VOLUME 6
HYDRAULIC MODEL TEST

115002924
May 10, 2019
Rev 0

LUANG PRABANG POWER COMPANY LIMITED
Luang Prabang HPP

Feasibility Study

Report – Volume 6 – Annex 6.5 Hydraulic Model Test

PÖYRY
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STRUCTURE OF THE FEASIBILITY STUDY

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Application of Xayaburi HEPP Surface Spillway and

Low-Level Outlet Model Tests Results for

Luang Prabang Hydroelectric Power Project

Water Engineering and Management
Department of Civil and Infrastructure Engineering
Asian Institute of Technology

May 2019

1 Introduction

1.1 Background

The Luang Prabang Power Company Limited (LPCL) is undertaking the Project development of Luang Prabang Hydroelectric Power Project (LP HPP) in Lao PDR. The Project site is located on the Mekong River, about 4 kms upstream with its confluence with the Nam Ou river and about 20 kms upstream of Luang Prabang.

As part of the design process, physical hydraulic model tests are required to study the hydraulic function of the main structures. Ideally, two distinctive physical models are required for this Project consisting of:

- Model 1 – Overall hydraulic model of the project structures and site topography
- Model 2 – Detailed model of the surface spillway and low-level outlets.

The Xayaburi Power Company Limited (XPCL), the developer of Xayaburi HEPP project, granted its permission to LPCL to use all data and studies prepared for the design and construction of Xayaburi HEPP for Luang Prabang HPP.

The concept, design and main dimensions of Luang Prabang HPP surface spillway and low-level outlets (LLO) are hydraulically similar to the ongoing Xayaburi HEPP which was already extensively tested and optimized at the AIT Hydraulics Laboratory in 2012-2013.

Therefore, the model test results of Xayaburi HEPP surface spillway and LLO can be applied and translated for Luang Prabang HPP. As such, the physical hydraulic model tests using detailed model of the surface spillway and LLO (Model 2) for Luang Prabang HPP may not be required since only limited new information can be likely gained by conducting another physical model tests of the surface spillway and LLO for Luang Prabang HPP.

On the other hand, physical hydraulic model test of the overall hydraulic structures and site topography (Model 1) is still necessary to verify and confirm the overall lay-out of Luang Prabang HPP as well as to validate the spillway and LLO model test results which were derived from sectional model tests.

This report presents the hydraulic conditions of the surface spillway and LLO of Luang Prabang based from interpretation of the model test results in Xayaburi HEPP. In interpreting and converting the Xayaburi HEPP model test results to Luang Prabang HPP, only the optimized design in Xayaburi HEPP which were finally adopted in the project were utilized.

1.2 Main Project Features

The key features of Luang Prabang HPP (see Figure 1) consist of the following, from right to left bank:

- A two-chamber navigation lock with upstream and downstream approach channels;
- A surface spillway with crest elevation at EL 289.0 m asl, equipped with six (6) radial gates each 19.0 m in width and 25.0 m high.
- Three (3) low-level outlets (LLO) with sill elevation at EL 275 m asl and equipped with 12.0 m wide and 16.0 m high radial gates and fixed wheel gates under pressure;
- Right bank pier, housing the auxiliary powerhouse, the terminal chute for the downstream fish migration and the feeding pond for the upstream fish migration attraction flow system;
- Powerhouse complex with seven (7) vertical Kaplan generation units as well as entrances and collector galleries for upstream and downstream fish migration;
- Left bank pier, housing the upstream fish migration facilities (fish locks); and,
- Left bank closing structure.

