Backwater Effect and Compensation due to Dam Construction on Nam Ngiep 1 Hydropower Project in Lao PDR

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Abstract

A 167 m high concrete dam was constructed related to the Nam Ngiep 1 Hydropower Project in Lao PDR and, as a result, a reservoir of 67 km^2 emerged. At the upper reaches of the reservoir, local residents enjoyed cultivation at the flood plain and near the riverbanks and a few houses existed in the expected inundation area by the reservoir. The residents feared that they would lose the land where they bore their lives and further land would be inundated by the backwater effect of the reservoir. The Nam Ngiep 1 Power Company (NNP1PC) estimated the inundation area based on a flood mark survey and a flood inundation simulation; and subsequently installed pegs as a benchmark for compensation measures and to show the predicted inundation area to the villagers. In addition, NNP1PC studied the possibility of drawdown during the rainy season to achieve an economic balance between minimised need for compensation and the loss of power generation. This paper presents the process of survey, study and compensation related to the backwater effect of the reservoir.

Keywords: Reservoir, backwater effect, flood mark survey, flood inundation simulation, compensation

1. INTRODUCTION

The Nam Ngiep 1 Hydropower Project (**NNP1**) is an Independent Power Producer (**IPP**) Project with Build-Operate-Transfer (**BOT**) scheme owned by the Nam Ngiep 1 Power Company (**NNP1PC**) established as the special purpose company for the project, invested by the Kansai Electric Power Company, the Electricity Generating Authority of Thailand (**EGAT**) and the Lao Holding State Enterprise. All the assets of NNP1 will be transferred to the Lao government after the commercial operation for 27 years. NNP1 consists of a main dam of 167 m high a and main powerhouse of 273 MW for power sales to Thailand, and a re-regulation dam of 20.6 m high and a re-regulation powerhouse of 17 MW to Lao PDR. The history of NNP1 is summarized that the financial close was concluded in September 2014, the main dam reservoir was started to be impounded in May 2018 just after the completion of the main dam RCC placing, and commercial operation is to be commenced in August 2019. Figure 1 shows the location of NNP1.

The main dam will form a reservoir of 70 km in length and 67 km^2 in area. At the upper reaches of the reservoir, local residents enjoyed cultivation at the flood plain and near the riverbanks and a few houses existed in the expected inundation area by the reservoir. The residents feared that they would lose the land where they bore their lives and further land would be inundated due toa further increase in water levels, caused by the so-called "backwater effect." The dam restricts the river flow, and during a flood from natural causes this can lead to an additional increase in water levels and inundations upstream. This increase in the upstream water level is termed the backwater effect. See Figure 3.NNP1 estimated the inundation area based on a flood mark survey and a flood inundation simulation, and subsequently installed pegs as a benchmark for compensation measures and to show the predicted inundation area to the villagers(Project Affected Peoples, or **PAP**s). In addition, NNP1PC studied the possibility of drawdown during the rainy season to achieve an economic balance between a minimised need for compensation and the loss of power generation.

2. IMPACTS BROUGHT BY MAIN DAM RESERVOIR

(1) Land Use within range of Reservoir and Interests of PAPs

In Southeast Asia, climatestypically alternate between rainy and dry seasons. Floods during the rainy seasons bring an abundance of nutrition to both the riverbanks. Local residents along the Nam Ngiep River, therefore, make a living there by agricultural activities such as cultivation of cereals and vegetables as shown in Photo 1.

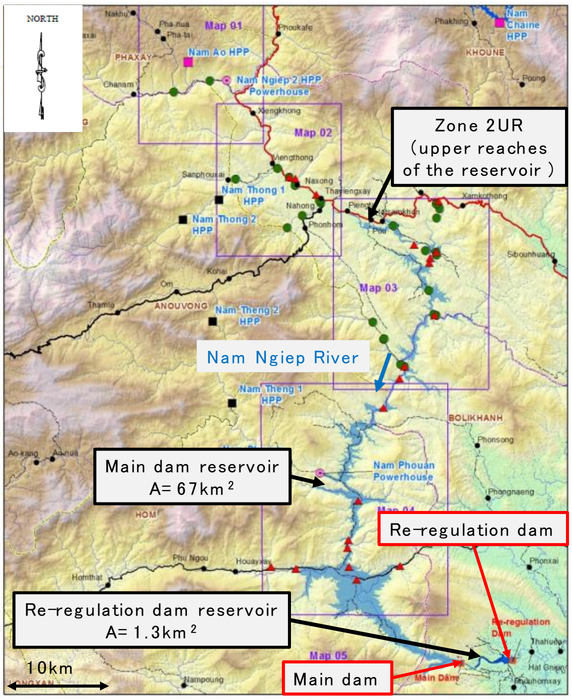

Figure1. Location of NNP1
(NNP1 is located along the Nam Ngiep River, tributary of the Mekong River in Lao PDR.)

