MINISTRY OF ENERGY AND MINES - LAO PDR

PAK LAY HPP FEASIBILITY STUDY REVIEW
FINAL REPORT
Final Version
## PAK LAY HPP FEASIBILITY STUDY REVIEW
### FINAL REPORT
#### Final Version

**DI-ECS 2017-020-01 January 2017**

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### REVISION

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### GLOSSARY

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>AMD</td>
<td>Annual Mean Discharge</td>
</tr>
<tr>
<td>BDP</td>
<td>Basin Development Plan (MRC)</td>
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<tr>
<td>CA</td>
<td>Concession Agreement</td>
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<tr>
<td>CEIEC</td>
<td>China National Electronics Imp&amp;Exp Corporation</td>
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<tr>
<td>CNR</td>
<td>Compagnie Nationale du Rhône (France)</td>
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<tr>
<td>COD</td>
<td>Commercial Operation Date</td>
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<tr>
<td>cumecs</td>
<td>cubic meter per second (cms)</td>
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<tr>
<td>DEB</td>
<td>Department of Energy Business (Vientiane – Lao PDR)</td>
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<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
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<td>DEPP</td>
<td>Department of Energy Policy and Planning (Vientiane – Lao PDR)</td>
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<tr>
<td>DSF</td>
<td>Decision Support Framework</td>
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<td>DSMS</td>
<td>Dam Safety Management System</td>
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<td>DSRP</td>
<td>Dam Safety Review Panel</td>
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<td>DWL</td>
<td>Dead Water Level</td>
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<td>EDL</td>
<td>Electricity du Laos (Vientiane – Lao PDR)</td>
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<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>EMP</td>
<td>Environmental Management Plan</td>
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<td>EP</td>
<td>Environment Program (MRC)</td>
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<td>EPC</td>
<td>Engineering Procurement Construction</td>
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<td>EPP</td>
<td>Emergency Preparedness Plan</td>
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<td>F/E</td>
<td>Filling-Emptying System of the lock</td>
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<td>FS</td>
<td>Feasibility Study</td>
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<td>FSL</td>
<td>Full Supply Level</td>
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<td>GOL</td>
<td>Government of LAO PDR</td>
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<tr>
<td>GSD</td>
<td>Grain Size Distribution</td>
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<tr>
<td>GW</td>
<td>one million kW</td>
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<tr>
<td>GWh</td>
<td>one million kWh</td>
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<td>HNL</td>
<td>Highest Navigable Level</td>
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<td>HOL</td>
<td>Highest Operating Level</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>PCR</td>
<td>Powerchina Resources Ltd</td>
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<td>PGA</td>
<td>Peak Ground Acceleration</td>
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<td>PDG</td>
<td>Preliminary Design Guidance (MRC)</td>
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<td>PMF</td>
<td>Probable Maximum Flood</td>
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<td>PMFM</td>
<td>Procedures for Maintenance of Flows on the Mainstream</td>
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<td>PNPCA</td>
<td>Procedures for Notification, Prior Consultation and Agreement</td>
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<td>POE</td>
<td>Panel Of Experts</td>
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<td>PPA</td>
<td>Power Purchase Agreement</td>
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<td>PWUP</td>
<td>Procedures for Water Use Monitoring</td>
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<td>PWQ</td>
<td>Procedures for Water Quality</td>
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<tr>
<td>SEA</td>
<td>Strategic Environmental Assessment</td>
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<tr>
<td>QX</td>
<td>X-year return period flood (X = 2, 5, 10, 20, 50, 100, 1000 or 10000)</td>
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<tr>
<td>TSL</td>
<td>Total Sediment Load</td>
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Executive Summary

The study presented in this report by CNR is the final conclusions of the review of Pak Lay HPP Feasibility Study.

This review was conducted from September 2015 to November 2016 by CNR on the four following technical topics:

- Hydrology,
- Safety of Dam,
- Sediment Transport and River Morphology,
- Navigation.

The components “fish migration and passage” & “water quality” require a very specific knowledge, which cannot be considered transposable by CNR from the Rhône River knowledge to the Mekong River. Thanks to a separate contract, the GoL has therefore assigned international consultants from Brazil who are experts of tropical fishes and water quality for those topics.

The CNR review is based on the final documentation provided by the Developer of Pak Lay project to the GoL on October 13th, 2016. The purpose is to review the FS at the Lao national level before submission of the HPP to MRC for PNPCA.

CNR assesses and checks the compliancy of the FS with regard to international standards. CNR does not only take into account design criteria but also operation criteria.

The four following technical topics are in CNR scope. For each topic, CNR here below provides in short the major final conclusions:

- Hydrology:
  - The design flood and check flood values have been reviewed according to CNR requirements in order to follow international standards and to ensure the consistency of Pak Lay HPP in the cascade of dams upstream Vientiane. This point was a major concern and has been addressed by the Developer.
  - Even if some efforts have been made to start monitoring the flow in the vicinity of the project, there is still a lack of QA&QC process. The Developer plans to add more QA&QC process once at least one year of data will have been collected.
  - The operation pattern has been fully reviewed and is now consistent with run-of-river concept. The Developer still needs to demonstrate the efficiency of its operation pattern for some ranges of discharge but the run-of-river concept has been accepted and understood.
  - The monitoring and forecasting system is presented in the FS. The proposed technical solution is consistent for flood management but will show some major limitations regarding power generation management. Anyway, this is not a blocking point at this stage and the Developer can address this issue later on, before construction.

- Dam safety: the design is sound. The main recommendations are as follows:
  - All the feasibility study should be cleaned of former assumptions and designs so that design, design criteria and drawings are consistent throughout the whole documentation.
  - The Developer shall update construction drawings at feasibility stage in order to have a consistent design throughout the report and drawings.
  - The general construction schedule was not updated in final documentation. It shall be provided in feasibility study.
  - The comprehensive dam safety reviews shall be mentioned.
  - The broad framework of the EPP is consistent with WB BP 4.37 annex A but needs to be detailed before construction.
  - All Mechanical and electrical control equipment shall be backed/double up to ensure a high level of capacity in case of emergency. This shall be described in a specific document or chapter of the description of the equipment, mainly for the spillway, even if the powerhouse equipment shall also be fully equipped for cases of emergency. The question at this stage of development will be on how the security equipment will in all cases enable to let the flood go through the facility and on what auxiliary systems will be provided to enable the power and control;
Opening gates pattern shall be provided in the feasibility study in order to check the capacity of the spillway. They should be adapted with regards to scouring tests on physical model.

Great care will be needed when setting operation procedures for the cleaning boat manoeuvring just upstream the dam in order to secure these operations.

The fish pass intake shall be considered as a water retaining structure and its design flood should be provided.

The design of cofferdams shall be completed with seepage assessment as curtain grouting is just in contact with impervious layers, as well as a suitable monitoring system for watering and dewatering procedure.

The material used for river closure is not specified. Its stability shall be controlled.

There is no emergency bulkhead for filling and emptying system of navigation lock.

Hourly limits to upstream and downstream water level fluctuations should be set and used in operation policies, as they are more relevant for both bank stability and riparian population.

- **Sediment Transport and River Morphology:** Current design with 11 surface spillways (220 m), 3 middle level spillways (212 m) and 2 bottom outlets (205 m) is a relevant foundation of a run-of-river scheme on the Mekong River.

  - This design with middle level and bottom outlets is potentially in capacity to pass from suspended to bed-load in a way that most closely mimics the natural timing of sediment transport in the river.
  
  - The Developer shall continue data collection, as well as hydrologic and sediment measurements in the future.
  
  - The current level of sediment on-site measurements is now relevant to increase the knowledge of this part of the Mekong, first in natural conditions. Due to these sound data, the Developer provides relevant studies of sedimentation impact, only additional information and simulations are still required to ensure the compliancy of the project and control its adverse impacts.
  
  - As a consequence of the new design, a new version of the reservoir operating pattern allows potentially mimicking the seasonal distribution of sediment supply. The Developer has to study more in detail specific operating conditions, liaise with sediment strategy plan. Several modes of operating the reservoir are now possible in the future, from high flows when flood occurs, to low flows when seasonal drawdown of the reservoir water level has to be mandatory for sediment issues.
  
  - All strategy measures can be optimized by sedimentation studies, like releasing operations for each modes of transport by seasonal drawdown for instance, in coordination with upstream and downstream HPP operators. Adaptive measures can be evaluated at feasibility stage, and if necessary and consistent, reservoir operating pattern could be adjusted in the future.

- **Navigation:**

  - The issues relative to lock design and navigation conditions have been improved in the frame of the review. Most of the MRC guidelines have been fulfilled even if there are still some points to be completed;
  
  - The lock design has been well studied thanks to a physical model (1/20) and is suitable for Pak Lay HPP scheme even if the following issues can be highlighted:
    
    - Operating conditions need to be adapted with respect to high velocities;
    
    - Physical model study report is missing and would have brought valuable information for a better understanding of the results obtained during the tests.
  
  - Lock equipment is compliant. Operation and maintenance policies have been more described even if some point still need to be detailed;
  
  - The flow conditions in approach channels have been studied on a 1/100 physical model:
    
    - The upstream lock approach seems to be safe even if velocities higher than 0.8 m/s (threshold value for Chinese guideline) can occur for discharge higher than 13 500 m³/s;
    
    - The downstream lock approach seems to be very disturbed (cross-current and backflow) and may raise problem for vessels;
    
    - Physical model study report is missing and would have brought valuable information for a better understanding of the results obtained during the tests;
  
  - The sediment issue is shortly addressed through a 2D numerical modelling study. It is strongly advocated to survey regularly (at least each year) the approach channels areas in order to implement dredging operations if necessary.

Pak Lay Developer did major efforts to meet all international standards and to provide relevant technical answers to all comments CNR experts did during the review.
As a consequence, Pak Lay HPP has been improved a lot. At the end of the FS review at Lao level, Pak Lay project is nearly fully compliant with MRC guidelines and international standards.

Remaining issues should be easily addressed by the Developer during the next stage of the project.

There is no blocking point for Pak Lay project.

The final design of Pak Lay HPP, featuring spillway, middle level gates and LLOs, should allow efficiently mimicking the impact of sedimentation upstream the dam site. In addition, this design is very flexible and will ease operation whatever the inflow is.
The Mekong is the tenth-largest river in the world. The basin of the Mekong River drains a total land area of 795,000 km² from the eastern watershed of the Tibetan Plateau to the Mekong Delta. The Mekong River flows approximately 4,900 km through three provinces of China, continuing into Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam before emptying into the South China Sea.

The Mekong River Basin includes seven broad physiographic regions featuring diverse topography, drainage patterns and geomorphology. The Tibetan Plateau, Three Rivers Area and Lancang Basin form the Upper Mekong Basin. The Northern Highlands, Khorat Plateau, Tonle Sap Basin and Mekong Delta make up the Lower Mekong Basin.

In 1994, the Mekong mainstream run-of-river Hydropower Study, led by the Mekong Secretariat Study team, identified and assessed opportunities for economic development without storage reservoirs along the Mekong River mainstream between the Myanmar border and Phnom Penh city. Thanks to this particular study and other studies achieved during the last twenty years, a list of hydropower projects considered in LAO PDR, based on run-of-river concept instead of large storage dam have been identified as best feasible options for the economic development of the whole LMB (Lower Mekong Basin).

Since 2006, interest in hydropower has escalated in the Lower Mekong Basin (LMB) accompanied by increasing private sector investment in power infrastructure. Today most Mekong River tributaries are already implementing cascades of dams (planned, under construction or in operation) with around 71 projects expected to be operational by 2030.

Over the past few years, investors and developers mostly from China, Malaysia, Thailand and Viet Nam have submitted proposals for twelve hydropower projects on the LMB mainstream.

According to the 1995 Mekong Agreement, which established the MRC, member Countries need to hold prior consultations in order to address the trans-boundary impacts that mainstream Mekong development may have on neighboring countries, before any commitment is made to proceed. The consultation process aims to prevent adverse impacts on riverine communities and the environment downstream.

Among these projects, the GoL through the Department of Energy and Business (DEB) of the Ministry of Energy and Mines (MEM) decided to proceed to an internal review at Lao level and examine the Feasibility Study of PAK LAY project submitted by POWERCHINA Resources Ltd. (Powerchina, PR China).

PAK LAY is located around 240 km upstream of Vientiane and about 30 km from Pak Lay District. The hydropower project is located downstream the 1275 MW Xayaburi HPP project (under construction) and upstream the planned Sanakham HPP project. The project was initially developed by Sinohydro Corporation Ltd (Sinohydro) along with China National Electronics Imp&Exp Corporation (CEIEC) thanks to a MOU signed with GoL in 2007. Rights and obligations arising from Sinohydro have then been transferred to Powerchina Resources Ltd (hereafter called PCR).

The project features a dam of 52 m height enabling a normal water level at 240masl, navigation locks, spillway, fish passage and the powerhouse. The powerhouse is equipped with fourteen units of 55MW each, totaling an installed capacity of 770 MW and expect yearly energy production of more than 4,140 GWh/y.
Figure 1: Location of Pak Lay HPP in the LMB
2 METHODOLOGY AND ORGANIZATION

2.1 Methodology and scope of the study

The Pak Lay run-of-river hydropower project proposed to Lao PDR by PRC along with CEIEC (China National Electronics Imp&Exp Corp.) is settled on the mainstream of the Lower Mekong Basin, 30 km far from Pak Lay district. The project implementation should bring potential opportunities for economic development of the region, mainly through enhanced electricity supply and improved conditions for inland navigation. The project should also integrate the most suitable mitigation measures in order to prevent any social and environmental impacts or other potential risks development in the four MRC Member Countries.

This review is held at National Level before any submission by the GoL to the MRC (see figure 2). The purpose of this study has been set up by the MEM in order to assess and optimize the project before submission, evaluate the level of compliance of the project with international standards and guidelines proposed by MRC for the mainstream dams in the LMB (MRC, 2009).

CNR analyzed the Feasibility Study submitted by the Developer to GoL in order to check their eligibility regarding these standards. The four following technical topics are assessed in particular by CNR:

1. Hydrology,
2. Safety of Dam,
3. Sediment Transport and River Morphology,

The components “fish migration and passage” & “water quality” require a very specific knowledge, which cannot be considered transposable by CNR from the Rhône River knowledge to the Mekong River. Thanks to a separate contract, the GoL has therefore assigned international consultants that are experts of tropical fishes and water quality for those topics.

The revision process is broken down as indicated in the red dotted line below. It is not a GO or NO GO process. GoL is the only one to deliver the green light to move forward to PDA and PNPCA.

![Figure 2: Project Validation Chart](image)

The project reviews are held at Lao Level, i.e. before any submission to the PNPCA process. The objective of the review at Lao level is to make sure that Pak Lay project is fully compliant with international standards before it can be validated by GoL and then submitted to MRC for PNPCA.
2.2 CNR presentation

Since 1994 CNR has been supporting LAO PDR regarding the development of the current LMB hydropower potential. CNR as operator of the largest French River in term of Hydropower production has provided his experience and expertise to help the stakeholders in the choice of the best master plan for economical and sustainable development of the Lower Mekong Basin.

CNR has been supporting the different LMB stakeholders including GoL regarding a large panel of engineering practices, including among others mainstream low head hydropower generation, navigation improvement, irrigation, tourism development and drainage management,… with a constant focus in sustainable environmental management.

Storage sites in the major tributaries should contribute not only to power generation but also to flow regulation on the Mekong mainstream. CNR also studied the impact of HPP development on Lao main tributaries seeing that this development should have an impact on the economy of mainstream projects.

A summary of CNR references is presented in table 1.

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<th>Date</th>
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<td>1994</td>
<td>Mekong Mainstream Run-of-river Hydropower development study</td>
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<td>Mekong Hydrological Cycle Observing System (4 countries of the LMB basin)</td>
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<td>Best practices in river regulating works for navigation safety and improvement on the Mekong River</td>
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<td>Mekong MRC guidelines for lock design and construction</td>
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<td>2009</td>
<td>Optimization study of the Mekong Mainstream Hydropower projects</td>
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<td>2009-2010</td>
<td>Feasibility study FS and ESIA of the THAKHO run-of-river HPP</td>
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<td>Peer-review of the Pöyry Compliance report for XAYABURI HPP on 3 areas: hydrology, navigation and sediments</td>
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<td>Assessment on sediment transport 1000 km of Mekong river U/S and D/S XAYABURI and recommendations for HPP operation.</td>
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<td>Development of a hydrology monitoring and forecasting system for XAYABURI Project, both during construction and operation</td>
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<td>GOL-MEM</td>
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Table 1: CNR references in Laos
2.3 Pak Lay HPP review in brief

2.3.1 Documents reviewed

The documents reviewed in the frame of this study are listed below:

- FS report
  - General description
  - Hydrology
  - Engineering Geology
  - Project Planning
  - Project Layout and Structure
  - Mechanical and Electrical
  - Construction Organization Design
  - Project Cost Estimation
  - Economic Evaluation
  - Drawings
- ESIA

The review also takes into account additional material prepared and sent to CNR by the Developer during the review process.

The last versions of the FS were released on September 7th and October 8th, 2016.

2.3.2 Principle of the review

For each topic reviewed, the objective is to check whether each issue corresponding to this topic is compliant or not with international standards. Depending on the level of complianty, CNR has requested some additional studies or suggested to redesign the project.

Figure 4: Principle of the review
### 2.3.3 Planning of the review

Initially, it was planned to have a 6-month review for Pak Lay project. The three main phases were as follows:

- Inception Phase including an inception report, an inception workshop and a site visit;
- Interim Phase including an interim report and an interim meeting;
- Final Phase including a final workshop and the delivery of the final report.

<table>
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<tr>
<th>N°</th>
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<td>B</td>
<td>PROJECT REVIEW</td>
<td>Intermediate report - REPORT B, Hydrologic data, navigation, sediment transport, Dam safety.</td>
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**Figure 5: Initial planning of Pak Lay FS review**

Finally, the process lasted a bit more than 12 months seeing that additional studies and some redesign were mandatory before reaching a 100% or nearly 100% level of compliancy for Pak Lay project. In addition, two site visits during low flow season and high flow season were necessary. Then, many additional exchanges were also needed to ensure good communication between the Developer and CNR experts. The purpose of these additional exchanges was to make sure that Developer had fully understood CNR concerns and agreed to address the corresponding issues. Additional exchanges consisted of emails discussions, exchanges of additional documentation and progress meetings in Vientiane.

<table>
<thead>
<tr>
<th>N°</th>
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**Figure 6: Final planning of Pak Lay FS review**

This report is the final report. It is based on the final documentation released by the Developer in September and October 2016. This documentation was discussed during the final workshop that took place in DEB office on September 21st, 2016.
3 MAIN CONCERNS ADDRESSED DURING THE REVIEW

This section highlights the main issues that were raised by CNR experts during the review. They lead to open and fruitful discussions with the Developer. They are usually the reasons why the project was not compliant or not fully compliant at the beginning of the review.

3.1 General issues

A. Monitoring

Feasibility study lacks of monitoring and site-specific data collection regarding water level, discharge and sediment measurements. This information is mandatory for QA&QC process and to make sure that discharge and sediment transport assessment made at the dam site are consistent with local specificities of the proposed dam location.

Site-specific data are also useful to check that discharge assessment at the dam site based on MRC gauging station located on the Mekong mainstream are consistent with local observed measurements.

This data is also mandatory for hydraulic modelling calibration and validation. In addition, for hydraulic modelling, the Developer should proceed to several surveys on water lines, topography and bathymetry all along the expected reservoir area. This information is of major importance for hydraulic calculation, the assessment of the base line before project implementation and the impact assessment of Pak Lay project (both upstream and downstream). Hydraulic modelling may also be used for the calculation of the backwater effect of the project.

Finally yet importantly, site-specific data are used as input to physical modelling. Therefore, the more reliable the data are, the more reliable the results are. If the Developer do not proceed to monitoring on site, it may be difficult to be confident in the results presented.

B. International Standards

End of August 2009, MRC has published the “Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin”. This document describes the major requirements that every project needs to fulfil before construction and operation. This report clearly highlights what MRC expects to read in a FS for the mainstream dams. It clearly highlights what MRC will be looking for during PNPCA and, if not available, what may lead to a not compliant project.

The report always remained at a preliminary stage. That is why MRC is working on a new release of this documentation. Interim reports are already available on MRC website (still available on November 3rd, 2016): [link]

The last version of this release is available since end of 2015.

In addition to MRC guidelines, Developer shall refer to international standards such as:

- ICOLD bulletins about safety of dams,
- World Bank operational policy on safety of dams,
- International best practices regarding monitoring and modelling,
- …

Usually, the Developer referred only to Chinese standards. If Chinese standards are more stringent than international standards, using Chinese standards is possible but the Developer should clearly highlight why Chinese standards are more stringent. If Chinese standards are less stringent than international standards, international standards shall be selected.

C. Documentation

Many comments made by CNR experts to the Developer are due to a lack of documentation. Some management plans are required and must be delivered together with the FS. If the concern is not addressed or simply not mentioned in the FS, then the project is not compliant just for this reason.
Another issue is about translation. Sometimes the documentation that is required by CNR experts is available but not in English. It is very important to provide the whole documentation in English at the beginning of the review.

D. Design, construction and operation
The Developer is quite familiar with design and construction stages. Even though the Developer is familiar with design and construction, the project is not fully compliant at the beginning of the review. However, design and civil works issues can usually be addressed in a correct manner by the end of the review.

Regarding other issues such as operation of a HPP and, more precisely, operation of a run-of-river project located in a cascade of dams, there is most of the time a lack of capacity and experience on the Developer side. During the review, CNR has always kept in mind that Pak Lay HPP shall be fully compliant with international standards during design, construction and operation stages.

By operation, CNR understands the follow-up of run-of-river concept, the definition of an appropriate operation pattern for the project and the management of the transparency of the project regarding flow, sediment and boats (considering only the 4 topics addressed by CNR) in order to ensure the safety of people and dams whatever the inflow is (see Section 3.2 for the presentation of the run-of-river concept).

E. Xayaburi HPP as a benchmark and consistency of the cascade
Xayaburi HPP is currently under construction (around 70% completed). It will be the first mainstream dam in Laos to start operation. COD is October 2019 but might be reduced by several months.

Xayaburi HPP is now a benchmark for every mainstream HPP. In addition, for safety reasons, no weak point can be allowed along the cascades of 5 HPPs that are planned upstream Vientiane.

Consequently:

- The spillway capacity of each single project must be consistent with the spillway capacity of the projects located both upstream and downstream;
- In order to deal with sediment rooting operation, Xayaburi Developer has implemented 4 low level outlets (LLO). This is required for every single project. Nevertheless, as Xayaburi already implemented and started operating such LLOs, it is mandatory that every project implement such LLOs. LLOs will also help every project having flexible operation patterns. A good design will allow having flexible operation and avoiding retro-fitting;
- Operation patterns of each project must follow run-of-river concept. In addition, they must be consistent and coordinated from upstream to downstream. At this stage of River Mekong development, it is not yet possible to deal with coordination. Nevertheless, it’s already possible to make sure that every single project follow the same concept and that operation of every single project is as flexible as possible so that natural flow conditions during flood events can be recovered from Pak Beng HPP to Sanakham HPP.

Figure 7: Cross section of Xayaburi dam featuring 7 spillway gates and 4 low level outlets
3.2 Run-of-river concept

3.2.1 Features and limitations of run-of-river concept

Basically the run-of-river concept is based on the following principles:

- The storage capacity of impoundments shall be neglected compared to river flow volumes, especially flood volumes;
- There is neither possibility of inter annual regulation nor seasonal regulation, even weekly;
• There is no significant active storage, with regards to the large storage of the entire reservoir. Use of the total storage capacity would lead to low water level, i.e. not enough head at the power station, limited draught jeopardizing navigation, high head for pumping stations;
• Output flow released downstream the dam nearly equals inflows upstream the dam;
• The turbine flow equals the Mekong River flow for river flow less than or equal to the design flow of the power station;
• Discharge through turbine should be adjusted in real time to fit Mekong River flow fluctuations;
• When the river flow exceeds the design flow of the powerhouse, the spillway gates are opened progressively allowing excess water to flow downstream. Spillway opening is made progressively in order to ensure safety downstream the dam and the stability of the riverbanks. The water level upstream the dam can be maintained at the normal water level as long as there is no major impact upstream the dam;
• For current floods, the operating water level shall be slowly decreased by several meters in order to respect natural flow regime;
• For major flood events, the operating water level should be similar to the natural flood regime of the river during such flood events. The dam shall have no impact on the water level. The project is then transparent.

To manage a run-of-river HPP, it is then mandatory to anticipate inflows as soon as possible in order to have enough time to decrease the water level upstream the dam when the discharge is increasing and reaching values equal or above on-going flood events.

This means that a hydrological monitoring and forecasting system must be implemented on site. The different water level and discharge values that are characteristic of a given run-of-river scheme must be assessed before starting dam operation. In addition, an appropriate operation pattern must be defined for each HPP.

### 3.2.2 Management of Operating Water Level

In normal operating conditions (input flow less than flow capacity of the power station), small variations of the pond operating water levels are acceptable. The variations must be comprised between a maximum operating water level (MOWL) and a minimum water level (mOWL), also called dead water level (DWL) in Pak Lay HPP FS. These variations aim at optimizing the energy production and management taking into account PPA and operation constraints (figure 8).

The variation of OWL upstream the dam is possible only when river flow is below the design flow of the powerhouse. Large water level variations are not acceptable because of the following constraints on:

• Navigation: minimum draught is required for boats to reach the lock upstream the dam. The tail of the reservoir must not be the weakest link of the navigable channel;
• Bank: bank stability can be affected by quick decrease of water level along the river;
• Environment: fauna and flora can be threatened by high daily water level variations along the river;
• Impact: OWL variations should not lead to any additional impact upstream or downstream the dam site.

When discharge values exceed the installed capacity of the powerhouse, a run-of-river hydropower station does not have available storage volume. The water level can be maintained at the normal value (NOL) as long as there is no major impact upstream the dam.

Then, for current floods (discharge above Qfl1 value and below Qfl2 value on figure 8), the operating water level should be slowly decreased by several meters in order to respect natural flow regime.

Finally, for major flood events (discharge above Qfl2 value), the operating water level should be similar to the natural flood regime of the river during such flood events. The dam should have no impact on the water level.

It is mandatory to anticipate inflows as soon as possible in order to have enough time to decrease the water when the discharge is increasing from Qfl1 to Qfl2. The different water level and discharge values that are characteristic of a given run-of-river scheme (like Qfl1, Qfl2, gradient of water level decrease from Qfl1 to Qfl2… see figure 8) must be assessed before starting dam operation.
3.2.3 Flood management

3.2.3.1 Normal conditions

In normal conditions, i.e. without floods, the surface of the pond area can be considered as nearly horizontal along the river upstream each dam, since the backwater slope is very low. All the flow crosses the powerhouse turbines. The spillway and bottom gates are closed until the input flow reaches the installed flow capacity of the powerhouse.

3.2.3.2 Flood conditions

During high flows and flood conditions (for example 30-year to 100-year return period floods), the slope of the backwater curve increases along the river upstream each dam.

With:

- $Q_{fl1}$: Flood discharge at which the OWL begins to decrease;
- $Q_{fl2}$: Flood discharge at which the upstream water level must be operated following natural conditions representative of high flood events.

Figure 10: Typical operation pattern of run-of-river HPP

With:

- $Q_{fl1}$: Flood discharge at which the OWL begins to decrease;
- $Q_{fl2}$: Flood discharge at which the upstream water level must be operated following natural conditions representative of high flood events.
Keeping the same regulated water level upstream dam would lead to too high backwater curves and inundation hazard.

Correct management implies to decrease operated level during flood, and even before the onset of the flood based on the observations and results provided by the hydrological monitoring and forecasting system. Spillway gates are partially and gradually opened and regulated level decreases. Decrease of water level is performed slowly in order not to create excess of flow downstream nor destabilize banks in the reservoir.

For largest floods, such as the 2000-year design flood, all spillway gates are fully opened, water level in the reservoir is close to the water level in natural conditions, preventing extra inundation hazard.

![Diagram of normal and flood periods with controlled water levels](image)

**Figure 11: Cascades of run-of-river projects operation**

### 3.3 Specific issues for Pak Lay HPP

#### 3.3.1 Hydrology

Main issues controlled, addressed and discussed during the reviews are as follows:

- Control the hydrological study made available by the Developer and hydrological data used,
- Control of design flood and check flood values,
- Study of HPP impact on hydrology both upstream and downstream the dam,
- Analysis of the operation pattern following run-of-river concept and its effect on reservoir water levels and water release (as compared to inflow),
- Presentation of Developer’s plans regarding the implementation of a hydrometeorological monitoring and forecasting system,
- Assessment of hydrology considering the impact of flows released by Yunnan Cascade and HPP under development on the main tributaries upstream each HPP. A first insight in climate change impact should also be provided. These points do not modify the design of the project but have an impact on the power generated by each project.
3.3.2 Dam Safety

Main issues controlled, addressed and discussed during the reviews are as follows:

- Stability of the dam,
- Seismic hazard study,
- Design of the spillway including overtopping, capacity of the spillway and selection of gates (radial gates with flaps are recommended when not already implemented by the Developer),
- During extreme flood events: access to the dam site, gate(s) failure...
- Management of construction period;
- Presentation and detailed descriptions of all the required plans:
  - Plan for construction supervision and quality assurance,
  - Instrumentation Plan,
  - Operation and Maintenance Plan,
  - Emergency Preparedness Plan,
  - Dam Safety Management System.

