LUANG PRABANG POWER COMPANY LIMITED
Luang Prabang HPP

Cumulative and Transboundary Impact Assessment
CIA/TBIA Report
Contact

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# Table of Contents

1. **INTRODUCTION** .................................................................................................................. 1
   1.1 Purpose of the CIA and TBIA Report ............................................................................. 2
   1.2 Significance of Cumulative and Transboundary Impacts ........................................... 2
   1.3 Relations to the Projects Specific Impact Studies ......................................................... 2

2. **THE PROJECT** .................................................................................................................... 3

3. **LEGAL AND ADMINISTRATIVE FRAMEWORK** ............................................................. 5

4. **CUMULATIVE AND TRANSBOUNDARY IMPACTS** ........................................................... 6
   4.1 Methodology and Approach ............................................................................................ 6
   4.2 Determination of Valued Ecosystem Components (VECs) ............................................ 6

5. **RELEVANT ISSUES** ............................................................................................................ 8
   5.1 Hydropower Development Plan .................................................................................... 8
      5.1.1 Hydropower Development at the Mekong Mainstream ......................................... 8
      5.1.1.1 Lancang Cascade .................................................................................................. 8
      5.1.2 Hydropower Development in Lao PDR .................................................................. 9
      5.2 Project Features ........................................................................................................... 10
      5.3 Reservoir Operation ..................................................................................................... 11
      5.4 Hydrology ..................................................................................................................... 12
      5.5 Physiography ............................................................................................................... 14
      5.5.1 Macroclimate .......................................................................................................... 16
      5.5.2 Data Collection and Processing ................................................................................. 16
      5.5.3 Discharge Data ......................................................................................................... 16
      5.5.4 Precipitation ............................................................................................................ 18
      5.5.5 Evapotranspiration .................................................................................................. 18
      5.5.6 Temperature ............................................................................................................ 18
      5.5.7 Hydro-Meteorological Characteristics ................................................................... 19
      5.5.7.1 Precipitation ....................................................................................................... 19
      5.5.7.2 Temperature & Evapotranspiration .................................................................. 19
      5.6 Inflow Hydrology ........................................................................................................ 20
      5.6.1 Discharge Time Series ............................................................................................. 20
      5.6.2 Water Balance Model ............................................................................................... 21
      5.6.3 Simulation Results of Natural Streamflow for the Calibration Period ..................... 23
      5.6.4 Inflow Time Series Luang Prabang HPP Site ............................................................. 24
      5.7 Flood Hydrology ........................................................................................................... 25
      5.7.1 Statistical Analysis .................................................................................................. 25
      5.7.2 Probable Maximum Flood ....................................................................................... 27
      5.8 Impact of Lancang Cascade .......................................................................................... 31
      5.8.1 Impacts to the Tonle Sap Great Lake System ......................................................... 33
5.2.12 Hydrological Impact of the Luang Prabang HPP - Conclusion ........................................... 35
5.3 Water Quality ......................................................................................................................... 35
5.4 Sediment Transport .................................................................................................................. 36
5.4.1 General Terms and Definitions .......................................................................................... 36
5.4.2 Findings from Literature Concerning Sediment Transport within the Mekong ............... 37
5.4.3 Trend Analyses .................................................................................................................... 39
5.4.4 Sediment Concentration .................................................................................................... 41
5.4.5 Conclusion and Findings Concerning Sediment Transport ............................................. 42
5.5 Fish and Fisheries ................................................................................................................... 45
5.5.1 Importance of Local Fisheries .......................................................................................... 45
5.5.2 Fish Species Identified in the Zone from Chiang Saen to Vientiane ................................. 45
5.5.3 Fish Migration Pattern in the Upper Mekong Migration System ..................................... 46
5.5.4 Fish Migration Facilities .................................................................................................... 48
5.5.4.1 General ........................................................................................................................ 48
5.5.4.2 Design Criteria ............................................................................................................. 48
5.5.4.3 Fish Migration Concept ............................................................................................... 49
5.5.4.4 Upstream Fish Passing Facilities .................................................................................. 50
5.5.4.5 Right Bank Fish Passing Facility (Upstream Migration) ............................................. 54
5.5.4.6 Downstream Fish Passing Facilities ........................................................................... 54
5.5.4.7 Main downstream migration facilities ......................................................................... 55
5.5.4.8 Fish Friendly Turbines ............................................................................................... 56
5.5.5 Conclusion and Findings Concerning Fish Migration and Fisheries ............................... 56
5.6 Food and Nutrition ................................................................................................................ 57
5.6.1 General Aspects ................................................................................................................ 57
5.6.2 Conclusion and Findings Concerning Nutrition ............................................................... 59
5.7 Impacts Related to Other Development Projects Construction ........................................... 59
5.7.1 China-Lao Railway Project ............................................................................................... 61
5.7.2 Pak Beng HPP .................................................................................................................. 63
5.7.3 Xayaburi HPP .................................................................................................................. 64
5.7.4 Hongsa-Chiangman Road and the new Bridge across Mekong River Project ................. 64
5.7.5 Development around Luang Prabang City and World Heritage status .............................. 65
5.8 Social Issues .......................................................................................................................... 65
5.8.1 Land Use Pattern ............................................................................................................. 66
5.8.2 Socio-Economic Parameters ............................................................................................ 66
5.8.3 Social conflict, risk of STD (sexually transmitted disease), human trafficking and other behavioural issues ........................................................................................................... 67
5.8.4 Transport ......................................................................................................................... 67
5.8.5 Conclusion and Findings Concerning Social Issues ......................................................... 67

6 CONCLUSIONS AND RECOMMENDATIONS ........................................................................ 68
6.1 Prediction of Cumulative Impacts .......................................................................................... 68
6.2 Prediction of Transboundary Impacts ................................................................................... 69

7 REFERENCES ......................................................................................................................... 71

ANNEX ......................................................................................................................................... 72
A) Used Literature concerning Sediment Transport within the Mekong ................................. 72
B) Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River (Kummu and Varis, 2006) ......................................................................................................................... 73
List of Figures

Figure 1-1: Project location................................................................. 1
Figure 2-1: Overview of the Luang Prabang HPP project sites.................. 4
Figure 5-1: Hydropower along the Mekong Mainstream.......................... 8
Figure 5-2: Hydropower project at the Mekong mainstream in Lao PDR........ 10
Figure 5-3: Mekong River basin and neighbouring countries.................... 13
Figure 5-4: Mekong River Catchment at Luang Prabang Dam Site.............. 14
Figure 5-5: Physiographic regions of the Mekong River basin (source: MRC). 15
Figure 5-6: River gauging stations at the Mekong mainstream............... 17
Figure 5-7: Precipitation Datasets for the Mekong Catchment................. 19
Figure 5-8: Potential Evapotranspiration of Mekong Catchment............... 20
Figure 5-9: Gauges and sub-catchments............................................. 21
Figure 5-10: Conceptual Structure of the Applied Water Balance Model........ 22
Figure 5-11: Comparison of Observed and Simulated Discharge (1980 – 1989) 23
Figure 5-12: Comparison of Mean Monthly Flows at Chiang Saen and Luang Prabang 23
Figure 5-13: Inflow Series 1951 to 2018 for Luang Prabang HPP Site........ 24
Figure 5-14: Mean Monthly Discharge Luang Prabang HPP Site.................. 24
Figure 5-15: Flow Duration Curve for Luang Prabang HPP Site.................. 24
Figure 5-16: Design Flood Values for Luang Prabang HPP Site.................. 26
Figure 5-17: 24-hour 5000 km² PMP map by the U.S. Weather Bureau....... 28
Figure 5-18: PMP isohyets for Main Mekong River PMF by the U.S. Weather Bureau 29
Figure 5-19: Left: PMP Depth-Area Relation........................................ 30
Figure 5-20: Assumed Synthetic Rainfall Development............................ 30
Figure 5-21: PMF Simulation for Luang Prabang HEPF............................ 31
Figure 5-22: Comparison of the Relative Discharge Change at Chiang Saen .... 32
Figure 5-23: Impact of the Lancang Cascade........................................... 32
Figure 5-24: Map of lower Mekong River Basin...................................... 34
Figure 5-25: Trend Analysis of Suspended Sediment Concentration........... 40
Figure 5-26: Trend Analysis................................................................. 41
Figure 5-27: Total Suspended Solid (TSS).............................................. 41
Figure 5-28: Longitudinal Evolution of Mekong River annual sediment load. 42

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List of Tables

Table 5-1: Hydropower plants in operation of the Lancang cascade ........................................ 9
Table 5-2: Mekong mainstream HPP projects as per GOL optimization study ............................. 10
Table 5-3: Catchment area and flow of Mekong River basin countries ................................. 13
Table 5-4: Overview of available flow data of Mekong River and tributaries .......................... 17
Table 5-5: Flood Discharges for Different Return Periods ...................................................... 26
Table 5-6: Dry Season Flood Discharges for Different Return Periods ................................... 27
Table 5-7: American Geophysical Union classification ......................................................... 37
Table 5-8: Relevant Tailwater Levels for the Fish Migration Facilities .................................... 49
Table 5-9: Potential cumulative impact by other development projects construction ............ 59
Table 7-1: Used literature upon sediment transport in Mekong River .................................. 72
Table 7-2: Estimations of mean annual sediment transport rates in Mekong .......................... 74
Table 7-3: Summary of the suspended sediment data ............................................................. 75
Table 7-4: Water discharge, SSC and TSS concentrations and fluxes .................................. 75
Table 7-5: Assumed sediment yield from principal sediment sources .................................... 79
Table 7-6: Estimated indicative times for reservoirs ............................................................... 80
Table 7-7: Plausible evolution of the sediment inputs ............................................................ 84
Table 7-8: Summary of monitoring frequency for discharge .................................................. 84
Table 7-9: Summary of annual sediment fluxes (Mt/yr) ........................................................... 85
Table 7-10: Sediment budget for sand, silt and clay ............................................................... 86
Table 7-11: Average annual suspended sediment loads (Source: IKMP & WWF, 2014) ........ 88
Table 7-12: Summary of field measurements and grain-size analyses .................................... 89
Table 7-13: Summary of bedload transport estimates based on field measurements .............. 89
Table 7-14: Summary of sediment transport estimates in the Mekong ................................. 89
LIST OF ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Complete Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS</td>
<td>Annual maximum series</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical Oxygen Demand</td>
</tr>
<tr>
<td>CIA</td>
<td>Cumulative Impact Assessment</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand</td>
</tr>
<tr>
<td>CIA / TBIA</td>
<td>Cumulative and Transboundary Impact Assessment</td>
</tr>
<tr>
<td>CRU</td>
<td>Climate Research Unit of the University of East Anglia</td>
</tr>
<tr>
<td>DESIA</td>
<td>Department of Environmental and Social Impact Assessment</td>
</tr>
<tr>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>DSMP</td>
<td>Discharge and Sediment Monitoring Project</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>ESIA</td>
<td>Environmental Social Impact Assessment</td>
</tr>
<tr>
<td>FSL</td>
<td>Full Supply Level</td>
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<tr>
<td>GOL</td>
<td>Government of Lao</td>
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<tr>
<td>GPCC</td>
<td>Global Precipitation Climatology Centre</td>
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<tr>
<td>HPP</td>
<td>Hydroelectric Power Plant</td>
</tr>
<tr>
<td>IFC</td>
<td>International Finance Corporation</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<tr>
<td>LPCL</td>
<td>Luang Prabang Power Company Limited</td>
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<tr>
<td>LP HPP</td>
<td>Luang Prabang Hydroelectric Power Plant</td>
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<tr>
<td>m asl</td>
<td>Meters above sea level</td>
</tr>
<tr>
<td>MONRE</td>
<td>Ministry of Natural Resources and Environment</td>
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<tr>
<td>MRC</td>
<td>Mekong River Commission</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>PDR</td>
<td>People's Democratic Republic (Lao PDR, Laos)</td>
</tr>
<tr>
<td>Q</td>
<td>Discharge</td>
</tr>
<tr>
<td>R</td>
<td>Mean annual runoff depth</td>
</tr>
<tr>
<td>ROR</td>
<td>Run-of-river</td>
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<tr>
<td>TBIA</td>
<td>Transboundary Impact Assessment</td>
</tr>
<tr>
<td>TRRM</td>
<td>Tropical Radar Rainfall Mission</td>
</tr>
<tr>
<td>TSS</td>
<td>Total Suspended Solids</td>
</tr>
<tr>
<td>SIA</td>
<td>Social Impact Assessment</td>
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<tr>
<td>VECs</td>
<td>Valued Environmental and Social Components</td>
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EXECUTIVE SUMMARY

Objective
Each hydroelectric power plant (HPP) generates impacts on society and on environment. Some impacts occur in the immediate surroundings and have no further effect on up/downstream regions. Others have greater impact radius and can therefore cause cumulative impacts in combination with other HPPs even causing impacts to neighbouring countries. The Mekong is a large international river, flowing through 6 countries before entering the East Sea of Vietnam. Therefore, a dam project on the main Mekong has a high potential of transboundary impacts.

The CIA/TBIA is particularly important to identify and describe the changes of the environmental and social conditions caused by the combined impact of the past, present and future (already planned) projects in this area, with a focus on transboundary effects, the Mekong being an international river. It also covers an assessment of these impacts and discusses possible mitigation measures.

Legal and Administrative Framework
In addition to adhering to Lao PDR laws, decrees, regulations and guidelines, the Luang Prabang HPP CIA/TBIA development refers to international policies, guidelines and standards including, but not limited to, the following specific documents:

- Draft cumulative impact assessment guidelines for hydropower projects in the Lao PDR (Department of Environment and Social Impact Assessment (DESIA) within the Ministry of Natural Resources and Environment (MONRE)) [8].
- Draft/preliminary/tentative guidelines for transboundary environmental impact assessment in the lower Mekong basin (Mekong River Commission, 2017) [9].

The CIA guidelines provide guidance and direction for both MONRE and proponents on the undertaking and assessment of cumulative impact assessment (CIA) in the hydropower sector consistent with the IFC’s:


Hydropower Development at the Mekong Mainstream
The estimated hydropower potential of the lower Mekong Mainstream (excluding China) is about 10,000 MW, while that of the upper Mekong (Lancang Cascade) in China is about 21,400 MW, the latter largely already developed or under construction.

In the lower Mekong, the construction of 2 hydropower plants on the Mekong Mainstream has started, the 1,285 MW Xayaburi HPP (just downstream of Luang Prabang HPP) and the 256 MW Don Sahong HPP.
The Project

The Luang Prabang HPP is planned on the Mekong River approximately 25 km upstream of Luang Prabang city, and about 4 km upstream of the confluence with Nam Ou River (Figure 1-1). The scheme will be part of a low-head hydropower cascade system along the Mekong River, with Pak Beng HPP approximately 170 km upstream, and Xayaburi HPP approximately 130 km downstream of the proposed site.

The Luang Prabang HPP is a run-of-river (RoR) plant planned for hydropower generation to export electricity to Thailand. The structure across the river consists of an RCC dam, a powerhouse and a spillway section, each of them approximately one third of the entire length. A navigation lock is foreseen at the right abutment.

CUMULATIVE IMPACTS

As there are several HPPs upstream and downstream of Luang Prabang HPP, which are currently either in operation, under construction or being planned, the cumulative and transboundary impacts of this cascade have to be identified and valued, and the incremental part of these cumulative impacts attributed to Luang Prabang HPP have to be pointed out.

Impacts which can occur to be cumulative and/or transboundary are as follows:

- Hydrological and hydraulic impacts such as change in flow pattern, flow velocity, backwater effects etc.
- Water quality
- Erosion, sedimentation and sediment transport
- Impacts of the HPP under climate change conditions
- Impacts to fish migration and fishery
- Food and nutrition
- Impacts related to construction
- Social issues

Based on project description and baseline environmental and social condition of Luang Prabang HPP study area, Valued Ecosystem Components (VECs) for the proposed Luang Prabang HPP are likely to include mainly the following:

(a) Hydrology
(b) Water Quality
Hydrological and Hydraulic Impacts

The Luang Prabang HPP is a run-of-river hydropower plant (ROR). Its inflow is equal to its outflow and no storage is used. However, to increase the potential energy the dam increases the water level of the upstream area, creating a reservoir with a surface area of around 49 km², reaching back to the planned Pak Beng HPP. The increase of the water depth increases the surface of the submerged area, leading to decreased velocities. This causes local impacts (reduced sediment transport and slightly different habitat conditions for aquatic life), which are discussed in the ESIA.

The backwater will affect the tailwater level at the Pak Beng HPP. Effects of ROR plants to their upstream and downstream hydrographs are marginal since they do not store water. Only during the start phase a storage takes place while the reservoir is being impounded to reach the FSL (15 to 20 days). Afterwards the operation maintains the water level at FSL with minor changes in elevation of approximately 1 m for minor floods, up to an increase of 2.2 m for the PMF. An impact to the flow pattern of the river only occurs with storage plants as they change the flow pattern of the river.

Impacts on Water Quality

Since the residence time of the water is rather short (range of approx. 3 to 9 days), the whole water volume will be exchanged due to the permanent operation of the turbine and the frequent operation of the low level outlets. Therefore, no dead zone (zone below minimum operation level in a storage power plant) occurs, and this also excludes the formation of a deep water zone with deteriorating water quality.

A proper cleaning of biomass and waste in the reservoir area before impoundment is mandatory to ensure the water quality can be maintained. Once this is considered there will be no additional significant impact to water quality during normal HPP operation.

Impacts on Erosion, Sedimentation and Sediment Transport

In the past some sound studies upon sediment transport of Mekong River have been carried out from different organisations and experts. Due to the high trapping efficiency and a very large storage volume of at least some of the Chinese reservoirs within the Lancang Cascade it is reasonable that sediment inputs from upstream the Chinese border are extremely reduced and this situation will last for a very long time (estimations indicate time spans of several hundred years).

In 1993 the first reservoir, Manwan, of the Lancang Cascade came into operation and trends for total sediment load can be split into a phase before and after that significant turning point of the Mekong’s sediment system. In the meanwhile, at least 6 mainstream dams of the cascade are in operation. It is clearly indicated that for the Post-Manwan era a significant and likely to be ongoing reduction of the suspended sediment concentration has been measured.

As a run-of-river plant Luang Prabang has no storage reservoir and no big head. The velocity near the dam ranges between 0.05 m/s with river flow of 1,000 m³/s to 0.2 m/s with average river flow (about 4,000 m³/s) to 0.5 m/s with river flow of 10,000 m³/s,
being generally higher further upstream along the reservoir. The velocities in the reservoir are sufficient to prevent the development of significant turbidity currents. For average turbine operation flow (about 3,000 m$^3$/s) flow velocities in the main channel area of the Luang Prabang HPP are between 0.2 and 0.4 m/s.

However, due to the fact that the barrage will increase the water table upstream and reduce the flow velocity some sediment will accumulate in some parts of the reservoir until a new equilibrium is reached. Once the accumulated sediments have decreased the flowed area, the velocity will increase again and more sediments will stay in suspension, being transported downstream eventually.

The results from the sediment modelling (see feasibility study, Poyry 2019), show in general a potential for sediment deposit along the entire reach, with a higher potential for deposition between km 2,052 and 2,164. Sediment is deposited in the upper part of the reach, thus less sediment deposits are shown further downstream near Luang Prabang HPP. Results of transported material show for the condition with Luang Prabang HPP a significant content of fine silt/clay material, while coarse silt is still transported out of the reach, whereas most of fine sand material is deposited.

**Impacts on Fish, Aquatic Habitats and Fishery**

With the possible cascade of run-of-river plants comprising of Pak Beng, Luang Prabang, Xayaburi, Pak Lay and Sanakham a major part of the area identified as upper Mekong migration system will have a change in its hydraulic conditions. This will have an effect on fish migration and habitat availability. Given the high biodiversity and the limited information on fish migration in the Mekong River, the full extent of this cannot be assessed in detail. However, if spawning areas are lost this will have a major effect to the fish population. A fish monitoring program will have to be implemented, and mitigative measures will have to be taken if required. The cascade will provide more deep water areas, but the rapids will be lost. According to MRC (MRC Tech. paper No. 8 [3]) fishes mainly migrate into areas further upstream of Pak Beng for spawning.