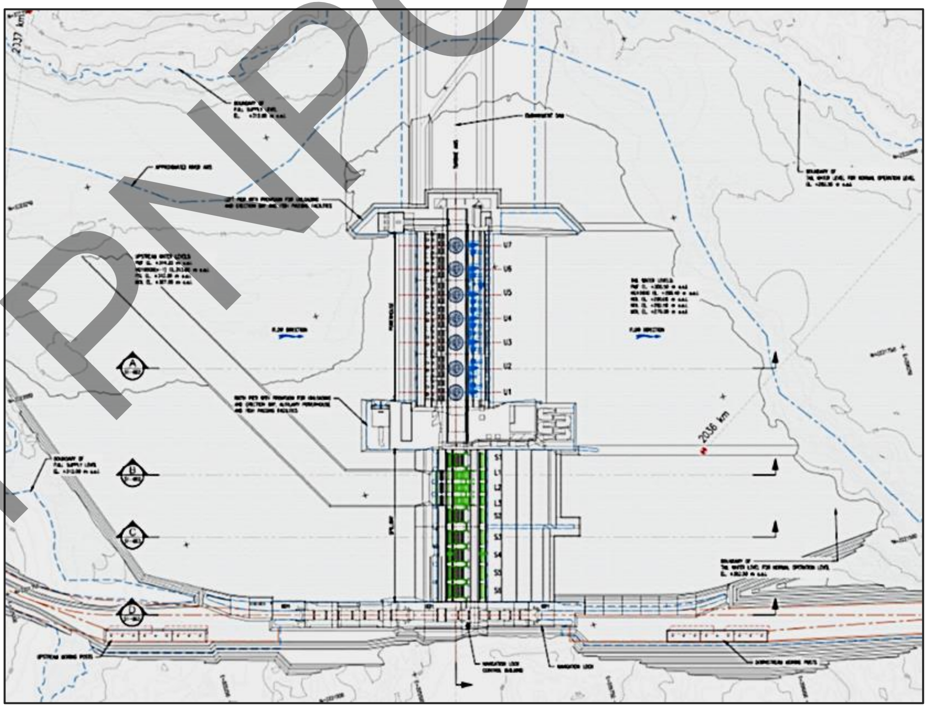

Figure 1 -Site plan and lay-out of proposed hydraulic structures

2 Physical Models

2.1 Design Similarity between Xayaburi and Luang Prabang Low-Level Outlets

The design and main dimensions of Luang Prabang and Xayaburi low-level outlets (LLO) are hydraulically similar. Both designs consist of a sloping chute inverts equipped with 12.0 m wide and 16.0 m high radial gates and fixed wheel gates under pressure. The relative elevations of the LLO invert, stilling basin and downstream excavated channel are also similar.

Based on the number of bays, Xayaburi HEPP has 4 LLO's while Luang Prabang HPP has only 3 LLO's. For comparison, the LLO sections of both projects are presented in Figures 2 and 3 below.

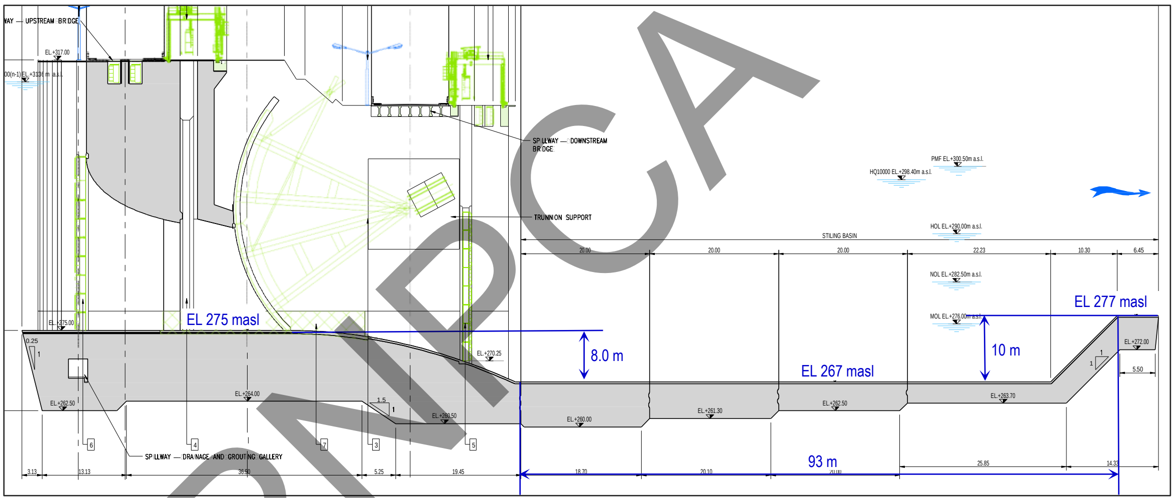

Figure 2 – Longitudinal section of LLO structure for Luang Prabang HPP (3 LLO's)