Photo1. Cultivation at Riverbanks during Dry Season
(Villagers are seen cultivating on the riverbank near the village)

At the upper reaches of the reservoir areacalled"Zone 2UR" (UR stands for Upper Reservoir)", a flat plain is widely distributed at the riverbanks where PAPs grow rice and other crops. The reservoir formed due to construction of the dam not only deprives PAPs of the current livelihood but also of future development of farmland. Thiscan become a matter of life or death and, therefore, a primary concern of the PAPs. Figure 2 shows the location of the one 2UR and Photo 2 shows the state of cultivation at the zone 2UR.

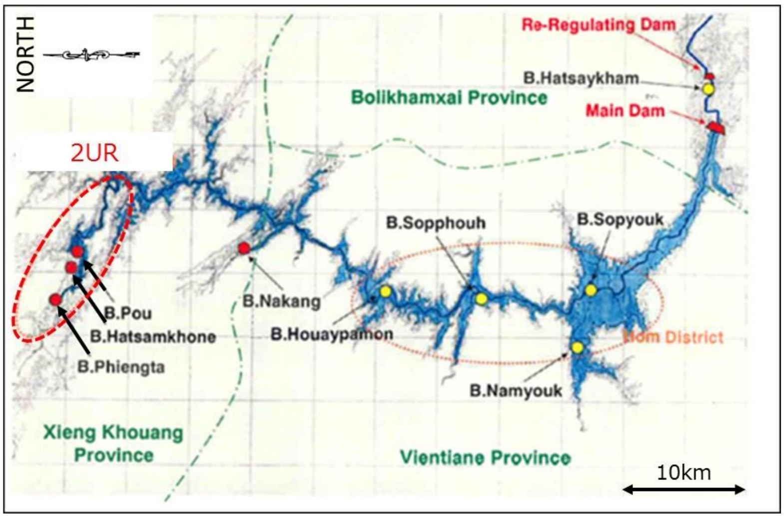

Figure 2. Location of Zone 2UR
(The reservoir impounding influences on Zone 2UR, located 70 km upstream of the main dam.)

Riverbank during Dry Season
(The riverbank for cultivation is seen)

Riverbank during Rainy Season
(The riverbank for cultivation is totally covered by flooded river)

Photo 2. State of Cultivation at Pou Village at Zone 2UR

These riverbanks, where some properties still exist, were frequently inundated in the past. It was not easy for PAPs to understand what area of land would be inundated due to the forming of the reservoir, and what the difference is between the area inundated by natural causes and the additional area due to the backwater effect.See Figure 3 and Figure 4. On various occasions they voiced their claim regarding the locations of the pegs, which in fact set out the boundary of the reservoir area by NNP1,fearing that the size of their land to be compensated would be underestimated. Figure 3 shows the image of the backwater effect at the zone 2UR. The blue-coloured area indicates the expected range of the backwater effect after reservoir impounding.

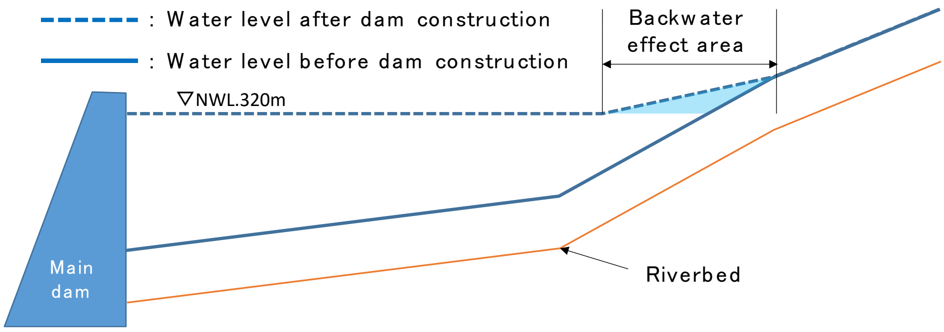

Figure 3. Image of Backwater Effect at Upper Reaches of Reservoir
(Backwater effect is a phenomenon that flooded inflow is dammed up by the reservoir, resulting in higher water level than that before dam construction.)