Only little is known about the spawning habitat requirements for most Mekong fishes. Generally spawning habitats are believed to be associated with rapids, pools and floodplains. In its natural stage this area has not many floodplains, but rapids and some deep pools. The loss of deep pools might be compensated by creation of the reservoir which will provide more and larger deep areas.

The flow velocities in the main channel area of the Luang Prabang HPP are around 0.2 to 0.4 m/s. This ensures drifting of eggs and larvae during normal operation conditions.

With the cascade of ROR plants (Pak Beng to Pak Lay) in place, the variety of flow conditions and habitats within that part of the Mekong is mostly lost.

**Impacts on Food and Nutrition**

Considering the fact that Luang Prabang HPP is a mainstream project with affected communities living along the Mekong and huge reliance on rice and fish for their dietary requirement, the project is expected to cause impact on the nutrient intake of the PAPs and possibly downstream communities. The actual impact needs to be further assessed with consideration of the fact that the project plans to develop a fish migration system to mitigate the impact or creating a barrier for fish migration.
An overarching study of recent upstream and downstream projects such as Pak Beng and Xayaburi may shed further light on the cumulative projects induced impacts. The type and quantum of impacts can further clarify appropriate coping and mitigation mechanism or improvements of the existing mitigation measures. Nevertheless, the project developer is expected to be responsible to ensure that food and nutrition requirements of PAP are addressed during the transition period of resettlement and for longer period for the most vulnerable households.

Social Impacts
Cumulative impacts will be rather short-lived and mostly related to the current ongoing construction works of the Chinese Lao railway project. As an additional disruption in river traffic, the travel and transportation along the Mekong River will be further impeded. The installation of navigation locks will serve to reduce these impacts. There will be a time loss to pass through the navigation lock but on the other hand, the resulting elevation of the water level and the reduced flow velocities upstream of the dam will simplify passage for boats transporting passengers and goods.

TRANSBOUNDARY IMPACTS

Hydrology
A transboundary impact from China to all the Mekong- downstream countries is given by the operation of the storage power plants in the Lancang cascade. The operation causes a flatter but wider hydrograph since peak flows are cut, but low flows increase. As a ROR-plant Luang Prabang HPP is not affecting the hydrograph and has no further hydrological effect to the downstream countries. Accordingly there is no hydrological impact to the Tonle Sap great lake system from Luang Prabang HPP.

However a positive transboundary effect to be mentioned here is given from the Lancang cascade to the Pak Beng-, Luang Prabang-, Xayaburi- cascade: Since the Lancang cascade changed the flow pattern more water is released during dry month whereas the spillway peaks are lower. Therefore more energy can be produce in the latter cascade in an average year.

Sediment Transport
The Lancang cascade causes a significant transboundary effect to all downstream countries concerning sediment transport as described in chapter 5.2.10. The Pak Beng, Luang Prabang, Xayaburi run-of-river cascade will, for some time slightly reduce sediment transport until new equilibriums in their backwater areas are reached.

As described in chapter 5.2.10 the reduction of sediment transport due to the impoundment of the Manwan reservoir has immediately impacted the following approx. 800 km downstream section. But further downstream (ca. 1,160 km), near Luang Prabang it took over 3 years to recognize this effect. It is assumed that the buffer volumes from sediments within the river compensated the impact during this time (CNR, 2013c).

The distance from Luang Prabang HPP to Hueang confluence, where Mekong reaches the Thai border is approx. 330 km. It can be assumed that the phase with reduced sediment release from Luang Prabang HPP can be recognized in Thailand quite early.
For other downstream countries like Cambodia (more than 1,000 km downstream) and Vietnam (more than 1,500 km downstream) the impact to sediment transport from this run-of-river cascade is rather low. Main reductions is caused by the Langcang cascade and the dams on the Mekong tributaries (e.g. Nam Ngiep 1 or Nam Theun 1).

**Fish and Fishery**

According to Poulsen et al [5] the upper fish migration system seems to be relatively isolated, with little exchange between it and the other more south located migration systems. It is therefore being 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 Cambodia and Vietnam.
INTRODUCTION

The Mekong River is one of the largest rivers in the world: it is the 12th by length, the 7th in Asia, and the 10th by discharge. The river originates from a high mountainous area in Qinghai province crossing Xi Zang before flowing along the whole length of Yunnan province in China. Then it flows across Myanmar, Laos, Thailand, Cambodia and Vietnam, where it enters the East Sea of Vietnam.

There are 18 dam projects proposed for the main Mekong River, among which 8 upstream projects are located in the territory of China, with 3 among them already under operation presently. There are 8 projects proposed in Lao territory.

Luang Prabang hydroelectric power project (Luang Prabang HPP) will be the 10th in the cascade to be constructed on the main course of Mekong River from the upstream, and to be the 2nd project constructed in Lao territory.

The Luang Prabang HPP is planned on the Mekong River approximately 25 km upstream of Luang Prabang city, and about 4 km upstream of the confluence with Nam Ou River (Figure 1-1). The scheme will be part of a low-head hydropower cascade system along the Mekong River, with Pak Beng HPP approximately 170 km upstream, and Xayaburi HPP approximately 130 km downstream of the proposed site.

The Luang Prabang HPP is a run-of-river (RoR) plant planned for hydropower generation to export electricity to Thailand. The structure across the river consists of a RCC dam, a powerhouse and a spillway section, each of them approximately one third of the entire length. A navigation lock is foreseen at the right abutment.

Figure 1-1: Project location
1.1 Purpose of the CIA and TBIA Report

With a focus on sustainability, Lao laws and regulations require environmental and social studies for large scale hydroelectric power stations and for the construction of transmission lines. Mitigation measures have to be incorporated for mitigating damages to the physical and socio-economic environment. In addition, compliance with the laws and regulations is required in order to receive the environmental compliance certificate.

As part of the environmental and social requirements a cumulative and transboundary impact assessment (CIA/TBIA) has to be prepared for the Luang Prabang HPP.

The CIA/TBIA is particularly important to identify and describe the changes of the environmental and social conditions caused by the combined impact of the past, present and future (already planned) projects in this area, with a focus on transboundary effects, the Mekong being an international river. It also covers an assessment of these impacts and discusses possible mitigation measures.

1.2 Significance of Cumulative and Transboundary Impacts

Hydropower and dam projects are often placed in wide public attention due to their direct and visible environmental and social impacts. Whereas some environmental and social impacts of hydropower projects might not be of significant relevance individually, the cumulative sum of such impacts may grow to significant and undesired results, which can have undesirable effects on other countries, the so-called transboundary issues. Such cumulative and transboundary effects may relate to different levels from small scale impacts to the impacts of several hydropower plants.

1.3 Relations to the Projects Specific Impact Studies

The coverage of an ESIA study is generally limited to the directly impacted area. Whereas an ESIA concentrates on the impacts of one specific project, the CIA/TBIA tries to analyse the combined impacts of a series of projects, future developments and plans, either implemented together or in a sequence. The present cumulative and transboundary assessment concentrates on assessing the impacts of the proposed Luang Prabang HPP project in the context of other existing or planned developments. The definition of the potential impact area will normally extend far beyond the impact area of a project-specific ESIA study. It should also be noted that the CIA/TBIA for a dam project is not limited to cumulative impacts of other dam projects, but will have to include effects of other development projects in the region as long as there is the possibility of interactions.
2

THE PROJECT

The Luang Prabang HPP (LP HPP) project is to be located at km 2,036 in the Mekong lower catchment. It is a low-head power plant with its full supply level (FSL) at 312 masl, its target is electrical power generation for export.

The project is fully in line with the GOL’s energy policy considering that: (i) it is a private-participation project; (ii) it will export the generated electricity; and (iii) the project developer shall commit to ensure accountability and transparency of environmental and social impact management.

The Luang Prabang HPP is located approx. 25 km upstream of Luang Prabang. It is a barrage type hydroelectric run-of-river scheme which comprises:

- Powerhouse equipped with 7 Kaplan turbine(generator sets (200 MW each). The total installed capacity is 1’400 MW, and the maximum gross head is 36.80 m
- Auxiliary units using water from fish attraction flow for the upstream and downstream migration facilities (approx. 180 m³/s), totalling to a maximum of 60 MW capacity
- Spillway structure with six (6) radial surface gates (19 m x 25 m, sill level 288.0 m asl). Three (3) low level outlets (12 m x 16 m, sill level 275.0 m asl)
- Two-step navigation lock system for 2x500 DWT vessels
- Fish pass system for up- 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. Alternatively to Thailand with an approximate 250 to 300 km length.

Major related projects and development that could have interferences with the Luang Prabang HPP are the following; Pak Beng HPP, China-Lao Railway Project, Xayaburi HPP, Hongsa-Chiangman road including possible bridge across the Mekong River and development around Luang Prabang city which has an UNESCO World Heritage status.
Figure 2-1: Overview of the Luang Prabang HPP project sites
LEGAL AND ADMINISTRATIVE FRAMEWORK

A large number of environmental and social laws and regulations define the requirement of environmental and social studies. Specific laws and regulations have been referred to in the environmental and social studies, particularly in the ESIA (see [7] chapter 2). In addition to adhering to Lao PDR laws, decrees, regulations and guidelines, the Luang Prabang HPP CIA/TBIA development will refer to international policies, guidelines and standards including, but not limited to, the following specific documents:

- Draft cumulative impact assessment guidelines for hydropower projects in the Lao PDR (Department of Environment and Social Impact Assessment (DESIA) within the Ministry of Natural Resources and Environment (MONRE)) [8].
- Draft/preliminary/tentative guidelines for transboundary environmental impact assessment in the lower Mekong basin (Mekong River Commission, 2017) [9].

The CIA guidelines provide guidance and direction for both MONRE and proponents on the undertaking and assessment of cumulative impact assessment (CIA) in the hydropower sector consistent with the IFC’s:


In addition to the Lao PDR statutes and regulations, the GoL is also a signatory of the agreement on the cooperation for the sustainable development of the Mekong River basin (Mekong River Commission, 1995). The MRC supports a joint basin-wide planning process with the four countries, called the basin development plan, which is the basis of its integrated water resources development programme. The MRC is also involved in fisheries management, promotion of safe navigation, environmental protection, irrigated agriculture, watershed management, environment monitoring, flood management and exploring hydropower options.
CUMULATIVE AND TRANSBOUNDARY IMPACTS

Each hydroelectric power plant (HPP) generates several impacts to the society and the environment. Some impacts occur in the immediate surroundings and have no further impact to up/downstream regions. Others have greater impact radius and can therefore cause cumulative impacts together with other HPPs even causing impacts to neighbouring countries. As described in chapter 1 the Mekong is a large international river, flowing through 6 countries before entering the East Sea of Vietnam. Therefore a dam project on the main Mekong has a high potential for transboundary impacts.

As there are several HPPs upstream and downstream of Luang Prabang HPP, which are currently either in operation, under construction or being planned (as shown in Figure 5-1) the cumulative and transboundary impacts of this cascade have to be identified and valued, and the incremental part of these cumulative impacts attributed to Luang Prabang HPP have to be pointed out.

The cumulative and transboundary impacts associated with the Luang Prabang HPP, which refer principally to the combined effects of the various proposed projects within the Mekong River Basin, which together with the Project will cause significant changes in the river basin are described in the following chapters. Relevant conclusions and recommendations are given in chapter 6.

4.1 Methodology and Approach

Referring to the Draft Cumulative Impact Assessment Guidelines for HPP in Lao PDR, May 2016 (Ref 7-1), the methods and tools for undertaking CIA and TBIA rely upon the basics used when undertaking an ESIA and a number of additional methods. Several approaches/methods are available for assessing cumulative impacts. The following methods in combination are normally used when assessing cumulative impacts:

- Specialist opinion;
- Specific consultation and questionnaires with relevant stakeholders;
- Using checklists;
- Risk matrices as commonly used to assess the consequence and likelihood of impacts;
- Review of available planning documents, investment programs, public permits and previously prepared ESIA; and
- Undertaking an assessment of mitigation for incremental impacts using past experience, best available techniques, good/best practices, and expert opinion.

4.2 Determination of Valued Ecosystem Components (VECs)

VECs are defined as any part of the environment that is considered important by the proponent, public, scientists, and government involved in the assessment process. Importance can be determined on the basis of cultural values or scientific concern. The attributes related to a VEC can include biological, cultural, ecological, environmental, physical and social issues. VECs for hydropower projects within Lao PDR are likely to include the following

(a) Air and Noise;
(b) Affected Peoples and Resettlement;
(c) Cultural and Ethnic Archaeology and Heritage;
(d) Erosion and Sedimentation Transport;
(e) Fish and Aquatic Habitats;
(f) Natural Resources;
(g) Terrestrial Habitats;
(h) Hydrology; and
(i) Water Quality and Quantity.

However, based on project description and baseline environmental and social condition of Luang Prabang HPP study area, VECs for the proposed Luang Prabang HPP are likely to include mainly the following:

(a) Hydrology
(b) Water Quality
(c) Erosion and Sedimentation Transport
(d) Fish, Aquatic Habitats and fisheries
(e) Food and Nutrition
(f) Social Impacts
5 RELEVANT ISSUES

5.1 Hydropower Development Plan

5.1.1 Hydropower Development at the Mekong Mainstream

The estimated hydropower potential of the lower Mekong Mainstream (excluding China) is about 10,000 MW, while that of the upper Mekong (Lancang Cascade) in China is about 21,400 MW, the latter largely already developed or under construction. In the lower Mekong, the construction of 2 hydropower plants on the Mekong Mainstream has started, the 1,285 MW Xayaburi HPP (just downstream of Luang Prabang HPP) and the 256 MW Don Sahong HPP.

Figure 5-1: Hydropower along the Mekong Mainstream

5.1.1.1 Lancang Cascade

The hydropower developed in the upper Mekong River basin in China (also called Lancang cascade) consists of run-of-river, but also large storage plants, most of them...
already in operation or under construction (see Table 5-1). The total active storage volume of these plants is about 23,200 million m$^3$, or about 25% of the mean annual flow of the Mekong River entering the lower Mekong River basin from China.

The regulation effect of these large storage schemes will have a significant effect on the annual flow pattern in the lower Mekong River basin, mainly a shift of the flow from the monsoon season to the dry season, resulting in an increase of the dry season flows and a decrease of the flood hydrographs.

The largest reservoirs of the Lancang cascade are in operation since 2013 (Xiaowan) and 2015 (Nuozhadu), and their impact is already considered in the flow records of the last 4 years. The study “Optimization study of Mekong mainstream hydropower” (2009) estimated the impact of the Lancang cascade as an increase on low dry season flows between 58% (Pak Beng, Luang Prabang) and 46% (Sanakham). For more information see also chapter 5.2.10, Figure 5-22 and Figure 5-23.

Table 5-1: Hydropower plants in operation of the Lancang cascade

<table>
<thead>
<tr>
<th>HPP</th>
<th>COD</th>
<th>Capacity [MW]</th>
<th>Head [m]</th>
<th>FSL [masl]</th>
<th>Storage [M m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gongguoqiao</td>
<td>2012 (?)</td>
<td>750</td>
<td>77</td>
<td>1,319</td>
<td>120</td>
</tr>
<tr>
<td>Xiaowan</td>
<td>2013</td>
<td>4,200</td>
<td>248</td>
<td>1,236</td>
<td>9,900</td>
</tr>
<tr>
<td>Manwan</td>
<td>1995</td>
<td>1,500</td>
<td>99</td>
<td>994</td>
<td>257</td>
</tr>
<tr>
<td>Dachaoshan</td>
<td>2003</td>
<td>1,350</td>
<td>80</td>
<td>895</td>
<td>367</td>
</tr>
<tr>
<td>Nuozhadu</td>
<td>2015</td>
<td>5,500</td>
<td>205</td>
<td>807</td>
<td>12,300</td>
</tr>
<tr>
<td>Jinghong</td>
<td>2010</td>
<td>1,500</td>
<td>67</td>
<td>602</td>
<td>249</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>14,800</strong></td>
<td><strong>776</strong></td>
<td></td>
<td><strong>23,193</strong></td>
</tr>
</tbody>
</table>

5.1.1.2 Hydropower Development in Lao PDR

The Mekong River Commission carried out a study “Mekong mainstream run-of-river hydropower” in 1995 and identified a total of twelve projects with a total capacity of 13,000 MW, where 9 of them were considered promising, which are Pak Beng, Luang Prabang, Xayaburi, Pak Lay, Sanakham, Pak Chom, Ban Koum, Phou Ngou and Don Sahong (see Figure 5-2).

In 2009 a study “Optimization study of Mekong mainstream hydropower” has been carried out by GOL – Ministry of Energy and Mines (see Table 5-2). This study optimized the upper 5 projects at the Mekong mainstream in Lao PDR, from Pak Beng HPP down to Sanakhan HPP.
Figure 5-2: Hydropower project at the Mekong mainstream in Lao PDR.

Table 5-2: Mekong mainstream HPP projects as per GOL optimization study.

<table>
<thead>
<tr>
<th></th>
<th>Kilometrage</th>
<th>Capacity [MW]</th>
<th>FSL [masl]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pak Beng</td>
<td>2,188</td>
<td>1,230</td>
<td>345</td>
</tr>
<tr>
<td>Luang Prabang</td>
<td>2,036</td>
<td>1,410</td>
<td>310</td>
</tr>
<tr>
<td>Xayaburi</td>
<td>1,930</td>
<td>1,260</td>
<td>275</td>
</tr>
<tr>
<td>Pak Lay</td>
<td>1,818</td>
<td>1,320</td>
<td>240</td>
</tr>
<tr>
<td>Sanakhan</td>
<td>1,772</td>
<td>570</td>
<td>215</td>
</tr>
</tbody>
</table>

These are all ROR projects. Don Sahong, while located on the Mekong mainstream, is a special case: it uses only one of the numerous channels into which the Mekong splits at the Khone Falls and therefore, unlike the others in the list, does not use all the water in the river, and does not block it completely.

5.1.2 Project Features

The Luang Prabang HPP site is located on the Mekong River at kilometre 2,036, approximately 25 km upstream of Luang Prabang. It is a barrage type hydroelectric Run-of-River scheme which comprises:
• Powerhouse equipped with 7 Kaplan turbine/generator sets (200 MW each). The total installed capacity is 1'400 MW, and the maximum gross head is about 36.8 m
• Auxiliary units using water from fish attraction flow for the upstream and downstream migration facilities (approx. 180 m³/s), totaling to a maximum of 60 MW capacity
• Spillway structure with six (6) radial surface gates (19 m x 25 m, sill level 288.0 masl), and three (3) low level outlets (12 m x 16 m, sill level 275.0 masl)
• Two-step navigation lock system for 2x500 DWT vessels
• Fish pass system for up- 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. Alternatively to Thailand with an approximate 250 to 300 km length.

The Luang Prabang HPP is located at the right river bank (see Figure 1-1), where space is available for the construction of the main structures. The navigation lock will be located at the right river bank allowing vessels and ships a safe approach and passage. The powerhouse will be in the centre of the river, and will have two erection bays on each end of it. The split erection bay concept provides on the one hand advantages for assembly and installation of the equipment (lifting devices can operate independently from each other), and on the other hand provides space (upstream and downstream of the erection bays) to host the facilities for upstream and downstream fish migration.

The construction of the HPP is planned to be done within one major construction stage, i.e. all major structures will be erected within a large single construction pit while the Mekong River is diverted. After completion of the main construction works (concrete works and installation of the main hydro-mechanical equipment, spillway and navigation lock operational, intake gates and draft-tube stoplogs at powerhouse in place and set) the Mekong River will be diverted through the spillway (low level outlets) and the left bank closing structure (e.g. RCC dam) will be constructed under the protection of up- and downstream cofferdams while wet testing and commissioning can start.

Construction works will be mainly done from the right river bank, which can be reached by an existing access road from Luang Prabang (Mekong River in Luang Prabang needs to be crossed by ferry boat). Transportation of bulk material to site can be done via vessels or by road. Alternatively, material from China could also be transported to Luang Prabang by railway (actually under construction, completion expected in 2021) and vessels.

