six suspended sediment collected from Supanuvong station, Luang Prabang station and Houa Yo collected in April 2019;
- Sediment transport information and data from published papers and reports.

2.1.1 General comment on data

The discussion of data interpretation is contained in subsequent sections of this report. These comments are restricted to the range of data presented, consistency and presentation.

Very limited new or site-specific sediment transport data are provided by the developer. The developers have relied on published or existing sediment data sets, such as those held by the MRC, or obtained during the investigations for the Xayaburi hydropower project. The review of the available literature and data sets provides a relevant and consistent overview of geomorphology and sediment transport in the region of the development. The developer directly used the following data sets:

For a trend analysis of sediment transport, the following data sets were used and sourced from the Thai Department of Water Resources:

- Sediment concentrations at Chiang Saen between 1962 and 2012 (with major gaps and inconsistencies)
- Monthly flow rates from 1962 to 2014

For the sediment transport modelling the following data sets were used:

- Sediment loads from the Mekong River Commission Discharge Sediment Monitoring results based on Chiang Saen and Luang Prabang
- Sediment grain-size information based on the Mekong River Commission Discharge Sediment Monitoring results for Luang Prabang,

The report provides a good literature review of the range of sediment data sets available, and the historic 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, which is recommended in the revised DG 2018. Providing site specific measurements is warranted as the conditions at the Luang Prabang dam site are not accurately captured by either the Chiang Sean monitoring site, which will under-estimate sediment transport relevant to the dam site due to of several large tributaries entering in the intervening reach, or the Luang Prabang monitoring site, which is located downstream of the major tributary Nam Ou, and will over-estimate sediment transport at the proposed dam site.

Although limited, the new data collected by the developer related to sediment transport should be shared with the MCs, including descriptions of the field and laboratory methods used, and any QA/QC data.

Substantial spatial data has been collected for the project and impoundment areas, but there is a lack of spatial information for the downstream river channel, which includes the confluence of the Mekong and Nam Ou, and the backwater of the Xayaburi hydropower project. This reach is and will remain hydraulically complex due to the interaction of regulated flow from the Nam Ou with the regulated flow in the Mekong (recognising the regulation in the Mekong is primarily attributable to the Lancang cascade, but hydropower projects on the tributaries and storage in the Luang Prabang impoundment will also affect flows.

Some of the data presented were difficult to understand or interpret due to a lack of explanation regarding the graphs, tables or other formats. This included:

- A gap in the information is the omission of a plan (map) view in the Feasibility Study showing the dam, the impounded area and the km markers along the extent of inundation. Figure 2-4 shows marked kilometres to 2055 km, whereas the Feasibility Study includes discussion of areas upstream of this location. For example, for the sediment modelling most sedimentation was found to occur between km 2092 and 2116. It would be useful to see where this area is in plan view to allow interpretation of the results with respect to channel morphology;
- In Figure 5.5 it would be useful to have a location map, a scale and a legend that did not have such a wide range of results in a similar colour of green, and an enhanced explanation of what the scale reflected e.g., what are values in purple on the scale? They appear to be the percentage of values falling within the range, but this is not clarified;
- The text states that Figure 12-5 shows the natural condition and impounded condition, but all data sets appear to reflect the impounded river at different flow rates. Including the natural state would be useful for understanding how the depth of the impoundment changes with distance upstream. The scale in Figure 12-5 indicates km and ranges from 0 to 140,000, suggesting the scale should be in metres;
- Table 12-5 lacks units and an explanation of what 0.005/1.96 indicates for the final modelling scenario;
- Table 6-5 is referred to as demonstrating a decrease in the suspended sediment and total suspended solids concentrations before and after construction of the Lancang dams, however the table shows the number of samples available for each time period, not the concentration of suspended sediment in the samples;
- There is a minor issue with the detailed maps of the inundated area presented in the EIA volume. In the upper reaches of the impoundment, there are limited areas where the proposed impounded area does not include the entire width of the existing channel and are obviously in error.

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 the available information related to sediment transport modelling including sediment trapping in impoundments that has been completed under various MRC projects (e.g. MRC Hydropower Mitigation Guidelines-Case Study, Council Study sediment transport modelling). These projects are directly relevant to the Luang Prabang development and provide a basin context for the potential changes associated with the Northern Lao PDR cascade in general, and provide insights into each of the projects. This information could contribute to a more detailed cumulative impact analysis of the project.

2.2 Sediment transport (suspended sediment load, bedload, grain size)

The Feasibility Study 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.

The review includes studies that clearly show a decrease in sediment concentrations and loads following placement of the dams (e.g., Kummu and Varis, 2007; MRC, 2014) and studies that suggest little or no change (CNR, 2013; Liu et al., 2012). The Feasibility Study includes a trend analysis of flow and suspended sediment results from Chiang Saen and states the results show there has been a major reduction in sediment load. The Feasibility Study concludes the discussion on sediment loads with the following bolded statement:

"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 are considered for the Luang Prabang HPP site.

The FS recommends collecting additional site-specific sediment information upon which a comprehensive sediment management strategy for Luang Prabang can be based. Specifically, the FS recommends additional investigations and modelling related to sediment deposition in the impoundment's backwater and the remobilisation efficiency of flushing and sluicing. It recommends collecting suspended sediment, bedload sediment including mass and grain-size determination. These investigations are stated as being underway with the results to be incorporated into the study in later phases.

During the fieldtrip and discussions with the developer in December 2019, it was stated that additional sediment monitoring had commenced, but no details were provided as to the locations or frequency or details of the methods other than to say that monitoring included suspended and bedload sediments.