(2) Land Compensation at Upper Reaches of Reservoir

There are 3 villages at the zone 2UR, namely Phiengta, Hatsamkhone and Pou villages from upstream. As of the final survey in 2014[2], the number of households to be affected by the reservoir including houses, farmland and cemetery etc. was 194 in total within3 villages. In addition, that was an additional 28 households outside of the 3 villages[1][2]. Among them 12 households were required to be resettled. Following a consultation meeting with the PAPs, all the households optedto resettle in the same village. Following the wishes of the PAPs, NNP1PC built new houses for 5 households and compensated the others in cash as they chose to buildhousingthemselves. All the land including farmland and cemeteries were compensated for in cash through the consultation meetings with PAPs[2]. Figure 4 shows the range of the area inundated by the reservoir. The blue-coloured area indicates the reservoir and the red indicates the backwater effect area.

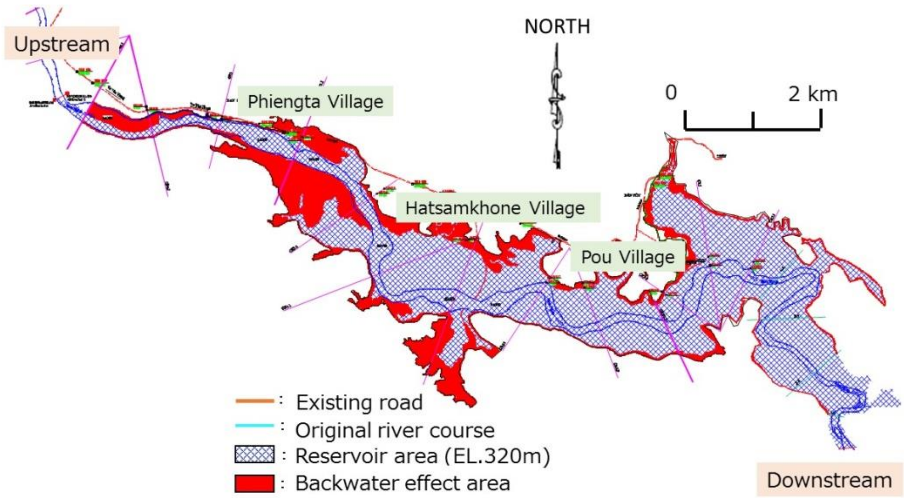

Figure 4. Range of Area to be inundated by Reservoir in case of 30-yearProbable Flood (1 km^2 in total is to be additionally inundated by backwater effect, out of 67 km^2 of the reservoir area.)

NNP1PC found a case in Thailand whereland to be inundated by anartificial30-year probablefloodingwascompensated. Though it would be difficult to accurately clarify whether aninundation stems from the backwater effect or not until a flood actually happens, it might be reasonable that land to be inundated by a 30-year probable flood are to be compensated because the term of the IPP project is normally set to be around 30 years.

It was extensively discussed atNNP1 whether further areas due to the backwater effect should be compensated or the reservoir water level should be controlled and lowered tosome extent to limitthe backwater effect. As mentioned below, for the NNP1 case economic impact due to the control of the reservoir water level is estimated to be substantialto the extent that this measure was not introduced, and instead ad-hoc compensation will be applied after flood inundation happens.