5.1.3 Reservoir Operation

The Luang Prabang HPP is a run-of-river type hydropower plant, i.e. the discharge through the powerhouse (powerhouse, spillway) equals the inflow, and the full supply level will be maintained most of the time during operation (increase or decrease of the FSL might be required during spillway operation or other exceptional operating cases). For practical purposes (control system) an “operating range” for the FSL of around 0.50 m will be required, i.e. the FSL will vary between 312.00 and 312.50 masl.

During flood operation the excess water (water not used for generation of electricity and/or operation of the navigation lock and fish migration facilities) will be spilled through the spillway. The spillway comprises low level outlets and surface spillway bays. The operation of the spillway will be as such that the first bays in operation will be the low level outlets in order to route “turbidity currents” through the spillway and to minimise sedimentation in the reservoir area.
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 spill of floating debris in front of the spillway into the tailwater area.

5.2 Hydrology

5.2.1 Introduction

This chapter covers the hydrological aspects for the Luang Prabang HPP, in particular:

- Expected inflow at dam site taking into account the impact of the operation of the Lancang cascade
- Design floods for the dam site
- Sediments and impact of the Luang Prabang HPP on the sediment balance of the Mekong River
- Impact of climate change

For the inflow analysis rather long time series are available for the Mekong River since the 1960’s. The upstream Lancang cascade and their large storage schemes have a considerable impact on the inflow characteristics, and only about 4 years of “impacted” flow series are available. Thus the “natural” time series needs to be transformed to reflect the large upstream storage schemes of the Lancang Cascade. However, no information on the operation of these schemes are available, and the transformation needs to be done based on assumptions, leading to additional hydrological uncertainties.

The design floods are determined based on a statistical approach (runoff- rainfall model) and the PMP/PMF is accordingly estimated to be 41,400 m$^3$/s.

5.2.2 Overview of Previous Studies

A study on Luang Prabang’s hydrology was carried out by 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.

Another study on the hydrology was done by power engineering consulting JS company 1 (2010): Luang Prabang hydropower project: feasibility study, meteo-hydrological conditions.

5.2.3 Catchment

5.2.3.1 Mekong River Basin

With a length of about 4,900 km the Mekong River is among the longest rivers in the world. It drains a total area of 795,000 km$^2$ and flows through six countries. The average discharge at its mouth into the East Sea of Vietnam is about 15,000 m$^3$/s, or a mean annual runoff of 470,000 million m$^3$.
Figure 5-3: Mekong River basin and neighbouring countries.

Table 5-3: Catchment area and flow of Mekong River basin countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Catchment Area [km²]</th>
<th>Catchment % of MRB</th>
<th>Flow % of total flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>165,000</td>
<td>21%</td>
<td>16%</td>
</tr>
<tr>
<td>Myanmar</td>
<td>24,000</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>Lao PDR</td>
<td>202,000</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>Thailand</td>
<td>184,000</td>
<td>23%</td>
<td>18%</td>
</tr>
<tr>
<td>Cambodia</td>
<td>155,000</td>
<td>20%</td>
<td>18%</td>
</tr>
<tr>
<td>Vietnam</td>
<td>65,000</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>795,000</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
The Mekong River basin’s biodiversity is immense, and is fundamental to the viability of natural resource-based rural livelihoods of about 60 million people living in the lower Mekong River basin (Gies, E., 2017 [15]).

5.2.3.2 Physiography

From the eastern watersheds of the Tibetan plateau the Mekong River flows through three provinces of China, continuing into Myanmar, Lao PDR, Thailand, Cambodia to the Mekong delta in Vietnam. The Mekong River basin includes seven broad physiographic regions featuring diverse topography, drainage patterns and geomorphology (see Figure 5-5).

The source of the Mekong River is at the Tibetan Plateau, the world’s most densely glaciated region located at more than 5,000 m above sea level. The Three Rivers Area is aptly named as the Mekong, Salween, and Yangtze all run alongside one another in a rugged mountainous region. The Mekong flows about 500 km through a deep ravine with no significant tributaries in this stretch.

The river is called Lancang in China. The Lancang Basin south of the Three Rivers Area is a highland and plateau about 2,000 to 3,000 m above sea level. The Mekong flows...
down a steep gradient and transitions to mid and lowland reaches. Smaller tributary catchments drain into the river from both sides.

The **Northern Highlands** form the upland region covering northeastern Myanmar, northeastern Thailand, and the northern areas of the Lao PDR. Large tributaries like the Nam Ta, Nam Ou, Nam Soung, Nam Khan, Nam Mae Kok and Nam Mae Ing join the Mekong River.

The **Khorat Plateau** is a lower terrain in northeastern Thailand, consisting mainly of sediment and eroded bedrock and surrounded by a rim of sandstone. The main tributaries in this area are the gently sloping Songkhram and Mun Rivers on the right bank and the steep Nam Ca Dinh, Se Bang Fai, and Se Bang Hiang Rivers on the left bank.

![Figure 5-5: Physiographic regions of the Mekong River basin (source: MRC).](image)

The Mekong River flows into the **Tonle Sap Basin** through a broad valley just north of Pakse. The Tonle Sap Basin is a large alluvial plain surrounded by hills. At the southern end of the basin, the mainstream breaks up into a complex network of branching and reconnecting channels.

The western and central parts of the Tonle Sap basin make up the **Great Lake**, also known as the Tonle Sap great lake, located in the Cambodian floodplain. During the dry season
the great lake drains into the Mekong River, during the wet season, the high flows in the Mekong River cause the Tonle Sap river to reverse flow and the great lake floods.

The Mekong Delta begins near Phnom Penh and ends up as a huge flat plain in southern Vietnam. Near the mouth the Bassac river branches away from the mainstream, and both rivers split up into a number of smaller distributaries, forming the plains of the Mekong delta.

5.2.3.3 Macroclimate

The climate in Lao PDR can be described as tropical monsoon climate, characterized by strong Monsoon influence with high rainfalls, high humidity and considerable amount of sun. There are two distinctive seasons in Laos, the dry season and the rainy and humid season. Regions in the mountains have a slightly cooler, more temperate climate.

The pronounced rainy season is from May through October with rainfalls between 120 mm and 290 mm, with the rainiest months August and September. The dry season is relatively cool from November to February, and hot in March and April before the monsoon rains start. The monsoon rains are generally irregular in start of the rains, duration and intensity.

The average annual rainfall in Luang Prabang area is about 1,360 mm; the coldest month is January with an average temperature of 20.5°C (minimum 1°C), and the hottest month is April with an average temperature of 28.1°C (maximum 44.8°C). With raising altitude, the climate gets cooler and rainier, with more frequent pre-monsoon showers and abundant rains in the monsoon period.

5.2.4 Data Collection and Processing

The hydrological data collected and used for this study is summarised in this chapter.

5.2.4.1 Discharge Data

Water level and discharge data were available from gauging stations at the Mekong River and selected tributaries as shown in Figure 5-6 for the periods and timely resolution as listed in Table 5-4. At the Mekong mainstream long time discharge data (starting in 1960) are available for two gauging stations, Chiang Saen upstream of the project site close to the border triangle between Lao PDR, Thailand and Myanmar, and Luang Prabang downstream of the site.
Figure 5-6: River gauging stations at the Mekong mainstream.

Table 5-4: Overview of available flow data of Mekong River and tributaries.

<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>River</th>
<th>Daily Data</th>
<th>Hourly Data</th>
<th>15 min Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luang Prabang</td>
<td>Mekong</td>
<td>05/60-10/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chiang Saen</td>
<td>Mekong</td>
<td>05/60-10/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ban Xiangkou</td>
<td>Mekong</td>
<td>05/16-10/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ban Tonphuang</td>
<td>Mekong</td>
<td>04/16-10/18</td>
<td>04/16-11/16</td>
<td></td>
</tr>
<tr>
<td>Pakbeng Bridge</td>
<td>Mekong</td>
<td>09/16-10/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ban Soupanouvong</td>
<td>Mekong</td>
<td>07/16-10/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xayaburi d/s</td>
<td>Mekong</td>
<td></td>
<td>04/16-11/16</td>
<td></td>
</tr>
<tr>
<td>Muong Nga</td>
<td>Nam Ou</td>
<td>01/88-12/17</td>
<td>08/15-11/16</td>
<td></td>
</tr>
<tr>
<td>Ban Hat Nga</td>
<td>Nam Ou</td>
<td></td>
<td>08/15-11/16</td>
<td></td>
</tr>
<tr>
<td>Ban Mixay</td>
<td>Nam Khan</td>
<td>01/88-12/17</td>
<td>08/15-11/16</td>
<td></td>
</tr>
<tr>
<td>Ban Sibounhom</td>
<td>Nam Seuang</td>
<td>01/87-12/14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2.4.2 Precipitation

Precipitation data sets have been collected and used from the following sources:

- **GPCC** (Global Precipitation Climatology Centre of the German Meteorological Service DWD, gridded ground observations (see also https://www.dwd.de/EN/ourservices/gpcc/gpcc.html)

- **APHRODITE** (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation - daily gridded precipitation (see http://www.chikyu.ac.jp/precip/)

- **TRMM** (Tropical Radar Rainfall Mission, a joint US-Japan remote sensing mission (see http://trmm.gsfc.nasa.gov/)

- **GPM** (Global Precipitation Measurement see https://www.nasa.gov/mission_pages/GPM/main/index.html )

- **GSOD** data (Global Surface Summary of the Day – GSOD; station data; https://catalog.data.gov/dataset/global-surface-summary-of-the-day-gsod)

5.2.5 Evapotranspiration

The gridded evapotranspiration dataset of CRU (Climate Research Unit of the University of East Anglia; http://www.cru.uea.ac.uk/data) was used. It calculates potential evapotranspiration based on the Penman-Monteith formula.

5.2.6 Temperature

Two temperature data sets have been used:

- **CRU** (Climate Research Unit of the University of East Anglia; Gridded temperature dataset of; http://www.cru.uea.ac.uk/data)

- **GSOD** data (Global Surface Summary of the Day – GSOD; station data; https://catalog.data.gov/dataset/global-surface-summary-of-the-day-gsod)
5.2.7 Hydro-Meteorological Characteristics

5.2.7.1 Precipitation

The catchment area of the Mekong River on Chinese territory shows low precipitation below 1000 mm/y in the North. The precipitation gradually increases towards the South. In Laos the mean annual precipitation reaches values up to 2000 mm (see Figure 5-7).

Figure 5-7: Precipitation Datasets for the Mekong Catchment

GPCC data (left) and TRMM data (right)

5.2.7.2 Temperature & Evapotranspiration

The CRU dataset shows a potential evapotranspiration of below 800 mm in the northern part of the catchment in China. The values gradually increase up to 1200 mm towards the south (Figure 5-8).
5.2.8 Inflow Hydrology

The following chapters present the most important information on the model structure, the input data, the calibration and simulated results. Additional information can be found in Volume 6.1 - Annex Hydrology, Section 1 – Rainfall Runoff Model.

5.2.8.1 Discharge Time Series

Long discharge time series on the Mekong River in the project area are available at Chiang Saen and Luang Prabang gauge (Figure 5-9). The biggest lateral inflow between these two gauges is the Nam Ou, which flows into the Mekong directly downstream of the proposed location of Luang Prabang hydropower plant. Smaller tributaries are the Nam Khan and Nam Suang.

In order to be able to estimate the share of inflow to Luang Prabang HPP from the sub-catchment between the gauges Chiang Saen and Luang Prabang as well as the impact of the Lancang Cascade a water balance model was set up.
5.2.8.2 Water Balance Model

The water balance model is applied to simulate long and consistent time series of runoff in the Mekong basin and to analyze the impact of upstream hydropower development.

The daily water balance model used in this study has been already applied extensively in many climatic regions of the world, among others in the Alps, southern Africa and the Philippines. The conceptual structure of the model is similar to the well-known HBV-model.

Inputs to the model are daily values of precipitation, temperature and potential evapotranspiration. The model determines rainfall from precipitation data, considering interception storage in the vegetation layer. Actual evapotranspiration is a function of soil moisture and potential evapotranspiration. Runoff generation is a non-linear function of soil moisture. The generated runoff is split into fast and slow components to simulate different response times of surface-flow and base-flow.

Figure 5-10 shows a schematic representation of the model structure. The depicted processes are calculated for each spatial element of the model, with all flows in the unit of millimeters.
The rainfall runoff model covers the whole catchment area of the Lancang/Mekong from its source to the gauge Luang Prabang. It is divided into 18 sub-basins. For each sub-basin outlet (e.g. the gauges and Luang Prabang HPP), runoff is transformed to streamflow in m³/s and streamflow is accumulated according to the topology of sub-basins.

![Figure 5-10: Conceptual Structure of the Applied Water Balance Model](image)

**Input Data**

**Precipitation**

Since no available precipitation data set covers the whole period for which discharge data is available a continuous precipitation time series was constructed from various sources. This was done by combining TRMM, Aphrodite, GPCC and GPM precipitation data. From 1951 to 31/10/1998 the daily variation of the Aphrodite dataset was combined with monthly GPCC precipitation sums. From 01/11/1998 to 30/05/2016 the same procedure was done with the daily variation of the TRMM data. From 01/06/2016 to 31/10/2018 the GPM data was used with a correction factor.

**Temperature**

Until 15.12.2017 the temperature input is based on CRU monthly values interpolated on daily time-steps; since 16.12.2017 it is based on interpolated GSOD station data.

**Lancang Cascade**

The hydropower plants of the Lancang Cascade are implemented in the model as 6 computation points:

- Gongguoqiao
- Xiaowan
- Manwan
- Dachaoshan
- Nuozhadu
- Jinghong

Each hydropower plant is represented with a volume-area-elevation relation, simplified operation rules and its operation start date.
5.2.8.3 Simulation Results of Natural Streamflow for the Calibration Period

The most relevant points of calibration are the outlet of the sub-basin of Chiang Saen Gauge and Luang Prabang gauge for which long time series beginning in 1960 are available. Additionally the discharge observations from Muang Ngoy, Ban Sibounhom and Ban Mixay were used. The calibration was done taking into account the operation start date, the impoundment of the reservoirs and the operation of the hydropower plants at the Lancang.

Figure 5-11 shows as an example of the results of daily discharge simulations at Chiang Saen and Luang Prabang Gauge for the period of 1980 to 1989. In Figure 5-12 the comparison of the observed and simulated mean monthly flow for the period of 1961 to 1990 is presented.
5.2.8.4 Inflow Time Series Luang Prabang HPP Site

The calculated inflow time series (1951-2018) for Luang Prabang HPP, considering operation of the Lancang cascade, leads to a mean annual flow of 3,293 m³/s.

Figure 5-14 shows the mean monthly discharges at Luang Prabang HPP site, and Figure 5-15 depicts the resulting flow duration curve for Luang Prabang HPP.

Figure 5-13: Inflow Series 1951 to 2018 for Luang Prabang HPP Site

Figure 5-14: Mean Monthly Discharge Luang Prabang HPP Site

Figure 5-15: Flow Duration Curve for Luang Prabang HPP Site
5.2.9 Flood Hydrology

5.2.9.1 Statistical Analysis

This chapter describes the Flood Frequency Analysis carried out for the Luang Prabang HPP. Additional information and data can be found in Volume 6.1 - Annex Hydrology, Section 2 – Flood Frequency Analysis.

The flood frequency analysis for Luang Prabang HPP was carried out with the Annual Maximum Series (AMS) from 1960-2009 for Luang Prabang Gauge and 1960-2018 for Chiang Saen Gauge.

The data of the two gauges was used directly since no impact on the flood peaks from the Lancang reservoirs is expected. Each peak of the AMS occurred during the months of July and October when the reservoirs are filled. Additionally the meteorological data shows that the storm events mainly take place downstream of the Lancang reservoirs.

Since there were doubts about the reliability of some peaks for Luang Prabang gauge only the peaks until the year 2009 were used (from 2006 to 2009 the peaks were taken from the Annual Mekong Flood reports by the MRC\(^1\)). For Chiang Saen the peaks of the years 2006 to 2008 were also taken from these reports.

As the observation records are daily mean values and no instantaneous discharge data is available in the region, maximum flood peaks were estimated based on a method proposed by Sangal (1983). Sangal’s approach relates the flood peak with daily mean data of the day of the peak and the previous and the following day:

\[ Q_{\text{max}} = \frac{(4 \cdot Q_2 - Q_1 - Q_3)}{2} \]

with

- \( Q_1 \): daily mean \( Q \) on day preceding the flood peak
- \( Q_2 \): daily mean \( Q \) on day of flood peak
- \( Q_3 \): daily mean \( Q \) on day after the flood peak

The FFA was done applying the software tool HQ-Ex by DHI-Wasy. This tool features several extreme value distributions and methods of parameter fitting. All available distributions are fitted to the observations. The design flood estimates were calculated as the mean of the results of all applied distributions.

The Creager formula was used to calculate the discharge values for the return intervals of interest for the Luang Prabang HPP site from the results for Chiang Saen and Luang Prabang Gauge.

**Design Floods**

The resulting design floods for Luang Prabang HPP site are listed for different return periods in Table 5-5, and shown graphically in Figure 5-16.

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\(^1\) Mekong River Commission (2006-2009): Annual Mekong Flood reports; see: www.mrcmekong.org

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### Table 5-5: Flood Discharges for Different Return Periods

<table>
<thead>
<tr>
<th>Return interval</th>
<th>Q LP HPP [m³/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>12,800</td>
</tr>
<tr>
<td>5</td>
<td>16,200</td>
</tr>
<tr>
<td>10</td>
<td>18,200</td>
</tr>
<tr>
<td>20</td>
<td>20,000</td>
</tr>
<tr>
<td>30</td>
<td>21,000</td>
</tr>
<tr>
<td>50</td>
<td>22,200</td>
</tr>
<tr>
<td>100</td>
<td>23,800</td>
</tr>
<tr>
<td>200</td>
<td>25,300</td>
</tr>
<tr>
<td>500</td>
<td>27,300</td>
</tr>
<tr>
<td>1,000</td>
<td>28,800</td>
</tr>
<tr>
<td>5,000</td>
<td>32,100</td>
</tr>
<tr>
<td>10,000</td>
<td>33,500</td>
</tr>
</tbody>
</table>

### Figure 5-16: Design Flood Values for Luang Prabang HPP Site

#### Dry Seasons Floods

The dry season is defined as the time between January and May. For this period a series of annual dry season maxima was developed for the gauges of Chiang Saen and Luang Prabang. Dry season flood estimates for the two gauges were calculated as described above for the annual maxima. To calculate the discharge values for the investigated return intervals for Luang Prabang HPP the Creager formula was used.

Application of the flood estimation procedure with results of the hydrological model (instead of observations) for simulations with and without considering upstream hydropower operation shows a tendency of lower dry season peaks under influence of the Lancang Cascade. Due to uncertainties in the peak simulation, the dry season flood estimates were based on observed historical discharge data, and are therefore estimated slightly conservatively.
Table 5-6: Dry Season Flood Discharges for Different Return Periods

<table>
<thead>
<tr>
<th>Return interval</th>
<th>Q LPQ [m³/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2,300</td>
</tr>
<tr>
<td>5</td>
<td>3,100</td>
</tr>
<tr>
<td>10</td>
<td>3,700</td>
</tr>
<tr>
<td>20</td>
<td>4,300</td>
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<tr>
<td>30</td>
<td>4,600</td>
</tr>
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<td>50</td>
<td>5,100</td>
</tr>
<tr>
<td>100</td>
<td>5,700</td>
</tr>
<tr>
<td>200</td>
<td>6,300</td>
</tr>
<tr>
<td>500</td>
<td>7,100</td>
</tr>
<tr>
<td>1,000</td>
<td>7,800</td>
</tr>
</tbody>
</table>

5.2.9.2 Probable Maximum Flood

The Probable Maximum Flood (PMF) is estimated by applying a Probable Maximum Precipitation (PMP) storm as input for the hydrological model of the Mekong basin (see Section 5.2.8.2). The PMP storm is constructed based on a comprehensive meteorological study for the Mekong basin by the U.S. Weather Bureau (1970\(^2\)).