3.3.3 Sediment Transport and River Morphology

Main issues controlled, addressed and discussed during the reviews are as follows:

- Control that the 3 major modes of sediment transportation are considered:
  - Very fine particles transported as uniform suspension or washload (i.e. clay and silt),
  - Fine bed-material particles transported as graded suspension (i.e. fine sand),
  - Coarse bed-material particles transported as bed-load (i.e. coarse sand and gravel);
- Analysis of field data collected at the dam site and in the reservoir area (concentration and grain size distribution of suspended load, concentration of graded suspended load, gradation curve of bed load...).
- Control of the project design that must include LLOs: According to MRC guidelines, bottom gates should be located as low in the dam as possible, as wide as possible, and in sufficient number;
- Considering input data and design, control that the reservoir operation curve will better mimic the seasonal distribution of sediment supply and allow limiting the sedimentation rate in the reservoir especially for bed-materials like sand and gravel. The purpose is to go back nearly to natural flow conditions at the dam site whatever the inflow is when all the gates are fully opened;
- Assessment of the sediment management strategy and the sediment monitoring system proposed by the Developer.

3.3.4 Navigation

Main issues controlled, addressed and discussed during the reviews are as follows:

- Lock design:
  - General design such as head, length, width that must fulfil specific requirements for navigation on the mainstream,
  - Design of the filling and emptying system,
  - Control of its hydraulic performances (lockage time, flow velocity in the culvert...),
  - Analysis of forces exerted on the vessel,
  - Risk of overfilling or over emptying of the lock;
- Lock approach and alignment:
  - Flow conditions both upstream and downstream for the range of discharge values corresponding to the operation of the lock,
  - Safety of access both upstream and downstream,
  - Length of guiding walls both upstream and downstream,
  - Sediment deposition in upstream and downstream approach channels and corresponding mitigation measures;
4 PAK LAY PROJECT PRESENTATION

4.1 Pak Lay HPP location

Pak Lay HPP is located in the Pak Lay District of Xayaburi Province in Lao PDR, upstream the city of Pak Lay. The catchment area is 278 400 km².

Figure 12: Location of Pak Lay HPP in Lao PDR

4.2 Pak Lay HPP main features

The facility has a design capacity of 770 MW and the power production should be sold to EDL. The maximum dam height is 51.2 m. The power house features 14 bulb units for a design head around 14.5 m. The normal water level upstream the dam is 240 m asl.

More information is provided in the following tables (source: Pak Lay FS report). Figure 5 provides an overview of the project layout.
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</tr>
<tr>
<td>Reservoir capacity</td>
<td>$10^6$ m³</td>
<td>890</td>
</tr>
<tr>
<td>Live storage</td>
<td>$10^6$ m³</td>
<td>58.4</td>
</tr>
<tr>
<td>Reservoir area</td>
<td>km²</td>
<td>-</td>
</tr>
<tr>
<td>Project benefit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installed capacity</td>
<td>MW</td>
<td>770</td>
</tr>
<tr>
<td>Annual utilization of installed capacity</td>
<td>h</td>
<td>5357</td>
</tr>
<tr>
<td>Annual average generating capacity</td>
<td>GWh</td>
<td>4124.8</td>
</tr>
<tr>
<td>Improved channel length</td>
<td>km</td>
<td>-</td>
</tr>
<tr>
<td>Tonnage of ships</td>
<td>t</td>
<td>500</td>
</tr>
<tr>
<td>Total tonnage of ship passing</td>
<td>$10^6$ t/y</td>
<td>2.430</td>
</tr>
</tbody>
</table>

Table 2: Pak Lay HPP main features (1/3)
<table>
<thead>
<tr>
<th>Main structures</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design aseismic intensity</td>
<td>g</td>
<td>0.133</td>
</tr>
<tr>
<td>Type</td>
<td>-</td>
<td>Concrete gravity dam</td>
</tr>
<tr>
<td>Dam crest elevation</td>
<td>m asl</td>
<td>245</td>
</tr>
<tr>
<td>Maximum dam height</td>
<td>m</td>
<td>50.98</td>
</tr>
<tr>
<td>Dam crest length</td>
<td>m</td>
<td>942.75</td>
</tr>
<tr>
<td><strong>Spillway</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weir crest elevation</td>
<td>m asl</td>
<td>220</td>
</tr>
<tr>
<td>Spillway length</td>
<td>m</td>
<td>-</td>
</tr>
<tr>
<td>Number</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>Size (WxH)</td>
<td>m³</td>
<td>16 x 20</td>
</tr>
<tr>
<td><strong>Low level outlet</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weir crest elevation</td>
<td>m asl</td>
<td>212</td>
</tr>
<tr>
<td>Number</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Size (WxH)</td>
<td>m³</td>
<td>16 x 28</td>
</tr>
<tr>
<td><strong>Powerhouse structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powerhouse designed working flow</td>
<td>cms</td>
<td>6101</td>
</tr>
<tr>
<td>Unit installation elevation</td>
<td>m</td>
<td>208.5</td>
</tr>
<tr>
<td>Powerhouse size</td>
<td>m³</td>
<td>400x22.5x52.44</td>
</tr>
<tr>
<td><strong>Navigation lock</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size (WxHxwater depth)</td>
<td>m³</td>
<td>120x12x4</td>
</tr>
<tr>
<td>Maximum working head</td>
<td>m</td>
<td>21</td>
</tr>
<tr>
<td>Reservation area for 2nd lock</td>
<td>-</td>
<td>Right edge</td>
</tr>
<tr>
<td>Total length</td>
<td>m</td>
<td>164.5</td>
</tr>
<tr>
<td><strong>Fishway</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom slope</td>
<td>%</td>
<td>2.06</td>
</tr>
<tr>
<td>Width</td>
<td>m</td>
<td>6</td>
</tr>
<tr>
<td>total length</td>
<td>m</td>
<td>1017</td>
</tr>
<tr>
<td>Flow velocity</td>
<td>m/s</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3: Pak Lay HPP main features (2/3)
### Table 4: Pak Lay HPP main features (3/3)

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of units</td>
<td>-</td>
<td>Bulb</td>
</tr>
<tr>
<td>Number of units</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>Rated output</td>
<td>MW</td>
<td>56.41</td>
</tr>
<tr>
<td>Maximum head</td>
<td>m</td>
<td>20</td>
</tr>
<tr>
<td>Rated water head</td>
<td>m</td>
<td>14.5</td>
</tr>
<tr>
<td>Minimum head</td>
<td>m</td>
<td>7.5</td>
</tr>
<tr>
<td>Design discharge</td>
<td>cms</td>
<td>6101</td>
</tr>
<tr>
<td>Rated discharge</td>
<td>cms</td>
<td>435.79</td>
</tr>
</tbody>
</table>

**Estimated cost**

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Project Cost</td>
<td>MUSD</td>
<td>1511.5</td>
</tr>
<tr>
<td>Total Investment</td>
<td>MUSD</td>
<td>2142.2</td>
</tr>
</tbody>
</table>

**Figure 13: Pak Lay HPP General Overview**

![Pak Lay HPP General Overview](image)
Figure 14: Pak Lay HPP General Layout (1/2)

Figure 15: Pak Lay HPP General Layout (2/2)
5 HYDROLOGY

5.1 Scope of the review

Following the objectives of the review presented in Section 3.3.1, this section will focus on:

- Analysis of hydrological studies, including input data and flood assessment,
- Assessment of the upstream dams impacts on flows (Yunnan Cascade and dams on tributaries in Laos),
- First insight in climate change impact,
- Analysis of the planned operation pattern of the project and its effect on reservoir water level and water release values (as compared to inflow).

The present analysis is based on the following documents provided by the Developer and elaborated by Hydrochina Zhongnan:

- Pak Lay Hydroelectric Power Project Feasibility Study, version transmitted to CNR in September 2016,
- Chapter 2 – Hydrology of Pak Lay Hydroelectric Power Project Feasibility Study:
  - Version of September 7th 2016,
  - Version of October 8th 2016.

5.2 Analysis of Hydrological Studies

The hydrological report includes:

- a general overview of the catchment with the overview of physical geography, location of Pak Lay HPP and a brief presentation of some HPP projects in Yunnan,
- meteorological information including some general statements about meteorological stations and their main features,
- presentation of the basic hydrological data used in the FS, including presentation of the station network and data available,
- calculations of runoff series at the dam site taking into account Luang Prabang and Chiang Khan gauging stations,
- assessment of flood events, with the properties of storm and corresponding flow generated, interpolation of flood data and assessment of design flood and check flood values,
- assessment of the rating curve at the dam site cross-section.

5.2.1 Hydrological data

Hydrological data used in the FS are based on MRC hydrological stations at Luang Prabang (1960-2015) and Chiang Khan (1967-2015). Daily discharge values from Chiang Khan gauging station have been used from 1960 to 2015. This means that the period 1960-1967 has been reprocessed for Chiang Khan gauging station according to data from Luang Prabang gauging station over the same period of time.

The Developer uses all the historical data available for each gauging station. It is very important to have data up to 2015 seeing that:

- 2008 flood, which is a major flood on the Mekong basin upstream Luang Prabang, is included;
- Regarding low flows during the dry season, the last 2 years are characterized by major impacts of water released by Yunnan Cascade. The flows of these 2 recent years have no impact on the design of the project. However, it is useful to take them into account regarding:
  - the study of typical dry years,
  - the assessment of construction site safety during low flows,
  - the impact on the HPP power generation capacity of an increase of discharge during the dry season.

The Developer also collected and analysed data available at Pak Lay DMH gauging station in Pak Lay city. Nevertheless, this station has very limited data and poor data quality.
The Developer proceeded to measurements on site at the beginning of the project development (December 2007). The gauging station was lost during August 2008-flood event. The Developer installed new manual gauging stations during the FS review following experts’ requirements in March 2016. An automatic one has been working at the dam site since June 2016. Time for data collection is necessary before the Developer can rely on this data for the design of the project. However, the Developer could already proceed to QA&QC assessment of existing methodologies used in the FS in order to make the design of the project.

Usually, the FS lacks QA&QC process:

- There is very limited control of data quality for water level measurements, discharge assessment and rating curves.
- There is limited analysis of the consistency of input data. MRC data are directly adopted mainly because this data is published by MRC;
- The Developer should provide evidence that reprocessing the data in Chiang Khan from 1960 to 1967 according to Luang Prabang data is relevant. In addition, reprocess is based on an area ratio method, which is the same method as the one used to assess flow at the dam site. This implies that from 1960 to 1967 flow at the dam site is depending only on Luang Prabang data;
- The Developer shall calibrate the methodologies according to on-site measurements. The Developer shall at least control the accuracy of the methodologies based on observed data. For example, the Developer shall control the accuracy of the methodologies used to assess discharge values at the dam site based on observed data water level and discharge values at this location.

The Developer shall continue collecting site-specific data (water level, discharge...) and use this data as input to the modelling. This data shall also be used to control the quality of the methodologies used by the Developer in the FS.

### 5.2.2 Assessment of flows at the dam site

Calculations of flows at the dam site are based on Chiang Khan and Luang Prabang gauging stations with an area ratio method. The mean flow of the dam site is estimated at 4,060 m$^3$/s over the period 1960-2015. The Developer shall control the interpolation method based on data collected nearby the dam site.

The rating curve at the dam site is based on the water level correlation between gauging stations from January 2008 to March 2009 and the rating curves of Chiang Khan and Luang Prabang gauging stations. At this stage, there are limited analysis of existing rating curves quality and limited discharge measurements available. The few measurements already available are not used by the Developer to calibrate the rating curve (figure 16). The Developer prefers waiting one year of hydrological data to complete the rating curve.

The Developer could already make a preliminary update of the rating curve according to the measurements already available. It is not mandatory to wait one-year data collection before starting updating the rating curve.
In a word:

- the Developer shall confirm the rating curve definition based on measurements at the dam site and not only based on calculation;
- the Developer shall proceed to continuous water level monitoring and regular discharge measurements at the dam site, even after the first one-year data sample is collected.

### 5.2.3 Flood estimation

Design flood (DF) and check flood (CF) values selected by the Developer for Pak Lay project are respectively the 2,000-year flood i.e. 34,700 m$^3$/s and the 10,000-year Flood i.e. 38,800 m$^3$/s. These values are consistent with recent recommendations made by ICOLD and French branch of CIGB. They are also consistent with other projects located both upstream and downstream (cf. Section 3.1 regarding the consistency of the cascade of dams upstream Vientiane, table 5).
Finally, the Developer adopts the flood values of the 2009 Mekong Mainstream Optimization Study performed by MRC and CNR for the Ministry of Energy and Mines (table 6).

<table>
<thead>
<tr>
<th>Return Period (y)</th>
<th>Developer (cms)</th>
<th>Optimization Study (cms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>19000</td>
<td>19000</td>
</tr>
<tr>
<td>10</td>
<td>21100</td>
<td>21100</td>
</tr>
<tr>
<td>20</td>
<td>23000</td>
<td>23000</td>
</tr>
<tr>
<td>50</td>
<td>25500</td>
<td>25500</td>
</tr>
<tr>
<td>100</td>
<td>27200</td>
<td>27200</td>
</tr>
<tr>
<td>200</td>
<td>29000</td>
<td>29000</td>
</tr>
<tr>
<td>500</td>
<td>31200</td>
<td>31200</td>
</tr>
<tr>
<td>1000</td>
<td>33000</td>
<td>33000</td>
</tr>
<tr>
<td>2000</td>
<td>34700</td>
<td>34700</td>
</tr>
<tr>
<td>5000</td>
<td>37000</td>
<td>37000</td>
</tr>
<tr>
<td>10000</td>
<td>38800</td>
<td>38800</td>
</tr>
</tbody>
</table>

Table 6: Revision of estimated Flood discharge at Pak Lay Dam Site
5.2.4 Hydrological monitoring and forecasting system

Implementing an automatic hydrological monitoring and forecasting system is mandatory for several reasons:

- safety control during construction, operation and management of hydropower project;
- power generation optimization during operation;
- water resource management of a multi purposes HPP (navigation, fish migration, irrigation, power generation….);
- control of water level, inflow and outflow in order to operate Pak Lay HPP following the run-of-river concept.

The Developer plans to implement such system. First gauging stations are already under operation at the dam site. The system will be useful during the next development stage in order to finalize the optimization of the project (validation of rating curves and methodologies for example). It has to be maintained during construction and operation.

Developer’s plans regarding monitoring are based on the assumption that the Developer will exchange information in the future with Developers located upstream Pak Lay HPP. As a consequence, Pak Lay Developer does not need to monitor the flow upstream Luang Prabang city.

![Diagram of Pak Lay HPP hydrometeorological monitoring and forecasting system](image-url)

Figure 17: Pak Lay HPP hydrometeorological monitoring and forecasting system
This option might not be sufficient depending on:

- the time needed for flow release and water level decrease in case of flood event coming,
- the propagation time of flood event from Luang Prabang to Pak Lay HPP that has to be confirmed on observed data and hydraulic model calculations,
- the lead time required by the offtaker regarding power declaration.

The Developer fully understands the need for monitoring and forecasting. He also addresses the issue in the FS. And yet, he shall clearly state in the FS that, if needed, the current proposed monitoring system will be updated and upgraded during construction to ensure safe operation of Pak Lay HPP whatever the inflow is and to fulfill PPA requirements.

5.3 Lancang River Dams Impact on Flows at Pak Lay

5.3.1 Modeling and simulation of Yunnan Cascade

The impact of Lancang River dams was studied by CNR and P. Adamson in the framework of the Optimisation Study performed in 2009 for MEM, for the five projects planned in Lao PDR (Pak Beng, Luang Prabang, Xayaburi, Pak Lay and Sanakham).

This analysis was conducted with the assistance of the modelling team from MRCS Information and Knowledge Management Programme (IKMP) in accordance with an agreement between MRC and MEM.

The main conclusions on the flow conditions are as follows:

- The results presented in the Optimization Study are the first ones to be based upon detailed hydrological modelling at daily time step, having benefited from key data of Yunnan dams (see location on figure 18);
- These data cover the design head, installed capacity, minimum and maximum operating levels, tail water level, turbine discharge design, available active storage and reservoir area and volume versus level curves. Characteristics of Lancang River dams are reported in table 7.
- These data allow the simulation of daily flows along the dam cascade in Lao PDR for the 1985-2000 period. Simulations are based on the inflow and the available reservoir storage. Operational rule curve has been determined for each reservoir, for maximizing power and energy and minimizing spill.

In the frame of the current Pak Lay Feasibility Study review, the purpose is to assess the impact of Yunnan Cascade on low flows and high flows that will have an impact on power generation capacity of the project. The purpose is neither to provide a detailed study of the whole catchment area nor to review the design of Pak Lay project (review of DF and CF or review of the powerhouse capacity for example).

Based on the trends calculated in the frame of the Optimisation Study, CNR has assessed the impact of Yunnan Cascade on Pak Lay hydrology and has provided a first assessment of the lag time on the onset of the flood season due to Yunnan Cascade operation. To go further and get more accurate results, the Developer already started addressing specifically this issue (see Section 4.3 of the FS).
5.3.2 Impact assessment of the Yunnan Cascade

5.3.2.1 Impact on the annual flow regime

The natural flow regime of Mekong River in the project area is largely influenced by the SW Monsoon with a coherent and largely unvarying annual hydrograph. Thus, the impacts of flow regulation by Yunnan cascade are readily apparent at Pak Lay dam site. In Laos, impacts propagate from downstream the border with China to Pak Lay area. Figure 19 summarizes these impacts for Pak Lay dam site.
Figure 19: Annual daily discharge hydrographs and Annual flow duration curves at Pak Lay dam site in baseline conditions and with influence of Yunnan cascade (1985-2000)
5.3.2.2  

*Impact during the low flow season*

The major impact of Lancang River dams on LMB hydrology is that the flow increases during the low flow months from December to May. This is already observed on years 2014 and 2015 daily flows in comparison with average daily flows in the past (figure 20).

![Figure 20: Daily discharge values during years 2014, 2015 and 2016 at Luang Prabang gauging station in comparison with average statistical observations from 1939 to 2008](image)

Flow increases from nearly 60% at Pak Beng HPP to 45% at Sanakham HPP (table 8).

<table>
<thead>
<tr>
<th></th>
<th>Pakbeng</th>
<th>Luang Prabang</th>
<th>Xayaburi</th>
<th>Pak Lay</th>
<th>Sanakham</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1 160</td>
<td>1 170</td>
<td>1 360</td>
<td>1 390</td>
<td>1 450</td>
</tr>
<tr>
<td>Influenced</td>
<td>1 840</td>
<td>1 850</td>
<td>2 030</td>
<td>2 060</td>
<td>2 120</td>
</tr>
<tr>
<td>Increase</td>
<td>58%</td>
<td>58%</td>
<td>50%</td>
<td>48%</td>
<td>46%</td>
</tr>
</tbody>
</table>

Table 8: Mean discharge (cumecs) during the low flow months of January to May and the percentage increase under regulation by Yunnan Cascade (Optimisation Study)
Table 9: Pak Lay mean monthly discharge (in cumecs) and the percentage of variation under regulation by Yunnan Cascade (1985-2000)

A major positive impact is with respect to the critical low flow sequence, usually a key consideration in determining the reliability of power and energy outputs and operational criteria. For Pak Lay HPP from 1985 to 2000, analysis of mean monthly discharge values shows that the discharge increases by about 45% under regulation from December to May (table 9). Mean monthly discharge values decrease by about 10% from June to November.

The probability distribution of the monthly low flow shows the same tendency of increase under regulation at Pak Lay dam site (table 10).

During the low flow season, such increases:

- substantially add to the production of energy for a better economic viability of Pak Lay hydropower project;
- need to be taken into account in order to adapt safety procedures at the construction site during low flow construction phases in case of sudden increase of the flow on the Mekong River due to water release by the Yunnan Cascade.

5.3.2.3 Impact during the flood season

Another positive impact of the Yunnan cascade is the flood peak reduction by 10 to 15% on average during the rainy season when refilling takes place in Lancang River reservoirs. This impact of the Yunnan cascade on flood risk is reduced for floods greater than the 20-year flood and shall not be taken into account in the assessment of Design Flood and Check Flood values.

Besides, cyclones and tropical storms that have historically been responsible of the extreme events in the northern regions of the Lower Mekong Basin, generally affect the south of the Yunnan cascade and not so much the catchment area of the large Lancang River.

The flood risk decrease with influence of Yunnan cascade is presented in table 11.

<table>
<thead>
<tr>
<th>Month</th>
<th>Baseline (cms)</th>
<th>Yunnan (cms)</th>
<th>Ratio_1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1572</td>
<td>2314</td>
<td>47.2%</td>
</tr>
<tr>
<td>Feb</td>
<td>1192</td>
<td>1936</td>
<td>62.4%</td>
</tr>
<tr>
<td>Mar</td>
<td>1058</td>
<td>1790</td>
<td>69.2%</td>
</tr>
<tr>
<td>Apr</td>
<td>1184</td>
<td>1855</td>
<td>56.7%</td>
</tr>
<tr>
<td>May</td>
<td>1906</td>
<td>2364</td>
<td>24.0%</td>
</tr>
<tr>
<td>Jun</td>
<td>3425</td>
<td>3418</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Jul</td>
<td>6864</td>
<td>5523</td>
<td>-19.5%</td>
</tr>
<tr>
<td>Aug</td>
<td>9046</td>
<td>7438</td>
<td>-17.8%</td>
</tr>
<tr>
<td>Sep</td>
<td>8765</td>
<td>8088</td>
<td>-7.7%</td>
</tr>
<tr>
<td>Oct</td>
<td>5900</td>
<td>5661</td>
<td>-4.1%</td>
</tr>
<tr>
<td>Nov</td>
<td>3682</td>
<td>3535</td>
<td>-4.0%</td>
</tr>
<tr>
<td>Dec</td>
<td>2269</td>
<td>2847</td>
<td>25.4%</td>
</tr>
<tr>
<td>Average</td>
<td>3924</td>
<td>3910</td>
<td>-0.4%</td>
</tr>
</tbody>
</table>

Table 10: Distribution of monthly minimum discharge (cumecs) at Pak Lay dam site for several return periods

The flood risk decrease with influence of Yunnan cascade is presented in table 11.
### 5.3.2.4 Temporal aspect

The total active storage of Lancang River dams is equivalent to 25% of the mean annual flow volume that enters LMB from China.

Refilling of Lancang River dams causes a delay of approximately 10 days in the onset of the flood season at Pak Lay dam site.

### 5.3.3 Concluding remarks

According to the Feasibility Study, impact of Yunnan Cascade operation is taken into account. Results provided by the Developer are of the same order of magnitude as assessment by CNR. The main differences are due to the studied period of time (1985-2000 for CNR and 1960-2005 in the FS). CNR recommends considering this impact to assess energy generation taking into account discharge transfer from rainy season to the dry season thanks to the Yunnan Cascade. The Developer should provide relevant information about power generation in the frame of the Feasibility Study.

Discharge values during the dry season are already increasing thanks to Yunnan Cascade operation. For the safety of the site during the construction period and the flow conditions during Mekong River closure, the Developer should make sure that statistical analysis of low flows provided in the Feasibility Study are relevant with the impact of Yunnan Cascade on low flows.

### 5.4 Impact of planned hydro projects in Lao PDR on Flows at Pak Lay

The influence of planned dams on Lao Tributaries has not been modelled during the Optimisation Study with the MRC DSF model. However, the storage capacity of planned dams on Lao large tributaries that should have an impact on the inflow of Pak Lay project is around 11.4 km$^3$.

Potentially these dams could, if operated accordingly, have a contribution to flood mitigation and to increase flow in dry season. These Lao dams should have similar hydrological impacts as the Lancang River ones have but with a lower magnitude than Yunnan cascade dams seeing the smaller scale of these hydropower projects.

Pak Lay Developer already started to consider the qualitative impact of hydropower development in Laos on Pak Lay HPP. However, at this stage, the Developer did not provide any quantitative assessment. CNR suggests here below a preliminary estimate of such impact. The Developer will have to go more into details to get results that are more accurate.

#### 5.4.1 Modeling and simulation of planned hydro projects in Lao

##### 5.4.1.1 Data

This study is based on MEM data. In the framework of the Thakho project performed by CNR in 2010, MEM had provided data on around one hundred projects being studied, under construction or being commissioned throughout the country. Planned HPPs located on the main tributaries of the Mekong river located upstream Pak Lay project have been selected (table 12).

The Nam Ou project comprises 7 schemes. Nam Ou 7 located upstream of the Nam Ou river has the highest capacity. The capacity of the Nam Ou 7 project is big enough to reinforce inflows along the entire Nam Ou cascade throughout the dry season. According to the information provided by MEM, dam projects located downstream of Nam Ou 7 project integrate inflows from upstream. Therefore, additional discharges downstream of Nam Ou 7, for example, will be smoothed in all the succeeding schemes of the Nam Ou. Thus, if Nam Ou 1 can have a very high design discharge and achieve a high-energy generation during the dry season, it is partially due to Nam Ou 7.

<table>
<thead>
<tr>
<th>Dam site</th>
<th>Regime</th>
<th>Return Period (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>2</td>
</tr>
<tr>
<td>Paklay</td>
<td></td>
<td>13800</td>
</tr>
<tr>
<td></td>
<td>Yunnan Cascade</td>
<td>11700</td>
</tr>
</tbody>
</table>

Table 11: Annual maximum discharge (cumecs) at Pak Lay dam site under baseline and regulated flow regimes for several return periods
Hydropower projects on Nam Feuang have a very low storage capacity in comparison with the other projects. These hydropower projects can be neglected.

For projects on Nam Nga and Nam Pouy, not enough data were provided by MEM. They are just mentioned in table 12 for information.

Nam Nga is a right bank tributary of Nam Ou. Nam Nga 1 project has a huge storage capacity. There is no information available to know whether this project is taken into account in the data provided by MEM for Nam Ou 1 project.

### Table 12: Characteristics of planned hydro projects in Lao upstream Pak Lay project

<table>
<thead>
<tr>
<th>Project</th>
<th>Head (m)</th>
<th>Design discharge (cms)</th>
<th>Installed capacity (MW)</th>
<th>Full supply level (m asl)</th>
<th>Minimum operating level (m asl)</th>
<th>Active storage ($10^6 m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nam Tha 1</td>
<td>66</td>
<td>290</td>
<td>168</td>
<td>455</td>
<td>443</td>
<td>676</td>
</tr>
<tr>
<td>Nam Nga</td>
<td>97.3</td>
<td>107.9</td>
<td>97.8</td>
<td>440</td>
<td>407</td>
<td>1565</td>
</tr>
<tr>
<td>Nam Ou 1</td>
<td>21</td>
<td>1045</td>
<td>180</td>
<td>305</td>
<td>300</td>
<td>10</td>
</tr>
<tr>
<td>Nam Ou 2</td>
<td>11</td>
<td>932</td>
<td>90</td>
<td>320</td>
<td>316</td>
<td>8</td>
</tr>
<tr>
<td>Nam Ou 3</td>
<td>43</td>
<td>831</td>
<td>300</td>
<td>375</td>
<td>370</td>
<td>14</td>
</tr>
<tr>
<td>Nam Ou 4</td>
<td>16</td>
<td>558</td>
<td>75</td>
<td>400</td>
<td>395</td>
<td>9</td>
</tr>
<tr>
<td>Nam Ou 5</td>
<td>25</td>
<td>514</td>
<td>108</td>
<td>430</td>
<td>425</td>
<td>11</td>
</tr>
<tr>
<td>Nam Ou 6</td>
<td>68</td>
<td>368</td>
<td>210</td>
<td>510</td>
<td>490</td>
<td>363</td>
</tr>
<tr>
<td>Nam Ou 7</td>
<td>90</td>
<td>238</td>
<td>180</td>
<td>630</td>
<td>600</td>
<td>1134</td>
</tr>
<tr>
<td>Nam Pha 1</td>
<td>111</td>
<td>142</td>
<td>147</td>
<td>550</td>
<td>515</td>
<td>2738</td>
</tr>
<tr>
<td>Nam Soung 1</td>
<td>36</td>
<td>130</td>
<td>40</td>
<td>325</td>
<td>315</td>
<td>88</td>
</tr>
<tr>
<td>Nam Soung 2</td>
<td>123</td>
<td>120</td>
<td>134</td>
<td>460</td>
<td>435</td>
<td>2015</td>
</tr>
<tr>
<td>Nam Khan 1</td>
<td>56</td>
<td>195</td>
<td>102</td>
<td>340</td>
<td>320</td>
<td>805</td>
</tr>
<tr>
<td>Nam Khan 2</td>
<td>139</td>
<td>110</td>
<td>140</td>
<td>470</td>
<td>450</td>
<td>528</td>
</tr>
<tr>
<td>Nam Khan 3</td>
<td>79</td>
<td>70</td>
<td>47</td>
<td>560</td>
<td>532</td>
<td>861</td>
</tr>
<tr>
<td>Nam Feuang 1</td>
<td>57</td>
<td>57.12</td>
<td>28</td>
<td>340</td>
<td>334</td>
<td>30</td>
</tr>
<tr>
<td>Nam Feuang 2</td>
<td>130</td>
<td>22.89</td>
<td>25</td>
<td>570</td>
<td>565</td>
<td>5</td>
</tr>
<tr>
<td>Nam Feuang 3</td>
<td>211</td>
<td>11.28</td>
<td>20</td>
<td>820</td>
<td>815</td>
<td>5</td>
</tr>
<tr>
<td>Nam Pouy</td>
<td>78.2</td>
<td>60</td>
<td>43.73</td>
<td>340</td>
<td>320</td>
<td>499</td>
</tr>
</tbody>
</table>

MEM data on other planned hydropower projects located on the main tributaries include inflow data and releases (including spillage, that is to say overflows during the high-flow season).