2.2.1 Comments on sediment transport

Using the existing literature to understand sediment transport in the catchment is a sound starting point for a Feasibility Study, and the summary of investigations captures information that is relevant to the LPHPP development. The conclusion of the discussion, shown above, is somewhat confusing as it is not clear whether the 'dam' causing the decrease in sediment loads refers to the Chinese dams or the proposed Luang Prabang dam. Based on the subsequent discussion in the sediment modelling section, in which 22 Mt/yr is adopted as the average annual sediment load, the lower range in the above statement appears to have been adopted, and pre – dam and post – dam refer to the Lancang cascade.

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 mainstream Xayaburi hydropower project, or the Nam Ou cascade.

An area that merits greater attention with respect to sediment transport is the Mekong mainstream downstream of LPHPP. The interaction between the flow in the Mekong, the discharge from the Nam Ou tributary and backwater from the Xayaburi HPP already make this a complex hydrologic and hydraulic area; the development and operation of the LPHPP will increase the complexity with respect to sediment transport due to a decrease in sediment discharge, and short-term changes in hydrology and hydraulics associated with the switching on and off of turbines.

In this reach water and sediment released by the LPHPP will mix with flow and sediment discharged from Nam Ou, and depositional patterns will be governed by the combined river flows and the extent of the Xayaburi backwater. Understanding sediment deposition in this area is important because additional sedimentation in the Mekong channel can increase local flooding risks, increase the risk of erosion and affect the overall movement of sediment through the cascade. These inter-relationships and inter-dependencies between tributary and mainstream HPPs in the area are not discussed with respect to sediment transport, and are relevant to 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 (methods of collection not indicated) for which no application is described. The riverbank samples results are presented in the report, and show high variability, with median grain-sizes ranging from 0.03 to 0.3 mm. The results from the suspended sediment samples are not presented.

The revised DG 2019 recommends at least one-year of site-specific sediment monitoring results be collected 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 developer informed the MRC PNPCA team that sediment monitoring is on-going. This information should be provided to the MCs as part of the JAP.

The discussion of sediment management strategies and mitigation measures is very limited in the FS. Only one strategy is presented which is based on the opening of the Low-Level Outlets (LLO) when flow rates exceed that required by the powerhouse and ancillary services (fish passing facility and navigation). This approach will result in pressure flushing, which will remove sediment from a limited area upstream of the LLO, but not mobilise sediment deposited further upstream. This strategy is adequate for managing sediment deposition immediately behind the LLO to ensure the gates are always operable, but it is not an effective strategy for promoting sand and coarser sediment movement downstream and through the project on an annual or seasonal basis to minimise transboundary impacts as recommended in the PDG 2009.

More appropriate strategies include sediment routing, e.g. lowering water levels during periods of high sediment inflow to maximise the sediment maintained in in suspension and discharged from the impoundment, or sediment flushing, involving the rapid drawdown of water levels to erode and mobilise sediments deposited in the impoundment. Both sediment routing and sediment flushing would be most effective if conducted as a conjunctive sediment management operation in the cascade. These strategies require the water level in the impoundment to be drawn down to increase water velocities and to facilitate sediment erosion and mobilisation. There is no discussion of manipulating water levels for sediment management in the FS. This is discussed in more detail in Section 2.5, Infrastructure and operating regime.

During discussions with the developer in December 2019 and February 2020, the developer commented that the implementation of sediment flushing would require coordination and management by the Government of Lao PDR and involve the entire Northern Lao PDR cascade. In the absence of this high level management, the confirmed the approach to sediment management would be limited to the opening of the LLO during high flowsThis approach will not maximise the downstream transport of sediment, and does not align with the PDG 2009.

Based on the information provided by the developer, it is up to the Government of Lao PDR to provide information to the MCs regarding sediment flushing. Any strategy developed by the GoL should include a communication and warning system to alert the downstream communities and the MCs when sediment flushing operations will occur.

The proponent suggests that eventually a new sediment equilibrium will be established which will increase sediment discharge (especially course sediment) from the impoundment. Given the volume of the proposed storage (~1,256 Mm^3) and the expected rate of sediment input (~24 Mt/year or approximately 10 Mm^3/yr), this new equilibrium will require decades to centuries to establish as it requires development of a coarse-grained delta extending from the headwater of the impoundment to the dam wall. Strategies that promote the rapid movement of material downstream and through the impoundment, such as sediment flushing, are recommended by the PDG 2009 and should be considered by the developer to hasten downstream sediment transport.

Once sediment is passed through the Luang Prabang dam, it will enter the headwaters of the Xayaburi impoundment, and need to be transported down the length of the Xayaburi backwater and any additional downstream impoundments before entering a 'free-flowing' reach of the Mekong River. The timescale for sediment equilibrium to be achieved within the cascade is many decades to centuries if active sediment management strategies are not implemented at the cascade level. During this time there will be transboundary impacts associated with sediment starvation, with Thailand experiencing the most immediate impacts. If it is considered that active sediment management is not plausible at the cascade level, then alternative mitigation measures, such as sediment augmentation downstream of the final HPP project in the cascade should be considered to minimise transboundary impacts.

There is a recommendation in the FS to collect additional data upon which sediment management and mitigation strategies can be based, which suggests options such as sediment flushing may be investigated and considered in the future. However, as currently presented, there is no intention by the developer to implement sediment flushing, which falls short of the PDG 2009 guidance with respect to sediment mitigation strategies. The inclusion of LLOs in the infrastructure design of the project would allow future adoption of sediment flushing, so the lack of proposed sediment flushing is an operational consideration rather than an infrastructure constraint.