Probable Maximum Precipitation

The PMP study of the U.S. Weather Bureau is based on analysis, adjustment and maximization of extreme storm in the region, providing a general methodology and generalized maps to determine PMP storms based on the location of the storm in the Mekong basin and the catchment area affected by the storm. One of the main results of the study is a map of 24-hour PMP depth for areas of 5,000 km\(^2\) for the middle and lower Mekong basin (Figure 5-17).

For the main Mekong River and its large catchment areas, the U.S. Weather Bureau Report provides specified PMP storms for three different parts of the catchment, and a set of assumptions concerning previous and surrounding rainfall. The map showing the isohyets of these PMP storms, with a zoomed-in excerpt for the storm north of Luang Prabang, is shown in Figure 5-18.
As the center of the northern storm of the map in Figure 5-18 is located almost 200 km upstream of Luang Prabang HPP, and as PMP storm depths are lower further north (see map in Figure 5-17), another storm was constructed by shifting the storm pattern of Figure 5-18 100 km south. Due to the higher precipitation depth and closer location, this shifted storm leads to higher PMF discharges at Luang Prabang HPP, and was therefore adopted as design PMP storm. Both PMP storms are depicted in Volume 6.1 - Annex Hydrology, Section 3 – Probably Maximum Flood.

The left graph in Figure 5-19 shows the depth-area-relation of the storm in the U.S. Weather Bureau map (“USWB storm” in the graph), and for the shifted storm. The right graph shows the temporal distribution of precipitation depths for a prior storm of 3 days and the PMP storm of 3 days for the center of the storm, with the peak value according to the shifted map values. The depths of the four days preceding the PMP peak and the day after are constructed as specified in the U.S. Weather Bureau Report.

According to the procedure described there, precipitation was distributed in space as shown in the map for the peak days of the prior and the PMP storm. Precipitation for the days around the peak days was distributed uniformly in space within the PMP storm extent.
Due to the large catchment area, and the related travel time of river discharge, precipitation input was also specified for the weeks preceding the double-peak PMP event. The values were again based on assumptions in the U.S. Weather Bureau Report, by fitting a smooth curve to monthly mean values described there (see Figure 5-19). As the purpose of this preceding rainfall is only to reach a certain (high) level of discharge before the PMP storm, a more realistic temporal distribution was not considered. The spatial distribution of preceding precipitation was based on the spatial pattern of mean monthly precipitation.

**Figure 5-19:** Left: PMP Depth-Area Relation
Right: Temporal Development of the PMP for the Center of the Shifted Storm

Due to the large catchment area, and the related travel time of river discharge, precipitation input was also specified for the weeks preceding the double-peak PMP event. The values were again based on assumptions in the U.S. Weather Bureau Report, by fitting a smooth curve to monthly mean values described there (see Figure 5-19). As the purpose of this preceding rainfall is only to reach a certain (high) level of discharge before the PMP storm, a more realistic temporal distribution was not considered. The spatial distribution of preceding precipitation was based on the spatial pattern of mean monthly precipitation.

**Figure 5-20:** Assumed Synthetic Rainfall Development

In the Weeks before the PMP Double-Peak Storm Event for the Catchment Directly Upstream of Luang Prabang

**Results**

The application of this preceding rainfall and the PMP storm as input data for the hydrological model of the Mekong basin (described in Section 5.2.8.2) yielded the PMF discharge simulation for Luang Prabang HPP shown in Figure 5-21, with a discharge peak of 41,400 m³/s.
Due to the temporal development of the preceding rain, as suggested by the U.S. Weather Bureau, with slightly decreasing precipitation in September, before the double-peak PMP storm, simulated Mekong discharge also slightly drops in September, from its highest value in the end of August.

However, the discharge directly before the first extreme storm is considered sufficiently high: for Chiang Saen, the value on the day before the start of the double-peak storm is 12,560 m³/s. This value is significantly higher than the highest ever recorded discharges before observed flood events at Chiang Saen, of 9,600 m³/s (in 1971), 8,900 m³/s (in 1970), and 8,200 m³/s (in 1966), and is therefore considered sufficiently conservative for a PMF estimation.

![Figure 5-21: PMF Simulation for Luang Prabang HEPP](attachment:image)

5.2.10 Impact of Lancang Cascade

To estimate the future inflow to Luang Prabang HPP the operation of the Lancang Cascade has to be taken into account; therefore the model output for the period 1960-2018 cannot be used directly as the inflow time series. For this reason a model run was done from 1951 to 2018 assuming that the hydropower plants at the Lancang Cascade were operating during the whole period which leads to the best estimation of the future inflow at Luang Prabang HPP.

Figure 5-22 shows the coefficients for the relative flow change at Chiang Saen on a monthly basis due to the impact of the Lancang hydropower plants, and compares the results of the current simulations with values developed by the MRC (2005\(^3\)). The current estimates show an increase of inflow for the dry season months of February to May that is even higher than anticipated by MRC.

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\(^3\) The MRC Basin Development Plan, BDP Library Volume 7 September 2005, MRC Decision Support Framework (DSF) and BDP applications; Mekong River Commission

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Figure 5-22: Comparison of the Relative Discharge Change at Chiang Saen

The impact of the Lancang Cascade on the Luang Prabang HPP inflow is shown in Figure 5-23. The blue graph shows the duration curve for the natural inflow of the period 1960 to 1990 (this period has been selected to have undisturbed flow conditions), and the green graph shows the results of the hydrological model taking into account the Lancang Cascade for the same time period. The flood peaks are slightly lower, while the dry season flows are significant higher than the natural inflow and well above 1,100 m$^3$/s.

The orange graph shows the transformation of the inflow series using the MRC Factors. This graph is somehow between the natural inflow and the simulated inflow series.

Figure 5-23: Impact of the Lancang Cascade

On the Flow Duration Curve at Luang Prabang HPP site
5.2.11 Impacts to the Tonle Sap Great Lake System

The natural Tonle Sap river system has created the great Tonle Sap lake, which is mainly fed by the Mekong due to an interesting natural phenomenon. From October to May water flows from the Tonle Sap into the Mekong. During the wet season however the Mekong increases that much, that its water table is higher than the one from its tributary coming from the great lake. Therefore, the flow direction changes and the Tonle Sap lake is fed by the Mekong during the wet season. This phenomenon creates a floodplain that extends over 15,000 km$^2$ and stores up to 76.1 km$^3$ of Mekongs annual flood-pulse [12] (Kummu et al. 2014). Overall 53.3% of the water entering the Tonle Sap lake comes from the Mekong, 34% comes from 11 river tributaries and 12.5% directly from rainfall [12] (Kummu et al. 2014).

The impact of hydropower plants to the Tonle Sap system was investigated in different studies. The study “Dams on Mekong tributaries as significant contributors of hydrological alterations to the Tonle Sap floodplain in Cambodia” [13] (Arias et al. 2014) describes estimated impacts to this system caused by dams in this area. It identifies the proposed 42 dams in the Sesan, Srepok and Sekong (3S) rivers (see Figure 5-24) as most critical projects causing a major impact to the flow pattern of the Tonle Sap system.
Figure 5-24: Map of lower Mekong River Basin.
Floodplains and dams (black dots are HPP in operation and under construction) and 3S development scenario (purple triangles). The green triangle shows a water level gauge station at the great lake [13] (M.E. Arias et al. 2014).

The 3S system contributes nearly a quarter of the total Mekong discharge in this area. The paper concludes that the 3S scenario could independently increase the great lakes 30-day minimum water level by 30±5 cm and decrease annual water level fall rates by 0.30±0.05 cm/day [13] (Arias et al. 2014).

All the storage power plants in the Mekong and its tributaries upstream of the Tonle Sap system will contribute their impact to the great lake. The Luang Prabang HPP however is not a storage power plant and will not change the hydrograph, nor the flow pattern of the Mekong. Therefore it will not cause any additional impact to the Tonle Sap system.
5.2.12 Hydrological Impact of the Luang Prabang HPP - Conclusion

The Luang Prabang HPP is a run-of-river hydropower plant (ROR). Its inflow is equal to its outflow and no storage is used. However, to increase the potential energy the dam increases the water level of the upstream area, creating a reservoir with a surface area of around 49 km², reaching back to the planned Pak Beng HPP. The increase of the water depth increases the surface of the submerged area, leading to decreased velocities. This causes local impacts (reduced sediment transport and slightly different habitat conditions for aquatic life), which are discussed in the ESIA.

The lengths of the backwater will affect the downstream water level at the HPP Pak Beng. Effects of ROR plants to their upstream and downstream hydrographs are marginal since they do not store water. Only during the start phase a storage takes place while the reservoir is being impounded to reach the FSL (15 to 20 days). Afterwards the operation maintains the water level at FSL with minor changes in elevation of approximately 1 m for minor floods, up to an increase of 2.2 m for the PMF. An impact to the flow pattern of the river such as shown in Figure 5-15 only occurs with storage plants as they change the flow pattern of the river.

5.3 Water Quality

If a hydropower plant in a cascade causes poor water quality the probability that the reservoir of the downstream HPP is affected is very high. Only in case the river stretch in between is long and turbulent a proper self-purification might take place. To ensure good water quality it is mandatory to do a proper biomass- and waste clearing of submerged areas. However, since the cascade is a cascade of ROR plant the residence time of the water is rather short (range of approx. 3 to 9 days), the whole water volume will be exchanged due to the permanent operation of the turbine and the frequent operation of the low level outlets. Therefore, no dead zone (zone below minimum operation level in a storage power plant) occurs, and this also excludes the formation of a deep water zone with deteriorating water quality.

A proper cleaning of biomass and waste in the reservoir area before impoundment is mandatory to ensure the water quality can be maintained. Once this is considered there will be no additional significant impact to water quality during normal HPP operation.
5.4 Sediment Transport

Estimation of sediment transport rates and conditions in large rivers is a complex process. A wide range of data collection is necessary both in terms of physical/granulometric parameters and temporal patterns. Erosion and deposition has to be analysed within the river and at its floodplains. In case of Mekong River all this has to be assessed over a huge longitudinal extent from the river’s source in China to its delta into the East Sea of Vietnam in Vietnam.

It is clear that impacts on Mekong’s sediment regime may be of international importance as retention of sediments can cause river bed degradation or even incision on further downstream sections. Besides that, of course the impact of hydropower dams onto their own backwater section is crucial in terms of ecological and economic sustainability of such a project and so it is also for Luang Prabang HPP.

Basic information of sediment transport within the planned Luang Prabang reservoir shall be mainly extracted from existing studies. A sediment monitoring program will be started at the beginning of the operation phase.

5.4.1 General Terms and Definitions

In general sediment transport process types are classified as follows:

- **Washload:** very fine particles (typically clay and silt) that never settle down in a channel
- **Uniform suspended load:** rather fine particles that are uniformly distributed over the vertical water column due to the flow turbulence
- **Graded suspended load:** Coarser particles that are transported within the water column but with a gradation in vertical direction
- **Bedload:** Coarse material that is transported typically via rolling, sliding or saltating in continuous or intermittent contact with the riverbed

Technical names of certain particle sizes according to the classification of the American Geophysical Union are given in Table 5-7.
5.4.2 Findings from Literature Concerning Sediment Transport within the Mekong

In the past some sound studies upon sediment transport of Mekong River have been carried out from different organisations and experts. For Luang Prabang HPP the main characteristics and load estimations regarding Mekong’s sediment transport shall be taken from these publications. A summary of relevant information and the main conclusions of each study is presented in the annex A) to J). The most important findings of these studies are presented as follows:

Due to the high trapping efficiency and a very large storage volume of at least some of the Chinese reservoirs within the Lancang Cascade can reasonably be assumed that sediment inputs from upstream the Chinese border are extremely reduced and this situation
will last for a very long time (estimations indicate time spans of several hundred years) (SEG, 2011).

The reduction of sediment load caused by the Lancang Cascade depends on the distance in downstream direction. For example at Gaiju (China), which is located only 15 km downstream of Manwan, the first dam who was taken into operation within the cascade, and also at Chiang Saen, which is approx. 800 km downstream of Manwan, a significant downward bend in the curve of cumulated annual sediment loads appears more or less immediately after commissioning of Manwan Reservoir in 1993. At Luang Prabang, approx. another 360 km further downstream and draining a substantial larger catchment (approx. +50% against Chiang Saen) this downward bend in the curve of cumulated annual sediment load was recognized not before 1997 (CNR, 2013c).

While in former studies the total sediment load of Mekong River was mostly estimated to a value of about 160 Mt/y, recent investigations indicate lower values of approx. 72 Mt/y (Koehnken, 2014). However, more conservative estimations in respect to Luang Prabang HPP still expect a range of 90-120 Mt/y for the foreseen future (Liu et al, 2012).

A reason for some inconsistency in the estimations of sediment loads may be the high proportions of sand size materials, leading to over- or underestimation of the total load through measurements of suspended sediments, because sand is transported via different mechanisms in different river sections (as bedload or suspended) (IKMP & WWF, 2014).

Another important aspect is that sediment load analysis based on TSS measurements are reliable only to a limited degree, firstly because of some weaknesses in the sampling technique and secondly because of the high proportion of sand in the transported sediment. But also SSC-measurement based analysis are expected to have uncertainties in the range of 20-30% (ICEM, 2010).

Based on the various literature findings (e.g. SEG, 2011; IKMP & WWF, 2014) the proportions of the total sediment loads according to the main source regions are roughly as follows:

- prior Manwan 45% (up to 55%) originate from China / actual 16%
- prior Manwan 5% originate from Chinese border to Laotian-Thai border near Pak Chom (mainly from Wang Chao Fault Zone)
- prior Manwan 50% originate from rest of the catchment (mainly from Central Highlands and Khorat Plateau)

The estimated sediment loads for project relevant locations are as follows (values based on Liu et al, 2012; Koehnken, 2014 and ICEM, 2010):

- Chiang Saen: prior Manwan 90.8 Mt/y / actual 10.8 Mt/y (suspended)
- Luang Prabang: prior Manwan 107.7 Mt/y / actual 22.3 Mt/y (suspended)
- The bedload estimate for Chiang Saen based on measurements is 1.6 Mt/y
- Mean annual sediment load of Nam Ou: approx. 6.2 Mt/y

From the above values the suspended sediment load for the Luang Prabang HPP dam site can be estimated to be in the range of roughly 15 to 100 Mt/y. While the greater value stands for a historical value, responsible for the period before the construction of the Lancang Cascade, the lower value reflects quite recent but rather short term measurements. In terms of safe and conservative design and in respect to known uncertainties in
field data a range of 20-24 Mt/y for the total sediment load (washload, suspended and bedload) is proposed for the dam site.

Based on the findings of Koehnken (2014) a rough estimation on the grain-size distribution for the dam site is:

- approx. 80% sand (mostly fine sand with up to 25% of medium sand)
- approx. 20% silt

The reduction of bedload as expected consequence of the Lancang Cascade is probably delayed, due to compensation through existing in-channel storages (CNR, 2013c).

5.4.3 Trend Analyses

A trend analysis of sediment concentrations at Chiang Saen has been carried out. The analysis is based on monthly suspended sediment loads from 1962 to 2012 (with major gaps and inconsistencies) and monthly flow rates from 1962 to 2014, both provided by the Thai Department of Water Resources (the trend analysis of the sediment data for Chiang Saen can be found in Volume 6.1 - Annex Hydrology, Section 4 – Trend analyses sediment concentrations Chiang Saen).

The data has been converted to mean sediment concentrations and plotted against time. For the period between 1976 and 1992 no sediment data was available. The period is divided into pre-dam and pro-dam periods, reflecting the development of the Lancang Cascade starting from 1993 with the Manwan Dam. Figure 5.25 shows the trend analysis for the 12 months of the year.
Figure 5-25: Trend Analysis of Suspended Sediment Concentration

For Calendar Months for Pre-dam (Pre-Manwan) and Post-dam (Pos-Manwan) periods
5.4.4 Sediment Concentration

According to the report on Discharge and Sediment Monitoring Project (DSMP) (The Mekong River Commission (MRC), 2011), comparison between the Total Suspended Solids (TSS) concentrations and the average daily flow at Chiang Saen, Chiang Khan and Luang Prabang monitoring stations are as shown in Figure 5-27.

Figure 5-27: Total Suspended Solid (TSS)
Concentrations and Average Daily Flow at 3 selected Monitoring Stations

Source: MRC, 2011 (The Mekong River Commission (MRC), 2011)
The TSS concentration shows the same patterns of variation as the flow, the higher concentrations being associated with higher flows. Maximum TSS value is related to the first or second flood peak of the wet season and decreases through the dry season.

**Sediment Load at Luang Prabang HPP**

The French consultant Compagnie Nationale du Rhône (CNR) calculated an inflow of suspended sediment into the Luang Prabang HPP of 105 Mt/year with possible year to year variations of 50-135 Mt/year similar to the Xayaburi reservoir (Compagnie Nationale du Rhône (CNR), 2013). The assessment of Mekong River annual sediment load is presented in Figure 5-28.

*Figure 5-28: Longitudinal Evolution of Mekong River annual sediment load*

Adapted from (Compagnie Nationale du Rhône (CNR), 2013).

The Nam Ou in its natural state used to bring large amounts of sediments, it is however not known to what extent this has been reduced by the implementation of the Nam Ou and Nam Khan cascade. Wash load, although being the biggest part of the sediments load, will barely be deposited in the reservoir since it can be assumed that the flow velocity will be high enough to keep the sediments in suspension.

**Conclusion and Findings Concerning Sediment Transport**

The backwater section of Luang Prabang HPP is a quite straight channel, deeply cut in bedrock of a narrow valley. The river width is between 50-100 m for low flow conditions and 200-300 m during wet season conditions. The channel slope is between 0.25-0.30 m/km (CNR, 2013b).

Sediment deposits consist mainly of sand size fractions characterized by $d_{50}$ in the range of approx. 0.25-0.45 mm. They are accumulated around emerged rocky outcrops or on depressions along the banks. Some sediment supply through tributaries is given by the rivers Nam Tha and Nam Beng. However, larger sediment inputs are not delivered until
tributaries located already downstream of the planned dam site, like especially through Nam Ou River. Currently deposition of sediments is more likely downstream the project area, as there follows a section with lowered river slope (CNR, 2013b).

Turbidity (density) currents are defined as currents moving by gravity, because of their higher specific density in relation to the density of pure water. Turbidity currents are known to develop in large reservoirs, where the water velocity is extremely low and forces due to differences in the density of water layers (due to sediments concentration as well as differences in temperature, etc.) become dominant.

As a run-of-river plant Luang Prabang has no storage reservoir and no big head. The velocity near the dam ranges between 0.05 m/s with river flow of 1,000 m$^3$/s to 0.2 m/s with average river flow (about 4,000 m$^3$/s) to 0.5 m/s with river flow of 10,000 m$^3$/s, being generally higher further upstream along the reservoir. The velocities in the reservoir are sufficient to prevent the development of significant turbidity currents. For average turbine flow (about 3,000 m$^3$/s) flow velocities are presented in Figure 5-29. For the total rated discharge through the powerhouse (about 5,000 m$^3$/s) the flow velocities are presented in Figure 5-30.

![Figure 5-29: Flow velocities towards the powerhouse for Q=3,000 m$^3$/s](image)
Additionally, occurrences of turbidity currents are not probable due to the rather low water depth in the reservoir and the very fine suspended sediments. Non-stratified flows during floods are expected with comparatively higher sediment concentrations at the bottom and lower concentrated water towards the surface.

A spillway arrangement with low level outlets (in addition to conventional surface spillways) and an approach channel connected to the river thalweg guiding the sediment laden flows to the low level outlets is foreseen. The low level outlets for sediment flushes are opened prior the spillway gates once the inflow is higher than the turbine flow. Such a transparent arrangement shall allow an adaptive approach for the global sediment management to be provided during operation. Accordingly, the sedimentation in the backwater area can be minimized. As shown in Figure 5-27 the TSS concentration (which is correlating with the sediment concentration) is related to the flow. With the start of the wet season when the flow increases, sediment loads do so too.

This is when the low level gates are opened. At further flow increase the spillway gates will open (meanwhile low level gates are fully opened) and flush additional sediments out.