Data are provided on a monthly time step basis from 1966 to 1995 or from 1966 to 2000 depending on the projects. The data are not homogeneous for all the projects. However, based on this information, differences between inflows and releases are assessed on a monthly time step basis over the period 1985-2000 in order to get the same period of study for both Yunnan cascade and planned hydro projects in Lao impacts.

#### 5.4.1.2 Methodology

Projects numbered 1 are located downstream of each river. The impacts of the planned hydropower projects located on the main tributaries in Lao will depend on discharges that will be released by these projects. Hence, the aim of this study is to assess inflows and releases for the following projects: Nam Ou 1, Nam Pha 1 and Nam Tha 1, Nam Soung 1 and Nam Khan 1. These projects will be referred to as downstream projects.

For Nam Pha 1 and Nam Tha 1 projects, estimations are based on inflows and releases provided by MEM.
For the 3 remaining tributaries, estimations take into account inflows of each downstream project and releases of projects located upstream.

Based on these data, influenced inflows for each downstream project are assessed on a monthly time step basis.

As Nam Pha 1 project data are the only ones covering the whole period 1985-2000, they are used to determine the gaps between, on the one hand, mean monthly inflows and releases calculated over the period 1966-1995 and on the other hand, monthly inflows and releases calculated for each year from 1996 to 2000. Then, the assumption is made that the gaps observed for Nam Pha 1 project are the same in terms of percentages as the gaps that could be observed for the monthly discharges of other tributaries. This assumption implies that all the tributaries have the same natural hydrologic regime. As can be seen on figure 21, this assumption is relevant over the period 1966-1995.

Finally, we get inflows and releases data for the main tributaries located upstream Pak Lay project. These data are monthly discharges. They allow assessing the difference between inflows and releases of the main tributaries upstream Pak Lay project for each month of the period 1985-2000. Starting with the influence of Yunnan Cascade, these data allow calculating the complementary impact of planned hydro projects in Lao PDR located upstream Pak Lay project.

![Figure 21: Hydrologic regime of the main tributaries upstream Pak Lay project for the period 1966-1995 (assessment based on inflows provided by MEM)](image)

**5.4.2 Impacts assessment of planned hydro projects in Lao PDR**

In the following figures, “Yunnan cascade” will refer to the discharges influenced by Lancang River schemes. “YC & Planned hydro projects in Lao” will refer to the discharges influenced by both Lancang River schemes and projects on the main tributaries in Lao PDR upstream Pak Lay dam site.

All the results are calculated over the period 1986-2000. The year 1985 is partly dedicated to initialize MRC DSF model. Therefore, the beginning of 1985 cannot be used for the statistical analysis of the impact assessment of planned hydro projects in Lao PDR.
5.4.2.1 Impact on the annual flow regime

The impacts of flow regulation by Yunnan cascade are as follows:

- Discharge increase during the low flow season: +43% on average from December to May;
- Discharge decrease during the high flow season: -11% on average from June to November;
- The mean annual discharge does not change significantly.
The impacts of planned hydro projects in Lao PDR exacerbate the impacts already calculated for the Yunnan cascade (figure 22):

- Discharge increase during the low flow season: +63% on average from December to May and +14% in comparison with discharges influenced by the Yunnan cascade;
- Discharge decrease during the high flow season: -16% on average from June to November and -6% in comparison with discharges influenced by the Yunnan cascade;
- The mean annual discharge does not change significantly.

![Figure 22: Annual daily discharge hydrographs and annual flow duration curves at the Pak Lay dam site in baseline conditions and with influences of Yunnan cascade and planned hydro projects in Lao PDR](image-url)
5.4.2.2 Impact during the low flow season

A major impact of hydropower schemes upstream Pak Lay, both in China and on the tributaries in Lao PDR, is with respect to the critical low flow sequence, usually a key consideration in determining the reliability of power and energy outputs and operational criteria.

Annual minimum monthly discharges at Pak Lay have been studied over the 15 years of the analysed period (table 13). These annual minimum monthly discharge values highlight that the 5-year return period discharge increases by 80% and 107%, under regulation respectively of Yunnan cascade and planned hydro projects in Lao PDR.

Planned hydro projects in Lao PDR exacerbate Yunnan cascade impacts.

<table>
<thead>
<tr>
<th>Damsite</th>
<th>Regime</th>
<th>Return Period (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Paklay</td>
<td>Baseline</td>
<td>1010</td>
</tr>
<tr>
<td></td>
<td>Yunnan Cascade</td>
<td>1740</td>
</tr>
<tr>
<td></td>
<td>YC &amp; Planned Hydro Projects in Laos</td>
<td>2070</td>
</tr>
</tbody>
</table>

Table 13: Distribution of minimum monthly discharge (cumecs) at Pak Lay dam site for several return periods

5.4.2.3 Impact during the flood season

Flood season flows are reduced due to the refilling of dams taking place both in China and in Lao PDR at the same time at the beginning of the rainy season each year.

However, the impact of the upstream dams in Lao PDR on flood risk is relatively small. For instance, the 10-year return period flood at Pak Lay dam site is reduced by 11% and 17%, respectively for Yunnan cascade and YC & Planned hydro projects in Lao PDR.

<table>
<thead>
<tr>
<th>Damsite</th>
<th>Regime</th>
<th>Return Period (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Paklay</td>
<td>Baseline</td>
<td>13800</td>
</tr>
<tr>
<td></td>
<td>Yunnan Cascade</td>
<td>11700</td>
</tr>
<tr>
<td></td>
<td>YC &amp; Planned Hydro Projects in Laos</td>
<td>11040</td>
</tr>
</tbody>
</table>

Table 14: Annual maximum discharge (cumecs) at Pak Lay site under baseline and regulated flow regimes for several return periods

5.4.2.4 Temporal aspect

The refilling of the reservoirs both in China and on the tributaries in Lao PDR causes delays in the onset of the flood season. The delay is around 10 days between Baseline and Yunnan cascade, and another 5 days between Yunnan cascade and planned hydro projects on tributaries in Lao PDR upstream Pak Lay dam. The total delay is of approximately 2 weeks between Baseline and YC & Planned hydropower projects in Lao PDR.

Planned hydropower projects in Lao PDR exacerbate the impacts already calculated for the Yunnan cascade.

5.4.3 Concluding remarks

Planned hydropower projects on the tributaries in Lao PDR upstream Pak Lay project will increase hydrological impacts of Yunnan cascade by increasing low flows and decreasing high flows.

Such impacts will add substantially to the economic viability of Pak Lay project particularly during the low flow season. However, they could be mitigated by the evolution of water use in the Mekong Basin (irrigation and water supply) and Climate Change. Additional studies shall be provided in order to better assess all these impacts and their consequences in terms of water volumes and timing. Monitoring will also help confirming the impacts mentioned above (see figure 20 at Luang Prabang gauging station for example).

The Developer considers that there is not enough data to deal with planned HPPs in Laos. To go further, it is necessary to update input data. A request shall be submitted to MEM by the Developer in order to collect these data and to complement those the Developer may already have (for example on Nam Ou River). Some more hydroelectric power projects in Laos and their main features should be included in the study if relevant data can be provided by MEM.
CNR recommends considering both the impact of Yunnan Cascade and the impact of HPP development upstream Pak Lay to assess energy generation taking into account discharge transfer from rainy season to the dry season. The Developer should provide relevant information about power generation in the frame of the Feasibility Study.

5.5 Impact of Climate Change on Flows at Pak Lay

The Developer should provide a first insight on climate change impact. The level of uncertainty is very high regarding the impact of climate change. Yet, as the end of the concession agreement will be around 2050, climate change cannot be ignored.

MRC provides some information about climate change at the scale of LMB. This information is available on MRC website. CNR provided some references to the Developer during the final workshop:

- Impact of climate change and development on Mekong flow regimes, First assessment, 2009, MRC report,

More references can be found on the web and on MRC website in particular.

5.6 Planned Operation Pattern of Pak Lay and its Effect on Reservoir Water Levels and Outflow (as Compared to Inflow)

5.6.1 Overview of Pak Lay HPP impacts

As Pak Lay HPP is a run-of-river project, there is limited storage capacity once the reservoir is full of water. Besides, there is no transfer of water from the rainy season to the dry season. Therefore, if operated according with the run-of-river concept, effects of Pak Lay HPP on Mekong River flow will be negligible in comparison with impacts on Mekong River flow coming from dams located on the mainstream in China and on the main tributaries in Laos.

Nevertheless, the Developer must take into account the two following major impacts:

- **Upstream the dam**: in case of flood event, inflow is increasing. The waterline slope may increase as well. If the operator maintains the water level upstream the dam site, some locations upstream the dam site that are not flooded in natural conditions might be flooded because of the project;
- **Downstream the dam**: in case of flood event, inflow is increasing. To prevent flooding upstream, the operator has to decrease the water level upstream the dam site by opening the gates of the spillway.

Decreasing the water level upstream the dam site while inflow is increasing at the same time means that outflow is higher than inflow. This operation must be safe in order to protect local people, cities (such as Pak Lay city) and villages from any damages due to the operation of the dam.

To deal with these potential adverse impacts, the Developer must implement a monitoring and forecasting system (cf. Section 5.2.4). The Developer must also define an operation pattern that will allow him managing water level, inflow and outflow in an efficient and safe manner.

5.6.2 Pak Lay operation pattern

According to the FS, the planned operation pattern is based on the results presented in figure 23:

- **For inflow below 6100 cms**, the discharge is flowing through the powerhouse. The water level is varying between 239 and 240 m asl, defined as minimum and maximum water level values during normal operation of the powerhouse;
- **From 6100 to 16700 cms**, the discharge is higher than the capacity of the powerhouse. Part of the discharge is then flowing through the spillway gates that are opened gradually. Gates opening is made in order to limit adverse impacts downstream. The water level is 240 m asl. The powerhouse is shut down when the net head is lower than the minimum power head of the units;
- **From 16700 to 21600 cms**, the water level is decreased gradually until the spillway gates are fully opened and the water level values recover nearly natural conditions;
- Above 21600 cms, the spillway is fully opened. The HPP is not controlling any more the water level values. The river recovers nearly natural conditions.

The operation pattern proposed by Pak Lay Developer is following run-of-river concept. In addition, the Developer provides the results of many backwater calculations in Section 4.11.3 considering both natural conditions and backwater effect of Pak Lay HPP.

However, there is a need for:

- some clarifications for discharge values from 16700 to 21000 cms: the Developer provides the water line for 19000 cms in natural conditions and in case the spillway gates are fully opened. It is mandatory to demonstrate the efficiency of the operation pattern by providing the results in case the water level at the dam site is around to 234.5 m asl according to the operation pattern;
- generally, some clarifications for the range of discharge values from 167000 cms to 21000 cms according to the operation pattern;
- some demonstrations of the efficiency of the operation pattern based on water line surveys the Developer shall make during the rainy season.

Actually, at this stage, it is mandatory to consider the run-of-river concept and to propose a relevant operation pattern. The operation pattern of figure 23 shall be considered as a preliminary version at this stage. Once operation starts, the Developer will monitor the impact of this operation pattern. In case there are some remaining impacts, the Developer will have to adjust and update it in order to ensure safe flow conditions at any time.

![Figure 23: Planned operation pattern of Pak Lay HPP (Pal Lay FS, Section 4.12.2)](image-url)
5.7 Impact of Pak Lay Dam on U/S & D/S hydrology

As a run-of-river hydropower project, Pak Lay dam globally does not change the flow downstream the dam, since the total storage capacity is limited. Pak Lay reservoir will never be used to store water during the wet season in order to support the dry season discharge.

Only infra day discharge transfers can be performed if not changing global discharge released downstream. These transfers could be operated in case of:

- peak hour hydropower discharge, if any and only from 239 m asl to 240 m asl;
- sediment rooting operation;
- adjustment of reservoir water level during flood events.

Experience along the Rhone River and other rivers shows that peak hour hydropower discharge can affect bank stability downstream of the dam if water level variations are too rapid and water level range too large. In addition, quick variations of the water level can lead to dangerous flow conditions for navigation and other activities along the riverbanks (fishing, gardening...). In the reservoir, quick water level drawdown can also affect bank stability, producing landslide.

Drawdown and filling of the reservoir must be done sufficiently slowly and monitored carefully in order to limit its impact on the flow and on the riverbanks stability both upstream and downstream the dam site.

If the Developer expects to perform large daily flow variations at Pak Lay dam site, he shall monitor riverbanks stability downstream of the dam and in the reservoir area. If bank erosion is too important, water level regulation must be adjusted.

Appropriate discharge monitoring and forecasting is also needed for a better water level regulation. The Developer addresses this issue in Section 4.13 of the FS. He proposes:

- to define gradient values for the maximum daily flow variation of the reservoir water level;
- to monitor the water level;
- to monitor riverbank stability in the areas where landslides may occur;
- to implement an emergency response plan and a warning system to inform people about reservoir water level and outflow adjustment;
- to adjust the operation of the reservoir water level in order to ensure safety flow conditions anytime.

The Developer will deal with the adverse impacts of reservoir operation. He shall clearly state that, if necessary, he is committed to update and adjust in the future his mitigation and control measures based on observed data.

5.8 Conclusions for Hydrology

5.8.1 Recommendations regarding Hydrology

The design flood and check flood values have been reviewed according to CNR requirements in order to follow international standards and to ensure the consistency of Pak Lay HPP in the cascade of dams upstream Vientiane. This point was a major concern and has been addressed by the Developer.

Even if some efforts have been made to start monitoring the flow in the vicinity of the project, there is still a lack of QA&QC process. The Developer plans to add more QA&QC process once at least one year of data will have been collected.

The operation pattern has been fully reviewed and is now consistent with run-of-river concept. The Developer still needs to demonstrate the efficiency of its operation pattern for some ranges of discharge but the run-of-river concept has been accepted and understood.

The monitoring and forecasting system is presented in the FS. The proposed technical solution is consistent for flood management but will show some major limitations regarding power generation management. Anyway, this is not a blocking point at this stage and the Developer can address this issue later on, before construction.
### 5.8.2 Tables of completion

<table>
<thead>
<tr>
<th>No.</th>
<th>Guidance regarding Hydrology</th>
<th>Final stage 2</th>
<th>Priority (PNPCA, Construction, Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>General description of natural geography, with the catchment area and situation of the Paklay HPP site</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>12</td>
<td>Meteorological conditions with description of climate and some statistics on meteorology</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>13</td>
<td>Description of the basic hydrological data used, with presentation of the station network, and data available</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>14</td>
<td>Calculations of runoff at hydrological stations and at the dam site with calculation of daily flow for some representative years (wet, normal and dry years)</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>15</td>
<td>Estimations of flood, with the properties of storm and flood generated, evaluation of flood frequency at hydrological stations, evaluation of design flood at the dam site</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>16</td>
<td>Elaboration of a rating curve at the dam site</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>21</td>
<td>Calculations of flow at the dam site</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>22</td>
<td>Design flood</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>23</td>
<td>Dry year</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
<tr>
<td>24</td>
<td>Impact of HPP during flood</td>
<td>Completed</td>
<td>PNPCA</td>
</tr>
</tbody>
</table>

Some results are presented in section 2.5.4. Yes data are limited and the Developer doesn’t have 1y of data. Anyway, it’s possible the data available for QA/QC process of currently used relationship between flow and WL. This shall be done. CNR still doesn’t understand why the Developer doesn’t update the curve of fig. 2.5.5 based on measurements (blue dots). Some preliminary results still are requested. Some results are presented in section 2.5.4. Yes data are limited and the Developer doesn’t have 1y of data. Anyway, it’s possible the data available for QA/QC process of currently used relationship between flow and WL. This shall be done. CNR still doesn’t understand why the Developer doesn’t update the curve of fig. 2.5.5 based on measurements (blue dots). No reference to the different types of flood events in the Mekong mainstream. The Developer still plans to impound the reservoir and transfer water from SE period to PE period if the power is supplied to Thailand. WL would vary between 239 and 240 m asl in this case.
### 3. Impact of HPP located upstream Paklay project

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Status</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Yunnan Cascade</td>
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</tr>
<tr>
<td>32</td>
<td>HPP in Lao PDR</td>
<td>Not fully completed</td>
<td>Still not fully completed seeing that the Developer understands the concern but doesn’t fully address it at this stage even with limited input data that would allow him to get preliminary results.</td>
</tr>
<tr>
<td>33</td>
<td>Other impacts and mitigation of Yunnan cascade and Lao PDR HPP impacts</td>
<td>Not fully completed</td>
<td>Still not fully completed seeing that the Developer understands the concern but doesn’t fully address it at this stage even with limited input data that would allow him to get preliminary results.</td>
</tr>
<tr>
<td>34</td>
<td>Capacity review</td>
<td>Completed</td>
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</tr>
</tbody>
</table>

### 4. Planned operation pattern of Paklay project and its effects on reservoir WL and water release

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Status</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>Planned operation pattern</td>
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</tr>
<tr>
<td>42</td>
<td>Run of river dam management during the dry season</td>
<td>Completed</td>
<td>Ok</td>
</tr>
<tr>
<td>43</td>
<td>Run of river dam management during the rainy season</td>
<td>Not fully completed</td>
<td>Table 4.11.3.13 for Q = 19000 cms doesn’t show the water line according to the operation pattern. The table only shows results in case the gates are fully opened and in natural conditions. Results considering the operation pattern have to be added (WL upstream the dam should be around 234.2 m als). Results for 27000 and 18000 cms could be interested as well.</td>
</tr>
<tr>
<td>44</td>
<td>Run of river dam management during flood event</td>
<td>Completed</td>
<td>Ok</td>
</tr>
</tbody>
</table>

### 5. Impact of Paklay dam on U/S and D/S hydrology

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Status</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
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<td>51</td>
<td>Basic analysis of Paklay dam impact</td>
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</tr>
<tr>
<td>52</td>
<td>Drawdown and filling of the reservoir of the run-of-river scheme</td>
<td>Not fully completed</td>
<td>Following Developer’s comments and mitigation and control measurements proposed in section 4.13, Developer shall clearly state that he is committed to update in the future, if necessary, based on observed data. Considering the comment, the priority is switched to construction because this issue will need to be addressed during rainy seasons in Phase 1 and after diversion of the Mekong River (beginning of Phase 2).</td>
</tr>
<tr>
<td>53</td>
<td>Implementation of forecasting system</td>
<td>Completed</td>
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</tbody>
</table>

### 6. Automatic system of hydrological data collection and transmission

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Status</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
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<td>61</td>
<td>Existing monitoring system</td>
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<tr>
<td>62</td>
<td>Main purpose of the automatic monitoring system:</td>
<td>Completed</td>
<td>Developer’s comment about lead time shall be stated in the FS. For flood forecasting purpose, Scheme 1 seems to be ok during construction and operation. For power generation, Scheme 1 will not be sufficient depending on PPA constraints. The Developer shall clearly state that the current proposed monitoring system will be updated and upgraded during construction to fulfill PPA needs.</td>
</tr>
<tr>
<td>63</td>
<td>System coverage</td>
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<tr>
<td>64</td>
<td>Monitoring of the Mekong mainstream in Lao PDR</td>
<td>Completed</td>
<td>Consider comment 63</td>
</tr>
<tr>
<td>65</td>
<td>Monitoring of the main tributaries from China to Paklay HPP</td>
<td>Completed</td>
<td>Consider comment 63</td>
</tr>
<tr>
<td>66</td>
<td>Forecasting methods and tools</td>
<td>Not fully completed</td>
<td>Some details are already provided. The Developer shall clearly state that forecasting methodology and system is planned but that its implementation will take place at the beginning of construction.</td>
</tr>
<tr>
<td>67</td>
<td>Communication system</td>
<td>Completed</td>
<td>ok</td>
</tr>
<tr>
<td>68</td>
<td>Cost</td>
<td>Completed</td>
<td>not disclosed</td>
</tr>
</tbody>
</table>
6 DAM SAFETY

6.1 General requirements

As previously reported MRC and the national authorities consider that responsibility is placed on the owner / operator to adopt safe design standards and operating practices consistent with Lao PDR requirements and accepted international best practices as embodied by World Bank Operational Policy 4.37 on the Safety of Dams and by Periodic Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD) through the ICOLD Committee on Dam Safety (CDS). In addition, the PDG (MRC) state the general principle where, for the life of any dam, the owner is responsible for ensuring that all appropriate measures are taken and sufficient resources are provided for the safety of the dam, irrespective of its funding sources or construction status.

Along the life of the project preparation, construction and operation, international standards require that the Developer provides the following documents:

- Reviews by an independent Panel Of Experts (POE) of the investigation, design and construction of the dam and beginning of operations;
- A construction supervision and quality assurance plan, which normally covers the organization, staffing, procedures, equipment, and qualifications for the supervision of the construction of a new dam. It is used by POE to assess the need to fund components to ensure that dam-safety-related elements of the design are implemented during construction;
- An instrumentation plan, which is a detailed plan for the installation of instruments to monitor and record dam behavior and related hydro meteorological, structural and seismic factors. It is provided to the POE during the design stage;
- An operation and maintenance (O&M) plan: This detailed plan covers the organizational structure, staffing, technical expertise, and training required as well as the equipment and facilities needed to operate and maintain the dam. It includes but is not limited to O&M procedures and arrangements for funding O&M, including long- term maintenance and safety inspections. It can be a preliminary O&M plan at feasibility and detailed design stage. The plan is refined and completed during project implementation and the final plan is due not less than six months prior to initial impoundment of the reservoir;
- An emergency preparedness plan, which specifies the roles and responsibilities of all parties when dam failure is considered imminent, or when expected operational flow releases threatens downstream life, property, or economic operations that depend on river flow levels. It includes the following items: clear statements on the responsibility for dam operations decision making and for the related emergency communications; maps outlining inundation levels for various emergency conditions; flood warning system characteristics; and procedures for evacuating threatened areas and mobilizing emergency forces and equipment. The broad framework plan and an estimate of funds needed to prepare the plan in detail are provided during the design stage. The plan itself is prepared during implementation and is provided to the Panel for review not later than one year before the projected initial impoundment of the reservoir. In particular, it is important to have a clear communication strategy to engage with stakeholders on dam safety issues and emergency preparedness activities that directly involve or affect them.

In addition, the Pak Lay project is considered as a large dam according to the criteria used to compile the list of large dams in the World Register of Dams, published by the International Commission on Large Dams.

For such dams, the World Bank Operational Policy 4.37 on the Safety of Dams puts the aforementioned requirements and gives the following precisions:

*The primary purpose of the POE is to review and advise the borrower on matters relative to dam safety and other critical aspects of the dam, its appurtenant structures, the catchment area, the area surrounding the reservoir, and downstream areas. However, the borrower normally extends POE’s composition and terms of reference beyond dam safety to cover such areas as project formulation; technical design; construction procedures; and, for water storage dams, associated works such as power facilities, river diversion during construction, ship lifts, and fish ladders.*
6.2 Standards used for the feasibility study

The technical references are mainly Chinese standards. These standards can be followed along the project process, but information regarding compatibility between the use of Chinese standards and the reference standards should be provided on main issues such as Design Flood and Check Flood values determination, seismic hazard, and flow release capacity or mechanical & electrical back up.

References to Lao Electric Power Technical Standards, to the World Bank Operational Policy 4.37 on the Safety of Dams, to Periodic Technical Bulletins on the Safety of Dams issued by the ICOLD (in particular the n°125, n°130, n°142 and n°148) and to other international best practices are provided (ref. Chapter 5.5.5.3 of the FS). Globally, DF&CF determination, seismic hazard and flow release capacity have been upgraded since first submitted version of the FS and they are now consistent with international standards and other schemes on the Mekong as developed in the following chapters 6.4 to 6.7.

6.3 Hazards considered – Risk management

There is no specific chapter dedicated to the identification of hazards and design of countermeasures to associated risks. Such a risk analysis should be provided at feasibility stage.

6.3.1 Hazard considered

The feasibility study design document mainly considers the hazards due to earthquake (see chapter 6.4) and flood (see chapter 6.5). The design parameters are consequently fixed in order to prevent any damage in the most probable occurrence and consideration is given to safety parameters in the design development.

In feasibility study reports (chapters 1.2 and 1.3), several risks and impacts are briefly considered: earthquake, flood, reservoir leakage, reservoir bank stability, reservoir inundation, sediment runoff and reservoir induced earthquake.

The hazard which is not considered is mainly the overtopping scenario with particular attention at both bank lateral abutments for which the links with the natural ground is not detailed in the feasibility study. Two ways exist for the dam to overtop:

- Continuous flow as the water surface elevation exceeds the elevation profile of the structure in case of extreme flood higher than check flood or in case of equipment failure;
- Over wash from waves can occur even when the average water surface stays below the structure elevation profile in case of landslide in the reservoir, or earthquake.

A list of hazards that should be studied is provided below (the list is not extensive):

- Uncertainties with Spillway Discharge:
  - Spillway discharge curves used in flood routing being not accurate in all hydraulic conditions;
  - Debris may block spillway openings and significantly lower the discharge released downstream;
  - Gated spillways flow varies at a given water surface elevation depending on whether free flow or orifice conditions exist or not;
  - Gated spillways may be vulnerable to one or more gates failing during a flood, due to mechanical failures, loss of power or gate binding;
  - Gates are partially in maintenance and cannot be operated when flood arrives.
- Uncertainties with flood:
  - Check flood can be underestimated;
  - Over sedimentation upstream the dam modifies the hydraulic parameters.
- Natural hazards producing waves:
  - Strong winds or storms;
  - Landslide in the reservoir;
  - Earthquake.
- Other hazards:
  - Dam break upstream of project site producing waves.
6.3.2 Risks analysis

The risks to be evaluated and considered in the feasibility study shall then be based on the following probable hazards:

- Loss of human life;
- Secondary consequences and impairment of access to emergency services;
- Damage to homes;
- Main highways and minor roads;
- Interruption of important utilities;
- Substantial environmental damage downstream of dams.

There is no risk analysis provided in the feasibility study.

6.4 Earthquake safety

6.4.1 FS references

General information is provided in chapter 1.3.2 of the FS:

- no active fault within 5km and large fault further than 120km;
- no earthquake within 30km;
- 4 earthquakes of magnitude 4.7 at a maximum distance of 150km;
- earthquake magnitude (M) is smaller than 5;
- basic earthquake intensity of the dam site is VII degree;
- Peak Ground Acceleration (PGA) (10% in 50 years, 475 year return period) = 0.133g;
- Peak Ground Acceleration (PGA) (2% in 100 years, 5,000 year return period) = 0.384g;

A brief analysis of reservoir induced earthquake is provided in chapter 1.3.3.1 of the FS. The conclusions are that “the reservoir induced earthquake would be of Magnitude 5, with an intensity generally not exceeding VI”.

In chapter 1.3.7.1 of the FS, the same information as the one of chapter 1.3.2 is provided with regards to general seismic hazard but the paragraph on reservoir induced earthquake has not been upgraded since first submission of the FS.

In chapter 1.5.1.3 of the FS, the information has not been upgraded since first submission of the FS.

In chapter 1.11 Project characteristics of the FS, it is stated in the table presenting features of the project that basic intensity and designed intensity are grade 7.

In chapter 3.2.2 Earthquake of the FS, this information is documented and further developed. It is the main chapter about seismic analysis throughout the feasibility study.

In section 3.3.2.5, complements are provided about the risk of reservoir induced earthquake. The conclusions are that “the reservoir induced earthquake would be of Magnitude 5, with an intensity generally not exceeding VI”.

In chapter 3.7.1.1, the basic seismic intensity has not been upgraded since first submission of the FS.

In chapter 5.1.2, the information has not been upgraded since first submission of the FS.

In chapter 5.5.5.1, the 475 and 5,000 year return period earthquakes are considered respectively as OBE and SEE.

In chapter 5.9.5, it is explained that only the upper miter gate of navigation lock is considered for retaining water and therefore designed with seismic intensity degree VII. NB: under 5.9.5.1.a(9), the basic seismic intensity has not been upgraded anywhere since first submission of the FS.

In chapter 5.11.4.3, the basic seismic intensity has not been upgraded since first submission of the FS.