3. FLOOD INUNDATION SIMULATION

(1) Flood Mark Survey and Analytical Modelling

A flood inundation simulation,using1 dimensional non-uniform flow analysis, was carried outto estimate the impacts on land at the 3 villages by the backwater effect due to floods atthe Full Tank Level at Elevation Level (**EL.**) 320 m. The simulated area was between 3 km downstream from the Pou Village and 4 km upstream from the upper reaches of the reservoir, which is around 12 km long in total. There were 25 sectional lines within the simulated area;which consistedof 22 lines surveyed, and 3 lines where the riverbed elevations were interpolated by an averaged river gradient. A roughness coefficient of 0.04 was adopted for the riverbed, based on the results of river observation. Prior to the simulation, a detailed flood mark survey was undertaken to calibrate the analytical model. In 2011, the Typhoon Haima brought aflood discharge which peaked at2,400 m^3/s at NNP1. This wassimilarto the30-year probable flood of 2,530 m^3/sreferred to in the report published by the Mekong River Committee,and was comparable to the measured data of the river water level downstream of NNP1. Catchment areas at NNP1 and Zone 2UR were 3,700 km^2 and 1,854 km^2 respectively, and the flood of 1,270 m^3/s would occur at Zone 2UR proportionate to the size of the catchment area.

The flood mark survey[3] by the Typhoon Haima in 2011 was undertaken in 2015 through interviews with PAPs at the 3 villages where the backwater effect would be forecasted. It was found that the Typhoon Haimahadbrought the largest flood in recent years, and an accurate inundation map was drawn by referring to marks of the maximum water level. PAPs tend to remember the status around the river during the latest floods. So, their memories were very useful to verify the appropriateness of the analytical results. Especially, flood mark surveys in Southeast Asia, where the number of water level gauges is inadequate, rely on the memories of the local residents. Therefore, the sooner the flood mark survey is conducted after high floods occur, the more accurate the results are. Figure 5 shows the results of the flood mark survey at Hatsamkhone Village.

After the flood mark survey, pegs were set out along the contour line at EL. 320 m again. The interval between the pegs was typically 20 m, much closerthan previouslyatEL.200 m.PAPs also attended the pegging works for monitoring of our activities. It was confirmed that the existing pegs indeed sat on the contour line of EL. 320 m, except for a specificarea that had beendisturbed by river erosion since the survey carried out in 2015. So, PAPs realistically recognized the future reservoir area and trusted the accuracy of the pegs. Photo 3 shows pegs installed in this survey. Certainclaims were frequently raised byPAPs whenever surveyswere conducted that related to their assets (such as dimensions, elevation, etc.) because theseconcerned them themost. In order to gain the trust of thePAPs, it is important for project owners to buildgood relationships with themby executing thecompensation process in good faith and with integrity.

Incorporating the survey results into the analytical model, a sensitivity analysis showed that the maximum discharge at the zone 2UR was 1,570 m^3/s, larger than theestimated 1,270m^3/s mentioned in Section 3 (1). However, according to the report published by the Mekong River Committee[4], total cumulative precipitations by the Typhoon Haima was 240 mm and 170 mm at the zone 2UR and NNP1 respectively. That would explainwhy the actual maximum discharge was larger than that by the above estimation. Adjusted by the ratio of precipitations, the finalized analytical model was sufficiently accurate with anerror of 20 cm at the maximum, which is less significant for the topographical condition on site, in the river water level to evaluate the backwater effect.