During operation strict operation rules shall be enforced. They shall consider a sediment management plan to avoid sediment accumulation and/or high artificial sediment concentration downstream of the dam.

However due to the fact that the barrage will increase the water table upstream and reduce the flow velocity some sediment will accumulate in some parts of the reservoir until a new equilibrium is reached. Once the accumulated sediments have decreased the flowed area, the velocity will increase again (hydraulic law of continuity equation, see annex K) and more sediments will stay in suspension, being transported downstream eventually.
5.5  Fish and Fisheries

5.5.1  Importance of Local Fisheries

In 2013 MRC published the study “An introduction to the fisheries of Lao PRD” (Kent F. Hortle et al, MRC, 2013 [6]). The study provides good information concerning fishery:

- In Lao PDR, fisheries are an integral part of the lives of rural people, providing a major part of their animal protein intakes.
- The estimated consumption of inland fish is approximately 168,000 tons per year, while consumption of other aquatic animals is estimate at 40,600 tons per year.
- The estimated yields are conservatively valued at almost USD 150 million per year.
- The estimated fish consumption of inland fish per capita is 24.5 kg/year while the one for other aquatic animals account for about 4.1 kg/year and capita.
- The production of fish in the Mekong River and tributaries is assumed to be 70 kg/ha/year.
- More than 481 fish species have been identified in Lao PDR.

Considering the data from MRC one can estimate that with a surface area of 4,900 ha, the area affected by the backwater of the HPP Luang Prabang produces around 343 tons of fish per year. With this amount the yearly fish consumption of 14,000 Lao people can be covered (24.5 kg/capita and year). This is equal to 25% of the population of Luang Prabang town.

Those few figures show the substantial production of fish in the Mekong and its tributaries and it underlines the strong reliance of Lao people on fishery. The Luang Prabang HPP acts like a barrier in the river if no additional facilities are installed to ensure fish migration. This impact would most probably degrade the population of the fishes rapidly since they would be trapped between HPP Xayaburi and Luang Prabang HPP, as well as between the latter and HPP Pak Beng. Another important point is the fact that constructing LP HPP (or any of the other dams planned on this part of the Mekong) without fish passing facilities would make the great effort made in Xayaburi dam for enabling fishes to pass redundant, since any longer-range migration would then be definitely blocked.

To ensure that the fishes can migrate through the hydropower plant related facilities for up- and downstream migration () have to be installed. These facilities will be designed in consideration of the experience gained at Xayaburi HPP and following the MRC guidelines. Fish migration monitoring is being performed and species, biomass and migration pattern are being identified (ongoing during operation phase).

5.5.2  Fish Species Identified in the Zone from Chiang Saen to Vientiane

Within the Mekong system it is commonly distinguished between three different types of fish species groups (Welcomme 1985 [1] and Chanh et al. 2001 [2]). The species are classified into black-fishes, white-fishes and grey-fishes.

Black-fishes are species that spend most of their life in lakes and swamps on the flood-plains adjacent to river channels and venture into flooded areas during the flood season. They are physiologically adapted to withstand adverse environmental conditions, such as
low oxygen levels, which enable them to stay in swamps and small floodplain lakes during the dry season. They are normally referred to as non-migratory, although they perform short seasonal movements between permanent and seasonal water bodies. Examples of black-fish species in the Mekong are the climbing perch (*Anabas testudineus*), the clarias catfishes (e.g. *Clarias batrachus*) and the striped snakehead (*Channa striata*), (MRC tech. paper No.8, 2002 [3]).

White-fishes, on the contrary, are fishes that do long distance migration. They depend on habitats within river channels for the main part of the year. In the Mekong, most white-fish species venture into flooded areas during the monsoon season, returning to their river habitats at the end of the flood season. Important representatives of this group are some of the cyprinids, such as *Cyclocheilichthys enoplos* and *Cirrhinus microlepis*, as well as the river catfishes of the family Pangasiidae (MRC tech. paper No.8, 2002 [3]).

Grey-fishes are an intermediate between black-fishes and white-fishes. Species of this group undertake only short migrations between floodplains and adjacent rivers and/or between permanent and seasonal water bodies within the floodplain (Chanh et al. 2001 [2]; Welcomme 2001 [4]).

The zone of Mekong River from Chiang Saen to Vientiane (ca. 800 km), consists of a changing pattern of rocky outcrops, rapids, deep pools, shoals, ripples and sandbars creating a wide variety of aquatic habitats. There is a major area of deep pools around the confluence with Nam Ou. Four other localities where deep pools are found are near Chiang Kong/Houay Xai, in Xayaburi and at Chiang Khan (Halls and Kshatriya, 2009).

According to MRC 140 fish species in 30 families are represented in this area (MRC, 2010; SEA of Hydropower on the Mekong mainstream).

In previous studies, 160 species were found in the study area; 56 species caught during the fish sampling of EIA of Xayaburi HPP, 2010; 43 species caught during the fish sampling of EIA of Pak Beng HPP, 2013; 120 species caught during the fish sampling of the fish passing study for Xayaburi HPP, 2013; and 59 species caught during the fish sampling of aquatic ecology monitor program for Xayaburi HPP, 2018. For more details, it is referred to the ESIA for Luang Prabang HPP (Pöyry, 2019).

### 5.5.3 Fish Migration Pattern in the Upper Mekong Migration System

MRC reports that the so called upper Mekong migration system (MRC Tech. paper No. 8 [3]) reaches from approximately the mouth of Loei river up the border between Lao PDR and China. This section of the river (see Figure 5-31) is characterised by its relative lack of floodplains and major tributaries (although there are some floodplains associated with tributaries in the far north, i.e. the Nam Ing River, in Thailand). It is dominated by upstream migrations at the onset of the flood season, from dry season refuge habitats in the main river to spawning habitats further upstream.

The upper migration system appears to be relatively isolated, with little exchange to the further downstream migration systems.

Within rivers, deep areas are particularly important as dry season refuges. These areas are most often referred to as deep pools. The importance of these deep pools has been documented by the MRC fisheries programme (Poulsen et al., 2002 [5]) and is presented in Figure 5-31).

It seems that the stretch from Thakek to the mouth of Loei river is a functional barrier due to the lack of such deep pools. But the area from the confluence of Loei river up to the
border to China, which is this upper Mekong migration system, is exactly the area in which 4 additional run-of-river plants are planned beside the existing Xayaburi HPP.

Considering the barrier effect of the Luang Prabang HPP, the white species (long distance migratory species) are particularly vulnerable. Their vulnerability increases when it comes to a cascade of hydropower plants because they depend on many different habitats, are widely distributed and require migration corridors between different habitats. In a cascade of HPPs where each dam has a backwater effect to the next upstream dam the habitats do not differ much anymore and the white fishes have to overcome very long distances to find variety in habitats.

With the possible cascade of run-of-river plants comprising of Pak Beng, Luang Prabang, Xayaburi, Pak Lay and Sanakham a major part of the area identified as upper Mekong migration system will have a change in its hydraulic conditions. The cascade will provide more deep water areas, but the rapids will be lost. According to MRC (MRC Tech. paper No. 8 [3]) fishes mainly migrate into areas further upstream of Pak Beng for spawning.

Only little is known about the spawning habitat requirements for most Mekong fishes. Generally spawning habitats are believed to be associated with rapids, pools and floodplains. In its natural stage this area has not many floodplains, but rapids and some deep pools. The loss of deep pools might be compensated by creation of the reservoir which will provide more and larger deep areas.

![Fish migration pattern](image)

**Figure 5-31: Fish migration pattern**

LEFT: Number of species reported using deep pools in mainstream Mekong RIGHT: Fish migration in the study area (Poulsen et al, 2002 [5]). The red ovals show approximately the reservoir of Luang Prabang HPP.
Recommended mitigation measures

- State of the art fish up- and downstream migration facilities have to be installed in each of the hydropower plants in the cascade.
- Stretches with alternating rapids and deep pools upstream of Pak Beng should be protected to ensure future existence of spawning areas.
- A fish monitoring program will have to be implemented, and mitigative measures will have to be taken if required. The annual flood pattern triggers fish migrations and causes inundation of floodplains.

5.5.4 Fish Migration Facilities

5.5.4.1 General

Dams and barrages create a direct barrier for upstream and downstream migration of fish. Fish moving downstream can either pass over the spillway or will be drawn into the power intakes and consequently through the turbines; both can cause high mortality.

MRC Guidance (Mekong River Commission, 2009) were in general used where applicable. Pre-project monitoring at relevant locations are required to further assess the baseline conditions within the project area. For the time being database from MRC and Xayaburi HEPP were taken.

5.5.4.2 Design Criteria

The most relevant criteria to be used for the design of the fish migration facilities are as follows:

- Fish passage facilities for both, upstream and downstream migration should be incorporated.
- The Navigation Lock could also be used as additional fish passage during migration periods.
- The fish migration facilities shall operate the whole year, optimally between the lowest flow and the 1-year flood.
- Design of the upstream and downstream fish passage for fish between 5 cm and 300 cm, as well as downstream drifting eggs and larvae during wet season.
- Fish migration system shall use a minimum of 10% of low flow (Q_{95}) and 1% of the 1-year flood; two aspects should be incorporated into the design, attraction (locating the entrances for fish approaching the entrances) and passage (through the fishways).
- Maximum water velocity for short distances (< 0.2 m) is 1.4 m/s, maximum velocity in channels is 0.5 m/s.
- Minimum depth is 3.0 m under all flows.
- Use of fish friendly turbines.

To achieve effective attraction, the fish passage design was integrated into the earliest project concepts, as it influences the dam and powerhouse concept and alignment, abutment and training wall shapes, spillway and gate design, and stilling basin design.
Table 5-8 provides the relevant discharges in the Mekong River and tailwater levels which are relevant for the design of the fish migration facilities:

Table 5-8: Relevant Tailwater Levels for the Fish Migration Facilities

<table>
<thead>
<tr>
<th>Description</th>
<th>Discharge (m³/s)</th>
<th>Tailwater Level (m asl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Flow</td>
<td>1,170</td>
<td>276.70</td>
</tr>
<tr>
<td>1-year flood</td>
<td>10,650</td>
<td>287.43</td>
</tr>
</tbody>
</table>

5.5.4.3 Fish Migration Concept

The fish migration concept applied for the Luang Prabang HPP is widely based on the concept developed for the Xayaburi HPP, which was commissioned in May 2019. The first indications, however, are positive, as during the commissioning of the attraction flow system fish were already observed in the upstream fish migration system, which clearly shows that the fish are attracted by the attraction flows, they can find the various entrances into the system, and they remain in the system and find the fish lock where they are lifted up into the headwater. However, further and continuous monitoring of the system is required to gain information and better knowledge of the number and species using the system, and to continuously optimize it. The fish migration concept provides the following upstream and downstream migration possibilities as shown in Figure 5-32.

Figure 5-32: Overview of the Foreseen Fish Migration Facilities

During dry season (spillway not in operation), upstream migrating fish will be attracted by the powerhouse discharge and will enter into the upstream fish passing facilities developed over the entire length of the powerhouse, with entrances at the right pier (towards 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 fish locks, where the fish are lifted up into the headwater of the reservoir.

When both the powerhouse and the spillway are in operation during wet season, fish migrating upstream will be also attracted into the spillway discharge channel. Spill patterns inside the stilling basin will create a hydraulic barrier forcing the fishes to the side edges. A supplementary fish entrance on the left side of the spillway at the right pier is providing a pathway for upstream migratory fishes guiding them to the fish passing facilities at the downstream side of the powerhouse.

Fish passing through an additional upstream fish migration system at the right bank shall be considered as a supportive means for attracting and passing fish at the right bank of the project during operation of the spillway for upstream migration.

The main downstream fish migration system provides entrances along the entire upstream face of the powerhouse and a collecting gallery, where the fish are guided to the right pier and released down to the tailwater through the terminal chute. Downstream migration is also possible through the spillway (when in operation) and for smaller fish (smaller than the trash rack clear spacing) through the turbines of the powerhouse. The powerhouse is equipped with fish friendly turbines in order to reduce fish mortality during turbine passage.

5.5.4.4 Upstream Fish Passing Facilities

The main upstream fish passage facilities is incorporated in the powerhouse and comprise the following components:

- Entrances above the turbine draft tubes and on the left and right side of the powerhouse.
- A fish collecting gallery across the downstream side of the powerhouse connecting all entrances.
- Two large fish locks including fish crowder and movable screen floor on the left bank pier.
- A feeding pond at the right pier inclusive feeding system, with feeders along the collecting gallery and at the back of the fish locks, to create fish attraction currents throughout the collecting gallery and through the various entrances of the facility.
- A fish monitoring station

Entrances and fish collecting galleries

Fish migrating upstream attracted by the flow through the powerhouse can enter the upstream fish migration facility via one of the 2 x 7 entrances (2 m wide and 3 m high, sill at 273.5 m asl and 278.5 m asl), located at different levels above the turbine draft tubes along the entire length of the powerhouse, and additionally via the two openings of the right side entrance (b: 2 m x h: 7 m ; sill at 272.5 m asl and 279.5 m asl) or via the three openings of the left side entrance (b: 6 m x h: 7 m (2x) and b: 6 m x h: 3 m (1x); sill at 272.5 m asl and 279.5 m asl). During the wet season, fish can also use the two openings of the spillway entrance (b: 2 m x h: 7 m ; sill 279.5 m asl), as well as on the spillway tailrace side.
After entry into this system, fish heading up to the upstream area are successively passing through the collecting gallery and one of the two fish locks and are released into the headwater. The general arrangement of the upstream fish passage facilities are shown in Figure 5-33.

![General Arrangement of the Upstream Fish Migration Facilities](image)

**Figure 5-33:** General Arrangement of the Upstream Fish Migration Facilities

The flow pattern in the collecting gallery and in the tailrace channel (together with the main turbine outflow) will be checked during the next project stage (Tender Design) with a 3D-CFD modelling, and the position of the entrances, feeders of feeding galleries and geometry of flow passing structure be confirmed or modified/optimized, if need be.

The position of the spillway entrance will be adapted/optimized also during the next project stage depending on the spill patterns inside the stilling basin (in accordance with results of physical model test of the spillway), for the flows prevailing during the operation range of this entrance (wet season).

**Fish Locks**

Two parallel fish locks connect the fish pass to the headwater. Operation of a fish lock is very similar to the navigation lock. The operation cycle of the locks includes an attraction phase and a transfer phase. Both locks will operate alternately to maintain a continuous fish migration pathway.

During the attraction phase, flow is provided from the auxiliary powerhouse at the back of one of the fish lock chamber, to attract fish into approach channel and into the lock chamber itself. Each lock is provided with a fish crowder in its approach channel. The fish crowder will act as a trap during the fish attraction phase, forming an inscale with its two leaves. The two leaves of the inscale will close at the end of the attraction period and the fish crowder will force the fish to enter into the lock chamber. The transfer phase will
continue by closing the fish lock entrance gate and slowly filling the lock. A movable screen floor in the lock chamber will force the fish to move up with the raising water level. Once the water level in the lock chamber is equalized with the reservoir level, an exit gate will be open to release the fish into the headwater of the reservoir.
Feeding System

The feeding system provides fish attraction currents throughout the collecting gallery and through the various entrances of the facility, to guide the fish from the river to the fish locks.

The water for the feeding system operation is provided by the auxiliary units during the dry season (TWL < 283 m asl). Additional water is supplemented by a gravity water supply gallery during the wet season (TWL > 283 m asl). This water is collected in the feeding pond, in the right pier, and is sourced from the following:

- The water from the downstream migration, provided via two auxiliary units, between 80 and 120 m$^3$/s,
- Water from the third auxiliary unit taken from the headwater, 60 m$^3$/s,
- Via the gravity water supply (bypass) system from the headwater, up to 45 m$^3$/s.

From the right pier feeding pond a total of four feeding galleries provide the water for the attraction flow at the collection galleries and the various entrances:

- The feeding galleries 1 and 2 feed the right and the left part of the powerhouse fish collection galleries.
- Feeding gallery 3 feeds the entrances at the left pier.
- Feeding gallery 4 supplies the feeders located at the back of the two fish locks.

Hydraulic Design

The flow required for the operation of the upstream fish passage facility (attraction flow) varies with the tailwater level and ranges approx. from 80 to 180 m$^3$/s. The required flow depending on the TWL and corresponding water level in the feeding pond (due to the head losses in the feeding galleries) are given in the following Figure 5-34.

![Figure 5-34: Attraction Flow for Upstream Migration](image-url)
The flow velocities through upstream collection gallery entrances ranges from 1.0 m/s on the left side of the powerhouse to 0.85 m/s on the right side of the powerhouse. The velocity in the fish collecting gallery ranges from 0.2 m/s to 0.5 m/s, and depend on the tailwater level and the location in the gallery.

**Fish monitoring station**

For the upstream fish migration system a fish monitoring station is foreseen at the fish lock exit. For the time being a hydro-acoustic fish survey system is foreseen. However, the exact type and technology for the fish survey will be decided at a later stage in order to install a modern and state-of-the-art technology.

### 5.5.4.5 Right Bank Fish Passing Facility (Upstream Migration)

Fishes migrating upstream generally are guided by the current, preferentially keeping near the banks of the river. During the wet season when the spillway is in operation, fish will get attracted by the spillway discharge. For fishes at the right river bank, a possibility for upstream migration will provided near the Navigation Lock.

Thus, facilities for upstream migration are foreseen at the Navigation Lock comprising the following components:

- A Fish Lock downstream of the stilling basin next to the Navigation Lock.
- A culvert crossing the downstream approach channel, providing sufficient clearance for the moving ships and vessels at the downstream approach channel.
- An open channel at the right bank leading to the upstream approach channel.

The fish entering the fish lock will be lifted up to the headwater level, and will be released into the u/s culvert and channel leading to the upstream approach channel of the Navigation Lock. The flow in the approach channel of about 5 m$^3$/s will be used as attraction flow at the entrance of the fish lock.

When only the powerhouse is in operation (no spillway operation), the fishes will be attracted by the powerhouse discharge at the tailrace channel, and passage at the right bank will not be required.

An additional entrance inside the approach channel of the Navigation Lock connected to the Fish Lock which provides an additional upstream migration possibility. This entrance will be in operation during the main fish migration period (April, May).

The position of the right bank passage facility will be adapted/optimized during the next project stage (Tender Design).

### 5.5.4.6 Downstream Fish Passing Facilities

The downstream fish passage facility of the powerhouse comprises a collecting gallery above the powerhouse intakes and a downstream stepped chute (exit chute) to the tailrace channel.

Additionally fish-friendly turbine technologies are implemented to mitigate lethal injuries during turbine passage for smaller fish that will pass through the trash rack of the powerhouse intakes.

Finally, downstream migration through the spillway may occur as well when spillway is opened for spillage flows.
Figure 5-35 shows the general arrangement of the downstream migration system at the Powerhouse.

**Figure 5-35: Downstream Migration System**

### 5.5.4.7 Main downstream migration facilities

Downstream migrating fishes are to be collected at a fish collecting gallery at the upstream side of the powerhouse leading to the right pier. The 14 entrances to this gallery (2.5 m wide and 3.0 m high, sill at 302.0 m asl) are located above the inlet structures, and are provided over the entire length of the powerhouse. At the right pier a downstream chute will guide the fish into the tailwater area.

The total flow through the downstream migration facility ranges from 100 to 140 m$^3$/s and the corresponding velocity through the entrances of the collecting gallery ranges from 1.0 m/s to 1.4 m/s.

A constant discharge of about 20 m$^3$/s is used for the continuous operation of the downstream chute. The exceeding water (80 to 120 m$^3$/s) will be diverted and used for attraction flow for the upstream migration system (released through two auxiliary units into the right pier feeding pond). The downstream migration facilities need to operate during the entire year.

The flow pattern in this collecting gallery and at the flow splitting structure (to the two auxiliary units) will be checked during the Detailed Design stage with a 3D-CFD modelling. If required, the geometry of the intakes of the auxiliary units as well as the geometry of the fish exclusion screen (angle bar rack) to be installed at the intake are will be adapted.