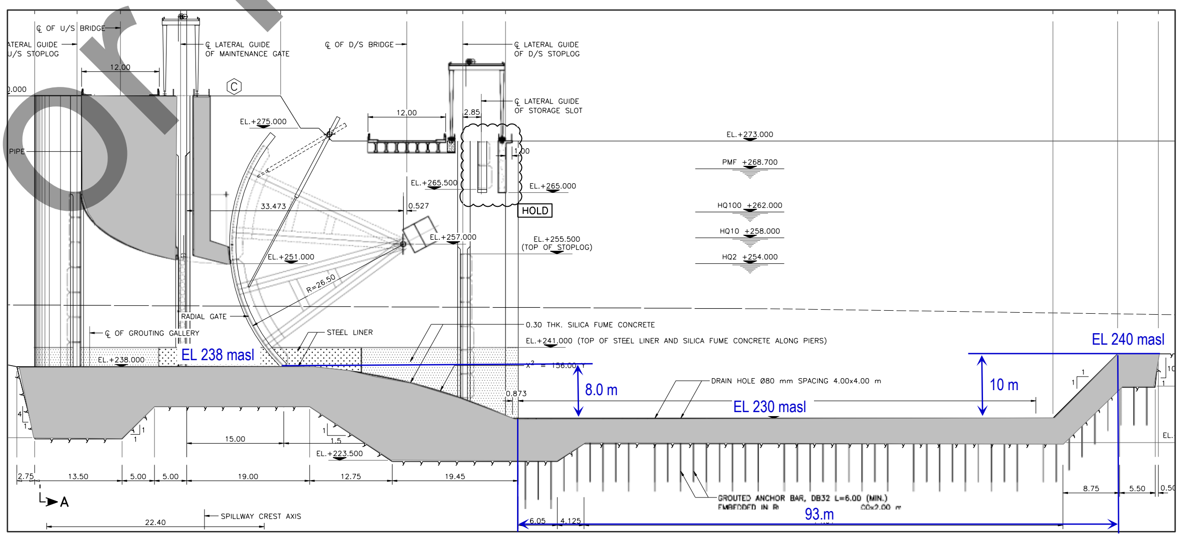

Figure 3 – Longitudinal section of LLO structure for Xayaburi HPP (4 LLO's)

2.2 Design Similarity between Xayaburi and Luang Prabang Surface Spillways

For the surface spillways, the design and main dimensions of Luang Prabang and Xayaburi are also hydraulically similar. Both designs utilized an ogee weir with 8.0 m high crests and equipped with radial gates each 19.0 m wide and 25.0 m high. The relative elevations of the spillway crest, stilling basin and downstream excavated channel are also similar.

Based on the number of surface spillway bays, Xayaburi HEPP has 7 surface spillways while Luang Prabang HPP has only 6 surface spillways. For comparison, the surface spillway sections of both projects are presented in Figures 4 and 5 below.

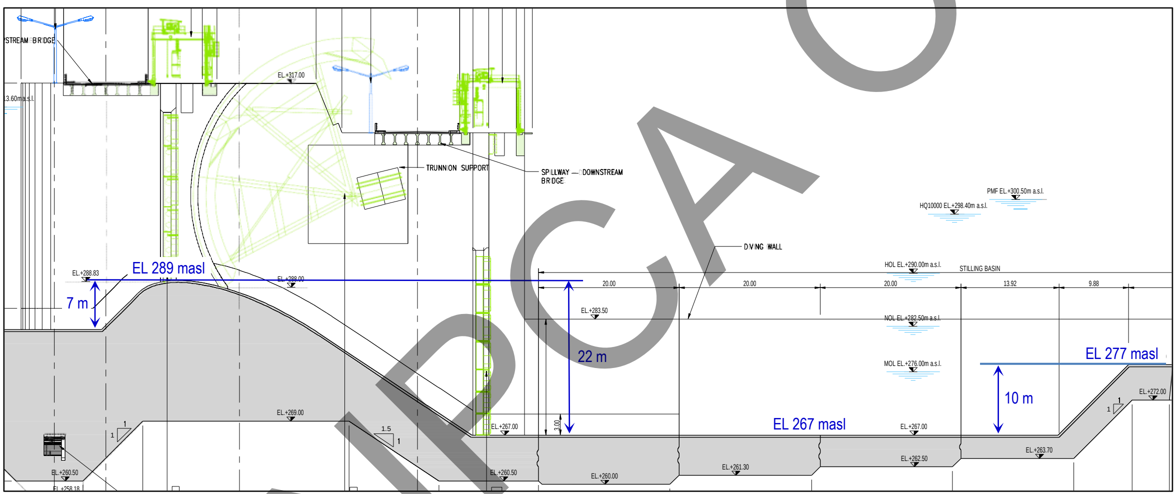

Figure 4 – Longitudinal section of overflow spillway structure for Luang Prabang HPP (6 bays)