There is no mention of either earthquake safety or seismic design in chapter 6 of the FS Mechanical & Electrical Equipment and Metal Structures.

In chapter 7.2.4, slope stability of temporary earth-rock cofferdam is assessed under seismic conditions but the considered earthquake is not provided.
Thus, treatment of earthquake safety is not consistent throughout the reports between civil engineering and mechanical equipment. It should be clarified by the Developer. The Developer shall also explain why only the upper miter gate is considered differently. An earthquake could occur when the upstream gates are opened and water is retained only by downstream gates.

6.4.2 Chronic of regional seismic events

As previously stated and according to feasibility report (see chapters 1.3.2 and 3.2.2), “within a radius of 150km, no records of major earthquakes have been found since 2150 B.C. Since 1973, records of 5 earthquakes have been found within a radius of 150 km with the largest magnitude being 4.7.

According to the map “Lao PDR: Natural Hazard Risks” issued by OCHA in 2011, the project is located in the zone of earthquake intensity degree VI (modified Mercali Scale). On this map, the earthquake intensity zones indicate where there is a 20% probability that degrees of intensity displayed will be exceeded in 50 years.

This is confirmed by a research on USGS public database at: http://earthquake.usgs.gov/earthquakes/map/.

The research was performed on December the 3rd 2015, from 15° to 21° North and from 98° to 104° East.

According to chapter 3.2.2 of the FS, the largest fault zones are northwestern Dien Bien Phu fault zone (120 km from the dam site) and Sagaing fault zone and Red River fault zone (500 km from the dam site). Thus no major fault seems to be located in the vicinity of the project. There is also a North North-East fracture called F1 near the dam site about 3 km on the left bank of the dam site (see drawing Pak Lay-FS-Geology-01). The Developer discards this fault from design as “no new activities have been found for micro relief through survey on earth surface and no records have ever been kept of the occurrence of moderately strong seismic activities along fault in history”. This can be adequate if proper prospection allows confirming the distance between the fault and the dam site. Nonetheless, the Developer shall keep in mind that no record of historical seismic activity does not mean that there will definitely never be any seismic activity in future.
6.4.3 Seismic design criteria

According to ICOLD bulletin n°148, the Developer should determine two earthquakes:

- the Safety Evaluation Earthquake (SEE) is the level of shaking for which damage can be accepted but for which there should be no uncontrolled release of water from the reservoir. It is the maximum level of ground motion for which the dam should be designed or analyzed;
- the Operating Basis Earthquake (OBE) is the level of shaking for which there should be no or insignificant damage to the dam and appurtenant structures. The dam, appurtenant structures and equipment should remain functional and damage should be easily repairable, as long as the occurrence of earthquake shaking is not exceeding OBE.

In some cases, more than one maximum design earthquake may be specified to reflect the differing response of several components of the structure to earthquake loading. This depends on the vibratory parameters of the structure studied. It is then important to analyze in details the response of the structure to specific ground motion parameters (frequency, duration, etc.) that need to be considered while specifying this event.

In the project of a dam with HPP, the powerhouse is a massive and compact mass of concrete. This mass may not follow the same seismic law as the spillway and especially the superstructures of sluice gates hoist which are critical equipment for flood control. As an example, reinforced concrete structures can be designed and checked for dynamic strength in order to prevent any permanent damages, but it shall also be checked that gates can still be operated and all the auxiliary system remains operative in extreme conditions.

A table of seismic parameters is given on figure 26. Such a table should cover the whole spectrum of the design earthquake and be compared to the structural sensitivity of auxiliary equipment such as sluice gate hoist for example.

<table>
<thead>
<tr>
<th>Designed seismic dynamic parameter</th>
<th>50-year exceeding probability</th>
<th>100-year exceeding probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>Return years</td>
<td>475</td>
<td>145</td>
</tr>
<tr>
<td>Amax (gal)</td>
<td>130.0</td>
<td>64.9</td>
</tr>
<tr>
<td>βmax</td>
<td>2.38</td>
<td>2.32</td>
</tr>
<tr>
<td>Tg (sec)</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>att(g) (= Amax/980)</td>
<td>0.133</td>
<td>0.066</td>
</tr>
<tr>
<td>γ</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3.2.2-3 Ground Motion Parameter Values of Bedrock at the Recommended Dam Site

Figure 26: Parameters for seismic design (source: Pak Lay HPP FS)
In the feasibility study, according to seismic risk assessment provided by Pak Lay Developer, seismic peak ground horizontal acceleration on bedrock site with exceedance probability of 10% in 50 years is 0.133g and the PGA on bedrock site with exceedance probability of 2% in 100 years is 0.384g. The basic seismic intensity in the project area is determined to be magnitude VII (modified Mercalli intensity scale), meaning that it would cause negligible damage in buildings of good design and construction.

According to ICOLD bulletin n°148, the SEE should be characterized by a very long return period such as 10 000 years for example, and the OBE by an earthquake of minimum return period of 145 years. Furthermore, the reservoir triggered earthquake should be treated when dam is higher than 100m or reservoir greater than 500Mm³.

With regards to the low seismic activity recorded in the area of the project, we consider seismic design of Pak Lay project to be consistent with international standards. Nonetheless, the different chapters dealing with earthquake and seismic design should be upgraded so that seismic design is consistent throughout all the feasibility study.

6.5 Safe passage of extreme floods

6.5.1 Introduction

Below are some extracts from chapters 1.5.1 and 5 of the FS about general considerations governing the design:

"According to the provisions of Classification & Design Safety Standard of Hydropower Projects (DL/5180—2003) issued in China, the hydraulic structure is a Grade I Large (I) type Project. Considering that the maximum head of the Hydropower Station is less than 30m, Grade1~4 backwater structures can be degraded by one grade when the total storage capacity is close to lower limit of the gradation index of the Project. […] the main structures such as permanent water retaining structure, water release structure, water retaining part of water retaining type power house, and the upper lock head of navigation lock are Grade 2 structures and their structure safety level is II; secondary structures such as retaining walls and slope protection are Grade 3 structures and their structure safety level is II. […] The lower lock head and sluice chamber are Grade 2 structures and their structure safety level is II."

The design criteria have been upgraded since the first submission of the FS. The latest are provided in chapter 5.5.5 of the FS. We consider only this data as corrections have not been conducted in all the other chapters.
The Developer shall clean all the feasibility study of former assumptions so that design criteria are consistent throughout the whole documentation.

Considered design and check floods for different structures of the installation as stated in the FS are summarized in table 15.

<table>
<thead>
<tr>
<th>Design standard</th>
<th>Item</th>
<th>Unit</th>
<th>Barrage</th>
<th>Power house</th>
<th>Navigation lock</th>
<th>Approach channel</th>
<th>Fish pass</th>
<th>Energy dissipation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design flood</td>
<td>Return period</td>
<td>Year</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
<td>N/A</td>
<td>N/A</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Discharge</td>
<td>m^3/s</td>
<td>34700</td>
<td>34700</td>
<td>34700</td>
<td>N/A</td>
<td>N/A</td>
<td>27200</td>
</tr>
<tr>
<td>Check flood</td>
<td>Return period</td>
<td>Year</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Discharge</td>
<td>m^3/s</td>
<td>38800</td>
<td>38800</td>
<td>38800</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Table 15: Considered design flood and check flood in the different structures

The fish pass intake shall be considered as a water retaining structure and its design flood should be provided.

<table>
<thead>
<tr>
<th>Item</th>
<th>P(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Qm</td>
<td></td>
</tr>
<tr>
<td>3880</td>
<td>3700</td>
</tr>
</tbody>
</table>

Figure 28: Design results of annual maximum flood corresponding to different frequencies at the dam site (source: FS table 5.5-4)

6.5.2 Estimation of extreme flood

The relevance of extreme flood hydrographs proposed by the Developer is discussed in chapter 5.

Since the reservoir hasn’t much surcharge storage and cannot be dedicated to flood control, the hydrographs are being used for checking the dam safety when the reservoir inflow peak discharge is close to the maximum spillway capacity.

It is assumed that flood runoff hydrographs integrate the drainage basin and channel response to precipitation, given some initial variable state of moisture throughout the watershed. To conduct risk analyses and dam safety evaluations, probability estimates for extreme floods are required. Probabilistic extreme flood hydrographs are developed to assess the adequacy of the spillway and pass the hydrograph peak without overtopping the dam. The hydrographs and probabilities estimates are used in risk analyses for dam safety.

These hydrographs can also be used to establish reservoir operating rules and determine diversions needed for construction.

6.5.3 Design Flood

The “Design Flood” as defined by ICOLD Bulletin 125 (p.191) “is the flood that has to be taken into account in the hydraulic design of spillways and energy dissipating structures, with a safety margin provided by the freeboard”.

Thus, it can be considered that the design flood level should occur with an important freeboard and no damage on the structure. This level of operation shall provide the best safety factors for all consideration of safety for civil engineering and equipment that shall not be damaged in any case for any flood up to this intensity.

According to ICOLD Bulletin 125 (p.173) the design flood is in the range \( Q_{1,000} \) to \( Q_{5,000} \) year return period. Thus we consider the project design flood of \( Q_{2,000} \) consistent with international best practices.
6.5.4 Safety Check Flood

The “Safety check flood” as defined by ICOLD Bulletin 125 (p.191) “represents the most extreme flood conditions to which the dam could be subjected without failure, but also with a low safety margin (scenario limit). In this case, a limited overtopping may be permitted for concrete dams, but not for embankment dams”.

It can be considered for this very exceptional flood that some limited extra costs and damages to waterways or loss of fuse devices are acceptable. Furthermore, the exceptional loads such as seismic or long term seepage impact should not be added to the impact of the increased water level: usually such extraordinary water level increase will have thus little or no impact on the main dam structure.

Some damages are also acceptable for floods between the design flood and the safety check flood. According to ICOLD Bulletin 125 (p.173) the safety check flood is either the Probable Maximum Flood or in the range of Q_{5,000} to Q_{10,000} year return period. Thus we consider the project safety check flood of Q_{10,000} consistent with international best practices.

6.5.5 Freeboard

As a reminder, the crest elevation of the concrete gate dams (including power stations and navigation locks) is 245.00 m asl.

The freeboard calculation is provided at chapter 5.6.3.1 of FS. Two operating conditions are considered: normal pool level (supposedly with exceptional wind and waves) and check flood level (with lower wind and waves).

On Pak Lay project, the normal operating upstream level is 240 m asl. At check flood peak flow and under steady flow the upstream water level is 239.02 m asl. According to calculations, the most critical situation is at normal pool under exceptional wind. In these conditions, the top elevation of wave wall at the dam crest is 244.99 m asl.

Thus, there is actually no need for a wave wall and we consider the freeboard sufficient as it is consistent with the altitude of the dam crest.

6.5.6 Higher floods and overtopping

About overtopping of concrete dams, we can quote the ICOLD bulletin n°142 chapter 3.2:

On the other hand, concrete dams are generally less sensitive [than embankment dams] to minor overtopping but can fail by erosion of the foundations of their toes, their side slope abutments or their associated approach embankments. In some instances, concrete dams may become unstable when subject to major overtopping.

Pak Lay dam is concrete only and the scheme is of run-of-river type. Such dams can be considered as little sensitive to erosion of the foundations of their toes, seeing that during flood events the downstream water level is high enough to dissipate the energy of overtopping waters. Moreover according to typical cross sections of flood release structures (ref. Pak Lay-FS-HS-17 to 19), it appears that downstream of all of these structures a concrete stilling basin is implemented, lowering the risk of erosion of the foundations of their toes. Downstream the powerhouse there seems to be a thin slab but it is not clear whether it is made of concrete or not (ref. drawing Pak Lay-FS-HS&EM-ZT-01).

There is no discussion about floods higher than the safety check flood. Nonetheless, an accidental situation has been tested on physical model where 3 sluices remain closed under safety check flood without overtopping. The maximum upstream water level would then be 244.80 m asl according to table 5.7-4.

Thus, we consider the safety against overtopping to be sufficient.

There is no detail on protection of banks at dam axis. Connections of dam with banks are excavated in rock (ref. 1.5.6.1-e). If rock is loose in these locations, consolidation by anchors and concreting might be needed. It is not considered by the Developer at this stage.

On the drawing General plan layout of structures (ref. Pak Lay-FS-HS-14), there are no upstream and downstream embankments represented. Such lateral embankments upstream of the installation do not seem necessary considering the topography in the vicinity of the dam site. Nonetheless, the drawing is not large enough to assess the risk of flood expansion that could by-pass the installation. The Developer should provide a
drawing with upstream topography and, if needed, planned embankments to avoid lateral flooding of surroundings.

6.5.7 Outline of the flood release structures

With regards to flood release, we can consider the following structures:

- 11 sluice gates with opening dimensions W16m×H20m, crest elevation at 220.0 m asl, each equipped by radial gate;
- 3 sluice gates with opening dimensions W16m×H28m, crest elevation at 212.0 m asl, each equipped by radial gate;
- 2 low level outlets with opening dimensions W10m×H10m, crest elevation at 205.0 m asl, each equipped by plane fixed wheel gate;
- But also the HPP with 14 bulb turbines with bottom elevation at 201.02 m asl that could be used for discharge.

The following structures cannot be considered:

- The navigation lock which is supposedly condemned for flows higher than 16 700 m³/s when navigation is stopped (nb: this value shall be confirmed). Miter gates could not be operated in dynamic waters;
- The fish pass which is supposedly condemned when upstream water level is above NOL and thus for flows higher than 37 700 m³/s (nb: this value shall be confirmed).

There is no other equipment that can be used for flood release (such as in-bank or by-pass release structure, storage reservoirs or overflow expansion basins for example).

The spillway is located on the right edge of the installation between the navigation lock and the powerhouse, which is on the left edge of the installation. The energy dissipation and erosion control structures, located downstream the spillway, are of underflow type. An apron is used for bottom protection downstream the sediment flushing bottom outlets, low-level surface bays and 6 high-level surface bays on the right; a down-digging stilling basin is adopted for the 5 crest high-level outlets on the left (ref. 1.5.6.2). There does not seem to be continuity between the downstream extremity of energy dissipation structures and the river bed. This should be corrected to avoid erosion.

NB: there are still mentions of slotted flip bucket downstream aprons even though they are not visible on drawings anymore. The Developer shall clean all the feasibility study of former designs.

6.5.8 Choice of the equipment

According to chapter 6.4.1 of the FS, the 14 surface sluice gates are equipped with a service radial gate while the 2 bottom outlets are equipped with a plane fixed wheel service gate.

The choice of radial gate is discussed in the feasibility study (ref. 6.4.1.4). It is admitted that radial gates have better flow pattern under partial open conditions. Secondly the vibration is weaker than that of the plain gate. Actually, the necessary length of the pier provides a better stability to the structure. In addition, the nonlinear contact of main wheel and rail of large plain gate deflection is avoided. Thus the risk of main wheel and rail damage resulting from increased contact stress can be prevented. Hoisting superstructures of flat gates generally behave differently from spillways, dams and powerhouses during earthquakes. This is not the case with radial gates as hoisting equipment is included in the spillway structure.

Finally, tainter gates with flaps would allow better managing upstream water level than gates functioning only as lower orifices for partial opening. They would also allow surface discharge to free debris and logjam. The Developer explains in chapter 6.4.2.1 of the FS that a trash cleaning boat is more convenient than upper flaps to release floating debris. Great care will be needed when setting operation procedures for such a boat maneuvering just upstream the dam in order to secure these operations. The Developer shall reconsider the question of flaps.

For surface sluice gates, the trunnion is set at 235.0 m asl so as to be above water for a 100-year flood. When the gate is fully opened, the lower part of the gate is at 241.0 m asl. This level ensures free flow conditions up to the safety check flood and eases the evacuation of floating debris.

Fixed roller gates are well adapted to low level outlets.
6.5.9 Spillway capacity for flood release

According to chapter 1.4.10 of the FS, for small to moderate flow values, discharge is released mainly by turbines and gates of spillway that are opened if necessary. For flows higher than 6100 m$^3$/s (discharge at full load of units) and lower than 16 700 m$^3$/s, units operate for power generation and extra flow is discharged by opening flood discharge equipment. When the flow rate gets higher than 16 700 m$^3$/s, the powerhouse is shut down and spillway gates are opened. Turbines are not used to release flow for floods higher than 16 700 m$^3$/s.

Whatever the choice of the gate technology is, the study of gate opening pattern is important in order to provide a prediction tool for the optimal management of flood events. The flow through the spillway may be submerged or unsubmerged depending on the tailwater level and gate opening.

In order to check the design of the flood release equipment it is necessary to determine the head discharge relationship ($Q=f(H)$) which depends on numerous parameters and flow conditions.

According to chapter 5.7.4.1 of the FS, the discharge through the spillway seems to be determined adequately depending on upstream water level. For surface spillway, a profile-bottom broad-crested weir with drown conditions (downstream water level affects upstream water level) is considered. For low level outlets, an orifice with drown conditions is considered.

The approach velocity and weir coefficient should be justified. The approach velocity coefficient has a huge importance on discharge capacity assessment. Methodology and results of hydraulic modelling tests about discharge capacity are provided in section 5.7.4.2 of the FS. Although little information is provided, results on physical model are consistent with the calculated discharge capacity.

No consideration is given on obstacles that could lower the discharge capacity of the spillway. However, an accidental situation has been tested on physical model with 3 sluice gates remaining closed. Under safety check flood conditions, maximum upstream water level would be around 244.80 m asl according to table 5.7-4 of the FS. Thus, no overtopping is observed.

There is no statistical assessment of the availability of gates considering a realistic maintenance program (anticorrosion painting, mechanical, etc.) and risks of failure (mechanical, electrical or human error). The latter is more important for Pak Lay HPP. Nonetheless considering up to 3 unavailable gates seems to be sufficient.

The discharge capacity of the global spillway is provided versus inflow and corresponding upstream water level in the table 5.7-1 of the FS. These data are used for stability study under design or check flood situations, considering the peak flow values and a steady flow.

![US water level (masl) = f(Discharge Flow (cms))]({attachment:image.png})

Figure 29: Discharge capacity of the spillway

The level of safety is compliant and the design of the spillway is sound.
6.5.10 Reliability of the spillway

A particular aspect of dam safety has recently received increased attention from owners and developers: the reliability of gated spillway. Design of spillway gates has not always been attributed due respect with regards to periodic test-operation and maintenance, probably because reliability of the gate structure and operating machinery were either considered inherent to the design or simply neglected at design stage.

Dam safety is also totally linked to the inability to operate a spillway gate. Moreover recent gate incidents have been recorded. They highlight problems with spillway gates. Gate operating equipment exists for old dams, and has the potential to affect overall dam safety in case of lack of maintenance for new facilities. MRC requires that all mechanical and electrical control equipment shall be backed/doubled up to ensure a high level of capacity in case of emergency. This shall be described in a specific chapter of the description of the equipment, mainly for the spillway, even if the powerhouse equipment shall also be fully equipped for cases of emergency too.

In chapter 6.2.3.2 of the FS, the Developer indicates that a diesel generator will be installed for HPP emergency power supply and that another diesel generator will be installed for dam crest emergency power supply. It is stated that these generators are sufficient to safely cutoff the powerhouse and operate "the maximum quantity of flood gates opened at the same time" (ref. 6.2.6.1 of the FS). This maximum quantity of gates shall be clearly stated.

Experience has shown that improving spillway gate reliability is a combination of appropriate components selection, good design details, and appropriate operation and maintenance procedures. The Developer has to consider reliability into the construction and operation management plan.

At this stage of development, the question will be on how the security equipment will, in all cases, enable the flood to go through the facility. What auxiliary systems will be provided to enable the power and control? Preliminary schemes shall be presented in a specific chapter of the feasibility study.

For a better understanding of the context, the Developer shall include the details provided for primary operation plan of the sluice gates in the detailed design.

The detailed operation plan, including the gate opening mode and the gate maintenance plan, will be provided before reservoir impoundment.

The regular inspection and maintenance to be performed for the gate seals, support parts, rails and hoists after the power station is put into operation shall at least clearly appear in the O&M documents as well as the frequency of sluice gates testing and the maintenance of hoists.

6.5.11 Hydraulic model testing for flood passage

The physical model is useful to check the hydraulic design. Methodology and results of hydraulic model test for discharge capacity are provided (ref. 5.7.4.2 of the FS).

Although little information is provided, results on physical model are very well fitting the calculated discharge capacity (ref. Fig 5.7-1 of the FS).

Overtopping tests were performed under safety check flood. No overtopping occurred even with 1 high level surface bay and 2 low level surface bays condemned (ref. Table 5.7-4 of the FS).

Several downstream scouring tests were performed. It appears that scouring is more serious when the inflow is around 16 700 m³/s than when inflow is much higher. It is consistent as in the latter case the downstream height of water is larger and there is actually less energy dissipation per cubic meter. Scours will open if side crest outlets (supposedly sluices n°9 to 14) are opened by 1 m with a difference between upstream and downstream water levels higher than 12 m or if they are opened by 2 m with lower water level difference. Unfortunately there is no clear recommendation about a limit difference between upstream and downstream water levels where side crest outlets could be opened without causing scouring. Generally, there are few conclusions that could be used to adjust operating pattern or the design of energy dissipation structures. Operating pattern of gates is presented in chapter 5.7.3 of the FS but no clear reference to results of model tests is provided.

It does not seem that:

- the distribution of flow velocity in the reservoir has been tested for several operation flows;
- tests were performed considering low sedimentation (after completion) and high sedimentation around the dam (after several years of operation);
- there was a specific model for sluices;
the spillway was tested at partial opening of the sluice gates to assess the discharge coefficient of the gates through measurement and experimentation.

As the discharge capacity of the spillway shall be controlled at any time of the maintenance program, all this procedure shall be provided in the report in order to examine the partial performances of the spillway in each case of maintenance or failure of some gates.

6.5.12 Safe passage of extreme floods during construction phases

Construction is planned in two main phases, lasting respectively 2 years and 4 months, and 4 years and 5 months. The schedule is described in chapter 7 of the FS. No planning update and no construction specific drawings were released with the final version of the feasibility study.

During the first phase, the flow is diverted on the left edge while construction is ongoing on the right edge (construction of the navigation lock, the spillway and right bank non overflow section).

During the second phase, the flow is diverted through the spillway on the right edge while construction is ongoing on the left edge (construction of 14 units of the powerhouse, left bank non overflow section and the fish pass).

According to Chinese Specifications for Construction Planning of Hydropower Engineering (ref. DL/T5397-2007), the diversion structures of phase 1 are Grade 4 structures. The water retaining standards for concrete cofferdam of Grade 4 diversion structures are the 5 to 10-year return period floods. The water retaining standards for earth-rock cofferdam are the 10 to 20-year return period floods. Considering water levels for each return period and the duration of each phase, the Developer eventually adopted the 20-year return period flood with a peak discharge of 23 000 m³/s.

For phase 2, the Developer adopted the 20-year return period flood with a peak discharge of 23 000 m³/s with regards to diversion standards. During installation of units, the 100-year return period flood is adopted with the peak discharge of 27 200 m³/s.

It seems rather low with regards to the duration of each phase. CNR recommends implementing as soon as possible a monitoring and forecasting system in order to ensure the safety of the project and the vicinity of the project, including Pak Lay city, during both construction phases whatever the level of safety is (see Section 5.2.4 of this report).

The developer should update construction drawings at feasibility stage in order to have a consistent design throughout the report and drawings.

6.5.12.1 Information from feasibility study

Stage 1:

First stage protections are presented on chapter 7.2.4 of the FS. Their main characteristics are set as follows:

- Upstream transversal protection: clay-core earth-rock cofferdam, crest at 235.5 m asl;
- Downstream transversal protection: clay-core earth-rock cofferdam, crest at 234.0 m asl;
- Longitudinal protection: concrete cofferdam, crest between 235.5 m asl and 234.0 m asl.

These cofferdams are constructed during the dry season from December of year 1 to February of year 2. Water retaining standards during erection of cofferdams and particularly final gap closing are P=10% (10-year monthly average of February). A corresponding flow of Q= 1 890 m³/s is considered although according to table 7.1.7-4 of the FS, average flow of February with P=10% should be 1 640 m³/s. It is not clear how the value of 1 890 m³/s was determined and the Developer shall clarify this point.

During phase one diversion period, the water of river course shall be narrowed to flow through the riverbed on left side. Water retaining standards of cofferdam during such period are P=5% (20-year all along the year), and Q=23 000 m³/s.

River closure:

The river closure is planned at mid-December of year 3. The P=10% flood is considered as standard flood (10-year monthly average flood of December). The corresponding flow is Q=3 190 m³/s. The closure is proposed to be realized by one-direction advancing from left bank to right bank. During closure, the right-bank 14 flood
discharge gates and closure gap shall be jointly used for flow discharge. After closure, only the spillway will be used for flow discharge. The dike crest elevation is 225.00 m asl and its crest width is 25 m.

Stage 2:

Second stage protections are presented on chapter 7.2.4 of the FS. Their main characteristics are set as follow:

- Upstream transversal protection: earth-rock cofferdam with clay-core above 227.0 and concrete grouting curtain below, crest at 238.5 m asl;
- Downstream transversal protection: earth-rock cofferdam with clay-core above 227.0 and concrete grouting curtain below, crest at 234.0 m asl;
- Longitudinal protection: concrete cofferdam, crest between 238.5 m asl and 234.0 m asl (same as first stage).

The new cofferdams are constructed during the dry season from December supposedly to March, between the end of year 3 and the beginning of year 4. Water retaining standards during erection of cofferdams are not clearly provided.

During phase 2 diversion period, the river course shall be narrowed to flow through the spillway. Water retaining standards of cofferdam during such period are different between cofferdam water retaining period (P=5%, i.e. 20-year all along the year, and Q=23 000 m³/s) and dam body water retaining period (P=1%, i.e. 100-year all along the year, and Q=27 200 m³/s).

6.5.12.2 Analysis

Water levels are provided by the Developer for each phase and location. Cofferdams seem to be at least 2.0 m above considered water level. Unfortunately, it is not clear how these water level values were estimated even though they have been tested on physical model. The narrowing of the riverbed will have a significant influence on flow patterns and water levels. A safety margin should also be provided with regards to waves and local wash or swirls. The basic design of the cofferdams seems satisfactory at this stage with respect to considered water levels.

A stability calculation model is provided. According to the results, sufficient safety is obtained. Nonetheless, it appears that 1st and 2nd stage transversal cofferdams are “rubble, rock ballast mixture, clay, etc.” and of “weathered rock ballast”, with upstream and downstream slopes protected by a compacted rock layer of thickness 1 m. This information suggests that materials will not be carefully graded and controlled. The design of cofferdams shall be completed with seepage assessment as curtain grouting is just in contact with impervious layers, as well as a suitable monitoring system for watering and dewatering procedure. The level of protection of the upstream cofferdam shall then be thoroughly controlled for both erosion and internal stability in case of extreme flood. These calculations shall be presented in the feasibility study and a prevention plan shall also be presented in case a voluntary flooding of construction area would be necessary for protection of the temporary structures above a certain water level of the river.

Little information is provided about river closure. No drawing is provided to localize the site and illustrate the principles. A dike crest at 225.0 m asl seems consistent with considered flow at present stage but it shall be revised if assumptions are modified. The material used for river closure is not specified. This topic shall be developed as the closure dyke will be a part of phase 2 cofferdam and will be used approximately for 3 years. Stability shall be controlled and internal erosion prohibited.

The general construction schedule was not updated in the final documentation. It should be provided in the feasibility study.

6.5.13 Conclusions about the safe passage of extreme floods

The values of design and check floods have been analyzed in chapter 5 of the FS. The upgraded values of DF and CF are now consistent with international standards.

The global spillway discharge capacity is consistent with the considered peak flow of design and check flood values. It has been checked on physical model. A specific test on physical model has been performed to check the impact of unavailability of the equipment during floods. Upstream water level would rise up to 244.8 m asl if 3 gates are locked under check flood, thus no overtopping would occur in this situation.
The Developer shall provide more information regarding the different patterns of gates opening. These patterns shall be elaborated considering results of scouring tests on the physical model. There shall be continuity between the downstream extremity of energy dissipation structures and the river bed to avoid erosion.

The Developer shall provide a drawing with upstream topography and, if needed, planned embankments to avoid lateral flooding of surroundings.

The Developer shall take great care when setting operation procedures for the trash cleaning boat that will be maneuvering just upstream the dam in order to secure these operations.

The design of cofferdams shall be completed with seepage assessment as well as a suitable monitoring system for watering and dewatering procedure. The material used for river closure shall be detailed as the closure dyke will be a part of phase 2 cofferdam and will be used approximately for 3 years. Stability shall be controlled and internal erosion prohibited.

Finally, the Developer shall clean all the feasibility study of former assumptions so that design, design criteria and drawings are consistent throughout the whole documentation. The general construction schedule was not updated in final documentation. It shall be provided in feasibility study.

6.6 Engineering Geology

6.6.1 Local geological context according to feasibility study

According to chapter 3.5.1.2 of the FS, “The outcropping stratum is the Permian stratum. […] Mudstone is deposited in local area subject to slight degree of metamorphism […]. The Quaternary is dominated by alluvial sediments and eluvial sediments. The alluvial sediments are deposited on the reef flat, terrace and main riverbed, and the eluvial sediments are distributed on the hillsides and mountain tops on both banks.”