The exit chute has been designed to minimize energy levels in the pools ($< -500 \text{ W/m}^3$) while ensuring a sufficient hydraulic profile at each weir between the pools (about

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2 m x 2 m), and for maximum head drop of 3 m from pool to pool. The flow in the exit chute is controlled by a combination of a flap and a sluice gate. A physical model test will be carried out to confirm the proposed geometry.

5.5.4.8 Fish Friendly Turbines

The main turbines for the Luang Prabang HPP will be provided with several fish-friendly features, which are directly related to mitigate lethal injuries at fishes passing the turbines downstream, such as:

- Reduction of the runner blades by turbine and reduction of rotational speed of the turbine in order to mitigate turbine induced mortality by blade strikes, one of the most relevant causes of mortality during turbine passage.
- A fish friendly guide vane design can further minimize turbulence and shear stress regions, thus improving the fish survival rate.
- High precision in manufacturing the periphery turbine components allows to reduce gaps and thus reduce water flowing through the gaps leading the subsequent turbulences.
- Fish friendly Kaplan turbines have oil free hubs compared. The servomotor is located inside the runner hub with the surrounding space filled with water and additives for corrosion protection. Such a design is a major positive impact on the water quality and thus on the environment compared to the conventional design.

5.5.5 Conclusion and Findings Concerning Fish Migration and Fisheries

The fish migration facilities are state of the art and therefore provide many options for migration from different start points up- and downstream of the HPP. However, it has to be expected that even with the best available technology some of the fishes will not use the migration system. So far, there is only limited information available on the migrating patterns and abilities of the around 160 species of fish known to live in this part of the Mekong. A first fish passing system as described here was installed at Xayaburi. There, monitoring has started, and it will be intensified once the entire migration system is operating. A similar monitoring program will also be carried out at LP HPP. It will be important to consider the data of this monitoring to quantify the effect of the Mekong ROR plant. Since the Luang Prabang HPP will use the same technology as the HPP Xayaburi (except for the fish ladder) the impact is estimated to be quite similar.

There are two very important facts which have to be considered and mitigated:

(1) Diversity of fish species and size of fish population
(2) Animal protein intake of local people

With the cascade of ROR plants (Pak Beng to Pak Lay in place, the variety of flow conditions and habitats within that part of the Mekong is mostly lost. The effect to the fishes is not completely clear. However, if spawning areas are lost this will have a major effect to the fish population. A fish monitoring program will have to be implemented, and mitigative measures will have to be taken if required. Besides, the spawning areas in the tributaries have to be identified and should be protected. Both measures should ensure the stock of fish species can be maintained.

The amount of fishes and the diversity of fish species is not only endangered by hydropower, but also by the growing population who often relies on fish as their main protein for PNPCA Only
source. Since 1985 Lao population is increasing on a quite linear growth of approximately 127,000 people/year (see Figure 5-36) and was estimated to be at 6.76 million inhabitants in 2016 (Wikipedia.org; 23-04-2019). The population is already lacking protein sources and therefore it is very important to maintain available protein sources. As presented in Chapter 5.5.1 it can be estimated that around 14,000 Lao inhabitants rely on the fishery in the backwater area of the Luang Prabang HPP. Considering the growth of the population it should be investigated if fish farming is an option for additional animal protein production and if it can be a part of the livelihood restoration of the project affected people. Other measures, as e.g. a fishery exclusion zone like the one which has been set up for Xayaburi, may later be recommended for implementation, depending on the results of the monitoring program.

![Figure 5-36: Demographics of Laos](image)

Figure 5-36: Demographics of Laos
Number of inhabitants in thousands (source: FAO data 2005)

### 5.6 Food and Nutrition

#### 5.6.1 General Aspects

The project area is located in Luang Prabang, Oudomxay and Xayaboury provinces in villages mostly along the Mekong River. In these parts most of the villagers are reliant on upland farming for rice. They meet their protein requirements from animal protein (especially fish from Mekong) while other supplements are raised in home garden or river bank gardens. NTFPs further provide subsistence supplement besides meeting basic needs, including food security during rice-deficit months.

The Luang Prabang HPP will inundate some agricultural land and change the conditions in the river. Therefore it is expected that some loss of food productivity is caused by the project. As described in chapter 5.5.1 and 5.5.5 a significant amount of Lao people rely on the animal protein production of this part of Mekong. It is recommended to ensure the project provides a sustainable offset and food security to the local people. It is expected that the cumulative impact of the project may not be that significant outside the project.
area. Most of the impacts will be localised within the project area and the resettlement area to be specific.

A strategic paper by MRC (Mekong River Commission, 2009) highlights that agriculture provides livelihoods for more than 70 percent of the Mekong Basin’s population, with 45 percent of the population considered to be below the poverty line. The environmental impacts of land-use change and irrigation development are more likely to be of cumulative nature and occur on a trans-boundary scale, water quality impacts can be local and cumulative, and can manifest on a trans-boundary scale. The study also identifies that barriers to fish migration reduce fish stocks, and could perhaps reduce the livelihoods derived from fishing by 30 percent or more.

As per another study “Food Security and Biodiversity in the upland Lao PDR: A Review on Recent situation of Causes and Effect” (Douangsavanh & Phouyyavong, 2009) highlights that Lao PDR lies within the primary center of origin and domestication of Asian rice (Oryza sativa L.) and rice cultivation in Lao appears to date back to at least 4000 BC. In the rice germplasm bank of the world maintained by the (IRRI), Lao is one of two countries that have contributed almost 90% of the global stock of rice varieties. However, villagers in Northern province experience a minimum of 3 to 4 months of rice insufficiency in a year, extending to a maximum of 5 or 6 months in some years. The project once constructed will either inundate some agricultural land (river gardens) or will resettle villages away from their current production bases.

A study conducted in Cambodia (IFRED, 2012) to analyse the impact of mainstream hydropower dams on food and nutrition security highlights that mainstream Cambodian dams are therefore predicted to reduce the supply of inland fish and other aquatic animals by between 34,000 to 182,000 tonnes from the baseline values. The uncertainty range depends mainly upon the hypothesized distribution of long-distance migrants’ spawning habitat, which highlights the importance of new research on spawning areas. The study concludes that after the construction of the mainstream dams there will be a further reduction of the already low number of individuals who have adequate levels (RDA, recommended daily allowance) of energy, protein and iron.

The study states that a reduction of 34% of the available fish and fish products for consumption would have a considerable impact on the proportion of the population living in the plains who are able to obtain their daily dietary allowances (RDAs), and who are already considered as the least nutrient-secure ecological zone. A reduction in the availability of fish and specifically of long-distance migrants, which is important for the provision of iron, would have a strong detrimental impact on the rural population driving iron security even lower and posing a risk to public health. Children, especially in rural areas, will also be directly affected by the reduction of inland fish availability. School children could be considered as the most food-insecure age group. The data on pregnant women’s nutrition shows that they are the most vulnerable group to protein reduction, with the lowest rate of protein RDA satisfaction. Therefore, the predicted reduction of per capita supply of inland fish and OAAs is expected to result in:

- negative effects on public health that affect strongly some of the most vulnerable population groups, such as those living in remote rural areas and school children;
- aggravation of existing malnutrition and creation of more people who cannot obtain the recommended daily allowance of key nutrients, thus exposing more people to health risks.
5.6.2 Conclusion and Findings Concerning Nutrition

Considering the fact that Luang Prabang HPP is a mainstream project with affected communities living along the Mekong and reliance on rice and fish for their dietary requirement, the project is expected to cause impact on the nutrient intake of the PAPs and possibly downstream communities. The actual impact need to be further assessed with consideration of the fact that the project plans to develop a state of the art fishpassing facilities to mitigate the impact of creating a barrier for fish migration. An overarching study of recent upstream and downstream projects such as Pakbeng and Xayaburi may shed further light on the cumulative projects induced impacts. The type and quantum of impacts can further clarify appropriate coping and mitigation mechanism or improvements of the existing mitigation measures. Nevertheless, the project developer is expected to be responsible to ensure that food and nutrition requirements of PAP are addressed during the transition period of resettlement and for longer period for the most vulnerable households.

5.7 Impacts Related to Other Development Projects Construction

Major related development projects that will be impacted by Luang Prabang HPP or vice versa are as follows:

- China-Lao Railway Project;
- Pak Beng HPP;
- Xayaburi HPP;
- Hongsa-Chiangman and the new Bridge across Mekong River Project; and
- Development around Luang Prabang City and World Heritage status

The development of constructions in the vicinity of the Luang Prabang HPP may result in cumulative impacts depending on the overlap of the construction timeframes. However, the cumulative impacts generated during the construction are expected to be local to neighbourhood in extent and either short or medium term. There would be varying potential for adverse cumulative construction impacts to arise with some of these projects.

The construction of other development project may result in cumulative impacts particularly at the worksites. The majority of cumulative interactions generated by the project construction and operation from combinations of relevant environmental and social impacts is presented in the Table 5-9.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>- Diversification of energy sources; Increase demand in the power sector;</td>
</tr>
<tr>
<td>Water</td>
<td>Increase demand for water availability;</td>
</tr>
<tr>
<td>Traffic</td>
<td>Increase demand for traffic and transportation;</td>
</tr>
<tr>
<td>Topics</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Economic</td>
<td>• Increased macro-economic growth;</td>
</tr>
<tr>
<td></td>
<td>• Increased government revenues and spending;</td>
</tr>
<tr>
<td></td>
<td>• Increased short term costs in debt service;</td>
</tr>
<tr>
<td></td>
<td>• Lower the growth of natural resources sectors (i.e. fisheries, agriculture);</td>
</tr>
<tr>
<td></td>
<td>• Increased industrial growth (i.e. logistic, mining);</td>
</tr>
<tr>
<td></td>
<td>• Loss of tourism;</td>
</tr>
<tr>
<td></td>
<td>• Increased poverty and loss of livelihoods of the poor;</td>
</tr>
<tr>
<td></td>
<td>• Food prices rising;</td>
</tr>
<tr>
<td></td>
<td>Temporary / permanently loss of existing infrastructure (i.e. irrigation, roads, agricultural land, river bank gardens and soused of livelihood);</td>
</tr>
<tr>
<td>Hydrology and Sediment</td>
<td>• Change of water levels and flow;</td>
</tr>
<tr>
<td></td>
<td>• Potential of catastrophic flood releases;</td>
</tr>
<tr>
<td></td>
<td>• Changes in extent and duration of flooding area;</td>
</tr>
<tr>
<td></td>
<td>Changes of downstream and upstream sediment transport, nutrient transport, and deposition;</td>
</tr>
<tr>
<td>Water Quality</td>
<td>• Change of surface water quality (i.e. release of wastewater, waste including hazardous waste and chemical release);</td>
</tr>
<tr>
<td></td>
<td>• High turbidity of water and impacts on ecosystem health and water supplies;</td>
</tr>
<tr>
<td></td>
<td>• Loss of nutrients on fine sediments, reduced the fertility of river and floodplain;</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>• Habitat loss and degradation of flora and fauna;</td>
</tr>
<tr>
<td></td>
<td>• Change in Key Biodiversity Areas associated with the Mekong River;</td>
</tr>
<tr>
<td></td>
<td>• Change in land use (i.e. wetland due to inundation);</td>
</tr>
<tr>
<td></td>
<td>• Loss of forest cover through construction activities and structures;</td>
</tr>
<tr>
<td>Aquatic</td>
<td>• Change in productivity of aquatic habitats;</td>
</tr>
<tr>
<td></td>
<td>• Loss in aquatic production;</td>
</tr>
<tr>
<td></td>
<td>• Change in the population of rare and endangered species;</td>
</tr>
<tr>
<td>Air Quality</td>
<td>• Increase of dust and particulate matter;</td>
</tr>
<tr>
<td>Climate Change</td>
<td>• Increased CO₂ from the emission of machinery;</td>
</tr>
<tr>
<td>Noise</td>
<td>• Increased of noise pollution;</td>
</tr>
<tr>
<td>Fisheries</td>
<td>• Loss of fish production due to the degradation and loss of spawning habitats and migration corridor;</td>
</tr>
<tr>
<td></td>
<td>• Loss of fish species;</td>
</tr>
<tr>
<td></td>
<td>• Loss in capture fisheries;</td>
</tr>
<tr>
<td>Topics</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
</tbody>
</table>
| Social  | • Change in health and nutrition;  
          • Reduction of primary protein source (i.e. loss of fisheries)  
          • Increased incidence of vector disease;  
          • Sexually Transmitted Diseases transmission in the labour force and the camp followers;  
          • Increase the risk of life and injury due to the construction, operation, and traffic;  
          • Social impact on land acquisition, resettlement, loss of access;  
          • Loss of homes, assets, agricultural land, riverbank gardens, agriculture land and, forest;  
          • Loss of community resources including cultural and historical sites;  
          • Loss of traditional knowledge/practices/cultures;  
          • Loss of Mekong River access and navigation;  
          • Loss of access to subsistence income (i.e. fishery);  
          • Loss of tourism attractions;  
          • Loss of landscape/aesthetic degradation, visual intrusion due to the construction and operation of the projects. |

To prevent or minimize negative impacts on the environmental and social, the implementation of an effective Environmental and Social Management Plan during construction and operation associated with the developed projects shall be implemented.

5.7.1 China-Lao Railway Project

As part of its Kunming-Singapore line, China is building a railway connecting Kunming, in Southern-China, to Singapore, running through Laos, Thailand, and Malaysia.

In Laos, a high-speed train line will stretch around 410 km from Boten, in the Lao-China border, to Vientiane, Lao capital and also a bordering city with Thailand (RFA, 2018). There will be a total of four major stations in Lao PDR: 1) Luang Namtha, 2) Luang Prabang - about 13 kilometers north of the city, 3) Vang Vieng, and 4) Vientiane (see Figure 5-37).
As shown in Figure 5-38, within the vicinity of the Luang Prabang HPP, the China-Laos Railway has two crossings across the Mekong River, the first one at Ban Sanok about 20 km downstream of Luang Prabang HPP, and the second one at Ban Lathan, about 7 km upstream of Luang Prabang HPP. In addition, there is an existing access road, about 5 m widths for the China-Laos railway running from Chomphet district passing through forest area to Ban Houaygno, the proposed Luang Prabang dam site with about 40 km length. This existing road might be used as an alternative access to the Luang Prabang HPP site at the initial stage.
As shown in Figure 5-38, relevant environmental and social impact by Chinese Railway construction activities at the train station and rail track construction sites, construction camps, workshops, tunnels, quarries, borrow and disposal areas, etc. is foreseeable mostly along the railway track (marked in red areas). Since the available imagery is outdated (dating from August 2017), it does not show the construction sites and related camps and workshops presently in place upstream of Luang Prabang, in the vicinity of the dam site. It is expected that the construction will be completed by the end of 2021, therefore, the impacts of the Chinese Railway construction (short duration is expected) to Luang Prabang HPP and vice versa are only occurring for a short time of period.

5.7.2 Pak Beng HPP

The Pak Beng HPP is located in the upper reaches of the Mekong River in Pak Beng District, Oudomxay Province, northern Laos. The Pak Beng HPP is planned to be a low head Run-of-River project with an installed capacity of 912 MW. The major structures planned are water retaining structures with 14 sluice gates, powerhouses, a 500 DWT navigation lock, and fish pass. Most of the electricity produced is meant to be transmitted to the Mae Moh Substation in Thailand through 500 kV transmission lines; this is 230 km away from the Pak Beng HPP; an outgoing transmission line of 230 kV will be connected to a local substation of about 110 km in distance.
As it is an ROR plant same as Luang Prabang, Pak Beng HPP will not change the flow pattern and therefore no hydrological impact is expected to Luang Prabang HPP. However, Pak Peng HPP has to use state of the art technology for fish migration and sediment transport, otherwise the measures taken at Luang Prabang HPP and Xayaburi HPP are meaningless since migration will be blocked further upstream and sediment will accumulate.

A close cooperation between the operators is highly recommended. Information about sediment flushes, spillway operation and fish migration shall be shared to minimize environmental impacts and for a proper monitoring of fish migration behaviour and development of the fish population etc.

5.7.3 Xayaburi HPP

The Xayaburi HPP is the first such project on the Mekong mainstream, downstream of China and would be capable of generating average of 7,400 GWh/y of electricity, mainly for export to Thailand.

The dam has an installed capacity of 1,285 MW with a dam 810 m long and 32 m high with 7 spillway gates, 4 Low-Level Outlets, a reservoir area of 49 km² and live storage of 225 Mm³. The normal operation water level is 275 masl.

The Xayaburi HPP is located on the downstream of the proposed Luang Prabang HPP thus will be subject to impact from Luang Prabang HPP in terms of water from flood release and power generation.

As it is a ROR plant Luang Prabang will not change the flow pattern and therefore no hydrological impact is expected to HPP Xayaburi.

A close cooperation between the operators is highly recommended. Information about sediment flushes, spillway operation and fish migration shall be shared to minimize environmental impacts and for a proper monitoring of fish migration behaviour and development of the fish population etc.

5.7.4 Hongsa-Chiangman Road and the new Bridge across Mekong River Project

The 114-kilometers Hongsa-Chiang Man Road (R4B), will be a shortcut new access from Thailand to Luang Prabang, Laos. The road begins at Ban Napong, Hongsa District, in Xayabury Province, and ends at Ban Chiangman, Chomphet District, Luang Prabang Province. It will have two 3.5-metre-wide lanes with 1-metre shoulder. The road construction began in early 2016 and is due to be completed in 2019. The road will help shorten the travel time from the Huai Kon border checkpoint in Nan of Thailand to Luang Prabang by half from the current five to six hours to less than three. This road can be used as an alternative route for the transportation of heavy equipment and materials from Thailand to Luang Prabang HPP.

In addition, there is a plan for construction of a new bridge across Mekong River at about 10 km upstream of the ferry port, Luang Prabang Province. This bridge will connect Hongsa-Chiang Man Road (R4B) to Highway No.13N thus providing a better connection between the two sides of the river to Luang Prabang City and Luang Prabang HPP.
5.7.5 Development around Luang Prabang City and World Heritage status

Luang Prabang City was registered and declared as a World Heritage Site in December 1995. Any development within the World Heritage boundary requires concurrences from World Heritage Office.

Luang Prabang provincial authorities have plans to expand the city in response to the increasing number of tourists to the World Heritage site. The Luang Prabang city expansion project covers 100 hectares of land starting from Donkeo village to Luang Prabang airport through Phanom and Nasangveuy villages.

The implementation of Luang Prabang HPP will affect the development around Luang Prabang City in both positive and negative aspects. The positive ones will be mainly relating to a significant increase in economic activities induced directly and indirectly by Luang Prabang HPP. For a negative impact, there will be high pressure from a large amount of labour influx to Luang Prabang area that requires careful management. In terms of tourism aspect in the area, one of most favourite tourist place is Pak Ou Cave, 4 km downstream of Luang Prabang HPP, and there are number of tourist boat travel from Luang Prabang to Thaxouang and Pakbeng, therefore, the implementation of Luang Prabang HPP has to consider means to facilitate current navigation activities in this stretch of the Mekong River. However, it has to be stated clearly that the project is located outside of the world heritage area. The latter covers the area of Luang Prabang town itself.

![Figure 5-39: Location of the Luang Prabang HPP related Development Projects](image)

5.8 Social Issues

Hydropower projects often meet resistance because of their social impacts that they cause mostly by involuntary resettlement of the communities displaced by the reservoir formation, construction of the main site besides other facilities and transmission lines. Often
these projects are remotely located causing displacement of indigenous populations and small villages which have traditionally being reliant on subsistence farming, livestock, forests and other natural resources such as the river for their livelihood and meeting their basic needs. This reliance is not only limited to livelihood but also strongly linked to their ethnicity, local culture, traditional beliefs, traditional knowledge and communal harmony.

The Luang Prabang HPP is a ROR project and hence may not cause significant submersion of villages and production assets as compared to other projects of similar capacity with a much bigger reservoir. However, the project will potentially affect 26 villages along the main Mekong causing disruption to their existing lifestyle, means of livelihood, heavy reliance on Mekong for transport, ethnic identity and cultural beliefs (3 major ethnic groups in the project). The project may also disturb the current land use pattern causing variation in land use and the associated market prices.