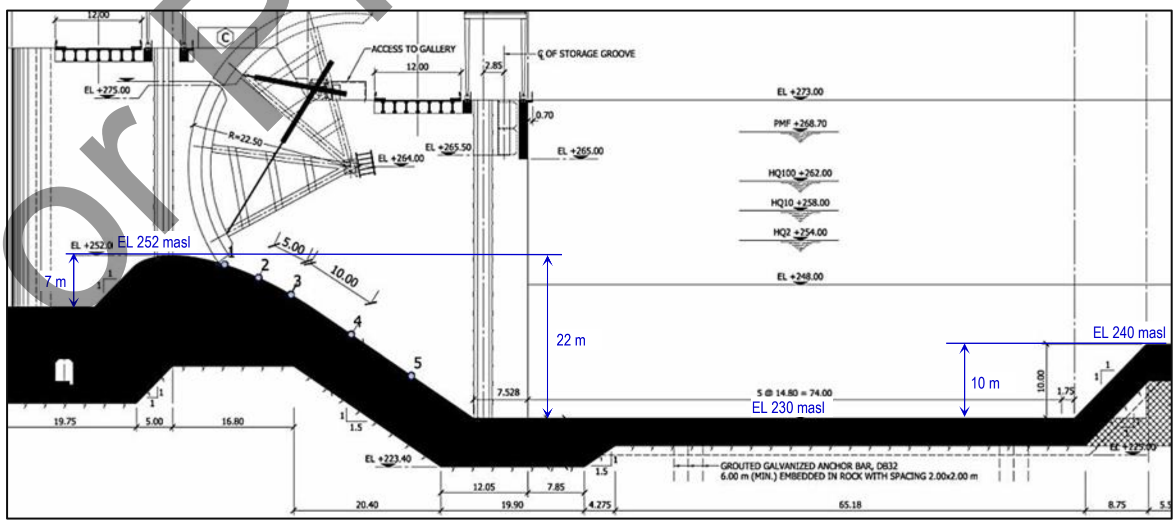

Figure 5 – Longitudinal section of overflow spillway structure for Xayaburi HEPP (7 bays)

2.3 Detailed Model Scale Relationships

The detailed model of the Surface spillways and Low-level outlets were built according to Froude-Similarity law implying that gravitational forces of the model can be transposed to prototype values. The geometric and dynamic similarity requirements between model and prototype were satisfied by constructing all model elements to an undistorted linear scale ratio (1/60) and testing all hydraulic quantities in their proper relationships based on Froude number similarity. Using subscripts *"m"* and *"p"* to denote model and prototype, respectively, the equal Froude number between model and prototype can be expressed as:

$$F_m = F_p \quad \text{or} \quad \frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}}$$

Where, F is the Froude number;

V is the mean velocity of flow;

g is the acceleration due to gravity, and;

L is the characteristic length.

Based from a scale of 1/60, the model dimensions and other parameters were scaled to prototype using the following relationships:

Parameter	**Scale Relation**	**Scale Ratio**
Length, L (Geometric)	$L_r = L_p/L_m$	60
Velocity, V (Kinematic)	$V_r = (L_r)^{1/2}$	7.74
Discharge, Q (Kinematic)	$Q_r = (L_r)^{5/2}$	27,885.48
Time, T (Kinematic)	$T_r = (L_r)^{1/2}$	7.74
Pressure, P (Dynamic)	$P_r = L_r$	60

2.4 Detailed Model of Surface Spillways and Low-Level Outlets

The layout of the detailed model of surface spillways and low-level outlets are shown in Figure 6 below. The detailed model represents a section of the overall spillway structure. It consists of two low-level outlets (LLO) with radial and fixed-wheel gates and one surface spillway with a radial gate (SS).

To allow the full dissipation of the turbulent flow from the feeding conduits, the detailed model was constructed with a 13 m long forebay section with three layers of flow straighteners and energy dissipators.