A minor comment regarding sediment transport is the contrary information provided related to turbidity currents. In Section 3.3 it is stated that the inclusion of LLO will allow the routing of turbidity currents through the spillway. Conversely, in the Conclusion Section (Section 6.4) it is stated that the water velocities within the dam, and the relatively low water depths in the reservoir will preclude the formation of turbidity flows, but during periods of high flow there will be a graded suspension in the river that will transport more material at depth. The latter description of suspended sediment transport is most applicable to the Luang Prabang situation, however during the wet season the velocities in the impoundment will be considerably lower as compared to the unregulated situation (Figure 4), so any sediment carried in graded suspension will be finer than is presently transported.

There is a contradiction with respect to the collection of site-specific sediment transport information in the documentation. The FS states that the monitoring has begun, whereas the EIA states that sediment monitoring will commence with operations. The two reports may be referring to different components of sediment monitoring, but insufficient detail was presented to determine if this is the case. Based on the discussions with the developer, site-specific sediment monitoring has commenced, although no details about the monitoring were provided.

2.3 Geomorphology information

The FS presents information relevant to the geomorphology of the area and potential impacts associated with the development in several sections of the documentation. 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 complex 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.).

Geomorphic impacts of the project are discussed in general, such as during operations some of the riverbanks will be prone to erosion due to the change in surface 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 considered to be low.

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

2.3.1 Comments on Geomorphology

Overall 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 to the 150 km river reach affected by the proposed LPHPP, or the river reach downstream of the project. 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 into the 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 are local, the bigger picture of how sediment is managed within the overall upper Lao PDR cascade is a critical transboundary issue.

There is no discussion regarding how fluctuating water levels within the impoundment could increase erosion of the shoreline. The FS states that water level fluctuations may occasionally occur for exceptional operational cases, but that there will not be any hydropeaking at the LPHPP. However, the potential impacts of possible hydropeaking or other water level fluctuations originating from the upstream Pak Beng hydropower project are not considered. These interactions again highlight the importance of coordinated operations and consideration of risks at the cascade level.

The developer's documents do not address the potential for increased sedimentation in the upper reaches of the impoundment associated with flushing of the Pak Beng development, or how these changes could affect the Nam Beng tributary, or increase flooding risks in Pak Beng.

The loss of exposed sand bars and rocky outcrops over a 150 km river reach has not been discussed in relation to the availability of these geomorphic habitat types for bird and other animal nesting. The proposed area of inundation contains a large number of 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 recommends that rapids and deep pools upstream of Pak Beng should be protected to ensure future existence of spawning areas.

2.4 Review of the proposed LPHPP

2.5 Infrastructure and operating regime

Attributes of the LPHPP infrastructure relevant to sediment transport and river geomorphology include the following:

- The project is located on the axis of a right bend in the Mekong River. The natural flow path of the river would direct water away from the proposed location of the powerhouse, but the project will excavate large volumes of material from the right bank, leading to the re-alignment of the main channel with the powerhouse and spillway. This will promote the retention of sediments in suspension and maximise bedload movement towards the LLO;
- Project infrastructure includes three main parts. From right to left, the spillway section, including LLO, the powerhouse, and a left bank closure structure. The three LLO are located on the bed of the river and have a sill level of 275 m asl, and dimensions of 12 by 16 m (width / height). The intakes to the turbines are situated lower in the channel, with the base located at 238 m asl.;
- A low-level outlet approach channel is shown in drawings but not described in the Feasibility Study. It appears this channel will direct flow towards the LLO during the second construction stage when a coffer dam is constructed over the Mekong River channel, and possibly direct bedload toward the LLO during normal operations. This interpretation was confirmed by the developers during discussions in December 2019. The main role of the channel is to direct flow towards the LLO during construction of the left bank closing structure;
- 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, and have substantially reduced water velocities relative to the free-flowing river;
- No sediment management infrastructure is incorporated into the powerhouse, or the left bank dam wall. During discussions in December 2019, the developer acknowledged that there was a high risk of sedimentation both upstream and downstream of the left bank closing structure.

Operational aspects of the project relevant to sediment management include:

- Water level fluctuations within the impoundment will be maintained within 0.5-m day^{-1} during normal operations which will minimise erosional impacts on the shoreline of the impoundment. The documentation did not discuss whether greater fluctuations might occur should the Pak Beng project operate in a peaking mode. In December 2019, the developer stated that the LPHPP would not operate in a peaking pattern;
- The low-level outlets will be opened prior to the surface gates during periods of high flow promoting the release of sediments from the base of the impoundment.

2.5.1 Comments on infrastructure and operations

The operations of the proposed LPHPP will be affected by and potentially affect numerous other hydropower projects. The downstream area is highly populated, and the river is used for tourism and navigation, which will be affected by the combined operations of the hydropower projects in the area (Xayaburi, Nam Ou cascade, Luang Prabang). The infrastructure and operating regime at LPHPP should provide flexibility such that operations can respond to a range of conditions and needs over the lifetime of the project.

The size and design of the LLO for sediment management are similar to Xayaburi, suggesting that the sediment loads could be passed through both impoundments under coordinated operations. Because of the similarity in design the physical test work results from Xayaburi have been scaled and applied to the LPHPP project, with site-specific hydraulic testing for Luang Prabang planned for the last quarter of 2019. Given the lack of site-specific test results, and the reliance on Xayaburi data, it would be useful to have operational information from Xayaburi regarding the use of the LLO during high flow events with respect to sediment transport. For example, channel cross-sections showing sediment deposition at the dam wall before and after use of the LLO at different flow rates, estimates of sediment discharged from the station at different water levels, measurements of sediment concentrations in the downstream river during gate operations, estimates of downstream sediment transport, or channel scour associated with the operation. These types of information would be useful to demonstrate to the MCs the effectiveness of the gates with respect to sediment transport.