It should be further noted that the project area also overlaps with the ongoing China-Lao Railway project. The overlap may magnify or diminish the impacts caused by the Luang Prabang HPP, however most of the impacts are likely to be magnified. Below the likely cumulative social impacts are presented.

5.8.1 Land Use Pattern

The villagers currently rely partly on slash and burn cultivation and upland rice. Relocation to relatively flat area and formalization of village boundaries at resettled sites will restrict the land availability and thereby increase the land price. Compensation paid for the lost land in original villages has also been a factor in inflating the land price in Lao PDR. Experience with other projects such as Nam Ngiep1 and Nam Theun1 project in central Laos have indicated that the compensation demanded by PAP (resettlers) has been steadily going up guided by rates of other nearby projects. These impacts will be further cumulated by the Lao China railway project.

5.8.2 Socio-Economic Parameters

Payment of compensation, subsidies and labour opportunities in the initial few years will infuse a lot of money in the local economy. This will increase the purchasing power of the PAP and the local communities benefitting directly from the increased economic activity. Though this is a positive impact yet if not managed well may become unsustainable over the time thereby causing poverty for some households.

Further increase in cash flow and economic activity around the project area may cause the price of commodities and other consumables to go up, thereby rolling the effect onto bigger district/province level markets. Further there is a possibility that the local market may not be able to cater to the increased demand of construction workers and camp followers in the years of construction.

This impacts will be further cumulated by the Lao China railway project, which already has created increased demand of commodities and other consumables.
5.8.3 Social conflict, risk of STD (sexually transmitted disease), human trafficking and other behavioural issues.

The construction of the dam and associated facilities will cause an increased influx of workers and camp followers. A fair percentage of these workers in Lao PDR are mostly from neighbouring countries as has been observed from other projects. This increased population will further augment the already existing population of workers and camp followers for the Chinese Lao railway project.

The increased population may cause undesirable impacts such as increased risk of STD, human trafficking, conflict between outsiders and locals, increased number of entertainment venues, traffic accidents and other related issues. It’s also possible that some of these population may even percolate to neighbouring provinces and so does the impact.

5.8.4 Transport

The main river channel will not be closed during the construction of the dam; it will be required to ensure navigable flow velocities. However, during river diversion before commissioning, and before the ship lock will be entirely functioning, navigation will be interrupted for a short while. Most of the villages in the project area have no or poor land connectivity and rely heavily on river transport for their daily routine. Further some of these villages are also rest/stop-over points for the cargo or tourists boats passing through the Mekong from Houay Xay in North West Laos to Vientiane and downstream.

However, construction of roads connecting the project site and within new resettlement areas will be a positive impact on the local and regional economy.

5.8.5 Conclusion and Findings Concerning Social Issues

Cumulative impacts will be rather short-lived and mostly related to the current ongoing construction works of the Chinese Lao railway project. As an additional disruption in river traffic, the travel and transportation along the Mekong River will be further impeded.

The installation of navigation locks will serve to reduce these impacts. There will be a time loss to pass through the navigation lock but on the other hand, the resulting elevation of the water level and the reduced flow velocities upstream of the dam will simplify passage for boats transporting passengers and goods.
6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Prediction of Cumulative Impacts

Hydrology and Hydraulic

Since the Luang Prabang HPP is a run-of-river plant it will not affect the hydrograph during operation. Upstream and downstream of the dam the hydraulic conditions change. The backwater effect of Xayaburi HPP defines the tailwater level at Luang Prabang HPP and therefore no river section remains, that has natural flow conditions. Upstream the backwater effect of Luang Prabang HPP reaches the tailwater of Pak Beng. The cascade of the three ROR plants cause lower flow velocities in the whole section. The river morphology is not much diversified anymore, since rapids and pools are mostly inundated as the backwater affected area of each HPP reaches the tailwater area of the upstream HPP.

Sediment Transport

Reduction of suspended sediments due to the Lancang Cascade and other dams at tributaries are evident, both based on findings within the existing literature and based on the trend analyses carried out by Pöyry.

Luang Prabang and Xayaburi HPP are equipped with low level gates, which are opened prior to the surface spillway gates and stay open as long as the inflow is larger than the turbine flow of the HPP. Further increase of flows lead to an additional release over the spillway. The technology used for sediment flushes from Pak Beng is currently not known. However since all projects on the Mekong mainstem are obliged to follow the MRC guidelines it is hereby assumed that suitable facilities will be installed. It can therefore be concluded that the cascade from Pak Beng to Xayaburi will reduce sediment transport somewhat until the backwater areas of each HPP are in a new equilibrium.

Fish and Fishery

Since the Luang Prabang HPP will use the same or better fish pass technology as used at HPP Xayaburi one can assume that the fishes passing one facility are also able to pass the other. If a similar technology is used for Pang Beng and other Mekong River HPPs it can be assumed that the effect will be quite the same. With a proper monitoring and interaction with the operator of all HPPs in the cascade this assumption can be proved.

As described in chapter 5.5.5 there are two very important facts which have to be considered and mitigated:

(1) Diversity of fish species and size of fish population
(2) Animal protein intake of local people

If no measures are implemented the amount of fishes and fish species is strongly endangered since spawning areas will be lost or not be reached anymore and the growing Lao population will increase fishery.

To ensure the variety of fish species and the population of the fishes can be maintained related measures should be considered. The operators of the hydropower plants should be obliged to do continuous fish monitoring, share date and publish them. The Lao government should control fishery, implement fishery exclusion zones in the vicinity of hydro-
power plants and provide alternatives, so fishery will not increase, although the local population will. The HPP operators should therefore be obliged to provide according sustainable livelihood restoration for project affected people.

**Pak Beng – Luang Prabang – Xayaburi: Cascade Impacts**

All three plants are ROR who will not change the flow pattern. However Pak Peng HPP has to use state of the art technology for fish migration and sediment transport, otherwise the measures taken at Luang Prabang HPP and Xayaburi are meaningless since migration will be blocked further upstream and sediment will accumulate.

A close cooperation between the three operators is highly recommended. Information about sediment flushes, spillway operation and fish migration shall be shared to minimize environmental impacts and for a proper monitoring of fish migration behavior and development of the fish population etc.

### 6.2 Prediction of Transboundary Impacts

**Hydrology**

A transboundary impact from China to all the Mekong- downstream countries is given by the operation of the storage power plants in the Lancang cascade. The operation cause a flatter but wider hydrograph since peak flows are cut, but low flows increase (see Figure 5-14 and Figure 5-15). As a ROR- plant Luang Prabang HPP is not affecting the hydrograph and has no further hydrological effect to the downstream countries. Accordingly there is no hydrological impact to the Tonle Sap great lake system from Luang Prabang HPP.

However a positive transboundary effect to be mentioned here is given from the Lancang cascade to the Pak Beng-, Luang Prabang-, Xayaburi- cascade: Since the Lancang cascade changed the flow pattern more water is released during dry months whereas the spillway peaks are lower (see Figure 5-14). Therefore more energy can be produce in the latter cascade in an average year.

**Sediment Transport**

The Lancang cascade causes a significant transboundary effect to all downstream countries concerning sediment transport as described in chapter 5.2.10. The Pak Beng, Luang Prabang, Xayaburi run-of-river cascade will, for some time, slightly reduce sediment transport until new equilibriums in their backwater areas are reached.

As described in chapter 5.2.10 the reduction of sediment transport due to the impoundment of the Manwan reservoir has immediately impacted the following approx. 800 km downstream section. But further downstream (ca. 1,160 km), near Luang Prabang it took over 3 years to recognize this effect. It is assumed that the buffer volumes from sediments within the river compensated the impact during this time (CNR, 2013c).

The distance from Luang Prabang HPP to Hueang confluence, where the Mekong reaches the Thai border is approx. 330 km. It can be assumed that the phase with reduced sediment release from Luang Prabang HPP can be recognized in Thailand quite early.

For other downstream countries like Cambodia (more than 1,000 km downstream) and Vietnam (more than 1,500 km downstream) the impact to sediment transport from this run-of-river cascade is rather low. Main reductions is caused by the Langcang cascade and the dams on the Mekong tributaries.
Fish and Fishery

According to Poulsen et al [5] the upper fish migration system (see Figure 5-31) seems to be relatively isolated, with little exchange between it and the other more south located migration systems. 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.
REFERENCES


[8] Draft Cumulative Impact Assessment Guidelines for Hydropower Projects in the Lao PDR (Department of Environment and Social Impact Assessment (DESIA) within the Ministry of Natural Resources and Environment (MONRE))


ANNEX

A) Used Literature concerning Sediment Transport within the Mekong

In Table 7-1 a list of the used literature is given (in chronological order of their publication date). For each of the listed literature the most relevant information is briefly summarized in the subchapters below.

Table 7-1: Used literature upon sediment transport in Mekong River

<table>
<thead>
<tr>
<th>Item</th>
<th>Title</th>
<th>Author</th>
<th>Commissioner / Publisher</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River</td>
<td>Matti Kummu and Olli Varis</td>
<td>Elsevier Geomorphology 85</td>
<td>10/2006</td>
</tr>
<tr>
<td>3</td>
<td>The MRCS Xayaburi Prior Consultation Project Review Report</td>
<td>Sediment Expert Group</td>
<td>Mekong River Commission Secretariat (MRCS)</td>
<td>03/2011</td>
</tr>
<tr>
<td></td>
<td>Annex 3 Review of Sediment Transport, Morphology, and Nutrient Balance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Changes in sediment load of the Lancang-Mekong River and its response to the hydro-power development</td>
<td>Liu et al.</td>
<td>4th International Conference on Estuaries and Coasts, Vietnam</td>
<td>10/2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ministry of Energy and Mines - LAO PDR</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Characterization of grain-size distribution of Mekong River sediments (from Chiang Saen to Nong Khai)</td>
<td>CNR ingénierie</td>
<td>Dep. of Energy Business (EB) - Energy Policy and Planning Dep. (EPP)</td>
<td>06/2013</td>
</tr>
</tbody>
</table>
B) Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River (Kummu and Varis, 2006)

In this paper a lot of important basics upon the Mekong and its sediment regime are presented. An overview of hydrologic conditions along the river can be found in Figure 7-1 and a summary of various estimations of Mekong’s sediment transport rates from various other studies is given in Table 7-2. It is mentioned that according to Gupta and Liew (2007) unlike other large alluvial rivers in the Mekong upstream of Cambodia only little sediment exchange between channel and floodplains occurs, meaning that most of the sediment is stored inside the channel. Due to the lack of available bedload data for the Mekong Basin this very important part of the sediment transport and the impact of dams onto it could not be analysed within the paper.

From the data used within the study it can be seen, that there are relevant observation data of suspended sediment concentration (SSC) and total suspended solids (TSS) for the Chiang Sean and Luang Prabang station which were not available to Pöyry for the preparation of this CIA / TBIA report. A more detailed list is given in Table 7-3. The original analyses of these data done within the paper are given in Table 7-4 and Figure 7-2. They show a clear reduction in suspended sediments by more than half at Chiang Saen station, which is the first station downstream of the Chinese Lancang Cascade.

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Figure 7-1: Mean flows at selected sites in the Mekong mainstream
And an indication of the major tributaries and their contribution in each reach (Source: Kummu and Varis, 2006)

Table 7-2: Estimations of mean annual sediment transport rates in Mekong
(Source of compilation: Kummu and Varis, 2006)

<table>
<thead>
<tr>
<th>Source</th>
<th>From China (%) / ×10^9 kg</th>
<th>Total in Mekong ×10^9 kg</th>
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</thead>
<tbody>
<tr>
<td>Milliman and Meade (1983)</td>
<td></td>
<td>160</td>
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<tr>
<td>Milliman and Syvitski (1992)</td>
<td></td>
<td>160</td>
</tr>
<tr>
<td>ADB (1997; ref Plinston and He, 1999)</td>
<td>50%</td>
<td>150–170</td>
</tr>
<tr>
<td>Roberts (2001)</td>
<td>50%</td>
<td>150–170</td>
</tr>
<tr>
<td>You (1998; ref Plinston and He, 1999)</td>
<td>84.8 ×10^9 kg</td>
<td></td>
</tr>
<tr>
<td>Department of Hydrology, Ministry of Water Resources, China (1992; ref Plinston and He, 1999)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7-3: Summary of the suspended sediment data

Availability in Lower Mekong Basin (Source: Kummu and Varis, 2006), relevant data for feasibility of Luang Prabang HPP marked in red

<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>MRCS hydrological database (HYMOS) Parameter: SSC</td>
<td>Chiang Saen</td>
<td>62, 68–75</td>
<td>N/A</td>
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<tr>
<td></td>
<td>Luang Prabang</td>
<td>62, 85–92</td>
<td>270</td>
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<td></td>
<td>Nong Khai</td>
<td>72–78, 81–92</td>
<td>558</td>
</tr>
<tr>
<td></td>
<td>Mukdahan</td>
<td>75–92, 82–92</td>
<td>1030</td>
</tr>
<tr>
<td></td>
<td>Pakse</td>
<td>62–92</td>
<td>N/A</td>
</tr>
<tr>
<td>MRCS Water Quality Monitoring Network database (WQMN) Parameter: TSS</td>
<td>Chiang Saen</td>
<td>85–92</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Luang Prabang</td>
<td>85–92</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Pakse</td>
<td>86–92</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Kratie</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 7-4: Water discharge, SSC and TSS concentrations and fluxes

In analyzed stations along the Lower Mekong River divided to pre-dam and post-dam periods (Source: Kummu and Varis, 2006)

<table>
<thead>
<tr>
<th>Station</th>
<th>Discharge Pre-dam (m³ s⁻¹)</th>
<th>Discharge Post-dam (m³ s⁻¹)</th>
<th>HYMOS Pre-dam (mg L⁻¹)</th>
<th>HYMOS Flux Pre-dam (× 10⁷ kg)</th>
<th>WQMN Pre-dam (mg L⁻¹)</th>
<th>WQMN Flux Pre-dam (× 10⁷ kg)</th>
<th>HYMOS Post-dam (mg L⁻¹)</th>
<th>HYMOS Flux Post-dam (× 10⁷ kg)</th>
<th>WQMN Post-dam (mg L⁻¹)</th>
<th>WQMN Flux Post-dam (× 10⁷ kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiang Saen</td>
<td>2741</td>
<td>2648</td>
<td>449</td>
<td>71</td>
<td>484</td>
<td>71</td>
<td>215</td>
<td>31</td>
<td>183</td>
<td>48</td>
</tr>
<tr>
<td>Luang Prabang</td>
<td>3623</td>
<td>4300</td>
<td>554</td>
<td>133</td>
<td>440</td>
<td>93</td>
<td>156</td>
<td>111</td>
<td>90</td>
<td>81</td>
</tr>
<tr>
<td>Nong Khai</td>
<td>4309</td>
<td>4757</td>
<td>257</td>
<td>76</td>
<td>219</td>
<td>72</td>
<td>218</td>
<td>133</td>
<td>156</td>
<td>111</td>
</tr>
<tr>
<td>Mukdahan</td>
<td>7452</td>
<td>7724</td>
<td>196</td>
<td>88</td>
<td>247</td>
<td>129</td>
<td>218</td>
<td>133</td>
<td>156</td>
<td>111</td>
</tr>
<tr>
<td>Pakse</td>
<td>8551</td>
<td>9913</td>
<td>33</td>
<td>81</td>
<td>136</td>
<td>101</td>
<td>218</td>
<td>133</td>
<td>156</td>
<td>111</td>
</tr>
<tr>
<td>Kratie</td>
<td>4872</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Suspended sediment fluxes in LMB
(average rates from HYMOS and WQMN)

Figure 7-2: Suspended sediment fluxes in the Lower Mekong Basin, before and after dam closure: averages from HYMOS (SSC) and WQMN (TSS) datasets (Source: Kummu and Varis, 2006)

This report emphasizes the existing uncertainties on the available sediment data at Mekong River. It is explained that according to Walling (2005) measurements of suspended sediment concentration (SSC) are more useful for estimating sediments loads than measurements of total suspended solids (TSS). It is also mentioned that according to USGS (2000) TSS is an inappropriate indicator of sediment load when there is more than 25% of sand size materials. An error bar of approx. 20-30% is recommended for the interpretation of SSC data.

Based on the time for which sediment measurement data is available, the following differentiation according the Lancang catchment is made:

- 1990-2000 (hydropower development): introduction of mainstream hydropower on the Lancang River (construction and operation of Manwan dam)
- 2000-2010 (hydropower escalation & soil conservation): intensification of mainstream hydropower and introduction of soil conservation strategies under Chinese governments “Green for Grain” program (Walling, 2009)

The sediment load from the Upper Mekong Basin is estimated with 85 Mt/y which corresponds to 50% of total sediment load in the Mekong. When the complete Lancang Cascade is in operation the total annual sediment load that enters Chiang Saen is estimated to reduce to 15-17 Mt/y. The mean annual sediment load of Nam Ou is stated to be at approx. 6.2 Mt/y.

For Ang Ngay Pool which is located north of Vientiane a bed load proportion of 1% of the total sediment load is estimated, which corresponds with 1 Mt/yr. The reduction of bedload inflow due to the Lancang Cascade is expected to be nearly 100% and this will lead to erosion of in-channel storage zones. The effects are expected to become noticeable within just a few water seasons in the sections neighboured downstream to the Lancang Cascade but it will take several decades to reach sections near Vientiane.

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9 MRC 2007: Annual Mekong Flood Report, Mekong River Commission, Vientiane 84pp
10 See footnote 8

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Figure 7-3: Some estimates of sediment load at Chiang Saen: pre and post Manwan (Source: ICEM, 2010)

Figure 7-4: Average annual mainstream sediment load (Source: ICEM, 2010)
Figure 7-5: Comparison of pre- and post-Manwan dam TSS concentrations at Chiang Saeng (top) and Luang Prabang (bottom), by Adamson, 2009b

In this report estimation of the relative sediment contribution from the main source areas are given:

- 45% originate from upstream Chinese border
- 5% originate from the section between Chinese border and Pak Chom (Laotian-Thai-border, approx. 100 km upstream Vientiane)
- 50% originate from Pak Chom to Delta

As natural sediment yield of the complete Mekong Basin a value of 160 Mt/yr is assumed in the study which is based on Walling, 2005\(^{11}\) and Kummu and Varis, 2006\(^{12}\).

A slightly different distribution and also alternative estimations upon Mekong’s total sediment load are given in the report (Table 7-5).

**Table 7-5: Assumed sediment yield from principal sediment sources**

in the Mekong River Basin for purposes of assessing transboundary effects (Source: MRCS, 2011)

<table>
<thead>
<tr>
<th>Location</th>
<th>Geology / Region</th>
<th>% of Sediment</th>
<th>Total Load (Mt/yr)</th>
<th>Notes</th>
<th>Other Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream of Manwan Dam</td>
<td>Alos Shear Zone and Tibetan Gorges</td>
<td>43%</td>
<td>69.0</td>
<td>Largest portion of sediment load originates from shear zone.</td>
<td>90 to 100 Mt/yr*; 45.8 Mt/yr**; 85 Mt/yr***</td>
</tr>
<tr>
<td>From Manwan Dam to Pak Chom Dam</td>
<td>Wang Chao Fault Zone and rest of catchment</td>
<td>5%</td>
<td>8.0</td>
<td>Wang Chao Fault Zone contributes slightly more than the entire low sediment yield catchment. Rough estimate places it at about ten times the specific sediment yield of the low-yield part of the catchment (rough ratoing of areas).</td>
<td>10 to 25 Mt/yr*</td>
</tr>
<tr>
<td>Downstream of Pak Chom Dam</td>
<td>Central Highlands, Khoral Plateau and rest of catchment</td>
<td>52%</td>
<td>83.0</td>
<td>Central Highlands is second largest sediment source to Mekong. Khoral Plateau is assumed to contribute very low loads.</td>
<td>30 to 72 Mt/yr*</td>
</tr>
</tbody>
</table>

Notes:

Based on different hydropower development scenarios (dam projects on main river and tributaries in China and Lao PDR) the sediment and morphological impacts have been assessed in the study. For these scenarios the trapped and passed-through sediment amounts were estimated. The results of the study’s assessment clearly indicate that for


the today’s status of already completed Chinese dams\textsuperscript{13} no sediment passes through the Lancang Cascade. If there are no active sediment management measures in place (or possible) which try to improve the longitudinal sediment continuity this situation will last for a very long time period because of the enormous storage capacity of the Chinese dams (Table 7-6). Further considerations within the MRCS study postulate an estimated sediment input reduction downstream the Chinese dams of about 90-100\% which corresponds to a load reduction of 61.3-69.0 Mt/y.