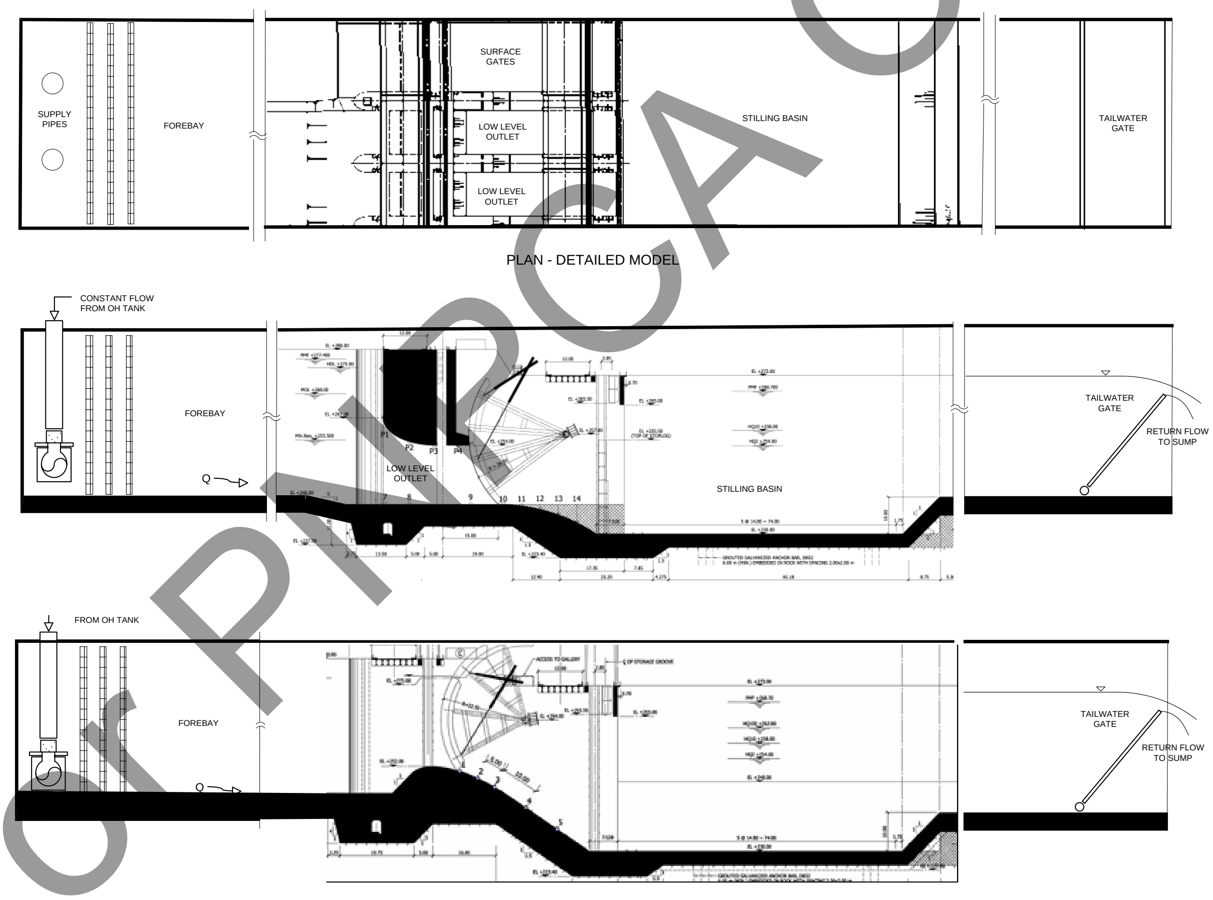

Figure 6 – Plan and section of the surface spillway and low-level outlet models

The completed detailed model of the surface spillways and low-level outlets built at a geometric scale of 1/60 is presented in Figures 7 and 8 below. The models represent the optimized designs of both SS and LLO developed from model test results of various operating scenarios in Xayaburi HEPP.

Figure 7 – Detailed model of the optimized design of the surface spillway (Scale 1/60)

Figure 8 – Detailed model of the optimized design of the low-level outlet (Scale 1/60)

3 Application of Xayaburi HEPP Model Test Results to Luang Prabang HPP

As previously mentioned, the design and main dimensions of Luang Prabang HPP surface spillways (SS) and low-level outlets (LLO) are hydraulically similar to Xayaburi HEPP. Therefore, the model test results from Xayaburi can be interpreted and transformed to Luang Prabang conditions.

Since the number of Surface spillways and LLO in Xayaburi and Luang Prabang are not equal, the total discharge capacities of the structures were first translated into discharge capacities of a single bay before transforming its equivalent values to Luang Prabang HPP.

3.1 Discharge Capacities of the Surface Spillways

The discharge capacities of Xayaburi surface spillways are presented in Table 1. By using these data and assuming a fully similar hydraulic conditions with Luang Prabang SS, the surface spillway rating of Luang Prabang HPP can be determined (see Table 2). The tailwater level at Luang Prabang (Table 3, Figure 9) is extracted from the Feasibility Study report of Luang Prabang HPP prepared by Poyry.