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. As previously discussed, this results in pressure flushing, which only mobilises a small volume of sediment from a cone shaped area 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 transport through sediment routing or sediment flushing. This is a substantial omission with respect to the PDG 2009. During discussions with the developers in December 2019, it was confirmed that the proposed operations of the LPHPP do not include any sediment mitigation strategies that involve the lowering of water levels in the impoundment. This approach will preclude the mobilisation of sediment deposited in the upper reaches of the impoundment and prolong the period until a coarse sediment can be passed through the dam;
- The LLO will operate whenever discharge exceeds the capacity of the powerhouse (5,355 m^3s^{-1}) and the flow required for the fish passage (80 – 120 m^3s^{-1}) and navigation systems (up to 100 m^3s^{-1}). Based on the flow duration curves in the Hydrology section of the FS, this flow is likely to be exceeded about 5 to 7% of the time, after accounting for the flow changes associated with the Lancang reservoirs. This suggests that the LLO should be operated at least on a yearly basis. Additional modelling that projects 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 relationship between the LLO discharge graph presented in the FS and the hydraulic data provided in the Hydraulic Model Test Report is not well explained. All discharge information related to the spillway is based on adjusting the Xayaburi physical test work results to the conditions at Luang Prabang (e.g. reducing the number of bays). The graph in the FS shows a distinct change in discharge as compared to Head at approximately 20 m head and ~1,800 m^3s^{-1} (Figure 1), whereas the data presented in the Hydraulic Modelling report shows a linear relationship. The results presented in the FS are based on the fully open LLO and surface spillways, whereas the results presented in the Hydraulic Model report are for the LLO operating in isolation. This accounts for the difference between the graphs, but raises questions about the combined operations of the gates. The target discharge for opening the surface spillway gates in addition to the bottom gates is not discussed with respect to sediment transport through the LLO. The test work upon which the results presented in the FS are based does not appear to be included in the Hydraulic report. A more complete explanation of the model, its set-up and calibration and how the results will be translated into operating rules for the the LPHPP is warranted;

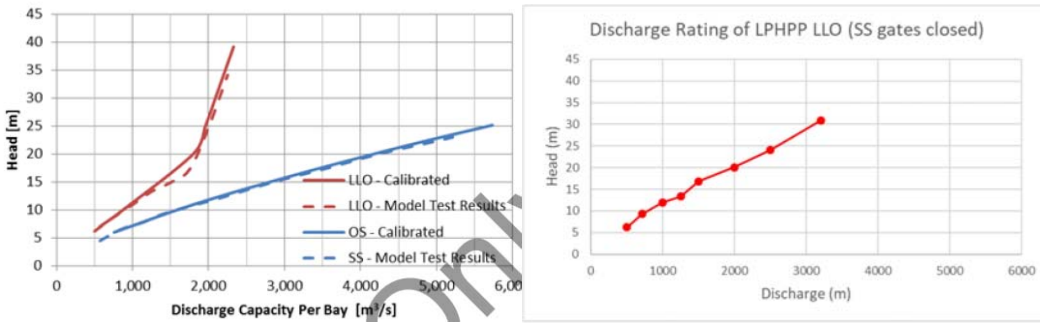

Figure 1. (Left) Discharge graph for the LLO in the FS (right) Discharge graph for the LLO based on the data in Table 5-Discharge rating of Luang Prabang HPP Low-level outlets (SS gates closed).

Other aspects of sediment management that warrant additional information or clarification include:

- The FS states that the LPHPP will not operate in a peaking mode, however, there is no consideration of lake level fluctuations or river fluctuations downstream of the LPHPP dam site if Pak Beng is operated in a peaking mode, and the potential impact of increased erosion due to these fluctuations;
- How sediment discharges released from the LPHPP will interact with the discharge from Nam Ou, or affect the backwater of the Xayaburi HPP is not addressed;
- 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. The applicability of dredging for sediment maintenance around the infrastructure is not discussed. During discussions with the developer it was acknowledged that sediment is likely to accumulate in these areas, and that physical removal will be required. No additional details were provided about the approach to be used for sediment removal, or how or where the dredged material would be disposed were provided.

2.6 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 the use of different grain-sizes. The model can predict sediment mobilisation and deposition, but not geomorphic changes to the channel such as bank erosion. The model calibration 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 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. Fine silt and clay sized material was generally transported through the impoundment, along with some coarse silt, whereas most of the fine sand and all of the coarser material is deposited.

Two-dimensional modelling 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. There is no discussion of whether these high flows will erode the downstream river channel or affect the infrastructure of the project. Given the very complex geology of the project site, and variable strengths and depths of weathering of the underlying stata, the potential for downstream channel erosion should be considered in detail in a subsequent phase of the projects.

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.

2.6.1 Comments on sediment transport modelling

Similar to other aspects of the FS, the information used and discussed is relevant and provides a good initial basis for the LPHPP development, 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, eliminating the potential for the model to predict preferential deposition in quiescent areas in otherwise fast flowing cross-sections. 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 MCs with the most reliable information possible. More details regarding the setup and calibration of the model should be provided to the MCs for transparency;
- 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 long-section used shows a relatively flat area in the upper section of the impoundment and a large change in elevation between km 2100 and km 2080 (Figure 2). The more detailed longitudinal section collected for the LPHPP FS captures the high frequency of deep pools within the impoundment, and shows a more continuous slope as compared to the model setup (Figure 3). These differences will affect the results, including a likely under estimation of the trapping efficiency by deep pools;