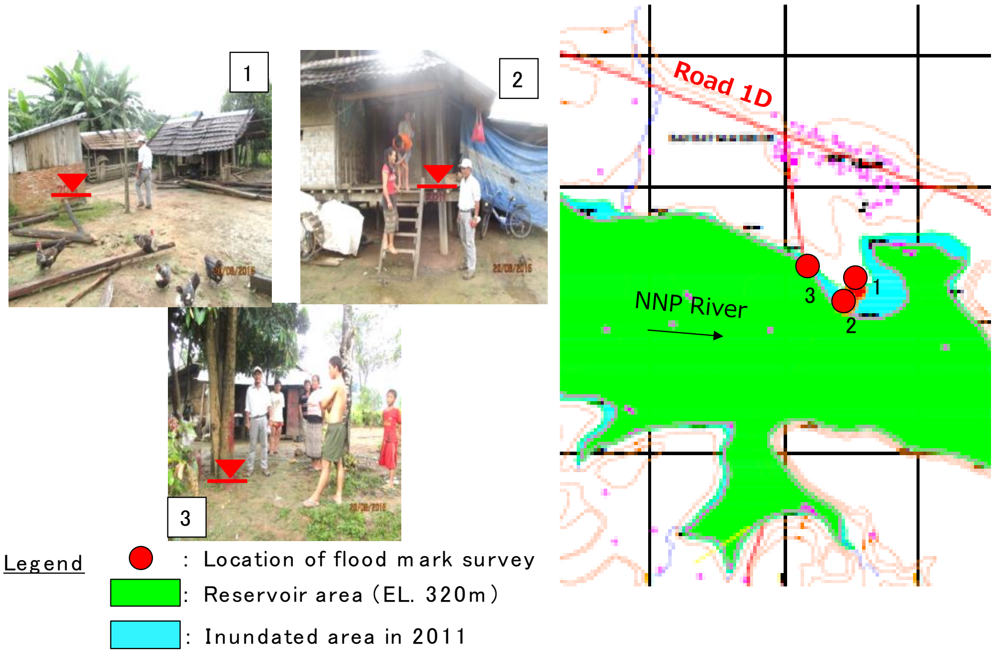

Figure 5. Flood Mark Survey at Hatsamkhome Village
(During the interview, villagers told us about the highest water level which they remembered. Inundated area due to typhoon Haima in 2011 was specified based on the level)

Photo3. Re-Installation of Pegs
(A new peg is seen in left side of the photo. On the right side PAPs are checking its position based on the map. An existing peg was seen on the right side as well, which was originally installed in the lower step but shifted by PAPs to the upper step so as not to interfere with cultivation.)

Initially, estimation of the non-uniform flow analysis was lower than the flood mark survey result by 2 m. Therefore, the simulated area was expanded to make the analytical model more accurate,as in the original model thewinding river courses at 500 m downstream and just upstream of the Pou Village as well asnarrow sections at just downstream of the Pou Village were not simulated, whereas at these locations bottleneck sections would be formed along the Nam Ngiep River. Figure 6 shows the location of river sectional surveys and Table 1 shows the comparative study results between the non-uniform flow analysis and the flood mark survey.

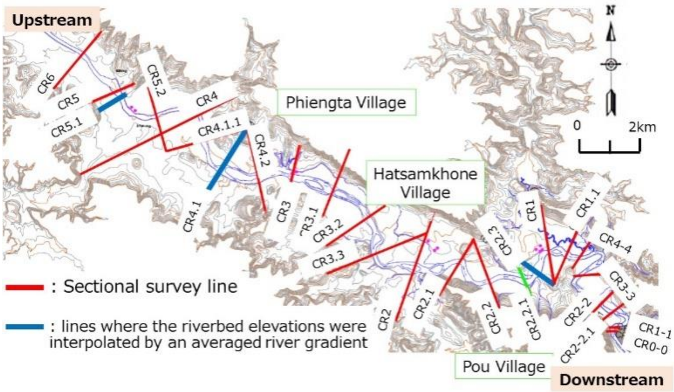

Figure6. Location of River Sectional Surveys
(8 sections were additionally surveyed in total from CR0-0 to CR1 because the river course was winding and narrow.)

Table 1. Comparative Study Results between Non-Uniform Flow Analysis and Flood Mark Survey

Village	Simulation	Survey	Difference
Pou	320.4	320.3	0.1
Hatsamkhone	321.9	321.7	0.2
Phiengta	324.5	324.7	-0.2

(Simulation results were quite close to the flood mark survey results with small differences of 0.2 m at the maximum. The simulation is considered to be sufficiently accurate.)

(2) Flood Inundation Simulation

A flood inundation simulation with and without reservoir was conducted based on sectional survey results. The software package “Non-Uniform Flow Analysis II”producedby Kawada Technosystem[5] was used for the non-uniform flow analysis. The simulation was conducted by standard sequential calculations based on the continuity equation and the equation of motion. EL. 320 m of the normal waterlevel was given at the lowest section as a boundary condition. Generally, the larger the scale of the flood is, the smaller the area of the backwater effect is; not just relative to the incremental water levels, but also in absolute figures. Therefore, not only 50-year probable flood but also 30-year and 2-year probable flood were used for the simulation to specify the area of the backwater effect. The flood amount in each return period at the zone 2UR was estimated based on the measurement data at NNP1. Figure 7 shows the result of flood inundation survey.

Incremental water levels by the backwater effect at Pou and Hatsamkhone Villages were estimated to be 2.9 m (EL. 320.4 m) and 1.7 m (EL. 320.8 m) in case of 2-year probable flood of 710 m^3/s; 1.2 m (EL. 321.6 m) and 0.7 m (EL. 322.6 m) in case of 30-year probable flood of 1,560 m^3/s; and 1.0 m (EL. 321.9 m) and 0.6 m (EL. 323.0 m) in case of 50-year probable flood of 1,750 m^3/s.