According to chapter 3.5.1.5 of the FS, the “thickness of overburden on the reef flat is less than 3.5 m, and the thickness of overburden at the main riverbed is 8.0 m ~ 28.0 m”.

6.6.2 Groundwater

Two regimes were identified by the Developer:

- porosity water in deposits of thin and loose material belonging to highly / medium pervious layer (1.0×10⁻⁵ m/s to 2.9×10⁻⁴ m/s);
- bedrock fissure water where q<5Lu in 59% of tested sections, 5Lu<q<10Lu in 21% of tested sections and 10Lu<q in 20% of tested sections.

There is no mention in FS text, including table 3.5.1-3 (List of Borehole Data at Upper Dam Site) that large voids have been found. Karst caves are mentioned in chapter 3.3.2.5 of the FS along fault F1. Such voids could potentially result in high seepage at various depths, higher than expected regarding the average permeability of water resistant layer.

6.6.3 Geotechnical conditions

Rock sampling test were performed (see chapter 3.1.5.6 of the FS). Rock mass was classified in table 3.5.1-7 from class II to class IV (from best to lowest mechanical qualities).

During excavation, great care will have to be given to rock quality. Deposits and loosened rock mass (classes IV & V) shall be removed. Removal of this material could lead to adaptations of foundation levels.

Powerhouse and dam foundation anti-sliding stability checking calculation and targeted treatment shall be conducted. Proper anti-seepage measures shall be taken. Reinforcement is likely to be needed below stilling basin.
6.6.4 Borrow pits and quarries

The Developer performed investigation in the area of the project to find the necessary construction material and especially (see chapter 1.3.6 of the FS):

- concrete aggregates (3.57 million tons);
- anti-seepage material (102,000 m$^3$);
- earth-rock filling (2.13 million m$^3$)

No suitable natural aggregates are found near the dam site. “Artificial” aggregate will be provided from Dajiang Quarry Area about 2 km away from the river left bank at dam site. The reserves of this quarry are estimated to about 8 million m$^3$.

The Developer plans to use a borrow area “at upstream terrace on the right bank” at dam axis. Its reserves are estimated to be 533,000 m$^3$ of earth material that can be used for impervious structure.

Rockfill material will mainly be made from excavated materials from powerhouse and spillway. Dajiang limestone quarry will be used only for high quality and graded rockfill material.

According to investigations performed by the Developer, the available reserves meet the requirements.

6.6.5 Design criteria

Design criteria that are considered for calculations are provided in tables 3.5.1-18 to 3.5.1-22 of the FS. It would be helpful to ensure consistency of used design criteria throughout the whole study.

6.7 Dam design

In this chapter, the purpose is:

- to check metal structures that should be available to cut off water flow in case of equipment failure;
- to analyze design of scour preventer structures and other points of interest such as, embankments, canals for groundwater control, management of local tributaries.

6.7.1 Spillway metal structures

According to chapter 6.4.1 of the FS:

- The 11 surface high level sluice gates are equipped with a service radial gate and slots for upstream and downstream bulkheads. Two upstream bulkhead gates are provided for common use. They must be operated in hydrostatic equilibrium only.
- The 3 surface low level sluice gates are equipped with a service radial gate and slots for upstream and downstream bulkheads. It is not clear how many upstream bulkhead gates are provided for common use and it shall be clarified. They must be operated in hydrostatic equilibrium only.
- The 14 surface sluice gates share one downstream bulkhead gate. The number of used segments is adapted for all the types of sluice gates. The bulkhead must be operated in hydrostatic equilibrium only.
- The 2 bottom outlets are equipped with a plane fixed wheel service gate. They share 1 emergency upstream bulkhead that can be used in dynamic waters and 1 downstream bulkhead that must be operated in hydrostatic equilibrium only.

In normal conditions, water is retained by the 14 radial gates at surface sluices and the 2 plane fixed wheel gates at bottom outlets. All these gates can be used in dynamic water.

One gantry crane is set on the dam crest. It is used to hoist upstream and downstream bulkheads and should allow taking the gates out of the slots. This last point is not clear on drawings (Pak Lay-FS-HS-16 to 19 Typical section of the FS). A specific detail on hoisting superstructures and equipment with lifting beam and gate in high position would be helpful.

The available width to go down on the sill between upstream bulkhead gate and radial gate (see drawings Pak Lay-FS-HS-16 to 19 Typical section of the FS) is 1.6 m according to elements provided by the Developer. It seems to be a bit low but the Developer estimates it is sufficient.
6.7.2 Spillway concrete structures

Although it is not directly linked to dam safety, the following issues might affect maintenance:

- There is little space available between upstream bulkhead and the radial gate. It does not seem possible to go down to the sill of radial gate with machinery or large equipment;
- It is not very clear which parts of the spillway are pre-stressed as quoted in chapter 5.7.3 of the FS;
- There is now a proper downstream fairing and downstream slots for maintenance bulkhead have been implemented (see chapter 6.4.1.8 of the FS).

6.7.3 Powerhouse metal structures

At the intake, bulkhead gates should be operated in hydrostatic equilibrium. These gates cannot be used for cut off. After completion of construction, there are 4 gates provided in total.

Downstream each unit there is a slot for a cut off gate in draft tube. This gate can be closed in dynamic water and must be opened in hydrostatic equilibrium. After completion of construction, 5 permanent emergency gates are provided. These gates can be used in case of unit failure to cut off the flow up to design flood downstream water level. They are operated by a gantry crane.

There are no slots for downstream bulkhead.

Although it is not directly linked to flow cut off equipment, 28 vertical trash racks are equipped in total (chapter 6.4.2.2 of the FS). The fact that grids are vertical could lead to a difficult removal of all the debris and logjam.

6.7.4 Navigation locks metal structures

6.7.4.1 Upstream head

In the upstream head, the main gates are miter gates and must be operated in hydrostatic equilibrium.

There are upstream emergency bulkheads that can be closed in dynamic waters and must be opened in hydrostatic equilibrium.

6.7.4.2 Downstream head

In the downstream head, the main gates are miter gates and must be operated in hydrostatic equilibrium.

There are downstream bulkheads that must be operated in hydrostatic equilibrium.

6.7.4.3 Filling system

There are trash racks provided at entrances of the water emptying system.

Water filling system is equipped with 2 upstream bulkheads that must be operated in hydrostatic equilibrium.

In normal conditions, the water filling system is controlled by the 2 working reversed radial gates. These gates can be opened in dynamic waters and are usually closed in hydrostatic equilibrium. But they can be closed in dynamic water in case of emergency.

Downstream the working gates of the water filling system and in addition to the service gate chamber, there are 2 bulkheads that must be operated in hydrostatic equilibrium.

Thus, there is no emergency bulkhead for the filling system.

6.7.4.4 Emptying system

Upstream the working gates of the water emptying system and in addition to the service gate chamber, there are 2 bulkheads that must be operated in hydrostatic equilibrium.

In normal conditions, the water emptying system is controlled by the 2 working reversed radial gates. These gates can be opened in dynamic waters and are usually closed in hydrostatic equilibrium. But they can be closed in dynamic water in case of emergency.
Downstream the working gates, there are 2 bulkheads in the water emptying system that must be operated in hydrostatic equilibrium.

Thus, there is no emergency bulkhead for the emptying system.

### 6.7.5 Fish pass metal structures

There is no upstream bulkhead gate for fish passage. The Developer stands that “for maintenance of service gate slot for flood control, water retaining shall be carried out by sandbag cofferdams”. In case of blockage at partial opening of the upstream service gate it could be difficult to effectively cut off the flow at the inlet.

The speed should be low in the upstream ‘channel’ part of the fish pass. Nonetheless, the Developer shall provide an upstream emergency bulkhead in order to keep a possibility to cut off the flow whatever the flow conditions are. This bulkhead could be closer to the dam than the upstream gate of the fish pass as long as it provides a continuity of water retaining structures with the rest of the dam.

As it could be needed to dry the fish pass up to the upstream gate, the minimum would be not to set the upstream gate at the exact upstream extremity of the fish pass. If lateral walls of the ‘channel’ were extended a little bit upstream the gate, it would allow to set the cofferdam within the upstream ‘channel’ part of the fish pass rather than upstream the fish pass in the river bed.

There are two service gates for upstream and downstream flood control that can be operated in dynamic waters. It is not clear why it is necessary that the downstream gate can be operated in dynamic waters. It is in any case mandatory to cut off the flow at the inlet before using the downstream gate in order to avoid overtopping.

There is no downstream bulkhead gate for fish passage.

### 6.7.6 Scour preventer

In chapter 5.7 of the FS, the Developer provides the guidelines he used for the design of these structures.

Apron is provided for the 2 bottom outlets, the 3 low-level surface bays and 6 high level surface bays on the right bank. Their lengths are respectively 42 m, 73 m and 45 m. The altitude of the apron of bottom outlets and low-level surface bays is 204 m asl. The altitude of the apron of the 6 right side high-level surface bays is 220 m asl.

The altitude of the stilling basin for other high level surface bays is 211.0 m asl. It is 90 m long and 96 m wide.

The methodology of calculation is provided in section 5.7.4.3 of the FS and yet the computed length of hydraulic jump (or rolling current energy dissipation if used) is not provided.

The energy dissipation and anti-scour structures are designed for the 100-year flood (27 200 m$^3$/s). This value seems consistent with project lifetime and with both water heads and downstream depths for several inflow values even though it is very low compared to ICOLD standards which recommend using the design flood.

### 6.7.7 Embankments

On the drawing Pak Lay-FS-HS-14 General plan layout of structures of the FS, no embankment (levee) is represented.

There is no information about upstream levees. As already stated in chapter 6.5.6 of the current report, some information may be needed depending on local topography. This shall be clarified and dealt with in the feasibility study.

According to chapter 1.4.10 of the FS, the maximum daily water level fluctuation is 3 m in the reservoir and 2.2 m downstream. It shall be checked that these limits are consistent with hydrologic events, especially for flows ranging from 16 700 m$^3$/s to 20 000 m$^3$/s.

The Developer shall define hourly limits to these fluctuations and use them in operation policies as they are more relevant both for bank stability and riparian population. Stability of natural banks shall be assessed with such water level fluctuations in order to provide embankments where needed.
6.7.8 Canals for groundwater control

In the reservoir, water head will rise as soon as the Developer starts operating the spillway. This water head rise will lead to an increase of groundwater levels and potentially to inundation of upstream surrounding plains. This impact could be at a local level only and remain marginal. The Developer has already addressed this issue saying in the FS that it is not important (chapter 3.3.2.3): “Since there is only a small population in the reservoir section above the upper dam site and the arable lands are limited, the impact of immersion is not large”. However, this risk shall be assessed more in details in the feasibility study.

On drawings, there is no canal represented in banks along the installation. Groundwater is not further dealt with in the FS report.

If necessary, a classical solution is to dig canals that control groundwater head along levees and banks in the reservoir and to monitor ground water head.

6.7.9 Management of local tributaries

It seems that no small tributaries are located nearby the dam site. There is no tributary either on drawing Pak Lay-FS-HS-14 General plan layout of structures. It should be noted that modification of groundwater levels may greatly affect the regime of upstream tributaries (see chapter 6.7.8).

6.7.10 Access roads

As detailed in chapter 7.5 of the FS, there is no national main line or provincial highway going to the dam site area on either bank. Water transportation between Luang Prabang and Vientiane provides only low shipping capacity.

A new bridge across the Mekong will be built about 1 km downstream of the dam axis. A new access road will be built between the mouth of Nam Phoun River and the dam site, with a bridge across the Nam Phoun River connecting the access road to existing roads.

Most outsourced materials will be transported by a combination of water and road transportation from Thailand to Pak Lay.

Large electromechanical equipment will be transported by sea to Laem Chabang Port near Bangkok and then to the dam site by roads.

It shall be checked by the Developer that access will always be possible even in case of floods, up to design flood and even check flood.

On the dam, powerhouse and ship lock, bridges are arranged at the top of water retaining structures (ref. chapter 5.5.6.2 of FS). The road to the dam and plant on the downstream left bank is higher than 237.5 m asl (ref. drawing Pak Lay-FS-HS-14 General plan layout of structures of the FS). The road to the dam on the right bank is not clear on drawing Pak Lay-FS-HS-14. Camps for the Employer, the Designer, the Supervisor as well as camps for living and handling officials are arranged on the right side of bridgehead of Mekong River Bridge at an elevation of 238.00 m asl (ref. chapter 7.7.3 of the FS). Thus they are above water level at check flood (240.53 m asl upstream and 236.70 m asl downstream the dam) and the dam site will be accessible for people living in these camps.

Unfortunately, there is no consideration in the feasibility study about access to the dam site in case of major flood through local roads. Low bridges and roads might be inundated a few kilometers from the dam site. Hence the installation might be unreachable for floods lower than the design flood, even though local roads are accessible.
6.8 Stability analysis

6.8.1 Dam (every water retaining structures)

Stability of the dam is supposedly assessed according to Chinese standards DL5108-1999 Design Specification for Concrete Gravity Dams although it is not referenced in chapter 5.6.3.2 of the FS. Stability against sliding and bearing capacity are checked. The different studied structures are:

- non-overflow dam on right bank slope dam section,
- left non-overflow dam section,
- non-overflow dam on left bank slope dam section,
- non-overflow dams at slope turning point,
- overflow dam at section with high-level surface bay without stilling basin,
- overflow dam at section with high-level surface bay with stilling basin,
- overflow dam at section with low-level surface bay.

These different sections of the installation are not localized on any drawing. It would be helpful, especially for non-overflow dam sections. The different combinations that were studied are summarized in table 5.6-3 of the FS as shown below.

<table>
<thead>
<tr>
<th>Calculation Condition</th>
<th>Upstream</th>
<th>Downstream</th>
<th>Self-weight</th>
<th>Hydrostatic pressure</th>
<th>Uplift pressure</th>
<th>Silt pressure</th>
<th>Wave pressure</th>
<th>Earthquake inertia force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic combination under persistent situation (normal pool level)</td>
<td>240.00</td>
<td>220.00</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Basic combination under transient situation (construction period)</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic combination under transient situation (maintenance period)</td>
<td>240.00</td>
<td>224.14</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Accidental combination 1 under accidental situation (check flood level)</td>
<td>240.53</td>
<td>236.70</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Accidental combination 2 under accidental situation (normal pool level + earthquake)</td>
<td>240.00</td>
<td>220.00</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Accidental combination 3 under accidental situation (the 3 release sluices cannot be opened under check level condition)</td>
<td>244.8</td>
<td>236.47</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 16: Calculation conditions and load combination (source: table 5.6-3 of the FS)

Calculation parameters are consistent with the dam materials. Considered water levels are clear. The methodology relative to seismic design is not clearly presented and dynamic water pressure is not treated. Stability against floating is studied for overflow dam. Seepage calculation is not provided.

The distribution of groundwater pressure is provided and consistent for non-overflow dams. Figures 5.6-1 to 3 of the FS clarify if protection apron and stilling basins are included to the overflow dam or not.
It seems that in maintenance there is no water load between upstream and downstream stoplogs. Stability against sliding is checked on overflow dam for maintenance conditions. The Developer could consider the probabilities of concomitant maintenance and flood or seismic combinations. Safety factors are provided. According to provided results stability against sliding, bearing capacity and floating are all checked.

It is not easy to understand how Check Flood situation could be more critical against sliding than standard situation in Non-overflow Dam (see table 5.6-4 to 7 of the FS). The hydrostatic head difference between upstream and downstream parts of the dam shall be greater in the latter.

Slight tensile stress appears in the dam bottom under standard situation and under earthquake. It should be localized.

### 6.8.2 Apron and stilling basin

Stability analysis of the apron against floating is provided in chapter 5.7.4.5 of the FS.

The longitudinal limits of the studied structure are not clear. A reference to transversal joints between gates in the spillway is made. And yet it is not clear whether protection apron and still basins are included to the overflow dam or not. Ground water pressure would be different if water tightness is continuous between spillway and stilling basin.

The remark about “1 generator for power generation” and the consequence it may have on the stability of the apron is not clear. It seems that in this situation the apron between the radial gate and a downstream cofferdam is dry but it should be confirmed.

The check condition n°2 “drainage failure” shall be explained.

Results are not presented but it is explained that aprons are not stable against floating by its self-weight and need to be anchored.

### 6.8.3 Powerhouse

Stability of the power house is assessed in chapter 5.8.10 of the FS.

The different combinations that were studied are summarized in table 5.8-1 of the FS as shown below.

Stability with 3 gates unavailable should also be assessed for HPP, even though by analysis of results in other situations there should not be any risk of instability even in this scenario limit.

Considered water levels are clear. The distribution of groundwater pressure is provided and consistent.

The Developer could consider the probabilities of concomitant maintenance and flood or seismic combinations. Safety factors are provided. Stability against sliding, floating and bearing capacity is checked in all situations.
### Table 17: Load combination (source: table 5.8-1 of the FS)

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Combination of Calculation Conditions</th>
<th>Type of Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic combination</td>
<td>Normal operation 1: Upstream water level: 240.00 m, Downstream water level: 220.22 m &amp; 235.60 m</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Normal operation 2: Upstream water level: 239.02 m, Downstream water level: 235.60 m &amp; 235.60 m</td>
<td>✓</td>
</tr>
<tr>
<td>Special combination 1</td>
<td>Unit maintenance: Upstream water level: 240.00 m, Downstream water level: 224.14 m &amp; 235.60 m</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Unit not installed: Upstream water level: 239.02 m, Downstream water level: 235.60 m &amp; 235.60 m</td>
<td>✓</td>
</tr>
<tr>
<td>Special combination 2</td>
<td>Abnormal operation: Upstream water level: 246.53 m, Downstream water level: 236.70 m &amp; 236.70 m</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Seismic condition: Upstream water level: 240.00 m, Downstream water level: 220.22 m &amp; 220.22 m</td>
<td>✓</td>
</tr>
</tbody>
</table>

#### 6.8.4 Navigation locks

Stability analysis of navigation locks is provided in chapter 5.9.5 of the FS. The different combinations that were studied are summarized in tables 5.9-8, 10 and 12 of the FS (see below).

Safety factors are provided. Considered water levels are clear. The distribution of groundwater pressure is provided and consistent.

It is not clear if hydrodynamic water pressures are considered in seismic situation. The Developer shall check the stability under seismic situation for both miter gates. The Developer could also consider the probabilities of concomitant maintenance and flood or seismic combinations.

The fact that stability under check flood is only checked for upstream bulkhead implies that downstream gate remains open during floods.

Allowable bearing capacity shall be provided in this chapter according to the grade of rock mass under foundation. Actually, the maximum calculated stress is about 2.15 MPa while allowable bearing capacity of class III rock is 2 MPa according to table 5.1-4 of the FS. Thus stability against bearing capacity is only checked if bedrock is of class II.

Stability against sliding and floating is checked under all situations. Stability against bearing capacity cannot be assessed directly as allowable bearing capacity is not provided.
### 6.8.5 General considerations

A sensitivity study of stability to parameters of ground and water levels would be useful for a better risk assessment.

The stability analysis does not include the study of potential differential movement of structure. In Pak Lay project it should not be of first importance as the installation is founded on bedrock.

Consolidation grouting will be carried out for foundations of main buildings, including the dam (see chapter 5.6.2 of the FS). Nonetheless, there is no discussion about sliding of deep layer of dam or base rock joints that could lead to sliding along rock weak structural plane.

Drainage of structures is planned by drainage holes behind grouting curtains of spillway, powerhouse and navigation locks and regularly under all the stilling basins downstream of the spillway.

---

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Calculation Condition</th>
<th>Water Retaining Gate</th>
<th>Self-weight</th>
<th>Soil Pressure</th>
<th>Hydraulic Pressure before the Gate</th>
<th>Hydraulic Pressure after the Gate</th>
<th>Uplift Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic combination</td>
<td>Operation</td>
<td>Service gate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>Bulkhead gate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Completion</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special combination</td>
<td>Check flood</td>
<td>Bulkhead gate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Earthquake</td>
<td>Bulkhead gate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 18: Load combination of the upper lock head under all conditions (source: table 5.9-8 of the FS)

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Calculation Condition</th>
<th>Self-weight</th>
<th>Soil Pressure</th>
<th>Hydraulic Pressure in the Lock Chamber</th>
<th>Ship Load</th>
<th>Uplift Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic combination</td>
<td>Operation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Completion</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 19: Load combination of the lock chamber under all conditions (source: table 5.9-10 of the FS)

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Calculation Condition</th>
<th>Water Retaining Gate</th>
<th>Self-weight</th>
<th>Soil Pressure</th>
<th>Hydraulic Pressure before the Gate</th>
<th>Hydraulic Pressure after the Gate</th>
<th>Uplift Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic combination</td>
<td>Operation</td>
<td>Miter gate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>Bulkhead gate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Completion</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 20: Load combination of the lower lock head under all conditions (source: table 5.9-12 of the FS)
6.9 Dam safety review

The Dam Safety Management System (DSMS) has been initiated (ref. chapter 8.2.11 of FS). An annual report will be produced. It will be submitted to governments and made public.

The objectives of the DSMS are set before construction. For next phases, it will be necessary to develop the DSMS accordingly to project advancement. Through construction, it is recommended to focus on the following issues that could impact global design:

- Dam failure,
- Defect risk analysis of flood discharge and energy dissipation facilities,
- Dam foundation leakage and bypassing leakage,
- Earthquake and Reservoir induced earthquake.

The Developer shall mention the comprehensive dam safety reviews as described in MRC preliminary design guidance. The dam safety reviews need to be scheduled at least once every five years and shall include a site inspection. The description of the inspection will include all works at the dam site, an assessment of the reservoir, in particular reservoir debris and a tour of the downstream area to reassess the downstream consequence classification. If the dam is exposed to conditions other than those on the day of the inspection (extreme flood, storm, etc.), the review engineer should review inspection records or speak to the owner about any anomalies that may have occurred during those conditions.

The dam owner should be interviewed about the following issues:

- operating and maintenance issues or incidents,
- equipment or system issues,
- dam performance,
- any issues involving other dam owners or stakeholders.

The effectiveness and adequacy of the operation, maintenance, and surveillance, must be reviewed. The review of the operation, maintenance, and surveillance should be undertaken using the Dam Safety Expectations (or equivalent analysis) listed in the “Operation, Maintenance, and Surveillance” document to be provided in a draft version by the Developer. In addition, the Dam Safety Review engineer should consult the MRC Guidance on Safety of dam and consider the questions listed in that subsection.

The review engineer should then be able to assess compliancy based on the documented procedures by auditing the operation, maintenance, and surveillance records, having discussions with staff on site, and judging the state of maintenance and site conditions during the site visit.

The dam safety review shall address the testing of equipment required to operate discharge facilities needed for safe passage of the design flood and any other flood that could endanger the dam (including backup equipment and emergency power supply). If the discharge gates and equipment have been tested or operated within a year and adequate documentation is available, a review of such testing or operation records may be adequate.

6.10 Construction supervision and quality assurance plan

The Construction supervision and Quality assurance plan is presented in chapter 8.1 of the FS. It shall be developed through the design process. It needs clarification about scope and levels of responsibility of the various divisions, and needs to present more operational procedures than methods as done so far.

6.11 Instrumentation plan

The safety of dam shall be monitored along the whole life of the facility operation. The importance of monitoring programs for dam safety is widely accepted and implemented. A well designed and executed instrumentation monitoring program can provide information that is needed for a solid understanding of the ongoing performance of a dam and shall help detect early signs of trouble.

Monitoring programs, including instrumentation and visual inspection, enable dam owners to check whether a dam is performing as expected or not and to detect a change in performance. This information is critical because the dam owner is directly responsible for the consequences of a dam failure. Therefore, a good dam safety monitoring program is a key component of every dam owner’s risk management program.
A detailed instrument plan for the installation of instruments shall then be provided at feasibility study stage explaining how shall be monitored and recorded dam behavior and related hydro-meteorological, structural and seismic factors.

In chapter 1.5.7 of the FS, it is stated that monitoring will concern:

- structure deformation and displacement,
- seepage flow,
- stress-strain and temperature,
- slopes displacement,
- underground water levels,
- environmental variables,
- silting,
- seismic activity.

This list is rather complete and more details about corresponding equipment are provided in section 1.5.7.2 of the FS.

The dam safety monitoring is mainly developed in chapter 5.11 of the FS. Equipment is further detailed. Monitoring frequency is given at the different stages from construction to operation. Inspection patrols are planned and described.

Some more powerhouse production oriented considerations are also provided in section 6.1.10.6 of the FS.

All these elements express that the Developer considers dam monitoring as a key issue even though it is not of first importance for the economy of the project. It would be helpful to implement on a general layout drawing the different equipment to check the global consistency of this instrument plan.

### 6.12 Operation and Maintenance (O&M) plan

The Operation & maintenance (O&M) plan is presented in chapter 8.2 of the FS. It shall be developed through the design process.

The organizational structure and staffing are provided and detailed.

The management of spare parts is presented but equipment and facilities are not detailed.

Regarding O&M procedures, operation and monitoring are well initiated. Project management systems and dam safety management are initiated.

The funding of O&M is not provided.

### 6.13 Emergency Preparedness Plan (EPP)

The EPP is initiated (ref. chapter 8.3 of the FS). Its broad framework is consistent with WB BP 4.37 annex A but needs to be detailed before construction. An estimate of funds needed is presented. The consultation initiated for ESIA is not presented in chapter 8.3 of the FS, neither is presented the communication strategy to reach and involve all concerned and affected people.

The broad framework shall present:

- clear statements on the responsibility for dam operations decision making and for the related emergency communications: to be further detailed;
- maps outlining inundation levels for various emergency conditions: to be provided;
- flood warning system characteristics: to be further detailed;
- and procedures for evacuating threatened areas and mobilizing emergency forces and equipment: to be further detailed.
6.14 Conclusions for dam safety

6.14.1 Conclusions related to design

Globally the design is sound. The main recommendations are as follows:

- All the feasibility study should be cleaned of former assumptions and designs so that design, design criteria and drawings are consistent throughout the whole documentation.
- The comprehensive dam safety reviews shall be mentioned.
- The broad framework of the EPP is consistent with WB BP 4.37 annex A but needs to be detailed before construction.
- All Mechanical and electrical control equipment shall be backed/double up to ensure a high level of capacity in case of emergency. This shall be described in a specific document or chapter of the description of the equipment, mainly for the spillway, even if the powerhouse equipment shall also be fully equipped for cases of emergency. The question at this stage of development will be on how the security equipment will in all cases enable to let the flood go through the facility and on what auxiliary systems will be provided to enable the power and control;
- In chapter 6.2.3.2 of the FS, the Developer indicates that diesel generators are sufficient to safely cutoff powerhouse and operate “the maximum quantity of flood gates opened at the same time”. The corresponding amount of gates shall be clearly stated.
- Opening gates patterns shall be provided in the feasibility study in order to check the capacity of the spillway. They should be adapted with regards to scouring tests on physical model.
- Great care will be needed when setting operation procedures for the cleaning boat maneuvering just upstream the dam in order to secure these operations.
- The fish pass intake shall be considered as a water retaining structure and its design flood should be provided.
- The general construction schedule was not updated in final documentation. It shall be provided in feasibility study.
- The Developer shall update construction drawings at feasibility stage in order to have a consistent design throughout the report and drawings.
- The design of cofferdams shall be completed with seepage assessment as curtain grouting is just in contact with impervious layers, as well as a suitable monitoring system for watering and dewatering procedure.
- The material used for river closure is not specified. Its stability shall be controlled.
- There is no emergency bulkhead for filling and emptying system of navigation lock.
- Hourly limits to upstream and downstream water level fluctuations should be set and used in operation policies as they are more relevant both for bank stability and riparian population.