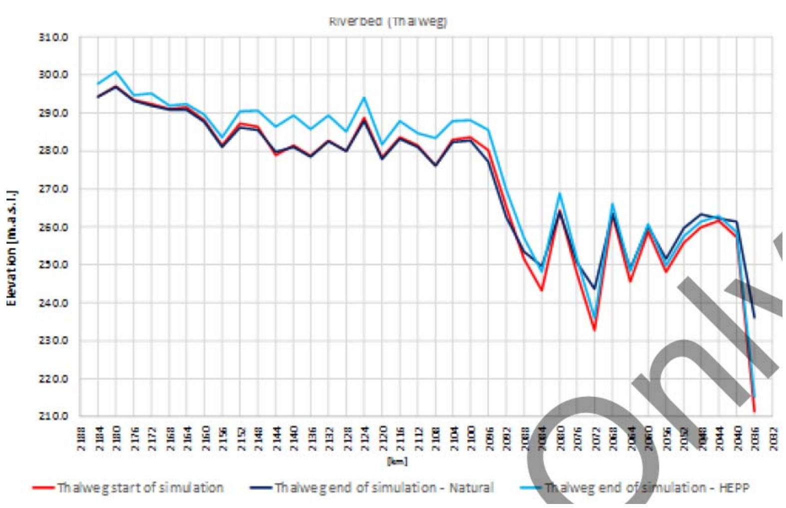

Figure 2. Modelling results from Feasibility study showing smoothed bottom topography and distribution of sediment deposition. Pöyry, 2019.

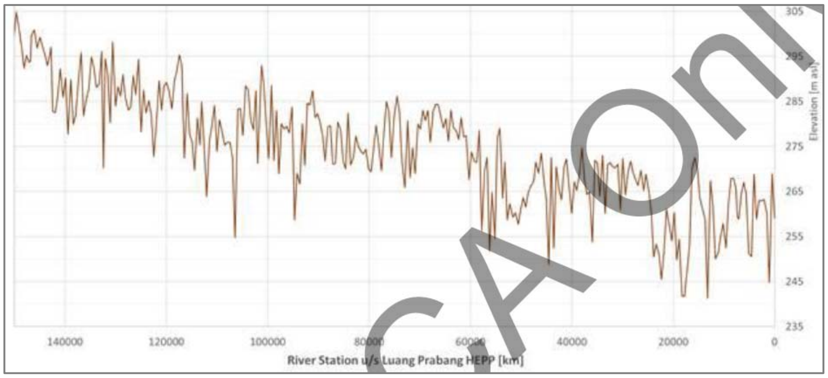

Figure 3. Bathymetry of the proposed LPHPP impoundment from the dam site to 140 km upstream showing high frequency of deep pools. Source Pöyry, 2019. Note that the x axis is incorrectly labelled as kilometres.

- The starting bed material is set at fine sand based on sediment samples collected from river banks in April 2019 from the impoundment area. Bed materials are generally much coarser than bank materials, and it is possible the grain-size present in the deeper channel is considerably coarser. Considering the high sensitivity of the model to the grain-size distribution of inflowing material, incorporating a realistic grain-size for the channel is critical;
- 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 of the impoundment contributes to a lack of deposition in the lower impoundment. These results are not related to the characteristics of the channel, such as how does the tight bend in the impoundment affect sediment transport;
- The modelling results should be compared to any available field results or other available modelling results. Because the model is based on information from Xayaburi, comparing model results from Xayaburi with measured results would be informative;
- There is no discussion regarding an increase in bank erosion during the construction period when water velocities around the project site will be very high during high flow events. The developers acknowledged this during discussions in December and stated that increased erosion is inevitable.

In general, the modelling results are consistent with water velocity results from the MRC ISH 0306 Case Study (MRC, 2017) that examined sediment transport through the Luang Prabang impoundment using the Delft 3D model as part of modelling the entire Upper Lao PDR cascade (Figure 4). The velocity results show a substantial reduction in velocity with distance downstream during both the dry and wet seasons, accounting for the lack of sediment transport downstream. The results highlight that in order to pass sediment through the impoundment either (1) a delta will need to form and prograde the entire length of the impoundment until it reaches the toe of the LLO and can be discharged using pressure flushing at high river flow, or (2) the operators will need to use sediment flushing to promote the movement of material downstream, thus lessening the time period before sediment can be released. The FS states that considerable periods will be required to establish a new sediment equilibrium, but there is no consideration of management actions such as sediment flushing that could reduce this time period, leading to a reduction in transboundary impacts;

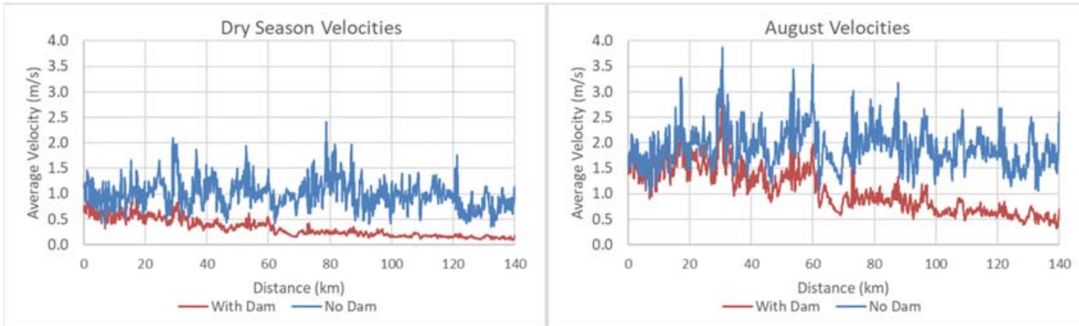

Figure 4. Predicted average water velocities in the Luang Prabang impoundment in the (left) dry season based on December to April results of Delft 3D modelling, and (right) in August . Blue line indicates water velocity in the river reach without impoundment, and red line shows decrease in water velocity following impoundment.