(3) Effect by Limitation of Reservoir Water Level

As described in Section 3 (2), the backwater effect will be caused by the reservoir impounding. A study to restrain the backwater effect by controlling the reservoir water level in the flood season was implemented. As a result of parametric study at 30-year probable flood, it was found that the backwater effect could be effectively restrained as shown in Figure 8 in the case that the reservoir water level was controlled below EL. 319.75 m.

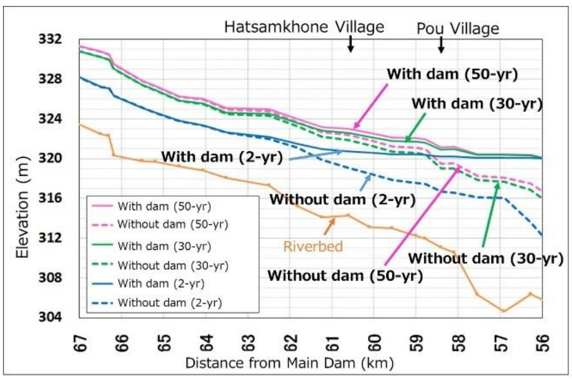

Figure 7.Result of Flood Inundation Survey
(It was indicated that the larger the scale of the flood is, the smaller the impact of backwater effect. It is because the flood is so large that backwater effect would be weakened.)

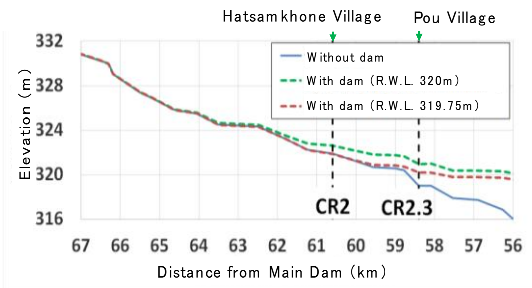

Figure 8.Restrain of Backwater Effect by Controlling Reservoir Water Level at 30-year probable Flood(the backwater effect was well restrained from 62.5 km to 59.0 km from the main dam thanks to the controlling reservoir water level.)

On the other hand, the control of the reservoir water level would cause loss ofpower due to reduction of effective head. Therefore, power loss due to the low reservoir water level was estimated. NNP1 is located in the tropical region, where inflow is extremely different between the rainy and dry seasons. We plan to apply a typical reservoir operation regimewherebythe reservoir water level is lowered down to the minimum operation level before the rainy season and subsequently recovers to the maximum water level by the inflow exceeding the planned discharge during the rainy season. Figure 9 shows the upper and lower rule curves reflecting the rules. The reservoir will be operated with the reservoir water level between the 2 curves. Due to the controlled water level set lower than the Full Tank Level, water level sometimes cannot reach the Full Tank Level as shown in the sampled green solid line in Figure 9, resulting in invalidate spillway discharge and head loss.

Trial and error calculation was performed using the monthly-averaged inflow data from 1984 to 2013 (30 years) to estimate the maximum power loss during that period. Table 2 shows the result of the estimation. The power loss was estimated to be 60 GWh for 30 years, whichwas not economically negligible. On the other hand, the exchange ratio of the reservoir, which is the ratio of annual cumulative inflow to the effective reservoir storage capacity, is sufficiently largeat around 4 times. In addition, since the possibility of flood occurrence is quite limited towardsthe end of the rainy season, therewould be a low possibility of requiredcompensationonan ad-hoc basis. Therefore it was decided that the controlled water level would not be set for the time being, and ad-hoc compensation would be applied for the backwater effect area when it happens. Even if the controlled water level is applied, the power loss should be reduced by further adjusting the current reservoir operation rules through the trial reservoir operation.