![Figure 30: Pak Lay HPP level of compliance on Dam Safety](image)
## 6.14.2 Table of compliance

<table>
<thead>
<tr>
<th>N°</th>
<th>MRC guidance regarding safety of dam</th>
<th>Status concerning compliance (Compliant, Not fully compliant, Not compliant)</th>
<th>CNR comments</th>
<th>Priority (PNPCA, Construction, Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>1. General requirement</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>187</td>
<td>Developers should base the approach to safe design, implementation and operation of proposed mainstream dams:</td>
<td>Compliant</td>
<td>Mainly Chinese standards are used. Laos Electric Power Standards, ICOLD bulletins, World Bank OP 4.37 and MRC PDG are referenced (ref. Chapter 5.5.5.3). There does not seem to be a comparison between used Chinese standards and “international best practice” on main issues (such as DB&amp;CF determination, seismic hazard, flow release capacity or mechanical &amp; electrical back up). Though, DB&amp;CF determination, seismic hazard and flow release capacity have been upgraded and are now consistent with international standards and other schemes on the Mekong (see comments to item 189).</td>
<td>PNPCA</td>
</tr>
<tr>
<td></td>
<td>i. Relevant national standards that impact on different aspects of dam safety.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ii. International best practice, as embodied the World Bank Operational Policy 4.37 on the Safety of Dams; and,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>iii. Periodic Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD) through the ICOLD Committee on Dam Safety(CODS).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Developers and owners claim they are responsible for all cost associated with the emergency preparedness plan (EPP). Though, DF&amp;CF determination, seismic hazard and flow release capacity have been upgraded and are now consistent with international standards and other schemes on the Mekong (see comments to item 189).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Developers and owners should be responsible for all cost associated with implementing all aspects of this guidance on the safety of dams. Developers / owners / operators should clearly detail all such costs in the project budgets for the design, implementation and operation stages.</td>
<td>Compliant</td>
<td>Developers and owners claim they are responsible for all cost associated with implementing all aspects of this guidance on the safety of dams in section 8.2.12.</td>
<td>PNPCA</td>
</tr>
<tr>
<td></td>
<td>All aspects of the World Bank Operational Policy (OD/GP 4.37) for the safety of dams should be reflected by developers and operators, including required reviews by an independent panel of experts of the investigation, design and construction of the dam and start of operations and sub-plans:</td>
<td>Not fully compliant</td>
<td>All plans are initiated (ref. 8.1 for Construction supervision plan, 8.1 for Quality assurance plan, 5.11 for Instrument plan, 8.2 for Operation &amp; maintenance (O&amp;M) plan, 8.3 for Emergency preparedness plan (EPP)). They shall be developed through the design process. Emergency preparedness plan needs to be completed (see comments on item 191). Plan for construction supervision and quality assurance needs clarification about scope and levels of responsibility of various divisions, and needs to present more operational procedures than methods as done so far.</td>
<td>Construction</td>
</tr>
<tr>
<td></td>
<td>i. a construction supervision plan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ii. a quality assurance plan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>iii. an instrument plan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>iv. an operation and maintenance (O&amp;M) plan, and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>v. an emergency preparedness plan (EPP).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Developers and operators should reflect the relevant International Commission on Large Dams (ICOLD) Dam Safety Bulletins in the project design, as well as the approach to project construction and operation.</td>
<td>Compliant</td>
<td>ICOLD bulletins are referenced (ref. Chapter 5.5.5.3). Their use is briefly explained in following chapters: *ICOLD 125 and CFPW 4 June 2013 referenced (ref. 5.5.5.1) about design and check floods -&gt; ok with project DF = Q2 000 &amp; CF = Q1 000. *ICOLD 142 referenced (ref. 5.5.5.3) about extreme flood -&gt; ok with general principles applied (freeload calculation, free surface up to CF, possibility to access to gates even at CF, stability assessed at level before overtopping, concrete dams with concrete energy dissipation structures are less sensitive to erosion of downstream foundation). *ICOLD 148 referenced (ref. 3.2.2.3) about seismic hazard (in ICOLD 148: SEE 10 000y return period, OBE 145y return period, RTE to be treated) -&gt; ok with considered earthquakes (OBE 475y, SEE 5 000y) and treatment of RTE M=5, I≤VI and lower than basic earthquake intensity.</td>
<td>Construction</td>
</tr>
<tr>
<td>189</td>
<td>In particular, developers / owners / operators should prepare and implement a Dam Safety Management System (DSMS) that reflects ICOLD guidance on establishing a systems approach to the management of dam safety. This starts from design and continues through to operation. The DSMS incorporates the production of an annual report on dam safety during the operation phase that is submitted to governments and made public.</td>
<td>Compliant</td>
<td>The DSMS has been initiated (ref. chapter 8.2.11). Annual report will be produced and submitted to governments and made public. The objectives are set before construction. For next phases, it will be necessary to develop the DSMS accordingly to project advancement. Through construction, it is recommended to focus on the following issues that could impact global design: Dam failure, Defect risk analysis of flood discharge and energy dissipation facilities, Dam foundation leakage and bypassing leakage, Earthquake and Ressorso induced earthquake.</td>
<td>Construction</td>
</tr>
<tr>
<td></td>
<td>Developers and operators should ensure there is full and effective consultation with local communities and local government authorities and all concerned organizations and agencies, especially with regard to the emergency preparedness plan (EPP). The EPP should include a communication strategy to reach and involve all concerned and affected people (i) in preparation of the EPP, and (ii) in training or capacity building to implement the EPP, and (iii) responding to any issues concerning annual Dam Safety reports.</td>
<td>Not fully compliant</td>
<td>The EPP is initiated (ref. chapter 8.3). Its broad framework is consistent with WB BP 4.37 annex A but needs to be detailed before construction. Estimate of funds needed is presented. The consultation initiated for ESIA is not presented in chapter 8.3, neither is presented the communication strategy to reach and involve all concerned and affected people. The broad framework shall present: * clear statements on the responsibility for dam operations decision making and for the related emergency communications. -&gt; To be further detailed * maps outlining inundation levels for various emergency conditions. -&gt; To be provided * flood warning system characteristics. -&gt; To be further detailed * and procedures for evacuating threatened areas and mobilizing emergency forces and equipment. -&gt; To be further detailed</td>
<td>Construction</td>
</tr>
<tr>
<td>190</td>
<td>Developers and operators should be responsible to check for periodic updates of the World Bank Operational Policy (OD/GP 4.37) as well as updates, or new Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD). At minimum, this check for updates should be routinely done in preparation of the annual Dam Safety report.</td>
<td>Compliant</td>
<td>The developer and the owner/operator will check for periodic updates of WB OP 4.37 and ICOLD Technical Bulletins on the Safety of Dams every year (ref. chapter 8.2.12).</td>
<td>PNPCA</td>
</tr>
<tr>
<td>191</td>
<td>Developers and owners/operators should be responsible for check for periodic updates of the World Bank Operational Policy (OD/GP 4.37) as well as updates, or new Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD). At minimum, this check for updates should be routinely done in preparation of the annual Dam Safety report.</td>
<td>Compliant</td>
<td>The developer and the owner/operator will check for periodic updates of WB OP 4.37 and ICOLD Technical Bulletins on the Safety of Dams every year (ref. chapter 8.2.12).</td>
<td>PNPCA</td>
</tr>
<tr>
<td>192</td>
<td>Developers and owners/operators should be responsible for check for periodic updates of the World Bank Operational Policy (OD/GP 4.37) as well as updates, or new Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD). At minimum, this check for updates should be routinely done in preparation of the annual Dam Safety report.</td>
<td>Compliant</td>
<td>The developer and the owner/operator will check for periodic updates of WB OP 4.37 and ICOLD Technical Bulletins on the Safety of Dams every year (ref. chapter 8.2.12).</td>
<td>PNPCA</td>
</tr>
<tr>
<td>193</td>
<td>Developers and owners should be responsible for all cost associated with implementing all aspects of this guidance on the safety of dams. Developers / owners / operators should clearly detail all such costs in the project budgets for the design, implementation and operation stages.</td>
<td>Compliant</td>
<td>Developers and owners claim they are responsible for all cost associated with implementing all aspects of this guidance on the safety of dams in section 8.2.13. Thus, it is not possible to check them in details.</td>
<td>PNPCA</td>
</tr>
</tbody>
</table>
7 SEDIMENT TRANSPORT

7.1 Scope of the review

Natural Sediment transport is the basis of the aquatic and wet land ecosystem. It influences directly the river morphology and the fauna and flora populations.

In case of bad maintenance or poor design of dams, the mainstream facilities can interrupt the natural continuity of sediment transport in river systems, leading to deposition in the reservoir and release hungry water downstream, which generally produce channel adjustments and potentially induce scouring phenomena.

It is recognized that excessive sedimentation of the reservoir will shorten the useful life of the facility and may interfere with the function of the facility, as well as increase the pressure on the dam and consequently the backwater effects. Changes in each river flow or sediment load can also induce changes in the form and dimensions of alluvial channels at downstream.

The project reviewed is a low head, run-of-river dam which usually trap less sediment than dams with large seasonal storages. Indeed, fine sediment is more readily held in suspension, and routing or flushing of fine and coarse sediment can be carried out more easily and efficiently if appropriate hydraulic facilities are included in the project layout. CNR has reviewed the main components proposed by the Pak Lay project Developer with thorough focus on each data collected and used, elaborated design as well as operating and maintenance schedule proposed for sediment transport management.

The comments will be based on final FS for each of the following topics:

- General requirements regarding sediment transport;
- Overview of the Mekong River morphology;
- Review of feasibility study regarding sediment issues.

7.2 General requirements regarding sediment transport

Sediment fluxes transported by large rivers like the Mekong River consist generally of (figure 31 and figure 32):

- Washload or very fine particles transported by uniform suspension (clay and silt),
- Bed materials transported by graded suspension (fine sand),
- Bed materials transported as bed-load at the river bottom according to rolling and small saltation processes (coarse sand, gravel and cobble).

![Figure 31: Schematic view of sediment transportation processes](image-url)
To characterize the fluxes and the typical grain size of particles corresponding to those different fractions, specific methodologies and equipment have to be implemented in the field. Some illustrations of relevant devices already deployed on the Mekong River are presented hereafter as a reminder (figure 33).

The objectives of those devices are in particular as follows:

- **Van Dorn or Niskin water trap bottle** (figure 33 a): characterization of very fine sediments in suspension (i.e. uniform suspension or washload) at different water depth, including solid concentration, grain size distribution...
- **Delft bottle** (figure 33 b): measurement of suspended bed-materials (or graded suspension) at different water depth, including solid discharge, grain size distribution...
- **Helley-Smith sampler** (figure 33 c): measurement of bed-materials transported as bed-load at the river bottom, including solid discharge, grain size distribution...
- **ADCP** (figure 34): hydro-acoustic technologies are also promising solutions for measuring suspended sand fluxes at high spatio-temporal resolution thanks to the acoustic attenuation and backscattering properties induced by a suspension of sediments.

![Figure 32: Classification of sediment transportation processes](image)

![Figure 33: Sampling devices deployed by CNR in August 2013 to characterize the Mekong River solid transport processes](images)
Figure 34: Computation of graded suspension of sand combining ADCP backscatter recording with backscatter calibration from samples collected with Delft bottle. Measurements presented were performed by CNR on the Mekong River at Luang Prabang on 13/08/2013.

Measurements performed with those devices highlight important specificities of sediment transportation processes:

- Sand particles in suspension are generally transported according to an increasing gradient of concentration from the flow surface down to the river bed (figure 35). As a result, those particles are indeed barely present at the flow surface (figure 36), meaning that surface sampling only do not reflect correctly the real proportion of sand in suspension. Consequently, appropriate devices have to be deployed to avoid a huge underestimation of fluxes corresponding to suspended bed-material.
- The grain size of particles deposited at the surface and subsurface of alluvial deposits is generally much coarser than those effectively transported as bed-load by the river for usual hydrological conditions (figure 37). As a result:
  - Bed-load fluxes evaluated from samples taken on river deposits only may be largely underestimated,
  - The deployment of appropriate devices such as those presented previously is required in the field to obtain relevant estimations of bed-load discharge.

Figure 35: Evolution of relative importance of sand particles with water depth according to water samples collected by CNR on the Mekong River at Luang Prabang in August 2013. Sampling depths below the water surface are as follows: (a) 0 m, (b) -8 m, (c) -12 m and (d) -14 m. Total depth is around 15 m.
Figure 36: Vertical evolution of the grain size distribution of suspended-sediments transported by the Mekong River at Luang Prabang according to samples collected by CNR with different devices.

Figure 37: Grain size distribution of bed-materials deposited and transported by the Mekong River at Luang Prabang. Bed-load measurements were performed by CNR on 05/08/2013 with a daily mean discharge around 10,000 m$^3$/s.
7.3 Overview of the Mekong River morphology in the study area

The Mekong River is a large river whose course crosses several geologic and climatic zones. Thus its channel is composed of many various units. Each unit shows specific morphology and behavior. Following a comprehensive field campaign performed by CNR from Chiang Saen down to Nong Khai, a morphological zoning has been proposed. The zoning takes into account the following indicators (figure 38):

- Nature of river bed material (rock or alluvium) and thickness of alluvium layer if any, distinguishing the 3 following cases: rock-incised riverbed, river bed with a fine alluvial layer and river bed with a thick alluvial layer;
- In-channel components: presence or absence of alluvial bars, in-channel islands, rocky outcrops, rapids…
- Characteristics of typical alluvial deposits: in-channel bars, side bars, point bars…
- Degree of overlapping observed on bar and islands;
- Major characteristics of the surrounding landscape and degree of confinement of the channel;
- Extension of the river bed at low flows and high flows;
- Longitudinal profile shape and evolution of the mean channel slope for low flows conditions;
- …

The proposed Pak Lay reservoir is included in the stretches numbered from 6 to 8 previously defined by CNR (figure 38):

- Reach n. 6: from proposed Xayaburi dam (Km 1930) to Ban Pak Toung (Km 1874);
- Reach n. 7: from Ban Pak Toung (Km 1874) to Houay Khi (Km 1843);
- Reach n. 8: from Houay Khi (Km 1843) to proposed Pak Lay dam (Km 1729).
7.3.1 From proposed Xayaburi dam (Km 1930) to Ban Pak Toung (Km 1874)

In the upper part of the proposed reservoir, the Mekong River flows towards South, corresponding approximately to a major geological fault. The river flows on rock through a set of near-straight channel bounded at the downstream end by a large bend.

The channel slope is ranging from 30 to 35 cm/km and it increases significantly compared to previous river unit. The river exhibits a deeply rock incised channel. Small rapids occur also steadily through narrow openings of rocks. Locally, the flow is sometimes divided in multiple channels around in-channel outcrops. These outcrops and rock protrusions often lead to impressive sand deposits that form in-channel bars during the falling stage of the wet season.

The river is confined in a narrow valley flanked by steep hills. The low flow channel width is comprised between 50 m and 100 m while during the wet season, the Mekong flows through a 200-400 m wide channel.

Two tributaries join the mainstream in that part, the so-called Nam Houng and Nam Pouy. Many other small tributaries likely to experience torrential floods and debris flow events contribute also to the sediment supply of the Mekong River in that stretch.

Figure 39: Huge sand accumulation on the Mekong River bank

Figure 40: Rock-incised channel with sandy side-deposits over bedrock benches

Figure 41: Rocky protrusion in the Mekong River channel

Figure 42: Rock outcrops on the river bank
7.3.2 From Ban Pak Toung (Km 1874) to Houay Khi (Km 1843)

In the intermediate stretch, the Mekong River flows through a straight channel incised in rock. The channel slope is around 30-35 cm/km. For low flow conditions the river flow divides frequently around in-channel rocky outcrops that are usually submerged during the wet season. Numerous rocky protrusions and isolated rock piles are also regularly visible. Sometimes, these outcrops lead to sediment accumulations that can locally form in-channel islands. The largest one by far is located at Don Son (Km 1852).

On the left side, the river is dominated by a mountainous range rising up to 1200 m asl, while low elevation hills (below 500 m) are present on the right side.

For low flows, the river width doubles compared to previous reach and is comprised between 100 m and 200 m. It extends up to 250-450 m during the wet season.

![Barely emerged rocky outcrop](image1)

![Mekong River channel flanked by small hills on the right side](image2)

![Rare example of large in-channel rocky outcrop covered by sand and gravel deposits (Don Son area)](image3)
7.3.3 From Houay Khi (Km 1843) to proposed Pak Lay dam (Km 1729)

In this short stretch, the river course is globally straight, even if a large meander resulting from the tectonic history is visible at the very beginning of the reach. The Mekong River valley is quite opened and surrounded by a landscape of hills. Some emerging limestone peaks are also visible in the upper part.

The river channel is continuously incised in the bedrock. This important feature explains the regular presence of rocky banks (some of them being quite steep) and the existence of wide rock benches possibly covered by thick sand deposits.

A significant change in the channel size has to be noted depending on the flow season. While the channel width ranges from 50 to 200 meters during the dry season, it is likely to extend up to 700 meters at the peak of the wet season. The channel slope is comprised between 15-20 cm/km.

Figure 46: Rocky outcrop covered by sand deposits

Figure 47: Narrow and rock-incised channel at Pak Lay during low flow period

Figure 48: View of the Mekong River at the end of the wet season flowing through a wide and opened valley
7.4 Review of feasibility study regarding sediment issues

7.4.1 Assessment of sediment characteristics and sediment supply in the proposed reservoir

The current level of field-investigations is strongly better than in the previous version of the FS. It helps the Developer to better assess sediment characteristics (MRC #127). Following CNR recommendations, in terms of on-site measurements advices and former data on the Mekong River from Chiang Saen to Nong Khai, the Developer performed relevant sediment fluxes measurements for Pak Lay project. It is absolutely crucial to continue to collect a comprehensive and a relevant set of in-situ observations during at least a complete hydrological cycle, and if possible to proceed to measurement in the next coming months and years. Current data are sufficient to develop sediment studies and to allow CNR finalizing its expertise.

The Developer shall keep in mind that those data are necessary to estimate the impacts of Pak Lay HPP on solid fluxes and river morphology, and to evaluate the cost of mitigation measures required for minimizing the reservoir sedimentation and related impacts (outlet works design, deposit management, erosion process prevention…).

Chiang Khan gauging station, which is located 112 km downstream Pak Lay dam site, is used for sediment analysis for suspended load. A new correlation between the monthly average flow and the monthly average suspended sediment discharge (2009-2015) has been proposed by the Developer instead of the former correlation based on data collected from 1967 to 1977.

For PNPCA, the Developer has to provide:

- Formula of these correlations including regression coefficient in order to validate the reference correlation: a linear formula seems to be more relevant, to avoid under-estimation for low flow and high flow (logarithmic scale).
- A comparison between recent Developer’s measurements and this new calculation, by plotting on-site data on figure 49 to confirm reference correlation. The Developer shall also take into account vertical variability of suspended load for different water level and its consequences on annual sediment volume. According to the previous FS, the average annual suspended sediment concentration of the Pak Lay dam site was 0.509 g/l compared to the new value which is set to 0.129 g/l on the 2009-2015 period. The average annual load discharge was 66 Mt compared to the current value of 16.5 Mt. The chapter 4.10.1 of the FS provides complementary analysis on average annual load discharge but a more recent hydrologic period than 1980-2000 (5 representative years) could be more relevant.
- Chiang Khan data will permit to assess the relative significance and the seasonal distribution only for suspended load, in case of eco-flushing operations below 16,700 cms (see sediment strategy). The Developer has to provide seasonal studies.
- Thanks to intensive surveys made by the Developer, sediment particle grading is currently known for specific discharges at different locations of the reservoir (See figure 52). After interim workshop, to avoid poor hypothesis coming from previous FS, CNR provided former data on the Mekong River to the Developer (figure 50, figure 51). A comparison was done between Developer's data and CNR's data: latter were chosen by the Developer for sediment studies. A sensitivity modelling test will be therefore possible by integrating these sound data in the next step to assess sedimentation impact, considering TSL lower curve, TSL medium curve and TSL upper curve.
- Characterizing the shape (roundness, angularity, sphericity...) and the quartz contents of transported sediments is also of utmost importance to assess whether turbines and concrete structures may be exposed to significant wear and abrasion risks or not, and to define appropriate mitigation measures if any.
- Diagrams presenting some measurements made during site surveys about sediment gradation (July & August 2016), taking into account hypothesis for calculation of average daily flux, figure 2.6.2.2 of the FS.
- A clear description of every devices used for sediment surveys by the Developer in 2015 and 2016.

![Data comparison regarding the GSD of deposit and flux (CNR)](image)

Figure 50 : Sediment Particle Grading in Pak Lay reservoir and Luang Prabang area (source: CNR Mekong River study for GoL, 2013)
Figure 51: Proposal of Sediment Particle Grading for Pak Lay reservoir and Luang Prabang area (source: CNR Mekong River study for GoL, 2013)

Figure 52: Suspended Sediment Particle Grading at the Dam site Reach (source: CNR Mekong River study for GoL in black and Pak Lay FS)
An evaluation of the overall suspended-load is under analysis (wash-load and sand in suspension), due to appropriate devices and methods which were deployed since September 2015. This is of major importance regarding operation.

In chapter 2.6.4.1 of the FS, the Developer presents the purpose of its sediment monitoring system:

"Upon its completion, due to the increased depth in the reservoir reach upstream from the dam site, the flow velocity decreases to a degree during the non-flood discharge period, and some of the river’s suspended sediments will deposit in the reservoir during the non-flood discharge period, thus occupying parts of storage capacity. The former channel form will change to a degree, and then the operation of hydropower station will be influenced. Sedimentation number, sedimentation position in the reservoir, erosion and deformation of downstream channel caused by the discharged clear water flow, and others will influence the safe operation of the reservoir and the change of downstream channel. As a result, it is necessary to carry out the planning for sediments monitoring, for the monitoring can conduct the reservoir dispatching, guarantee the safe operation, and decrease the influence on the downstream channel'.

Even if the Developer shall bridge the gap between its monitoring strategy and the sedimentation studies (studies implying to proceed to monitoring first), the sediment monitoring network has been defined more precisely. It now includes (MRC #122, #136, #137, #138 and #139):

- Tests inflow and outflow sediments of the reservoir (cross-section downstream of the upstream HPP);
- Monitoring of a few cross-sections (bathymetry) in all the reservoir each year (to be refined by the Developer) or several cross-sections after major floods;
- Monitoring of 2-3 gauging stations in the reservoir (on hourly or daily time step);
- Analyses of sediment sampling (GSD) for each bathymetric campaign;
- Annual monitoring report can conduct to adapt sediment strategy to solve adverse effects on sedimentation by current operating curve.

Regarding MRC requirements:

- #139 River banks along the new flood level line should be monitored to establish rates of erosion. Reaches associated with formation of (1) new mid-channel islands at the head of reservoirs, and (2) positions where tributary sediment deposits start intruding into reservoirs should be emphasized, as there may be scour associated with changes in these reaches.

In addition to bathymetric surveys, photographic surveys from aircrafts for land-use and river morphology analysis and overview are required before end of construction Phase 1 in order to establish a comprehensive baseline regarding the current morphological situation of the Mekong River from Xayaburi dam to Pak Lay city.

### 7.4.2 General plan layout

The layout scheme of hydraulic structures is presented on figure 53:

- powerhouse on the left bank,
- shiplock on the right bank,
- overflow dam on the right in the middle at different levels.

Compared to the longitudinal profile of the natural thalweg (figure 54), the crest elevation of the spillway weirs appears currently relevant. Low level and middle level outlets added to the surface spillway will allow controlling the solid concentrations precisely.

Such requirement is of utmost importance, as showed by principles in figure 55, (1) to recover natural-like flow conditions for low discharges when all gates are opened and the powerhouse is shut down and (2) to maintain the sediment continuity of the coarsest particles transported as bed-load.
Figure 53: General plan layout and upstream cross section of structures (source: FS)

Figure 54: Longitudinal profile of thalweg and weir crest elevation of Pak Lay spillways
Regarding MRC requirements:

- **#124 Developers should consider alternative dam sites at the feasibility stage (within the general location), with a view to select sites whose natural attributes, combined with the hydraulics of the river flow at the site best facilitate passage of sediment.**

- **#125 Natural channel features such as bends upstream of the proposed dam sites should be reviewed in the design stage. The potential of such bends to focus the bed load on the inside of the bend during high flow periods, and thereby reduce sediment problems at the proposed turbine intake locations should be considered. Dam layouts, including the location of the turbine intakes, low level outlet and spillway gates should be planned accordingly.**

- **#129 Use of the bottom flow gates should be optimized to pass coarse sediment in both dry and wet seasons, also taking into account the need to avoid sediment problems with operation of turbine intakes.**

Dam site selection shall consider not only the characteristics described in the FS report (mainly about power generation issues) but also hydraulic characteristics of the flow and the morphology of the Mekong in the vicinity of the project in order to ensure that the site selected is the best option regarding passage of sediment (See Mekong mainstream axis in figure 53). Some clarifications shall be provided at PNPCA stage. The Developer has to explain why another layout of the HPP cannot be relevant (by 2D calculations results for instance, See 7.4.5 of this report). Even if spillways are in the straight line of main current, the Developer has to determine the best position of each hydraulic structure (dam, spillway, powerhouse, navigation lock and fish way) regarding spillway capacity and local transportation process.
Figure 56: Typical section of Low Level Outlet (source: FS).

According to CNR experts, position, size, number and technology of spillway gates are relevant at this stage according to the following objectives (MRC #121, #126, #127) but some additional explanations are necessary in order to improve the compliancy status seeing that sediment transportation is one of the major issues to address while developing a HPP on the Mekong mainstream. The design of releasing structures (including vertical dimension of layout for gates) is crucial on the long run in order to:

- Facilitate a wide range of sediments to pass through the dam;
- Allow a broad variety of flushing techniques to be implemented;
- Recover free flow conditions from high flow to flood discharges;
- Allow adaptive and flexible sediment management strategies if required.

Regarding MRC requirements:

- **#120 Developers should design mainstream dams to pass fine suspended sediment and coarse bed-load material in a way that most closely mimics the natural timing of sediment transport dynamics in the river.**

To achieve these objectives and validate the design hypotheses, the use of the physical model is highly recommended to ensure discharge capacity of all hydraulic structures. Unfortunately, the Developer did not provide enough information regarding physical tests in chapter 5.7.4.2 of the FS. In order to be fully compliant, the Developer has to provide complementary data. With current operating pattern, free flow conditions can be recovered as soon as the flow reaches the 3-year return period flood. The Developer still has to demonstrate that Pak Lay HPP is transparent for low flows. flow below 16,700 cms (i.e. the 3-y return period flood) can occur during eco-friendly sediment routing operations (powerhouse is shutdown and spillway gates are opened). These pieces of evidence shall come from physical model tests of 1:100 scale for [1,000-16,700] cms without gates control (fully opened for every tested flow – free flow conditions to mimic natural station conditions). The objectives are:

- To provide additional details about physical model construction: maps, sensors (type and accuracy), position of sensors, calibration of control sills, calibration for roughness, relative uncertainty between discharge (input/output), photographs, etc.;
- To explain calibration step on water surface elevation and velocity pattern (reliability on natural stage by ADCP comparisons);
- To describe discharge curve after dam completion in case of sediment routing operation for discharge values below 16,700 cms, compared to natural curve;
- To provide additional physical model tests for Design Flood and Checked Flood with a variation of Downstream waterlevel +/- 1 m;
- To justify hydraulic structure positions regarding sediment constraints (in terms of bottom shear stress for instance);
- To evaluate the efficiency of sediment routing regarding each fraction of particles (See Sediment Management Strategy section).

![Figure 57](image.png)

*Figure 57: Results of design and test discharge capacities in case of full opening of gates of water release structures (source: FS).*

### 7.4.3 Reservoir operating pattern

The current operating pattern has been improved in comparison with the previous version (figure 58). This new pattern seems to be close to natural conditions when the spillway is opened (figure 59). Pak Lay HPP operating pattern is now consistent with run-of-river concept. The Developer shall keep in mind that the operating pattern must decrease as soon as possible so that natural-like flow conditions are recovered upstream the dam (for instance for P>20%). The Developer has also to pay attention to the residual difference between natural flow conditions and HPP impact for discharge higher than 20,000 cms: sedimentation studies have to demonstrate sediment delivery ratios seeing that an increase of water level induces a decrease of mean velocity, which may reduce the bottom shear stress.

The Developer provides spillway rating curve for discharge below 16,700 cms when the power plant is shut down. This information demonstrates whether quasi natural-like flow conditions can be recovered or not, especially in case of routing operations conducted according to an eco-friendly principle.
The Developer proposes a sediment dispatching mode and management measures of the reservoir, as follows:

- 2) In case of large sediment concentration and sediment discharge through monitoring, even though the inflow during flood season is less than 16,700 m³/s, the sediment can be discharged by opening the sluice gate or lowering the reservoir water level as appropriate.
- 3) To scour and discharge the coarse bed material deposited inside the reservoir efficiently, it is recommended that the reservoir water level be lowered to the lowest level for ecologically friendly sediment scouring every 2~5 years and the specific frequency can be determined as per the monitoring results of hydrology and sediment. The sediment discharge should synchronize with that at the upstream/downstream cascade HPPs.
- 4) The sediment releasing bottom outlet shall be subject to irregular opening/closing operations as appropriate, to prevent direct deposit of sediments behind the gate of such outlet, posing threats to the stability of structure. Besides, the operations above can prevent potential equipment rusting and aging due to long-term idling and can ensure that such gate can be opened in case of emergency.

For each point, the Developer has to precise which chapter of the FS rely on these operation cases (including efficiency).
7.4.4 Hydraulic and sediment dynamics modeling studies

Regarding available on-site measurements (see calibration step in paragraph 7.4.5 with 3 methods), the Developer proposes relevant calculations of reservoir backwater with 1D hydraulic model taking into account natural water surface profiles and reservoir backwater lines for several return periods (such as 20%, 10%, 5%, 4%, 2%, 1%, 0.5%, 0.2%, 0.1%, 0.05%, 0.02% and 0.01%). In order to clarify longitudinal results, the Developer has to include diagrams (longitudinal profiles in natural conditions and after dam completion).