Table 1 – Discharge rating of Xayaburi surface spillway (SS Gates fully open, LLO closed)

US Water Level (m, asl)	TW Level (m, asl)*	Head from SS Crest (EL 252)	Total Discharge Q (7 SS)	Discharge Q (One SS only)
255.90	241.80	3.90	2,000.00	285.71
260.10	246.50	8.10	6,000.00	857.14
265.20	253.70	13.20	14,581.00	2,083.00
267.40	256.00	15.40	18,480.00	2,640.00
271.70	260.00	19.70	26,744.00	3,820.57
277.60	265.80	25.60	40,000.00	5,714.29

**TWL is based from SS discharge with Paklay*

Table 2 – Discharge rating of Luang Prabang surface spillways (SS Fully open, LLO closed)

US Water Level (m, asl)	TW Level (m, asl)*	Head from SS Crest (EL 289)	Total Discharge Q (6 SS)	Discharge Q (One SS only)
292.90	277.80	3.90	1,714.29	285.71
297.10	282.40	8.10	5,142.86	857.14
302.20	288.90	13.20	12,498.00	2,083.00
304.40	291.10	15.40	15,840.00	2,640.00
308.70	295.20	19.70	22,923.43	3,820.57
314.60	298.60	25.60	34,285.71	5,714.29

**TWL is based from SS discharge only*

Table 3 – Tailwater rating of Luang Prabang HPP

Discharge Q (m3/s)	TW Level (m, asl)	Discharge Q (m3/s)	TW Level (m, asl)	Discharge Q (m3/s)	TW Level (m, asl)
516	274.77	10,000	286.93	22,900	294.97
1,000	276.31	12,500	288.85	24,400	295.59
2,000	278.59	13,700	289.71	25,800	296.04
3,000	280.18	15,000	290.62	27,800	296.67
3,213	280.43	17,000	291.95	29,300	297.12
4,000	281.34	18,800	292.98	32,700	298.13
5,000	282.44	20,600	293.89	34,100	298.53
7,500	284.87	21,700	294.42	39,500	300.01

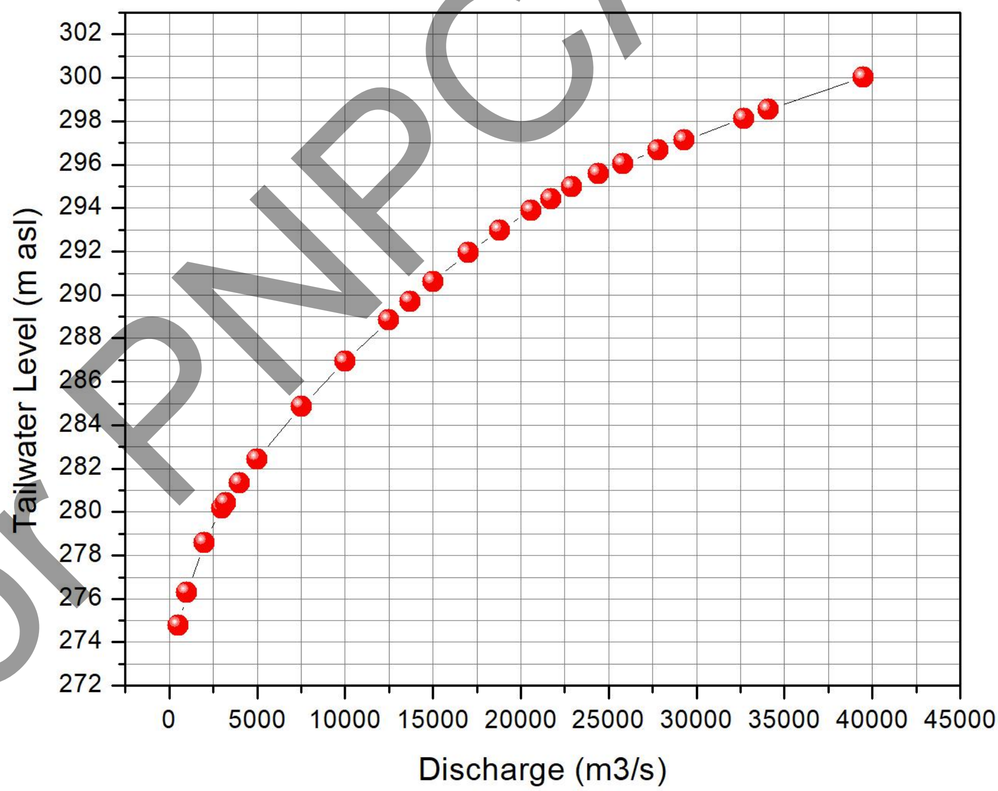

Figure 9 – Tailwater rating curve at Luang Prabang HPP dam site

3.2 Discharge Capacities of the Low-Level Outlets

For the low-level outlet structure, the discharge capacities of Xayaburi HEPP is presented in Table 4. By using these data and assuming a fully similar hydraulic conditions with Luang Prabang LLO, the equivalent LLO rating for Luang Prabang HPP was determined (Table 5).