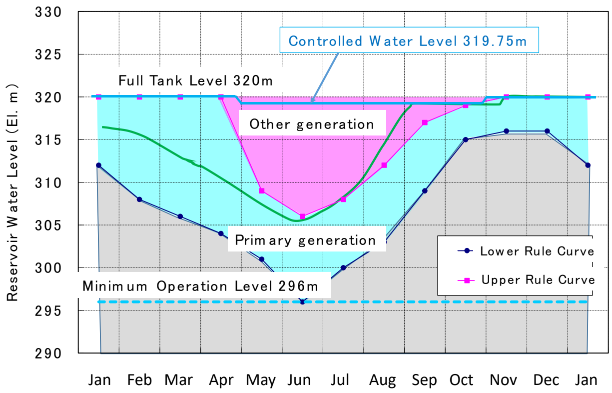

Figure 9. Reservoir Operation Rule Curve including Upper and Lower Rule Curves (with green solid line as a sample, indicating that spillage starts earlier than the water level reaches the Full Tank Level. Invalidate spillage and less effective head would cause the power

Table 2. Estimation of Power Loss

Case		Annual Power Generation (GWh)			
		Primary	Others	Total	Difference
A	F.T.L. 320m	34,431	5,798	40,229	-
B	Controlled W.L. EL. 319.75m	34,289	5,878	40,167	62

4. PRELIMINARY COMPENSATION AGAINST BACKWATER EFFECT

As described in Section 3 (3), permanent compensation was implemented at Pou and Hatsamkhone Villages. Eight households located below EL. 320 m at Pou Village were relocated to the higher elevation in the same village. Three households and their lands & properties located between EL. 320 m and EL. 321 m at Pou Village were elevated up to EL. 321 m by structural columns and embankments respectively ready for the backwater effect by 2-year probable flood. One household located between EL. 320 m and EL. 321 m at Haksamkhone Village was relocated to ahigher elevation in the same village. In cases of more than 2-year probable flood and up to 30-year probable flood, pre-warning system for evacuation of local residents and ad-hoc economical compensation will be undertaken for the inundation of local properties due to the backwater effect. Photo 4 shows a residence elevated by structural columns.

Photo 4. Residence elevated by Structural Columns
(Wooden structural columns are seen under the house. Private land was also elevated by embankment.)

5. LESSONS LEARNED FROM PROJECT

- Especially in developing countries like those in Southeast Asia, the availability of essential hydrological data,required to predict inundationsdue to floods and the backwater effect, tends to be limited. Looking to supplement the available data, NNP1 conducted surveys amongst PAPs toobtain information about previous inundations. As a result, the scale of a specificflood that had occurredin the past could be reproduced in a flood inundation simulation,that was augmentedin accuracy through calibration with flood mark information,which in turn was obtained from villagers livingin areas where the number of water level gauges wereinadequate.
- The newly formed reservoir has a significant impact on the lives of the PAPs and it was felt there wasa moral obligation to be transparent about this. It was found thatthe visualization of the future inundation area by using pegson site, and theprocess of obtaining supplemental information through consultation with the PAPs, noticeablycontributed to building trust with the PAP’s, resulting in a close and mutually beneficial relationship between the PAPsand the project owners. The PAPs ultimately benefitted from a fair, accurate and objective compensation and/or mitigation scheme. Inherently, a fair administration of the scheme isequally fundamental.
- Meanwhile the project owners benefitted from a transparent and methodical quantitative approach(also relying on information obtained from the PAPs) to find the most feasible balance between financial compensation for the backwater effect on the one hand, and the cost of power loss due to controlled reservoir water levels on the other hand. This transparency is also valuable because of the typical involvement in hydro-electric projects of NGO's, government(s), and financial institutions.
- Currently there does not appear to be a global standard for such a process however, considering (a) the social need for a fair, accurate and objective compensation and/or mitigation scheme, and (b) the demand for financial prudence and transparency it is hoped that this study will be introduced in future hydropower developments.
- Finally, it is advisableto continue to study the backwater effect because the riverbed elevation and morphology may change after reservoir impounding.

6. CONCLUSIONS

- Flood mark survey is undertaken through interviews with PAPs to draw an accurate inundation map by anticipated flood. And incorporating the survey results into an analytical model for flood inundation simulation, the accurate analytical model is finalized.
- Pegs are set out around the reservoir area to be inundated with PAPs. PAPs realistically recognize the future reservoir area and trust the accuracy of the pegs though certain claims are frequently raised by PAPs whenever surveys are conducted before.
- A flood inundation simulation with and without reservoir is conducted to specify the area of the backwater effect due to anticipated flood, and economic comparative study is conducted between loss of power due to controlled reservoir water level and expense for ad-hoc compensation.

7. REFERENCES

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