“Under open discharge or ecologically friendly sediment flushing scheduling modes, the water level in the reservoir area will be lowered, and the velocity will be increased and gradually approach the velocity under natural conditions”: as mentioned before, the Developer must bridge the gap between hydrodynamic conditions (before and after HPP) and sediment characteristics (bottom shear stress for instance) for different horizons (only 20-year bathymetric state is included at this stage for backwater study).

The Developer has to provide for PNPCA step:

- Pak Lay dam site rating curve shall be checked by ADCP measurements in the vicinity of the dam site and for a large range of discharges;
- A new version of natural discharge curve based on recent measurements (Sept. 2015 & August 2016), figure 2.5.5 of the FS;
- Backwater calculations are also necessary in tributary channels. Backwater effect of the main reservoir can indeed cause extra-flooding hazards by increasing water level conditions at hydraulic junctions.

7.4.5 Evaluation of impacts due to reservoir sedimentation

This section is focusing on the following MRC requirements:

- #121 Dams and intake structures should be designed to minimize the deposition and entrainment of sediment near the dam ensure long-term safe operation. Particular care should be taken to avoid sediment deposition that poses risks for the safe working of the flood passage capacity of the dam.
- #123 All planned sediment management strategies should be thoroughly evaluated and subject to independent expert review for their likely effectiveness and impact prior to implementation at the developer’s expense.
- #130 Seasonal drawdown of the reservoir to minimum operating levels and opening of gates to allow sediment pass-through should be carried out when sediment concentrations and sediment transport rates are high (e.g. passing of suspended sediment from the start of, or early in the flood season before larger flood flows to limit settlement in the reservoir).

Main comments about sediment studies are as follows:

- A sensitivity analysis on average concentration (upper, medium and lower curves) was performed by the Developer in accordance with normal operating curve, which is satisfactory. However, according to the FS “Based on an overall consideration of the river course characteristics, rainfall conditions, vegetation and human activities of the Mekong river upstream of Pak Lay HPP and in reference to the empirical results of the large rivers in China such as the lower reaches of Jinsha River and Lantsang River, it is proper and conservative to take the bed load to suspended load ratio as 3%”. This hypothesis on bed load is not acceptable.
- For global numerical 1D hydraulic study: a new calibration based on 3 methods is suggested by the Developer:
  - Method 1: Calculation of roughness coefficient in the reservoir area according to the measured section water levels in April 2008 (discharge in the reservoir area is about 1,150 m³/s);
  - Method 2: Calculation of the comprehensive roughness of reaches for different discharges planned according to the natural rating curves at the Xayaburi and Pak Lay dam sites;
  - Method 3: The roughness is calculated based on the water levels measured on August 26th and 27th, 2016 (11,000 m³/s).

Finally, the Developer prefers adopting calibration parameters from method 3: that is a relevant choice, in particular for safety reasons. It is better to make hypothesis based on relatively high flow measurements.

- To check the rationality of the calculation model and parameters, an analog calculation for sediment deposition in natural river channel has to be conducted by the Developer (from 20 to 100 years of deposition) in order to calibrate k and m parameters for natural conditions. It is essential to define the
baseline of the project. For the baseline, the Developer considers an equilibrium between inflow and outflow sediment volume. However, Chiang Khan data highlights that there is a higher annual sediment discharge rate from 1967-1977 than from 2009 to 2015. The project baseline is currently defined on the period 2009-2015. If the baseline situation is not correctly defined at this stage, misunderstandings will be unfavorable for project predictions at long term. It is a point of major importance in sediment studies.

Figure 60: 5-representative-year discharge and reservoir water level process diagram (source: FS)

Figure 61: 5-representative-year discharge and sediment concentration process diagram (source: FS)
Relative to previous hypothesis, sediment calculations provided several sediment delivery ratios for 20 to 100 years of operation. Basically, the smaller the suspended sediment gradation, the greater the reservoir sediment outflow and the higher the sediment delivery ratio in the same period of time. The Developer suggests retaining an 82% for sediment delivery ratio for long term, which means an 18% capture ratio for sediment in the Pak Lay reservoir. Such a ratio is not marginal. The upstream longitudinal impact is far from 75 km to dam site. Regarding #125 and #129 MRC requirements, a specific assessment of HPP layout shall be done.

Figure 62: Calculation results for sediment deposition of Pak Lay reservoir (source: FS)

Figure 63: Comparison of sediment deposition thalweg elevation of Pak Lay HPP reservoir for different years of operation (source: FS)

- The sensitivity analysis is performed mainly to consider the unfavorable conditions of increase of reservoir sediment inflow, and 2 sensitivity schemes are analyzed:
  - the first one consists in increasing the reservoir suspended sediment inflow by 10% and 20%;
  - the second one consists in considering ratio values of bed load discharge to suspended load discharge of 5% and 10%.
Even if tests about suspended load seems to be satisfactory, the Developer does not suggest any explanation about sill effect between average inner and average GSD curve. For the diagrams results of bed load calculations, the Developer has to provide deposition quantity and sediment delivery ratio (not only loss rate of regulation storage). The Developer shall also provide the geographical locations of deposits (longitudinal profile) to plan maintenance operations in the future.
- In 2D sediment mathematical modelling, the Developer performs calculations upstream the dam for long time series (20 to 40 years) but does not specify exhaustive boundary conditions: what is the sediment grain size distribution used (inner, average, outer GSD curve) and annual average volume of sediment? These results are interesting but specific simulations for drawdowns (below or above
16,700 cms) are required regarding sediment strategy measures. Figure 60 shows some events with an opening of spillway gates. The Developer shall provide information about the specific maintenance operation used to avoid up to 13 m of deposits upstream dam. The Developer has to provide a map with bottom elevation for 20 and 40 years calculations (not only deposit heights as proposed in Figure 64. Regarding results upstream turbine intakes, the Developer shall demonstrate the relevance of the sediment sill and present the kind of sediment (GSD, shape) that can be released throughout turbines.

![Figure 60: Sediment scouring and deposition in the river reach upstream of the dam after 20 and 40 years of operation of the reservoir (source: FS)](image)

Current FS provides numerous calculations in 1D, 2D and 3D hydraulic modelling, that are state of the art methods. However, the Developer shall better precise main objectives of these studies (in particular for 2D and 3D modelling) in order to supply sediment strategy measures (monitoring network, dredging operations, temporary operation curve, etc.).

At this final stage, with relevant measurements for all sedimentation transportation processes from suspended load to bed load, the Developer shall still provide more consistent sedimentation studies, such as:

- additional sensitivity tests on sediment transport parameters (k and m) with former correlation of Chiang Khan Station;
- additional calculations in case of eco-friendly sediment routing operation (not only for normal operating pattern) in order to estimate efficiency of maintenance operations on sediment;
- some sediment calculations for specific scenarios of drawdown between natural conditions and after dam completion (showing parameters of transport like bottom shear stress or friction velocity) in order to see whether sediment management strategy is relevant/sufficient or not to mobilize deposits or to transport sediments, from dam site to upper part of the reservoir;
- scientific references on Bed load/Suspended load rate (3%) or calculation methodology (specific for Mekong River);
- Local numerical 2D and 3D sedimentation impact studies: calibration states are required (in particular in terms of velocity pattern), goals of these studies shall be clarified, a clear link between modeling and sediment management strategy must be made (for maintenance operations, monitoring network in terms of frequency, etc...);
- Some current results show that middle or bottom outlets upstream channels are concerned by deposits: the developer shall describe mitigation measures to cope with this issue and assess the impact of deposits on releasing capacity of the spillway (link to 1D sedimentation impact).

In chapter 4.10.1 of the FS, the Developer writes that “Pak Lay Reservoir has storage of 890 million m$^3$ at NPL 240m, the mean annual suspended sediment runoff is 16.50 million tons at the dam site, and the ratio of reservoir storage to sediment runoff is about 71. When the power station is completed, the backwater in the reservoir area is not high, and sedimentation is not a prominent problem. In this stage, in addition to the reservoir sedimentation calculations, the impact of sedimentation in the project area on the operation of the
power station shall be the stressed*. This paragraph does not seem in accordance with above mentioned comments.

Regarding MRC requirements (for operation stage):

- **#131** For periodic flushing of fine sediment and flushing of coarse bed material:
  
i. All sediment flushing should be planned and carried out in coordination with the operators of other dams in the cascade.

  
  ii. Flushing of fine sediments should be routinely carried out every year. Less frequent flushing may result in consolidation of fine materials on the reservoir bed, making future flushing efforts technically difficult and costly.

  
  iii. Where it is possible to manage coarse and fine sediments separately, flushing of coarse sediment should be carried out after flushing of fine material considering ‘environmentally friendly flushing’ techniques described in paragraphs that follow later in this section.

  
  iv. For the most effective flushing of coarse bed material, the reservoir should be drawn down to the maximum extent, at least every 2 to 5 years. Sediment monitoring (as described later in this Section) should be used to decide the frequency.

- **#134** The sediment concentration of water released during flushing operations should be controlled and monitored to prevent negative impacts on downstream ecology (high sediment concentrations can lead to fish mortality and smothering of spawning areas – see also Section 5 on environmental flows).

- **#135** A maximum allowable downstream sediment concentration should be established based on ecological assessments. An initial limit can be based on the natural maximum sediment concentrations occurring during the flood season.

Coordination with others operators both upstream and downstream is strongly recommended in case of specific sediment operations, as well as normal operating conditions. The Developer has to take into account this constraint. It is necessary to clarify chapter 4 of the FS in terms of sediment management strategy: type of operation (flushes, routing operations) for each mode of transport (Bed Load, Suspended Load) and frequency. Validation cases have to be carried out from 1D/2D sedimentation calculations. If necessary to release sediments more frequently, the Developer should assess the possibility of doing eco-friendly sediment routing operation for flows lower than 16,700 cms (3-year return period).

For routing operation, measurement frequency has to be significantly shortened compared to normal and flood conditions (for instance every 30/60 minutes on average and up to 5 to 10 minutes when concentrations are increasing) in order to precisely control the gate opening according to the solid concentration measured downstream the dam.

### 7.5 Conclusion for sediment transport

#### 7.5.1 Conclusions

Current design with 11 surface spillways (220 m), 3 middle level spillways (212 m) and 2 bottom outlets (205 m) is a relevant foundation of a run-of-river scheme on the Mekong River.

- This design with middle level and bottom outlets is potentially in capacity to pass from suspended to bed-load in a way that most closely mimics the natural timing of sediment transport in the river. That hydraulic setting permits to change many “not compliant” statuses to “compliant” or “not fully compliant”.

A comprehensive and a relevant set of in-situ observations was collected at dam site and in the reservoir reach: concentration and grain size distribution of suspended load, concentration of graded suspended load, and gradation curve of bed load. The Developer shall continue data collection, as well as hydrologic and sediment measurements in the future.

- The current level of sediment on-site measurements is now relevant to increase the knowledge of this part of the Mekong, first in natural conditions. Due to these sound data, the Developer provides relevant studies of sedimentation impact, only additional information and simulations are still required to ensure the compliancy of the project and control its adverse impacts.
- As a consequence of the new design, a new version of the reservoir operating pattern allows potentially mimicking the seasonal distribution of sediment supply. The Developer has to study more in detail specific operating conditions, liaise with sediment strategy plan. Several modes of operating the reservoir are now possible in the future, from high flows when flood occurs, to low flows when seasonal drawdown of the reservoir water level has to be mandatory for sediment issues.

- All strategy measures can be optimized by sedimentation studies, like releasing operations for each modes of transport by seasonal drawdown for instance, in coordination with upstream and downstream HPP operators. Adaptive measures can be evaluated at feasibility stage, and if necessary and consistent, reservoir operating pattern could be adjusted in the future.

7.5.2 Table of compliance

<table>
<thead>
<tr>
<th>No.</th>
<th>Guidance regarding sediment management</th>
<th>Status concerning compliance (Compliant, Not fully compliant, Not compliant)</th>
<th>CNR comments</th>
<th>Priority (PNPCA, Construction, Operation)</th>
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<tr>
<td>120</td>
<td>Developers should design mainstream dams to pass fine suspended sediment and coarse bed-load material in a way that most closely mimics the natural timing of sediment transport dynamics in the river.</td>
<td>Not fully compliant</td>
<td>See Final stage 1 #120 Chapter 5.9.4.4 doesn’t exist.</td>
<td>PNPCA</td>
</tr>
<tr>
<td>121</td>
<td>Dams and intake structures should be designed to minimize the deposition and entrainment of sediment near the dam, ensure long-term safe operation. Particular care should be taken to avoid sediment deposition that poses risks for the safe working of the flood passage capacity of the dam.</td>
<td>Not fully compliant</td>
<td>All this stage, with relevant measurements for all sedimentation transportation processes from Suspended load to bed load; CNR is waiting for more consistent sedimentation studies: graphs presenting some measurements made during site surveys about sediment gradation (July &amp; August 2016), taking into account hypothesis for calculation of average daily flux, on Fig 2.6.2.2 a clear description of every devices used for sediment surveys (2015-2016) - scientific references on Bed load/Suspended load rate (3%/97%) or calculation methodology (specific for Mekong River); A new version of natural discharge curve based on recent measurements (Sept. 2015 &amp; August 2016), on figure 2.5.5 - local numerical 2 &amp; 3 dimensional sedimentation impact studies: calibration states are required; goals of these studies shall be clarified; a clear link between modeling and sediment management strategy must be made (for maintenance operations, monitoring network in terms of frequency, etc...). Some current results show that middle or bottom outlets upstream channels are concerned by deposits: the Developer shall describe mitigation measures to cope with this issue and assess the impact of deposits on releasing capacity of the spillway (link to 1D sedimentation impact).</td>
<td>PNPCA</td>
</tr>
<tr>
<td>122</td>
<td>Owners / operators should develop and implement a sediment monitoring program. This would routinely monitor reservoir sedimentation, particularly for deposition at the head of the reservoirs during the operation phase, and take and adjust mitigation actions when needed.</td>
<td>Compliant</td>
<td></td>
<td>PNPCA</td>
</tr>
<tr>
<td>123</td>
<td>All planned sediment management strategies should be thoroughly evaluated and subject to independent expert review for their likely effectiveness and impact prior to implementation at the developer’s expense.</td>
<td>Not fully compliant</td>
<td>See #121</td>
<td>PNPCA</td>
</tr>
</tbody>
</table>
### Site Selection and Design

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Recommendation</th>
<th>Compliance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>Developers should consider alternative dam sites at the feasibility stage (within the general location), with a view to select sites whose natural attributes, combined with the hydraulics of the river flow at the site best facilitate passage of sediment.</td>
<td>Not fully compliant</td>
<td>Dam site selection shall consider not only the characteristics described in the FS report (mainly about power generation issues) but also hydraulic characteristics of the flow and the morphology of the Mekong in the vicinity of the project in order to ensure that the site selected best facilitates passage of sediment. Some clarifications shall be provided in the FS.</td>
</tr>
<tr>
<td>125</td>
<td>Natural channel features such as bends upstream of the proposed dam sites should be reviewed in the design stage. The potential of such bends to focus the bed load on the inside of the bend during high flow periods, and thereby reduce sediment problems at the proposed turbine intake locations should be considered. Dam layouts, including the location of the turbine intakes, low level outlet and spillway gates should be planned accordingly.</td>
<td>Not fully compliant</td>
<td>See #121 and explain why another layout of the HPP cannot be relevant (by 2D calculations results for instance). Even if spillways are in the straight line of main current, the Developer has to determine the best position of each hydraulic structure (dam, spillways, powerhouses, navigation lock and fish way) regarding to spillways capacity and local transportation process.</td>
</tr>
<tr>
<td>126</td>
<td>The dam should be designed to allow for sediment routing (pass-through) and periodic drawdown to enhance sediment flushing. Sediment bypass channels and sediment traps may be considered as additional strategies for sediment management.</td>
<td>Compliant</td>
<td></td>
</tr>
</tbody>
</table>
| 127       | Developers should employ the best possible technology for sediment investigation and modelling of sediment transport in 3-dimensional flow environments to assess how sediment deposition (and downstream erosion) problems can be minimized. In this respect:  
   i. Mobile bed physical hydraulic models should be used (ideally at feasibility, but if not at the detailed design stage) because of their strength in simulating the complex nature of the hydraulic performance and flow passage past the dams and critical structures.  
   ii. One focus in modelling should be minimizing deposition at or near the spillway gates, and on minimizing entrainment of sediment through the turbines (in addition to hydraulic modelling of fish passages, as noted previously in section 3, paragraph 64).  
   iii. Physical hydraulic modeling with mobile bed simulation should also be used to clarify locations where scour and deposition will be most severe, and to identify practical mitigation solutions.  
   iv. Detailed scenarios for reservoir sediment deposition and scour should be developed in the detailed design phase, based on an understanding of factors such as the extent of the flooded areas of the future reservoirs, their seasonal fluctuations, and presence of bed rock outcrops and the influence of tributaries.  
   v. An approximate assessment of the depth of the deposits at the head of the reservoirs should be established.  
   vi. Predicted locations where future development of mid-channel islands and future changes to the river thalwegs will occur should be identified. | Compliant | |
| 128       | Appropriate gates should be incorporated into the dam design to allow sediment pass-through and periodic sediment flushing:  
   i. The dam design should include not only bottom gates to pass/flush the sediment, but also releases from mid-level gates (or spillways) and to allow dilution of the highly concentrated bottom waters that are released.  
   ii. Large bottom gates need to be included in the dam design for pass-through of density currents and flushing of coarse sediment. Bottom gates should be located as low in the dam as possible, as wide as possible, and in sufficient number.  
   iii. Fail-safe provisions, such as stop logs or additional gates, for dewatering the structures immediately upstream and immediately downstream of the bottom gates should be provided, in order for cleanout in the event of blockage. | Compliant | |

CNR ENGINEERING  
1.00947.001 – PAK LAY HPP FEASIBILITY STUDY REVIEW  
DI-2017-020 - FINAL REPORT Final Version  
January 2017
### 1. Dam operation

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Compliance</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>129 Use of the bottom flow gates should be optimized to pass coarse sediment in both dry and wet seasons, also taking into account the need to avoid sediment problems with operation of turbine intakes.</td>
<td>Not fully compliant</td>
<td>See #125</td>
</tr>
<tr>
<td>130 Seasonal drawdown of the reservoir to minimum operating levels and opening of gates to allow sediment pass-through should be carried out when sediment concentrations and sediment transport rates are high (e.g. passing of suspended sediment from the start of, or early in the flood season before larger flood flows to limit sediment in the reservoir).</td>
<td>Not fully compliant</td>
<td>See #121</td>
</tr>
<tr>
<td>131 For periodic flushing of fine sediment and flushing of coarse bed material: All sediment flushing should be planned and carried out in coordination with the operators of other dams in the cascade.</td>
<td>Not fully compliant</td>
<td>Coordination with others operators is strongly recommended. Clarify chapter 4 in terms of sediment management strategy: type of operation (flushes, routing operations) for each mode of transport (Bed Load, Suspended Load) and frequency. Validation cases have to be carried out from 1D/2D sedimentation calculations. If necessary to release sediments more frequently, the Developer should assess the possibility of doing eco-friendly flushes for lower flows than 16,700 cms (3-year return period).</td>
</tr>
<tr>
<td>132 Where hydraulic flushing is not possible, or effective, alternatives to removing sediments accumulated in the reservoir should be considered including mechanical removal by dredging in critical areas, or in combination with the use of sediment traps.</td>
<td>Compliant</td>
<td>Operation</td>
</tr>
<tr>
<td>133 Bottom-gates should be opened regularly to prevent accumulation of sediment directly behind the gates. This is to ensure that gates can be opened in an emergency and to prevent excessive accumulation behind the dam wall that could endanger structural stability.</td>
<td>Compliant</td>
<td>Operation</td>
</tr>
</tbody>
</table>

### 2. Eco-friendly flushing for sediment

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Compliance</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>134 The sediment concentration of water released during flushing operations should be controlled and monitored to prevent negative impacts on downstream ecology (high sediment concentrations can lead to fish mortality and smothering of spawning areas – see also Section 5 on environmental flows).</td>
<td>Not fully compliant</td>
<td>The sediment concentration of water released during flushing operations should be controlled and monitored to prevent negative impacts on downstream ecology (high sediment concentrations can lead to fish mortality and smothering of spawning areas – see also Section 5 on environmental flows).</td>
</tr>
<tr>
<td>135 A maximum allowable downstream sediment concentration should be established based on ecological assessments. An initial limit can be based on the natural maximum sediment concentrations occurring during the flood season.</td>
<td>Not fully compliant</td>
<td>Operation</td>
</tr>
<tr>
<td>136 Flushing of fine sediments should be routinely carried out every 2 to 5 years. Sediment monitoring (as described later in this section) should be used to decide the frequency.</td>
<td>Compliant</td>
<td>Operation</td>
</tr>
</tbody>
</table>

### 3. Monitoring and management

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Compliance</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>138 Deep holes in the reservoir reach that were previously present in the river bed should be monitored, to establish rates of infilling.</td>
<td>Compliant</td>
<td>Operation</td>
</tr>
<tr>
<td>139 River banks along the new flood level line should be monitored to establish rates of erosion. Reaches associated with formation of (1) new mid-channel islands at the head of reservoirs, and (2) positions where tributary sediment deposits start intruding into reservoirs should be emphasized, as there may be scour associated with changes in these reaches.</td>
<td>Not fully compliant</td>
<td>Not fully compliant</td>
</tr>
<tr>
<td>140 The developers / owner should be responsible to provide river bank erosion control with structures such as gabions if needed, for situations affected by changes in river channel position in the reservoir zones. See also paragraph 139 that relates to government consideration to have dam owners to set aside contingency funds, in case additional expenditures for bank protection works are needed to arrest problems attributed to the operation of the dam – or to provide an undertaking in the Concession Agreement to ensure that sufficient financial resources are available for such works.</td>
<td>Compliant</td>
<td>Operation</td>
</tr>
</tbody>
</table>
8 NAVIGATION ASPECTS, SHIPLOCK - NAVIGATION LOCK SYSTEM

8.1 Scope of the review and studies provided

The review of navigation issues concerning Pak Lay HPP scheme has been carried out according to the following criteria:

- Overall design of the navigation structures,
- Design and performances of the lock filling and emptying system (F/E),
- Navigation conditions and lock approaches,
- Lock equipment,
- Operating and maintenance policies.

Most of the information relative to the lock structure design is provided in chapters 5, 6 and 7 of the Feasibility Study:

- Project Layout and Main Structure;
- M&E Equipment and Hydraulic steel Structure;
- Construction Organization Design.

Two physical models have been implemented in Zhongnan Engineering laboratory in Changsha in order to carry out the lock design studies:

- A 1/100 scale model of the entire HPP scheme (see figure 66): this model is used to investigate flow and navigation conditions in upstream and downstream lock approaches;
- A 1/20 scale model of the lock F/E system: this model is used to check the lock hydraulic performances.

The physical model studies report have not been provided but part of the results have been included in chapter 5 of the FS.

In addition, experts from CNR have visited the 1/100 scale model in January 2016.

Figure 66 : Visit of Zhongnan Engineering laboratory – January 2016
8.2 Lock overall design

8.2.1 Location and size

The lock complex is located on the right bank of the Pak Lay HPP scheme. It is made of an upstream approach channel, a single-line one-step lock and a downstream approach channel. The maximum operating head is 21.0 m which is compliant with the one-step lock design.

In accordance with MRC specifications, the effective dimensions of the lock chamber are 120.0 m x 12.0 m x 4.0 m (length x width x water depth at sill). The lock crest elevation is set at 245.00 m, i.e. the same elevation as the dam crest one seeing that the upstream lock head is part of the water retaining structure. The downstream lock sill elevation is set at 215.00 m.

The Feasibility Study mentions the position of a second lock located on the right side of the first lock. Both geological conditions and lock access seem to be suitable for this expansion even if no drawing has been produced in order to check these issues.

8.2.2 Design Vessels and Navigation Standards

The feasibility report refers to class IV of Chinese standards, with 500 T design vessel, which seems a pertinent reference. The lock chamber dimensions correspond to 2 x 500t convoys (111 m / 10.8 m / 1.6 m), the smallest vessel formation covered in class IV.

8.2.3 Water Levels, Range of Operation of the Locks

The table here below presents the main reference water levels and corresponding flows indicated in the feasibility report.

<table>
<thead>
<tr>
<th>Frequency or flood return period</th>
<th>Flow m$^3$/s</th>
<th>Level in m ASL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downstream lowest navigable conditions</td>
<td>Minimum pool level of the downstream cascade</td>
<td></td>
</tr>
<tr>
<td>Downstream maximum navigable conditions</td>
<td>3-year flood</td>
<td>16 700</td>
</tr>
<tr>
<td>Upstream lowest navigable conditions</td>
<td>Reservoir dead water level</td>
<td></td>
</tr>
<tr>
<td>Upstream maximum navigable conditions</td>
<td>Normal reservoir water level</td>
<td></td>
</tr>
</tbody>
</table>

Table 21: Main reference water level values of Pak Lay lock

The operation range of the lock, especially the 3-year return period flood defined as the maximum navigation discharge, has been set in order to be consistent with navigation conditions of Xayaburi and Sanakham HPP located respectively upstream and downstream Pak Lay HPP.

The minimum downstream water level (219.00 m asl) corresponds to the minimum water level of Sanakham HPP. Consequently, there is no need to include a 1 m-safety margin in the downstream lock sill elevation in order to take into account potential bed incision. The minimum water level will be maintained at 219.00 m asl whatever the river bed elevation.
8.3 Nautical Accessibility and Approaches of the Lock

Nautical accessibility is mainly conditioned by the following factors:

- The plan geometry of the channel access (radius of curvature, length of alignments);
- The flow distribution and the energy dissipated downstream the different structures of the HPP, principally for Pak Lay the 11 sluice gates located on the left side of the lock;
- The manoeuvrability of the ship.

8.3.1 Usual considerations when entering or leaving a lock

8.3.1.1 Entering a lock

Entering the lock approach from upstream (vessel sailing downstream) requires a larger speed of the vessel through the water to counteract the cross currents which results in a relative high entrance speed. When the water level is decreased, the under keel clearance (UKC) and the maneuverability become smaller, thus controlling the vessel become harder.

Together with a smaller controllability while reducing speed, a large approach channel is strongly recommended in order to be able to align the vessel and maneuver properly into the lock.

When entering the lock approach harbor from downstream (vessel sailing upstream), the captain should be aware of cross currents especially when the sailing speed is relatively low. This is practically done by sailing upstream the river as much as possible before entering the approach harbor.

8.3.1.2 Leaving a lock

When leaving a lock, the cross current can need to be counteracted as well especially when sailing downstream. It is required to have a sufficient sailing speed which should be higher than the current speed.

Leaving is typically less critical than entering, as the engines are usually generating high thrust and thus give the ship a good maneuverability.

8.3.2 Usual guidelines for lock approach design

In Europe, the usual guidelines retained for the design of lock approach are:

- The longitudinal current has to be smaller than 0.5 m/s;
- The cross current has to be smaller than 0.3 m/s;
- At upstream side, a ship that leaves the line-up area to enter the lock may not be hindered by any cross current near the lock head;
- At downstream side, the flow pattern has to be symmetrical, as much as possible, to reduce the chance of eddy-currents and to reduce flow gradients.

The maximum allowable velocities are slightly higher according to the Chinese code:

- In the upper reach the maximum longitudinal velocity shall not exceed 0.5-0.8 m/s in the approach channel and in the waiting area the velocity shall not exceed 0.5 m/s;
- In the downstream reach the velocity shall not exceed 0.8-1.0 m/s. In braking and waiting areas the allowable cross current velocities is 0.15 m/s;
- During the ship entering or leaving the lock, the water in the guiding area should be still.

These issues are addressed in MRC guidelines but not as detailed as in European and Chinese standards.
8.3.3 **Upstream approach channel**

### 8.3.3.1 General design

The upstream approach is straightly connected to the natural waterway which gives very good access to the lock chamber. The ground elevation is set at 225.00 m asl and the minimum navigation level is 239.00 m asl which leads to a minimum water height of 14 m.

The width of approach channel is 38 m which represents about 3.5 times the design vessel width. A 454 m long closed guiding wall is implemented on the left side of the approach channel. The approach channel is made of a 310 straight line section followed by a 143 m curved section (radius of 360 m). This design is compliant with MRC specifications.

![Figure 68: Layout of the upstream approach channel](image)

### 8.3.3.2 Velocity and flow pattern

Measurements of the flow velocity in the entrance of the upstream approach channels have been carried out on the 1/100 scale physical model for the following discharges: 1 940 m³/s; 6 234 m³/s; 8 555 m³/s; 13 596 m³/s and 16 700 m³/s (3-year flood). Nevertheless, no information about the flow distribution between the powerhouse and sluice gates is provided.

The longitudinal and transversal components of the velocity (with respect to the flow direction) are presented in the chapter 5 of the Feasibility Study as illustrated on figure 69. No detail concerning the type of sensor used during the test and the measurement protocol has been provided in the report which does not allow assessing the accuracy of the given results.