- The FS does not quantify the model results, only states that clay and fine silt is transported through the impoundment and most of the fine sand is deposited. The model input was based on 22 Mt yr^{-1}, 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 by the dam corresponding to the percentage of fine sand in the load. This will reduce the concentration and alter the grain-size distribution in the downstream sediment load. Quantifying these processes and changes is very important for the predicting the overall change in sediment transport and transboundary impacts. A reduction in coarse material will have immediate impacts in the river downstream of the project, but limited impacts further downstream in the short-term, whereas a reduction in fine-grained material will have immediate impacts throughout the LMB. Additional quantification and discussion of the results, and downstream implications of findings is warranted;
- There is no sediment transport modelling associated with the proposed use of the LLO. A greater understanding of how much sediment, and what size fractions are likely to be mobilised during high flow events when the gates are open is warranted, especially as this is the proposed primary sediment mitigation strategy.
- During discussions in December, the developer suggested that sediment flushing would result in poor downstream water quality and posed safety risks as large volumes of water need to be released and was therefore not favoured as a mitigation strategy. Downstream sediment concentrations and water flows during and following flushing are controlled by many factors, including: the rate of sediment inflow and deposition, the frequency of flushing, the rate of water draw down, the duration of water level drawdown, the river flow at the time of drawdown and refill, and the rate of clean water release using surface gates. The developer should model a range of potential sediment flushing regimes to determine the potential impacts on downstream flows and water quality before dismissing this approach, as it provides the only opportunity to mitigate transboundary impacts associated with sediment trapping;
- The FS broadly discusses the interaction between the proposed LPHPP and upstream and downstream mainstream dams and the need for close cooperation regarding sediment flushing, spillway operation and fish migration but actual strategies based on cooperation are not presented. This is a very important issue and merits greater investigation and modelling effort, especially in the reach downstream of LPHPP and the backwater of Xayaburi where various processes could affect this reach. There is potential for increased deposition in this area unless water levels in Xayaburi are reduced to promote transport of the sediment downstream during periods when Luang Prabang or Nam Ou are discharging sediments. There is also potential for erosion in this reach due to sediment poor water being

discharged from both the LPHPP and Nam Ou depending on the extend of the Xayaburi backwater. This risk of erosion was demonstrated in the ISH0306 sediment modelling exercise, where channel erosion was predicted in the Xayaburi backwater due to upstream hydropower operations and sediment trapping (Figure 5). Erosion in the reach could induce channel instability and bank erosion. This is not a transboundary issue per se, however overall sediment management is a significant transboundary issue, with the efficient transport of sediments through the cascade critical for the maintenance of sediment delivery to the LMB downstream of the cascade. It is recommended that this reach be specifically investigated in future hydraulic and sediment transport modelling exercises, and that the operators of the Nam Ou cascade and Xayaburi HPP are consulted and included in developing the scenarios to reflect likely operations of each hydropower project.

In February 2020 the developers commented that they do not have access to information related to the operation of the Nam Ou cascade and therefore cannot consider the cumulative interactions from the various projects. If this is not feasible then it is another area where the Government of Lao PDR should be responsible for the development of a cumulative impact assessment to provide the information to the MCs.

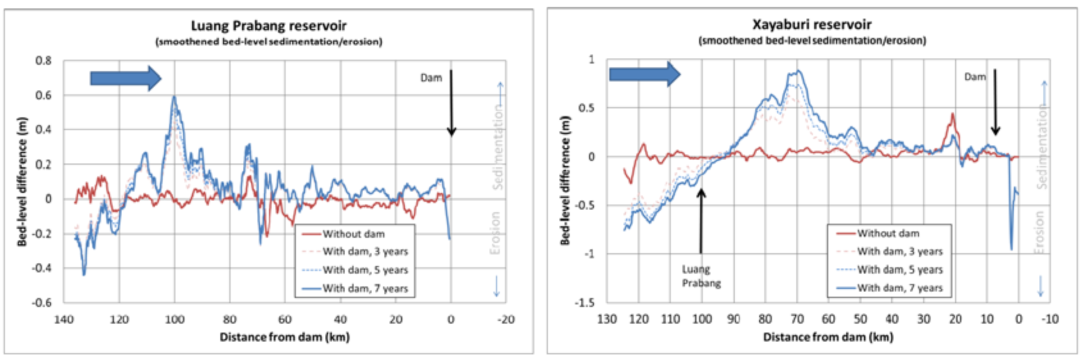

Figure 5. Sediment modelling results of the Luang Prabang and Xayaburi impoundments showing erosion of the river bed at the upstream end of each impoundment. Scenarios do not include sediment flushing. Source: MRC (2016).

- There is no sediment modelling examining sediment behaviour near the hydropower infrastructure, or downstream of the impoundment;
- 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 ISH0306, or for the Council Study. These investigations have included complex sediment models that should be drawn upon at least for comparison with the 1D model.

2.7 Transboundary impacts

The CIA-TBIA volume of the FS presents much of the same information and analysis regarding sediment transport as presented in the FS main volume. The conclusions presented in the CIA-TBIA analysis related to transboundary impacts include:

- The Lancang cascade has significantly reduced sediment transport to the LMB;
- The timeframe in which the impact from the reduction in sediment due to trapping occurred downstream varied with distance downstream, due to the buffering capacity provided by the sediment resident in the river channel;
- The LPHPP and other dams in the upper Lao PDR cascade will slightly reduce sediment delivery for some time until a new equilibrium is reached, but the volume of sediment

retained in the cascade is small compared to that captured in the Lancang cascade and tributary dams in Lao PDR;

- Due to the relatively short distance between the LPHPP and the border with Thailand, the impact due to sediment reduction from the proposed project will be rapidly felt;
- Impacts associated with a reduction in sediment include riverbed degradation and channel incision.