Table 4 – Discharge rating of Xayaburi HEPP low-level outlets (SS gates closed)

US Water Level (m, asl)	TW Level (m, asl)*	WL from LLO Invert (EL 238)	Total Discharge Q (4 LLO)	Discharge Q (One LLO)
244.20	241.80	6.20	2,000.00	500.00
247.30	242.80	9.30	2,842.00	710.50
250.00	244.30	12.00	4,000.00	1,000.00
251.30	245.40	13.30	5,000.00	1,250.00
254.80	246.50	16.80	6,000.00	1,500.00
258.10	248.50	20.10	8,000.00	2,000.00
262.00	250.40	24.00	10,000.00	2,500.00
268.90	252.70	30.90	12,843.00	3,210.75

**TWL is based from LLO discharge with Paklay*

Table 5 – Discharge rating of Luang Prabang HPP Low-level outlets (SS gates closed)

US Water Level (m, asl)	TW Level (m, asl)*	WL from LLO Invert (EL 275)	Total Discharge Q (3 LLO)	Discharge Q (One LLO)
281.20	277.40	6.20	1,500.00	500.00
284.30	278.60	9.30	2,131.50	710.50
287.00	280.30	12.00	3,000.00	1,000.00
288.30	281.20	13.30	3,750.00	1,250.00
291.80	281.80	16.80	4,500.00	1,500.00
295.10	283.30	20.10	6,000.00	2,000.00
299.00	284.90	24.00	7,500.00	2,500.00
305.90	286.50	30.90	9,632.25	3,210.75

**TWL is based from LLO discharge only*

3.3 Combined Discharge Capacities of the Surface Spillways and Low-Level Outlets

The discharge capacities of Luang Prabang HPP surface spillways and low-level outlets (rated separately) are presented in Figure 10. For LLO rating, the maximum water level during the experiments with optimized condition is only at EL 305.9 m asl. Therefore, to get some close estimates, values beyond this point were simply projected following the trend.

Based from this data, the combined discharge capacities of the surface spillways and the LLO's were derived (see Table 6 and Figure 11). From the combined surface spillway and LLO rating, the head water levels for a 10,000-year flood (33,500 m3/s) and PMF (41,400 m3/s) were determined at EL 309.0 m asl and EL 313.1 m asl, respectively.

It should be noted that during separate ratings of the surface spillways and LLO during the model tests, the tailwater levels used corresponds only to the prevailing LLO or surface spillway discharge being tested since both are rated separately. In actual operation however, when both LLO and surface spillways are operating simultaneously, the actual tailwater levels would be higher. Therefore, the model tests underestimated the tail water levels during the experiments. As a result, model tests results tend to provide slightly optimistic values especially for the LLO discharges. In order to apply correction factors, the effect of tailwater level on the discharge capacities of the LLO and surface spillways has to be assessed as well.