![Figure 69: Measurements of the velocity pattern at the entrance of upstream approach channel](image)

**Table 5.9.4.1-2 Distribution of flow velocity at the entrance area of the upstream approach channel when the discharge is 1940m³/s**

<table>
<thead>
<tr>
<th>Q</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>z0</th>
<th>z0'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 940 m³/s</td>
<td>0.5 m</td>
<td>2.0 m</td>
<td>3.0 m</td>
<td>0.5 m</td>
<td>2.0 m</td>
</tr>
</tbody>
</table>

Q = 1 940 m³/s
The range of transversal and longitudinal velocities is presented in the table 22:

<table>
<thead>
<tr>
<th>Discharge in m$^3$/s</th>
<th>Velocity range in m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Longitudinal</td>
</tr>
<tr>
<td>1940</td>
<td>0.10 - 0.15</td>
</tr>
<tr>
<td>6234</td>
<td>0.10 - 0.20</td>
</tr>
<tr>
<td>8555</td>
<td>0.10 - 0.40</td>
</tr>
<tr>
<td>13596</td>
<td>0.70 - 1.00</td>
</tr>
<tr>
<td>16700</td>
<td>0.90 - 1.10</td>
</tr>
</tbody>
</table>

Table 22: Velocity range in the entrance of upstream approach channel

The results show that velocities at the entrance of the approach channel are within the usual values for discharges up to 13500 m$^3$/s. For high discharge values, velocities are higher than the usual values retained by both European and Chinese standards.

It is then required to issue specific recommendations for approaching vessels even if approach should be easy thanks to the straight access from upstream.

The measurements of the velocities on the left hand side of the upstream guiding wall are missing and would have been useful in order to better check the cross currents.

### 8.3.4 Downstream approach channel

#### 8.3.4.1 General design

The downstream approach channel is connected to the natural river course by a 194 m long straight section and a 86 m long gently curved section (radius of 340 m). A 260 m long solid partition wall separates the approach channel from the downstream pool of the dam.

The ground elevation of approach channel is set at 216.00 m and the minimum navigation level is 219.00 m which leads to a minimum water height of 3 m. There is only 0.5 m left with respect to minimum draft. Consequently, the bathymetry needs to be regularly checked especially because this area will be sensitive to sediments deposits.

The width of approach channel is 38 m which represents about 3.5 times the design vessel width.

The proposed design is compliant with MRC requirements.

![Figure 70: Layout of the downstream approach channel](image)

#### 8.3.4.2 Velocity and flow pattern

Measurements of the flow velocity in the entrance of the downstream approach channels have been carried out on the 1/100 scale physical model for the following discharges: 1940 m$^3$/s; 6234 m$^3$/s; 8555 m$^3$/s; 13596 m$^3$/s and 16700 m$^3$/s (3-year flood). Nevertheless, no information about the flow distribution between the powerhouse and sluice gates is provided.

The longitudinal and transversal components of the velocity (with respect to the flow direction) are presented in the chapter 5 of the Feasibility Study as illustrated on figure 71. No detail concerning the type of sensor used
during the test and the measurement protocol has been provided in the report which does not allow assessing the accuracy of the given results.

Fig 5.9.1-10 Distribution of flow velocity at the entrance area of the upstream approach channel when the discharge is $13596 \text{m}^3/\text{s}$

<table>
<thead>
<tr>
<th>Q (m$^3$/s)</th>
<th>Longitudinal Velocities (m/s)</th>
<th>Transversal Velocities (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>0.00 - 0.10</td>
<td>0.00 - 0.10</td>
</tr>
<tr>
<td>6234</td>
<td>0.10 - 0.70</td>
<td>0.10 - 0.20</td>
</tr>
<tr>
<td>8555</td>
<td>0.10 - 0.70</td>
<td>0.10 - 0.40</td>
</tr>
<tr>
<td>13596</td>
<td>0.40 - 1.50</td>
<td>0.10 - 0.40</td>
</tr>
<tr>
<td>16700</td>
<td>0.50 - 1.60</td>
<td>0.10 - 0.40</td>
</tr>
</tbody>
</table>

Table 23: Velocity range in the entrance of downstream approach channel

The results show that the velocities at the entrance of the approach channel are within the usual values for all the discharges tested.

At 200 m downstream from the entrance, the flow pattern is very disturbed (change in flow direction, change in velocity magnitude) and the navigation conditions can be very different depending on the discharge and the sluice gates under operation. These conditions can make the approach more difficult for the ships and particular attention should be paid for discharge higher than 13 000 m$^3$/s.
The measurements of the velocities on the left hand side of the downstream guiding wall are missing and would have been useful in order to better check the cross currents and back flow effects.

8.4 Lock Design

8.4.1 Filling and emptying system design

8.4.1.1 F/E system main features

The retained F/E system is a bottom F/E type made of two staggered longitudinal culverts with lateral branches and bottom ports distributed symmetrically along the lock chamber. It is suitable for high head locks and consequently well adapted to Pak Lay HPP scheme.

Table 24 gives a detailed description of the components of the F/E system:

<table>
<thead>
<tr>
<th></th>
<th>Width in m</th>
<th>Height in m</th>
<th>Area in m²</th>
<th>Number</th>
<th>Total area in m²</th>
<th>sigma ratio</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake</td>
<td>1.7</td>
<td>3.3</td>
<td>5.61</td>
<td>5 per side</td>
<td>56.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Filling valve culvert</td>
<td>2.2</td>
<td>2.6</td>
<td>5.72</td>
<td>2 per side</td>
<td>11.4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Longitudinal culvert</td>
<td>2.2</td>
<td>3.3</td>
<td>7.26</td>
<td>2</td>
<td>14.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lateral branch</td>
<td>1</td>
<td>1.6</td>
<td>1.60</td>
<td>5 per culvert</td>
<td>16.0</td>
<td>1.10</td>
<td>Max. velocity assuming balance flow distribution in the 10 branches</td>
</tr>
<tr>
<td>Bottom port</td>
<td>0.5</td>
<td>0.4</td>
<td>0.20</td>
<td>8 per branch</td>
<td>16.0</td>
<td>1.00</td>
<td>Ports centered &amp; covering 48% of the chamber area</td>
</tr>
<tr>
<td>Emptying valve culvert</td>
<td>2.2</td>
<td>2.6</td>
<td>5.72</td>
<td>2 per side</td>
<td>11.44</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Outlet - Left side</td>
<td>1.3</td>
<td>2</td>
<td>2.60</td>
<td>4</td>
<td>10.4</td>
<td>-</td>
<td>Older design - Not been updated in the FS</td>
</tr>
<tr>
<td>Outlet - Right side -</td>
<td>1.5</td>
<td>3.3</td>
<td>4.95</td>
<td>2</td>
<td>9.9</td>
<td>-</td>
<td>Older design - Not been updated in the FS</td>
</tr>
<tr>
<td>lateral branch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outlet - Right side -</td>
<td>0.6</td>
<td>1</td>
<td>0.60</td>
<td>5 per branch</td>
<td>6</td>
<td>-</td>
<td>Older design - Not been updated in the FS</td>
</tr>
<tr>
<td>Ports</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 72 : Lateral view of the Pak Lay lock F/E system
The sigma ratio of a manifold is given by the ratio between the sum of the lateral branches section ($\sum s_i$) and the main culvert section $S$:

$$\sigma = \frac{\sum s_i}{S}$$

When designing a manifold, the sections of the main culvert and the lateral branches or ports should be chosen so that the sigma ratio is close to 1 in order to achieve a balance flow distribution along the openings.

Table 24 shows that this design criteria has been well respected for the lateral branches connected to the longitudinal culvert and for the bottom ports connected to the lateral branches.

The dimensions of the water outlets given in table 24 are not consistent with the drawings attached to the updated version of the FS but are referring to the older asymmetric design as presented on Figure 73.

![Figure 73: Water outlets – Older design (on the left) and updated design (on the right)](image)

The updated design is more suitable to achieve a balance flow distribution in left and right longitudinal culvert during emptying operation.

### 8.4.1.2 Lock equipment

- ✔ Filling and emptying valves

The lock filling operations are carried out thanks to two reverse tainter valves (one in each longitudinal culvert). The lock emptying operations are carried out thanks to two reverse tainter valves (one in each longitudinal culvert).

Each valve is equipped with upstream and downstream bulkheads that allow operating the lock even if one of the valve is in maintenance (see figure 74).
Figure 74: longitudinal cross section of the lock – Bulkheads on F/E valves

- Lock gates
  The upstream lock head is equipped with miter gate and upstream bulkhead; the downstream lock head is equipped with miter gate and downstream bulkhead.
  The upstream side of the downstream miter gate is also equipped with an anti-collision device in order to prevent any damage from a ships being out of control.

- Bollards and ladders
  Six floating bollards are distributed along the lock chamber and three ladders are located at lock chamber extremities and in the middle of the lock chamber which is enough for such lock.

8.4.2 Filling and Emptying System hydraulic performances

8.4.2.1 Main guidelines

MRC guidelines require the F/E system to fulfill the two following criteria:

- A total time transit of max 30 minutes for one step lock;
- Max hawser forces ≤ 0.1 % x water displacement of the vessel (in tons).

In addition to MRC guidelines, the usual requirements detailed hereafter must also be taken into account:

- The average velocity in a culvert section should not exceed 7-8 m/s in order to avoid too quick erosion of the concrete;
- The average velocity in the intakes section should not exceed 2-3 m/s in order to prevent vortices occurrence and extra head losses;
- The average velocity in the outlets section should not exceed 2-3 m/s in order to avoid extra head losses;
- Cavitation and air entrapment downstream of the F/E valves should be avoided.

8.4.2.2 Tests carried out on physical model

According to the FS, the tests detailed in table 25 have been carried out in the Changsha laboratory on a 1/20 scale physical model.

The tests conditions take into account the maximum head which is the critical configuration for the F/E system design. No test has been performed with the maximum downstream water level which could have given valuable information with respect to operating procedure.
Table 25: Tests carried out on the 1/20 scale physical model

It should be noted that no detail concerning the type of sensor used during the test and the measurements protocol has been provided in the report which does not allow assessing the accuracy of the given results.

8.4.2.3 F/E times and lockage time

- F/E times

The F/E times measured during the tests carried out on the physical model are presented in table 26 as given in the FS report. If the results seems to be compliant with the expected target times stemming from the preliminary calculation (based on analytical analysis of the F/E system and presented in the FS report), there is clearly a lack of consistency in the presentation of the results which does not allow issuing F/E time series as a function of valve operating time and initial head.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Operation type</th>
<th>Upstream WL in m</th>
<th>Downstream WL in m</th>
<th>Head in m</th>
<th>F/E valves operating time in min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lock filling - Use of both longitudinal culverts</td>
<td>240.00</td>
<td>219.00</td>
<td>21.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock emptying - Use of both longitudinal culverts</td>
<td>240.00</td>
<td>219.00</td>
<td>21.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Lock filling - Use of both longitudinal culverts</td>
<td>239.00</td>
<td>219.00</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock emptying - Use of both longitudinal culverts</td>
<td>239.00</td>
<td>219.00</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Lock filling - Use of only one longitudinal culvert</td>
<td>240.00</td>
<td>219.00</td>
<td>21.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock emptying - Use of only one longitudinal culvert</td>
<td>240.00</td>
<td>219.00</td>
<td>21.00</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Lock filling - Use of only one longitudinal culvert</td>
<td>239.00</td>
<td>219.00</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock emptying - Use of only one longitudinal culvert</td>
<td>239.00</td>
<td>219.00</td>
<td>20.00</td>
<td></td>
</tr>
</tbody>
</table>

Table 26: Filling and emptying times measured during the physical model tests

<table>
<thead>
<tr>
<th>Operation type</th>
<th>Number of longitudinal culvert used for F/E operation</th>
<th>Valve opening time in min</th>
<th>Head in m</th>
<th>F/E time in min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lock filling</td>
<td>2</td>
<td>1</td>
<td>21.00</td>
<td>7.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>8.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>between 3 &amp; 4</td>
<td></td>
<td>between 8.8 &amp; 10.3</td>
</tr>
<tr>
<td>Lock emptying</td>
<td>2</td>
<td>1, 2, 3 &amp; 4</td>
<td></td>
<td>not given</td>
</tr>
<tr>
<td>Lock filling</td>
<td>1</td>
<td>1, 2, 3 &amp; 4</td>
<td></td>
<td>between 14.5 &amp; 16.1</td>
</tr>
<tr>
<td>Lock emptying</td>
<td>1</td>
<td>1, 2, 3 &amp; 4</td>
<td></td>
<td>between 17.2 &amp; 18.7</td>
</tr>
<tr>
<td>Lock filling</td>
<td>2</td>
<td>1</td>
<td>20.00</td>
<td>7.40</td>
</tr>
<tr>
<td>Lock emptying</td>
<td>1</td>
<td>1</td>
<td></td>
<td>7.80</td>
</tr>
<tr>
<td>Lock filling</td>
<td></td>
<td>1</td>
<td></td>
<td>Total time (F + E) = 15.2</td>
</tr>
<tr>
<td>Lock emptying</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Total lockage cycle time

The total lockage cycle time corresponds to the time needed for a vessel to cross the lock complex starting from the upstream (respectively downstream) waiting area to the downstream (respectively upstream) waiting area. It is assessed in the FS report according to the following calculation:

\[ T = 4t_1 + t_2 + 2t_3 + t_4 \]

Where: 
- \( t_1 \) is the time for opening miter gate, which is taken as 1 min;
- \( t_2 \) is the time for vessel entering the gate, \( t_2 = 285 \) m/1 m/s = 4.75 min;
- \( t_3 \) is the time for filling and releasing of lock, which is taken as 9 min;
- \( t_4 \) is the time for vessel leaving the gate, \( t_4 = 137 \) m/1.4 m/s = 97.85 min.

It is calculated that the individual lockage time of vessel is: \( T = 28.38 \) min.

The result complies with the MRC requirement even if the cycle time should be calculated according to the following operations:
- \( t_1 \) - Gate opening time;
- \( t_2 \) - Time for the vessel to enter into the lock chamber;
- \( t_3 \) - Gate closing time and vessel mooring (supposing both operation can be carried out simultaneously);
- \( t_3 \) - Lock filling or emptying time;
- \( t_4 \) - Gate opening time and vessel unmooring (supposing both operation can be carried out simultaneously);
- \( t_4 \) - Time for the vessel to exit the lock chamber;
- \( t_1 \) - Gate closing time.

The total lockage time \( T \) should be then given by:

\[ T = 4t_1 + t_2 + 2t_3 + t_4 \]

### 8.4.2.4 Discharge and velocity

Average velocity and discharge have been calculated for the configurations 1 and 3 of table 25 and a valve operating time of 1 minute. The results are presented in the tables here below.

The calculation assumes a balance flow distribution in the lateral branches as well as in the bottom ports which will not be the case. It consequently leads to under-estimations of the maximum average velocity that will be reached in these parts of the F/E system in real conditions.
The results point out that for the maximum head and a 1 minute valve operating time:

- The average velocities in the longitudinal culverts, lateral branches and bottom ports are a little too high for configuration 1 and clearly too high for configuration 3 with respect to usual requirements;
- The average velocities in the valve sections require reinforced concrete or steel lining along 8 to 10 m downstream the valves.

It is strongly advised to increase the valve operating time in order to reduce the average velocity until an admissible velocity value is achieved. Such an increase will have a limited impact on the lockage time considering the comments made on Section 8.4.2.3 about the formula used by the Developer.
8.4.2.5 Forces exerted on the vessel

According to Paragraph 7 of Section 5.9.4.4 of the FS (page 5-167), mooring force is calculated on the basis of the following formula:

\[ P = k r \cdot \omega \cdot D \cdot W \cdot \sqrt{2g \cdot H} \]

\[ n' \cdot (\omega \cdot \chi) \]

The report also claims that the maximum force exerted on the design vessel for filling operation is 5.35 kN (~1% of vessel displacement) which is indeed compliant with the requirements. Anyway, it is impossible to check this issue only on the basis of the information released in the report since:

- The terms used in the formula are not specified and no explanation is given with respect to the retained coefficient;
- We do not know which data from physical model have been used (if any) to calculate F_max.

8.5 Conclusion for Navigation

8.5.1 Conclusions

The issues relative to lock design and navigation conditions have been improved in the frame of the review. Most of the MRC guidelines have been fulfilled even if there are still some points to be completed (see tables of compliancy hereafter).

- The lock design has been well studied thanks to a physical model (1/20) and is suitable for Pak Lay HPP scheme even if the following issues can be highlighted:
  - Operating conditions need to be adapted with respect to high velocities;
  - Physical model study report is missing and would have brought valuable information for a better understanding of the results obtained during the tests.
- Lock equipment is compliant. Operation and maintenance policies have been more described even if some point still need to be detailed;
- The flow conditions in approach channels have been studied on a 1/100 physical model:
  - The upstream lock approach seems to be safe even if velocities higher than 0.8 m/s (threshold value for Chinese guideline) can occur for discharge higher than 13 500 m³/s;
  - The downstream lock approach seems to be very disturbed (cross-current and backflow) and may raise problem for vessels;
  - Physical model study report is missing and would have brought valuable information for a better understanding of the results obtained during the tests.
- The sediment issue is shortly addressed through a 2D numerical modelling study. It is strongly advocated to survey regularly (at least each year) the approach channels areas in order to implement dredging operations if necessary.

![Figure 76: Pak Lay HPP level of compliancy on Navigation](image-url)
### 8.5.2 Table of compliance

<table>
<thead>
<tr>
<th>N°</th>
<th>Guidance regarding navigation</th>
<th>Final Report</th>
<th>Priority (PNPCA, Construction, Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>On stretches influenced by hydropower developments, the terms of reference shall refer to the same definitions of Highest Operating Level (HOL), Normal Operating Level (NOL), and Lowest Operating Level (LOL).</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
<tr>
<td>21</td>
<td>On free-flowing stretches, the terms of reference shall be defined by reference to hydrological statistics specifying Lowest Navigable Level (LNL), Mean High Navigable Level (MNL), and Highest Navigable Level (HNL).</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
<tr>
<td>22</td>
<td>The ship locks must be capable of raising transiting vessels from the downstream hydropower development level to the upstream hydropower development level or water level, or correspondingly, lower transiting vessels from the upstream hydropower development level to the downstream hydropower development level or water level, during all periods of authorized navigation on the Mekong River.</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
<tr>
<td>23</td>
<td>The maximum head (difference between Highest Operating Level and Lowest Navigable Level or Lowest Operating Level if there is a backwater effect from a downstream development) of one chamber shall be 30m. Locations that require the ability to traverse a height greater than 30 meters should use two locks in a series (tandem) arrangement.</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
</tbody>
</table>

#### 2- Dimension and Design Vessels

<table>
<thead>
<tr>
<th>N°</th>
<th>Guidance regarding navigation</th>
<th>Final Report</th>
<th>Priority (PNPCA, Construction, Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>The following considerations are made when proposing lock dimensions:</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
<tr>
<td></td>
<td>• The longitudinal profile of the river and related potential navigability of the river (slope, width, discharge and bend radius) after hydropower development;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The long-term economic potential of the region, and possibilities for waterborne transport and trade;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The need for consistency with lock dimensions on the Lancang River in PR China; and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The stipulations in the 2000 Quadrangle Agreement for Commercial Navigation between Lao PDR, Myanmar, PR China and Thailand, and the 1995 Mekong Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin between the four Lower Mekong Countries.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>The MRC conducted a Review of International Ship Lock Dimensions and their Relevance to the Proposed Hydropower Developments on the Mekong Mainstream. This study was based on benchmarking with international experiences, recommendations by the International Inland Navigation Association (PIANC), and assessments of Chinese waterway classifications in the case of rivers associated with hydropower developments.</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
<tr>
<td>26</td>
<td>Until the results of the Optimisation Study of proposed mainstream dams undertaken by the Government of Lao PDR are fully assessed, and further research on developing the most appropriate design vessel specification for Mekong navigation locks is conducted by MRC in 2009, the preliminary guidance offered for the dimensions of lock chambers is:</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
<tr>
<td></td>
<td>• Length: 120m</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Width: 12m</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Depth: 4m</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>With provision for future doubling of the locks (if traffic increases) in a parallel setup to a width of 24m.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>In order to ensure that the design of dams makes provision for subsequent increases in river navigation; it is strongly recommended that a parallel slot is reserved for a second lock on each dam to double capacity.</td>
<td>Compliant</td>
<td>PNPCA</td>
</tr>
</tbody>
</table>
## Lockage time and availability

<table>
<thead>
<tr>
<th></th>
<th>Requirement</th>
<th>Compliance Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Lockage time shall be a significant factor in determining the design. The objective shall be to develop an overall design that ensures lockage time is kept to a minimum; is consistent with safe operation; and fully takes into account the safe movement of vessels into and out of the locks.</td>
<td>Compliant</td>
</tr>
<tr>
<td>29</td>
<td>The total time for a complete lockage (target lock cycle) by the design vessel through each lock complex shall not exceed 30 minutes for a one-step lock and 50 minutes for a two-step &quot;tandem lock&quot;. All times are for a design vessel in fully laden condition.</td>
<td>Not fully compliant</td>
</tr>
<tr>
<td>30</td>
<td>The emptying/filling system shall be designed to conform to the requirements for maximum transit times and allow for the smooth and safe lockage of any type of boat smaller or equal to the dimensions of the design vessel. Regarding this objective, the design criterion shall be: Max hawser forces ≤ 1‰ x water displacement of the vessel (in tons).</td>
<td>Not fully compliant</td>
</tr>
<tr>
<td>31</td>
<td>The locks should be designed to operate at least 12 hour a day, every day of the year. Each lock complex shall be operational at least 98 percent of its scheduled time proposed by the developer. Anyway, this is not a blocking issue for the project.</td>
<td>Compliant</td>
</tr>
<tr>
<td>32</td>
<td>Outages related to incidental breakthroughs, unscheduled maintenance and other unexpected outages, such as those resulting from collisions, extreme weather conditions, or causes beyond human control shall not exceed 1 percent of the operating time each year.</td>
<td>Compliant</td>
</tr>
<tr>
<td>33</td>
<td>Service outages for scheduled maintenance shall be on 9 consecutive days (one working week and the two Week-ends) each year, during the same period for the whole Mekong mainstream waterway. The official body in charge of navigation coordination along the Mekong River will be responsible for specifying the dates for servicing.</td>
<td>Compliant</td>
</tr>
</tbody>
</table>

## Location and Alignment

<table>
<thead>
<tr>
<th></th>
<th>Requirement</th>
<th>Compliance Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Hydraulics (currents), river morphology (sedimentation) and wind exposure must be taken into account when determining the location and alignment of locks.</td>
<td>Compliant</td>
</tr>
<tr>
<td>35</td>
<td>Lock entry and exit by barges must be safe and easy, from both upstream and downstream sides. Especially downstream from the lock, cross currents produced by turbines and gates and local sedimentation have to be taken into account in the lock design.</td>
<td>Compliant</td>
</tr>
<tr>
<td>36</td>
<td>Fine material sedimentation occurs just upstream and downstream of the lock. Adapted design is necessary to mitigate sedimentation; and maintenance by dredging has to be foreseen.</td>
<td>Compliant</td>
</tr>
<tr>
<td>37</td>
<td>The lock sill-bottom level must include a safety margin (of at least 1m) to take into account bed incision downstream of the dam - in order to ensure sufficient draught over the entire life of the structures.</td>
<td>Compliant</td>
</tr>
<tr>
<td>38</td>
<td>Each lock should have a straight alignment of at least 250 metres on both sides to allow for the safe entry and exit of vessels. This alignment should be separated from the main flow of the river at least 250 metres in both directions from the hydropower barrage.</td>
<td>Compliant</td>
</tr>
</tbody>
</table>

## Construction

<table>
<thead>
<tr>
<th></th>
<th>Requirement</th>
<th>Compliance Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>Navigation will need to be maintained to the maximum extent possible during construction for the size of vessels that currently use the Mekong mainstream. The MRC will provide an indication of the size of such vessels in a subsequent version of this preliminary design guidance. Where disruptions are unavoidable, alternative road transit routes around the blocked areas should be considered as a means of mitigating their impact.</td>
<td>Compliant</td>
</tr>
</tbody>
</table>

## Service Life

<table>
<thead>
<tr>
<th></th>
<th>Requirement</th>
<th>Compliance Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Each lock complex shall have a functional lifetime of 100 years, providing that a convenient and scheduled maintenance policy is applied. Some components of the lock may have a service life shorter than 100 years. These components shall be designed to allow for easy replacement. The minimum service life of the main components shall be as outlined below and financial provision made for replacement when needed:</td>
<td>Compliant</td>
</tr>
<tr>
<td></td>
<td>• Metal structures: 50 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Hydraulic jacks: 15 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ball bearings, pulleys, etc: 25 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cables: 10 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Electrical equipment: 30 years</td>
<td></td>
</tr>
</tbody>
</table>

## Expansion

<table>
<thead>
<tr>
<th></th>
<th>Requirement</th>
<th>Compliance Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>The design of the locks system should include provision for the construction of a second line of locks. It is recommended the developer or hydropower dam operator be responsible for the construction of a second line of parallel locks when the number of lockages per year reaches at least 80 percent of the total maximum possible yearly lockages over a period of 3 successive years.</td>
<td>Compliant</td>
</tr>
<tr>
<td>42</td>
<td>Specifically, the layout and alignment in the design drawings shall consider the location of the chambers, gates, approach structures, control buildings, and other elements, in order to facilitate the construction and operation of the second line of locks. The design shall include details explaining how the second line of locks would be built in a way that minimizes construction costs and the distance between chamber central lines to allow the use of the same navigational approach channels.</td>
<td>Compliant</td>
</tr>
</tbody>
</table>
### 9. Design, operation, safety and maintenance

<table>
<thead>
<tr>
<th>Rule</th>
<th>Description</th>
<th>Compliance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>Floating bollards and wall ladders should be installed at appropriate intervals on the inside of the chambers. Ladders should be recessed into lateral walls.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>44</td>
<td>Considering the consequences of damage to the gates on the availability of the lock system, before the construction of a second line of locks, one gate protection device shall be provided inside the chamber. This device should be a fixed shock absorber protecting the downstream mask wall (above the downstream gate).</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>45</td>
<td>The developer shall prepare design and specifications for the locks to ensure they are functional and reliable. Important design objectives are to optimize operational efficiency and adhere to the minimum lock downtimes.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>46</td>
<td>The developer shall furnish a design that provides vehicular access to all aboveground structures for maintenance and operation, access for emergency response vehicles, and an overall layout for operating conditions that protects the safety of navigation in the locks.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>47</td>
<td>The developer shall design, procure, install, and commission all plant necessary for the optimum control and function of the lock complexes. This shall include process control systems; visual, audio, and electronic surveillance systems; and command and control communication systems. These systems shall include the ability to communicate with other locks on the Mekong mainstream waterway as well as to provide real-time and historic monitoring of lock usage data, information from which must be accessible by the MRCS or authorized riparian administration agencies.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>48</td>
<td>The developer shall design, procure, install, and commission all plant necessary for the optimum control and function of the lock complexes. This shall include process control systems; visual, audio, and electronic surveillance systems; and command and control communication systems. These systems shall include the ability to communicate with other locks on the Mekong mainstream waterway as well as to provide real-time and historic monitoring of lock usage data, information from which must be accessible by the MRCS or authorized riparian administration agencies.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>49</td>
<td>The developer shall design systems with sufficient redundancies in critical components to allow maintenance and repair without adversely affecting lock-transiting operations.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>50</td>
<td>The developer shall design systems with sufficient redundancies in critical components to allow maintenance and repair without adversely affecting lock-transiting operations.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>51</td>
<td>The developer shall develop a strategy for emergency access to both sides of each lock complex in the event of flooding or the loss of the lock gates. A description of emergency access and egress routes should be included in the layout.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>52</td>
<td>The developer shall provide designs to ensure durability; and that maintenance requirements are reduced to the lowest practical level. The HDO shall design systems with sufficient redundancies in critical components to allow maintenance and repair without adversely affecting lock-transiting operations.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>53</td>
<td>Lock gates and their maneuvering devices shall be protected with water projection systems against the consequences of a fire inside the chamber.</td>
<td>Compliant</td>
<td>PNPNA</td>
</tr>
<tr>
<td>54</td>
<td>Each lock complex shall provide for the lockage of vessels in a safe and efficient manner, without causing structural damage to vessels or lock facilities.</td>
<td>Compliant</td>
<td>Operation</td>
</tr>
</tbody>
</table>
9 CONCLUSION

Pak Lay Developer did major efforts to meet all international standards and to provide relevant technical answers to all comments CNR experts did during the review.

As a consequence, Pak Lay HPP has been improved a lot. At the end of the FS review at Lao level, Pak Lay project is nearly fully compliant with MRC guidelines and international standards.

Remaining issues should be easily addressed by the Developer during the next stage of the project.

There is no blocking point for Pak Lay project.

The final design of Pak Lay HPP, featuring spillway, middle level gates and LLOs, should allow efficiently mimicking the impact of sedimentation upstream the dam site. In addition, this design is very flexible and will ease operation whatever the inflow is.

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**Figure 77:** Pak Lay – Level of compliance for the 4 issues addressed by CNR (November 2016)
L’énergie au cœur des territoires