2.7.1 Comments on Transboundary Impacts

The CIA-TBIA correctly highlights the role of the Lancang cascade in reducing sediment input to the LMB. However, the report implies that the additional trapping of sediment by the upper Lao PDR cascade is minor compared to trapping in the Lancang cascade or the hydropower projects on the Lao PDR tributaries. The sediment modelling work completed by the MRC for the Council Study showed that the upper Lao PDR cascade exerts a substantial impact on sediment transport at the basin scale (Figure 6), accounting for 15% of the overall sediment trapping in the basin (including China) or 24% of the total sediment trapped in the LMB (excluding China). These findings are consistent with the sediment transport investigations presented in the FS that show that fine-sand and coarser material, that accounts for up to 75% of the sediment load at Luang Prabang, are trapped within the impoundment. A similar finding was provided by the modelling exercise in the upper Lao PDR case study modelling (MRC, 2017) that found a substantial reduction in sediment transport due to the presence and operation of the cascade (Figure 7), and by the Delta Study (DHI, 2015, Figure 8), with bedload transport reduced from over 20 MT yr^{-1} to <5MT yr^{-1} due to trapping in the northern Lao Cascade and tributary projects. These modelling results consistently show that sediment trapping by the cascade is substantial.

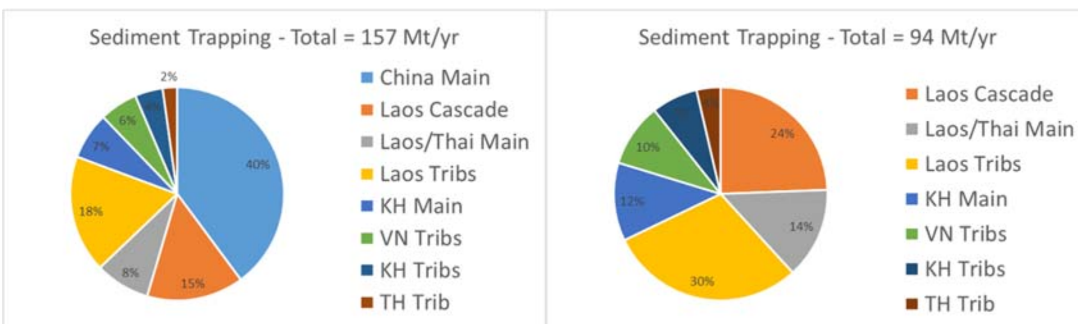

Figure 6. (Left) Sediment trapping in the Lancang cascade and Mekong River and (right) in the Lower Mekong Basin based on the results of the Council Study for the 2040 development scenario (MRC, 2017). Main = mainstream, Laos Cascade = upper Lao PDR cascade, Tribs = tributaries

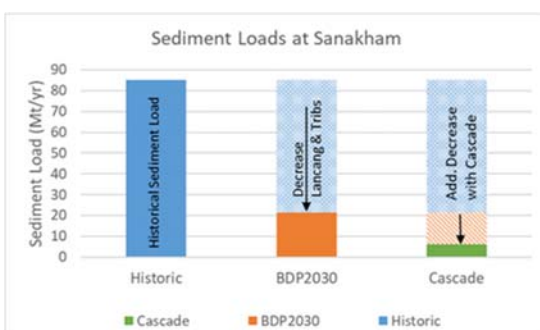

Figure 7. Summary of sediment trapping based on modelling of the upper Lao PDR cascade. Source: MRC, 2017.

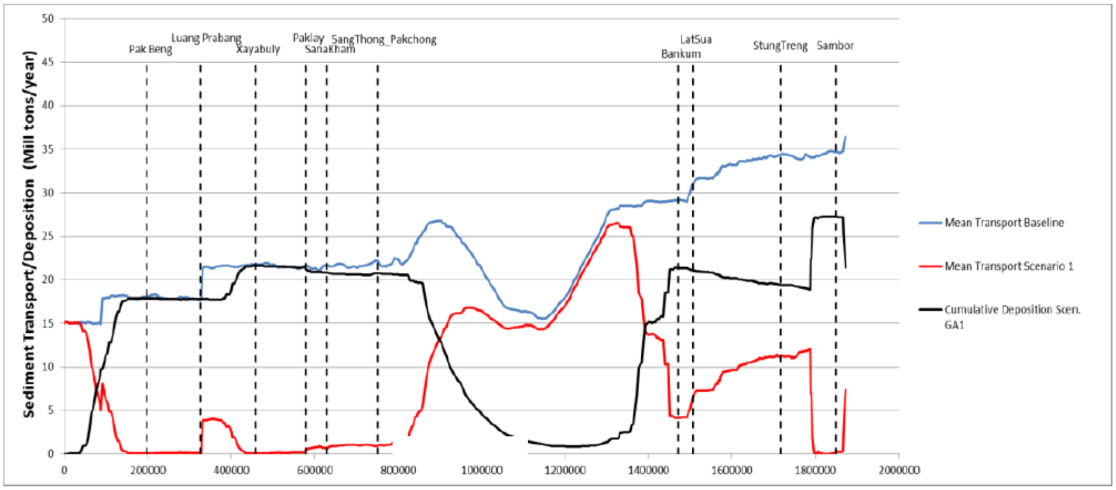

Figure 8. Summary of cumulative trapping and transport of sediment bedload in the LMB. Source: DHI (2015).

The EIA 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 progress to the point where a new equilibrium is achieved may exceed the lifetime of the project infrastructure. In effect, the impacts from sediment reduction could be considered permanent in the LMB unless substantial mitigation measures are included in the developments. This issue is not discussed in the CIA-TBIA Report.