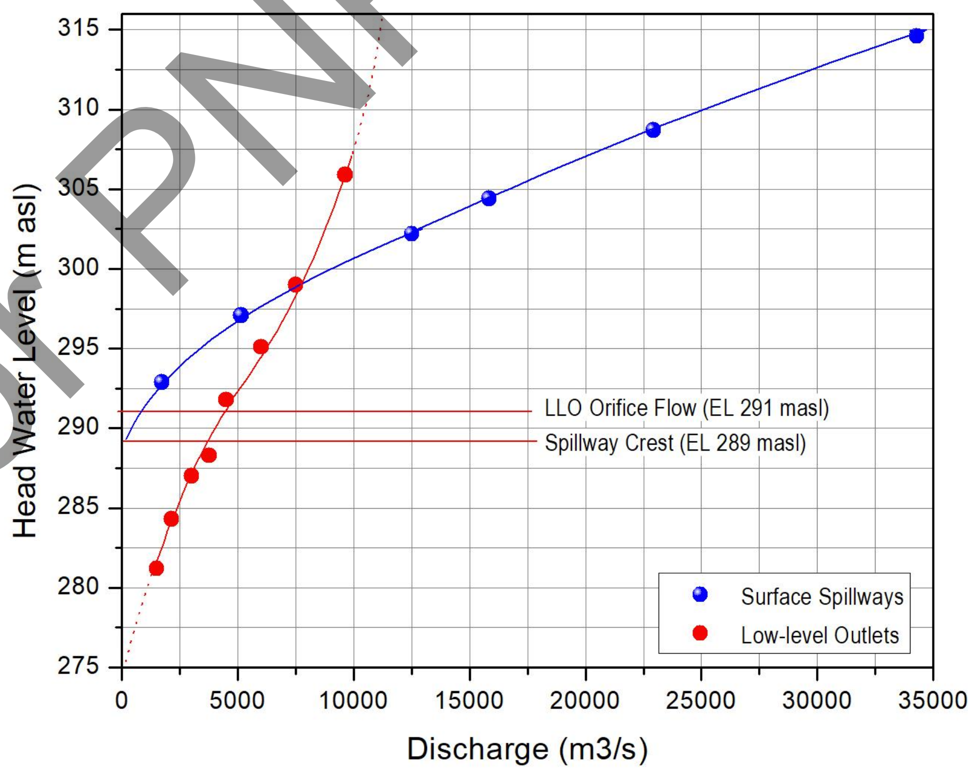

Figure 10 – Discharge rating curves of Luang Prabang Surface spillways and LLO's

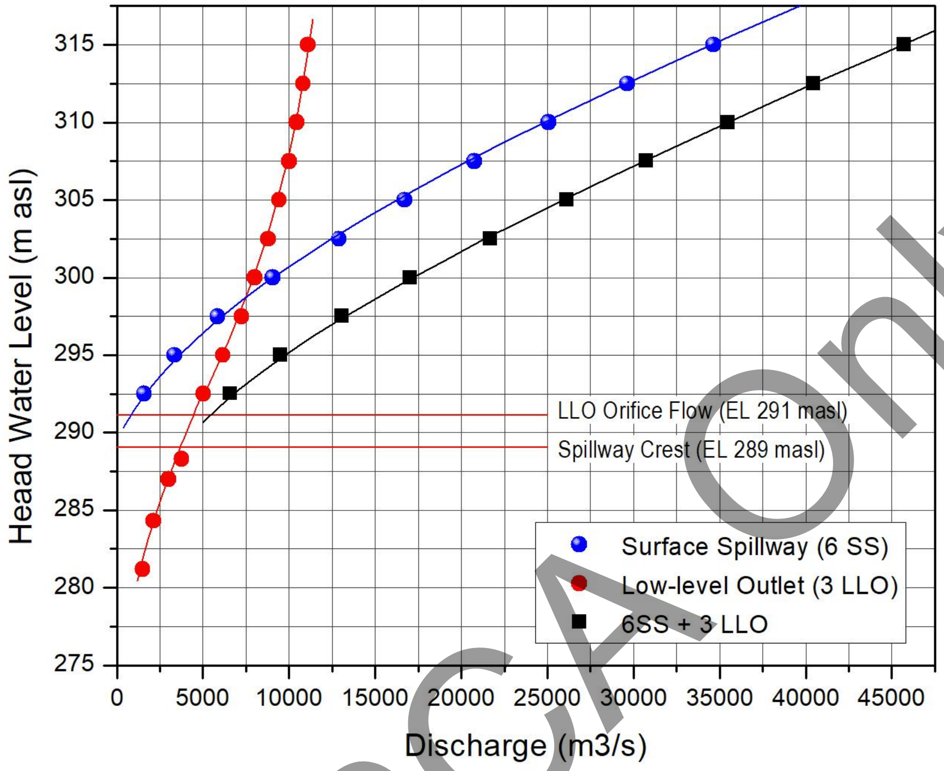

Figure 11 – Combined discharge rating curves of Luang Prabang Surface spillways and LLO's

Table 6 – Discharge rating of Luang Prabang Service Spillways and Low-level outlets

Surface Spillways (6 SS)		Low-Level Outlets (3 LLO's)		**Combined SS and LLO**	
HWL (m asl)	Discharge (m3/s)	HWL (m asl)	Discharge (m3/s)	**HWL (m asl)**	**Discharge (m3/s)**
292.5	1,587	281.2	1,500	292.5	6,606
295.0	3,351	284.3	2,131	295.0	9,509
297.5	5,845	287.0	3,000	297.5	13,077
300.0	9,044	288.3	3,750	300.0	17,046
302.5	12,901	292.5	5,019	302.5	21,697
305.0	16,702	295.0	6,158	305.0	26,115
307.5	20,759	297.5	7,232	307.5	30,759
310.0	25,065	300.0	8,002	310.0	35,496
312.5	29,627	302.5	8,796	312.5	40,443
315.0	34,647	305.0	9,413	315.0	45,736
		307.5	10,000		
		310.0	10,431		
		312.5	10,816		
		315.0	11,089		