Table 7-6: Estimated indicative times for reservoirs in the Chinese cascade to fill with sediment (Source: MRCS, 2011)

<table>
<thead>
<tr>
<th>Dam</th>
<th>Gross Reservoir Volume (km(^3))</th>
<th>Time to Fill Reservoirs with Sediment (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gongguoqiao</td>
<td>0.51</td>
<td>51</td>
</tr>
<tr>
<td>Xiaowan</td>
<td>19.80</td>
<td>500</td>
</tr>
<tr>
<td>Manwan</td>
<td>1.01</td>
<td>500+</td>
</tr>
<tr>
<td>Dachaoshan</td>
<td>0.94</td>
<td>500+</td>
</tr>
<tr>
<td>Nuozhadu</td>
<td>24.60</td>
<td>500+</td>
</tr>
<tr>
<td>Jinghong</td>
<td>1.14</td>
<td>500+</td>
</tr>
</tbody>
</table>

E) Changes in sediment load of the Lancang-Mekong River and its response to the hydropower development (Liu et al, 2012)

This paper postulates mean annual sediment loads for various stations along the Mekong River as follows (estimated for time period 1962-2003):

- Gajiu (15 km D/S Manwan dam) 38.0 Mt/y
- Chiang Saen 90.8 Mt/y
- Luang Prabang 107.7 Mt/y
- Nong Khai (near Vientiane) 85.4 Mt/y
- Mukdahan 111.4 Mt/y
- Khong Chiam 144.7 Mt/y

Opposite to other publications the effect of Chinese Lancang Cascade for Chiang Seng and downstream sections is classified as insignificant and that the sediment reduction caused by Manwan Dam does not extend beyond Chiang Saen. Reasons therefore are additional sediment inputs from tributaries and also riverbed erosion in the section downstream Manwan Dam as well as increased soil erosion due to artificial economical forest plantation.

\textsuperscript{13} Based on information from 2013 given on www.internationalrivers.org the following 6 Chinese dams are completed on the Lancang Cascade (Mekong): Gongguoqiao, Xiaowan, Manwan, Dachaoshan, Nuozhadu and Jinghong
An average annual sediment load of 145 Mt/y that is reaching the East Sea of Vietnam is estimated in the paper but for the foreseen future a reduction of this value to 90-120 Mt/y is roughly assumed.

F) Assessment of Xayaburi dam impact on solid transportation - Draft Final Report of Step 1 (CNR for Lao PDR, 2013a)

In this report - based on various other sources - the actual annual sediment load at Xayaburi Dam is given with approx. 105 Mt/y and an inter-annual variation range of 50-135 Mt/y. Furthermore for the next 20-30 years a decrease of the incoming sediment load at Xayaburi reservoir is estimated to the following values:

- 30-40 Mt/y considering existing reservoirs in 2010, i.e. Manwan, Dachaoshan and Jinghong
- 10-20 Mt/y considering existing reservoirs and planned sub-basin reservoirs as well as planned mainstream reservoirs at Upper Mekong Basin.
- 1-5 Mt/y considering existing reservoirs and all planned reservoirs for sub-basins and Mekong mainstream.

G) Characterization of grain-size distribution of Mekong River sediments (from Chiang Saen to Nong Khai) - Final Report (CNR for Lao PDR, 2013b)

The report was done for the Xayaburi HPP project and delivers morphological characteristics of the Mekong River for the section near Chiang Saen (km 2,365) to Ban Mak Nao (km 1,520).
The project area of Luang Prabang HPP is within the so-called “river unit 4” of that study, which goes from Ban Nam Tin (km 2,291) to Pak Ou (km 2,033), and it is described as follows:

- Near-straight channel bounded by sharp bends
- Deeply cut in bedrock in a narrow valley with steep highlands
- Sediment deposits are mainly composed of sand accumulated around emerged rocky outcrops and in depressions along the banks
- Sediment supply through tributaries Nam Tha and Nam Beng
- River width is between 50-100 m for low flow conditions, and 200-300 m at bank full discharge
- Channel slope is between 0.25-0.30 m/km

The information regarding the section downstream of the Pak Ou is that relevant sediment inputs are present due to the tributaries Nam Ou, Nam Xuang and Nam Khan and that sediment gets deposited because of a reduced channel slope of approx. 0.10-0.15 m/km. Because of the rock incised river bed in the Luang-Prabang project area depositions occur more or less only at emerged banks and natural basins. The results of the granulometric analyses for the $d_{50}$ are given in Figure 7-7.
H) Assessment of Xayaburi dam impact on solid transportation - Draft Final Report of Step 2 (CNR for Lao PDR, 2013c)

That report contains some important descriptions on how sediment inputs have been estimated:

- **Washload (uniform suspension)** => WQMN data from MRCS, daily sediment discharges estimated via calibrated sediment-rating curves
- **Suspended sand (graded suspension)** => field survey data at the dam site from 2012-2013, annual load is estimated out of sediment rating curve and flow-duration curve
- **Bedload** => calculated by 2 different transport formulas (MPM from 1948 and Camenen and Larson from 2005), annual load is estimated by applying these formulas onto the flow-duration curve

Some of the main findings are that:

- Due to the presence of the Lancang reservoirs there is a strong decrease in washload leading to a large proportional increase of bed materials (suspended sand and bedload) onto the total sediment load
- The impact onto the bed materials is supposed to be even higher but compensated for the moment, due to tributary supplies and huge in-channel stocks that delay the visible impact on sediment transportation and river morphology
It is quite probable that the sediment load at Xayaburi is strongly decreasing within the very next years.

Table 7-7: Plausible evolution of the sediment inputs
at Xayaburi reservoir inlet considering hypotheses on the sedimentary impact of dams likely to be built further upstream (Source: CNR, 2013c)

<table>
<thead>
<tr>
<th>Situation</th>
<th>Annual load (Mt/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Washload</td>
</tr>
<tr>
<td>Natural state (before 1993)</td>
<td>130</td>
</tr>
<tr>
<td>Current state (2013)</td>
<td>54</td>
</tr>
<tr>
<td>Future: low sedimentation rate in Yunnan Dam Cascade</td>
<td>33</td>
</tr>
<tr>
<td>Future: medium sedimentation rate in Yunnan Dam Cascade</td>
<td>24</td>
</tr>
<tr>
<td>Future: high sedimentation rate in Yunnan Dam Cascade</td>
<td>18</td>
</tr>
</tbody>
</table>


For the DSMP per year 34 measurements of discharge and suspended sediments were taken at 15 different locations along the Lower Mekong River. In the monitoring period from 2009 to 2013 a very wet year (2011) and also dry years (2010 and 2012) occurred. The frequency of the measurements was seasonally variable and had been intensified during wet season (Table 7-8).

Table 7-8: Summary of monitoring frequency for discharge, suspended sediment (SSC), sediment grain-size (SGSA) and bedload sampling (Source: Koehnkén, 2014)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSC &amp; Discharge</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>34</td>
</tr>
<tr>
<td>SGSA &amp; Bedload</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>17</td>
</tr>
</tbody>
</table>
Compared to historic measurements the DSMP results show a significant decrease in sediment transport, especially according the sediment inflow coming from China, which is reduced from approx. 84.7 Mt/y (1960-2003) to 10.8 Mt/y at Chiang Saen. The actual estimate for Luang Prabang is 22.3 Mt/y. The total suspended sediment load within the Lower Mekong Basin is estimated to have decreased from 160 Mt/y to 72.5 Mt/y. A summary of the calculated annual sediment loads is given in Table 7-9.

Approximately 60% of the sediment load is transported in August and September and 80% between July and October.

Table 7-9: Summary of annual sediment fluxes (Mt/yr)

<table>
<thead>
<tr>
<th>Mt/yr</th>
<th>CS</th>
<th>LP</th>
<th>CK</th>
<th>NK</th>
<th>NP</th>
<th>MUK</th>
<th>KC</th>
<th>PK</th>
<th>ST</th>
<th>KT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>7.28</td>
<td>18.87</td>
<td>14.06</td>
<td>14.27</td>
<td>56.30</td>
<td>119.46</td>
<td>206.43</td>
<td>62.08</td>
<td>48.02</td>
<td>44.16</td>
</tr>
<tr>
<td>2010</td>
<td>12.84</td>
<td>22.79</td>
<td>18.73</td>
<td>35.52</td>
<td>114.20</td>
<td>166.14</td>
<td>70.81</td>
<td>95.93</td>
<td>98.46</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>9.83</td>
<td>24.81</td>
<td>18.08</td>
<td>16.30</td>
<td>48.39</td>
<td>68.71</td>
<td>54.78</td>
<td>54.09</td>
<td>56.06</td>
<td>52.02</td>
</tr>
<tr>
<td>2012</td>
<td>9.11</td>
<td>24.56</td>
<td>20.48</td>
<td>16.97</td>
<td>62.02</td>
<td>91.09</td>
<td>91.24</td>
<td>77.75</td>
<td>99.72</td>
<td>87.16</td>
</tr>
<tr>
<td>Average</td>
<td>10.8</td>
<td>22.3</td>
<td>17.2</td>
<td>18.8</td>
<td>54.4*</td>
<td>96.5</td>
<td>116.4</td>
<td>65.7</td>
<td>76.8</td>
<td>72.5</td>
</tr>
<tr>
<td>Average no 2011</td>
<td>10.3</td>
<td>22.1</td>
<td>18.8</td>
<td>14.7</td>
<td>54.4*</td>
<td>92.0</td>
<td>104.0</td>
<td>64.5</td>
<td>72.0</td>
<td>66.0</td>
</tr>
</tbody>
</table>

* Sediment rating curve only available for 2012 and not applicable to flood year

The suspended sediments in the section between Chiang Saen and Luang Prabang are dominated by sand (medium to fine fractions, see also Figure 7-8 and Table 7-10). Bedload in Chiang Saen is dominated by gravel, pebbles and coarse sand (Figure 7-9) and is estimated to an amount of 1.6 Mt/y (corresponds to 15% of suspended load).

Figure 7-8: (left) Percentages of medium and fine sand, silt and clay in suspended load based on 2012 - 2013 average grain-size distribution results.

Fine sand is largest grain-size determined at Luang Prabang or Pakse so includes all coarser size fractions. (right) Average sediment grain-size results from 2012 – 2013 applied to average suspended sediment fluxes at monitoring sites. Sediment load at Koh Norea was combined with grain-size distribution at Tan Chau as no loads are available at Tan Chau (Source: Koehnken, 2014)
Table 7-10: Sediment budget for sand, silt and clay

in the LMB based on the average annual sediment loads (from rating curves) and average grain-size distribution results for the sites (Source: Koehnken, 2014)

<table>
<thead>
<tr>
<th>Site</th>
<th>Avg Sediment Load (Mt/yr)</th>
<th>Sand &gt;63μm Mt/yr (%)</th>
<th>Silt: 2-63 μm Mt/yr (%)</th>
<th>Clay &lt;2 μm Mt/yr (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiang Saen</td>
<td>10.3</td>
<td>9.1 (85%)</td>
<td>1.6 (15%)</td>
<td>0</td>
</tr>
<tr>
<td>Luang Prabang</td>
<td>22.0</td>
<td>16.6 (75%)</td>
<td>5.7 (25%)</td>
<td>Not determined</td>
</tr>
<tr>
<td>Nong Khai</td>
<td>14.7</td>
<td>9.8 (52%)</td>
<td>9.0 (48%)</td>
<td>0</td>
</tr>
<tr>
<td>Pakse</td>
<td>64.5</td>
<td>37.4 (57%)</td>
<td>27.7 (43%)</td>
<td>Not determined</td>
</tr>
<tr>
<td>Kratie</td>
<td>58.9</td>
<td>13.4 (20%)</td>
<td>40.7 (61%)</td>
<td>12.7 (19%)</td>
</tr>
<tr>
<td>Tan Chau*</td>
<td>Use interpolated load from Koh Norea =43.6</td>
<td>1.0 (2%)</td>
<td>19.3 (44%)</td>
<td>23.4 (54%)</td>
</tr>
</tbody>
</table>

*clay not determined at Pakse or Luang Prabang

Figure 7-9: Bedload monitoring results for Chiang Saen.

Graph on left shows grain-size distribution of bedload on each monitoring date; graph on right applies grain-size distribution results to calculated bedload loads and shows discharge on sampling days (Source: Koehnken, 2014)

According to the DSMP the sediment rating curves for Chiang Saen and Luang Prabang are steep compared to further downstream stations. Both curves are quite similar up to flows of approx. 5,000 m³/s. The derived sediment rating curves are shown in Figure 7-11.
Figure 7-10: Sediment concentrations

(left) Measured suspended sediment concentration and average daily discharge, (right) Suspended sediment flux based on SSC and measured discharge for stations Chiang Saen (top) and Luang Prabang (bottom) (Source: Koehnken, 2014)

Figure 7-11: Sediment rating curves

(left) Suspended sediment rating curves for 2011-2012 based on measured discharge and suspended sediment concentration; (right) calculated suspended sediment flux based on rating curves (lines) with measured values superimposed on the calculated results for stations Chiang
Saen (top) and Luang Prabang (bottom), discharge shown on right axis (Source: Koehnken, 2014)

J) Summary report of decision support for generating sustainable hydropower in the Mekong Basin - Draft 2 (IKMP & WWF for MRCs, 2014)

That report gives an updated estimate on the total suspended sediment load of approx. 72 Mt/y, which is a huge reduction to former estimates of up to 160 Mt/y. Main reason for this reduction is the capture of sediment in the Lancang Cascade and also in various tributary dams.

For Chiang Saen a proportion of up to 85% (9.2 Mt/y) of the suspended load is stated as sand size material, which may be transported as bedload as well as suspended load depending on the size and time phase of a flood. It is assumed that much of the previously described imbalances in the sediment budget of the Mekong may be addressed to the phenomena that sand is transported via different mechanisms in different reaches.

In comparison to historic findings a substantial decrease of suspended sediment concentrations and suspended sediment loads has been found (Table 7-11). The average annual sediment load at Chiang Saen has reduced from approx. 85 Mt/yr to approx. 11 Mt/yr. Chinese inflow of suspended sediment has decreased from 55% to 16%. The sediment inflow from the reach between Chiang Saen and Luang Prabang is estimated to 12 Mt/yr, which corresponds to approx. 17% of the actual total sediment load in Mekong River. The sediment load in this section is characterised by sand (suspended) and also gravels (bedload) and so there is the potential that this coarser material will be trapped by planned hydropower dams.

Table 7-11: Average annual suspended sediment loads (Source: IKMP & WWF, 2014)

<table>
<thead>
<tr>
<th>Source</th>
<th>Chiang Saen (Mt/yr)</th>
<th>Luang Prabang (Mt/yr)</th>
<th>Nong Khai (Mt/yr)</th>
<th>Mukdahan* (Mt/yr)</th>
<th>Pakse (Mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walling</td>
<td>84.7</td>
<td>76.8</td>
<td>72.3</td>
<td>107.3</td>
<td>147.4</td>
</tr>
<tr>
<td>DSMP</td>
<td>22.3</td>
<td>18.8</td>
<td>96.5</td>
<td>65.7</td>
<td></td>
</tr>
</tbody>
</table>

*Likely reflects over sampling of water column. Included for comparison, but absolute values should be considered with caution.

The main findings of an assessment upon the sediment transport processes done by the WWF are also summarized within the report. According to them no evidence of uniform suspension was found in the steep reaches of Mekong. Furthermore sand was also found in historic levees “which raises questions about the previously suggested theory that sand is a recent phenomenon in the river associated with land use may not be accurate”. Changes of transport processes between bedload, graded suspension and uniform suspension can lead to variability in suspended sediment concentrations and seems to be the reason for “imbalance” in sediment loads if for example only suspended sediment is considered. In the relevant section for Luang Prabang HPP the following results are given:

- Silt and clay is transported as wash load (as it is also for the whole Lower Mekong), and only very little amounts are deposited
- Sand is transported as graded suspension (during flood peaks) and also as bedload (at rising and receding flood conditions)
- Cobble and gravel is transported as bedload.

An overview of the results of sediment measurements carried out from September to October 2012 is also presented in the report (Table 7-12 and Table 7-13).

**Table 7-12: Summary of field measurements and grain-size analyses**

(Source: IKMP & WWF, 2014)

<table>
<thead>
<tr>
<th>Site/date</th>
<th>Discharge (m³/s)</th>
<th>SSC Range (mg/L)</th>
<th>SSC Avg (mg/L)</th>
<th>Sed Flux kg/s t/d</th>
<th>%Fine (D₉₀)</th>
<th>%Coarse (D₆₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luang Prabang 2/10/2012</td>
<td>4,812</td>
<td>118 - 174</td>
<td>155</td>
<td>746 kg/s 64,442 t/d</td>
<td>91% 14 μm</td>
<td>9% 70-230 μm</td>
</tr>
<tr>
<td>Kong Chiam 4/10/2012</td>
<td>9,025</td>
<td>104 - 195</td>
<td>140</td>
<td>1,265 kg/s 109,166 t/d</td>
<td>87% 9 μm</td>
<td>13% 64-115 μm</td>
</tr>
<tr>
<td>Kratie 28/09/2012</td>
<td>24,402</td>
<td>145-805</td>
<td>263</td>
<td>6,417 kg/s 554,490 t/d</td>
<td>86% 10 μm</td>
<td>14% 70-130 μm</td>
</tr>
</tbody>
</table>

**Table 7-13: Summary of bedload transport estimates based on field measurements**

(Source: IKMP & WWF, 2014)

<table>
<thead>
<tr>
<th>Site</th>
<th>Bedload Flux kg/s</th>
<th>Bedload flux t/d</th>
<th>D₉₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luang Prabang</td>
<td>5.5</td>
<td>477</td>
<td>0.60 mm</td>
</tr>
<tr>
<td>Kratie</td>
<td>146</td>
<td>12,600</td>
<td>0.38 mm</td>
</tr>
</tbody>
</table>

The outcomes of a study on sand and gravel mining in the Lower Mekong are summarized within the study. The most relevant are:

- Upstream of Vientiane only very limited volumes are extracted (87,000 m³ of sand, no gravel and 7,000 m³ of cobbles)
- The highest amounts of sediment extraction is done in Cambodia (~ 60%)

The revised sediment budget for Mekong River based on the findings of the report is given in Table 7-14.

**Table 7-14: Summary of sediment transport estimates in the Mekong**

(Source: IKMP & WWF, 2014)

<table>
<thead>
<tr>
<th>2009-2013 Monitoring Results</th>
<th>Chiang Saen</th>
<th>Kratie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average sediment (Mt/yr)</td>
<td>suspended</td>
<td>10.8 Mt/yr</td>
</tr>
<tr>
<td>% Sand</td>
<td>85% (9.2 Mt/yr)</td>
<td>20% (14.5 Mt/yr)</td>
</tr>
<tr>
<td>% Silt</td>
<td>15% (1.6 Mt/yr)</td>
<td>60% (43.5 Mt/yr)</td>
</tr>
<tr>
<td>Bedload estimate range (sand &amp; larger)</td>
<td>1.6 Mt/yr (measured)</td>
<td>1 – 16 Mt/yr (measured, modelled)</td>
</tr>
</tbody>
</table>
K) Hydraulic Continuity Equation

For a defined part in the river with no tributaries the following law occurs:

\[ Q_1 = Q_2 \]

with means the flow in section 1 is equal to the flow in section 2 when there is no confluence and no outflow in this part of the river. Since the flow is defined as velocity times flown area the following equation can be postulated:

\[ Q_1 = v_1 \cdot A_1 = Q_2 = v_2 \cdot A_2 \]

If the velocity in section 1 is smaller than the velocity in section 2 that means that the flown area is accordingly bigger in section 1 than in section 2.