The CIA-TBIA recognises there are delays in impacts progressing downstream but states that transboundary impacts will likely reach Thailand within a 'short' period due to the distance being only 300 km downstream. However, when discussing the potential impact on Cambodia, located 1,000 km downstream, or Vietnam, 1,500 km downstream, the CIA-TBIA states the impact will be minor due to the low sediment trapping in the cascade and the long distance downstream, implying 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 limited period of time, but over decades to century time-scales this cannot be assumed to be true. A more in-depth analysis and discussion of the long term impacts of sediment trapping in the cascade and tributary projects is needed with respect to the alluvial Cambodian floodplain and Vietnamese delta.

The CIA-TBIA describes potential downstream impacts in a general sense (riverbed degradation and channel incision, and bank erosion) but does not identify specific transboundary areas that will be susceptible to change, such as the large alluvial reach upstream of Vientiane / Nong Khai. The potential loss of land due to riverbank erosion is not discussed.

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 was not discussed, nor how far downstream these mitigation measures might be implemented.

There is no discussion regarding the reduction in sediment transport leading to clearer water in the downstream river. Reduced turbidity will increase light penetration into the river, resulting in a potential increase in temperature and primary productivity. These issues are discussed in the water quality section of the TRR.

2.8 Proposed monitoring

The FS briefly describes recommended monitoring, including the following components:

- Measurement of suspended sediment at the dam site, Luang Prabang, 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;
- Determination of grain-size for additional bed material samples collected form the proposed area of impoundment.

The FS states that LPCL has initiated sediment monitoring as per the recommendations in the chapter, and the results will be incorporated into the study in subsequent project phases. In contrast, the CIA-ESIA states that a sediment monitoring program will commence at the beginning of operations.

2.8.1 Comments on monitoring

The inclusion of site-specific sediment results in the FS would have been useful for understanding how sediment loads at the proposed project site differ from the long-term sites. Sediment results from Luang Prabang which are used in the FS include inputs from Nam Ou, Nam Khan and Nam Suong, so are likely higher than will occur at the actual dam site.

The proposed sediment and geomorphic monitoring regime 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. There is no mention of including cross-section measurements in the impoundment as part of the monitoring regime. In general, the proposed approach appears in line with the PDG 2009, but due to a lack of details no additional comment can be made.

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.

3 Comments on comparison of FS with the PDG 2009

Overall, the developer draws on reasonable and consistent information to provide an early basis for the project. However, many of the topics included in the PDG 2009 are addressed at only a general level, with insufficient detail to allow evaluation with respect to the PDG 2009. The consistent lack of detail is a short coming because it prevents the MCs from having a suitable level of understanding of the project on which to evaluate potential transboundary impacts. Important topics that warrant additional detail include the following:

- The proposed approaches for sediment management and minimising transboundary impacts omit any discussion of sediment flushing or sediment routing to improve the downstream transport of sediment. During discussions with the developer in December 2019, it was confirmed that the proposed operating regime does not include any sediment management strategies that involve the manipulation of water levels, and any such strategies would need to be developed and managed by the Government of Lao PDR. This is in direct contrast to what is recommended in the PDG 2009, and will not minimise, or mitigate downstream impacts. It may be that due to upstream sediment trapping, and the length of the created impoundment that sediment flushing will not enhance sediment transport through the system to any appreciable degree. If this is the case, it needs to be demonstrated, and the associated transboundary impacts of stopping sediment transport to the downstream river needs to be considered more fully;
- The LPHPP is located in a hydrologically complex area, due to the downstream confluence of the Nam Ou and Mekong Rivers, the backwater of the Xayaburi, and numerous 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. The strategies required to manage the system cannot be developed by one operator in isolation, but rather require input from all operators in the region, and the GoL. Although these coordinated operations cannot be expected to be developed by the LPCL alone, the FS could have provided examples showing how joint operations *might* occur, or at least explore the interaction between the LPHPP, the Nam Ou And the Xayaburi backwater.

Due to these omissions, and due to the general nature of much of the other information presented in the FS, many of the topics contained in the PDG 2009 are rated as 'not enough information to assess'. This also prevented in-depth comparison with the DG 2018 which builds on the PDG 2009 and recommends more comprehensive information. Overall, the proposal is considered to be 'not aligned' with the PDG as less than 60% of the paragraphs relating to sediment transport and geomorphology are consistent with the PDG.

References

CNR, 2013. Assessment of Xayaburi dam impact on solid transportation – Draft Final Report of Step 1; CNR ingenierie, Ministry of Energy and Mines, Lao PDR, February 2013.

DHI, 2015, Study on the Impacts of Mainstream Hydropower on the Mekong River, Draft Impact Assessment Report, Impact Assessment Methods and Results –Summary Version (The Delta Study). Prepared for Ministry of Natural Resources and Environment, Government of Viet Nam.

Halls, A. S. et al., 2013. *MRC Technical Paper No 31: Atlas of dep pools in the Lower Mekong River and some of its tributaries,* Phnom Penh: Mekong River Commission.

Kummu, M, and Varis, O, 2007. Sediment related impacts due to upstream reservoir trapping, the Lower Mekong River, Geomorphology 85, No 3-4, p275-293.

Liu C., He Y., Wang J., 2012: Changes in sediment load of the Lancang-Mekong River and its response to the hydro-power development. 4th International Conference on Estuaries and Coasts, 8-11 Oct. 2012, Water Resources University, Hanoi, Vietnam, 10 p.

MRC 2014, Discharge sediment monitoring project (DSMP) 2009 – 2013 Summary & Analysis of Results. Report by L Koehnken for the MRC, July 2014.

MRC, 2016. ISH0306 Study Development of Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries. Volume 4-Case Study Report, Version 1.0-Modelling, Scenarios and Impact Mitigation Assessment.

Pöyry, 2019. Luang Prabang Power Company Limited Feasibility Study. Rev 1, October 2019, For PNPCA Only