Effectiveness of Cascades Reservoir for Flood Control Operation and Electricity Production in Nam Ngum River

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Abstract. The paper presents the effectiveness of cascade reservoir for the flood control operation and electricity production. The hydropower plants are Nam Ngum 1 and 2 Hydropower Plants (NNG1 and NNG2 HPPs), which locates in central Laos. Both plants are not only electrical generation but also reduction the flood in downstream area, where it is mainly Vientiane, the capital of Laos. The NNG1 HPP was built in 1971 and the NNG2 HPP was built in 2010. The effectiveness for the flood control means that NNG2 HPP is included in the simulation before 2010. The study compares the reduction of flood period (flooding days) for the cases of with and without NNG2 HPP. The software used is HEC-ResSim3.1. Inflow data used is 34 years data between 1982-2016. The simulation results shown that the flooding days in the flood years are close to the actual recorded data. The flood days reduce, if NNG2 HPP is included into the simulation, for example in 1995 the flood days reduce from 23 days to 13 days. Direct benefit of water control is the increase of electricity production of NNG1 HPP. The simulation shows that, for the flood years between 1994 to 2011, the electricity production for the case of NNG1 HPP is increased 10.29% if NNG2 HPP is added into the simulation.

1. Introduction
Nam Ngum River is the main river in Laos, it starts in the mountain located in Xiengkhouang province, Lao northern region. The Nam Ngum River connects with Nam Lik River at the Vientiane province and connects to Mekong River in the Vientiane capital with approximately 354 km of length, covering 16,800 square km of drainage area as shown in figure 1, which is the Nam Ngum basin. The Nam Ngum River has potential the electricity production as well as certain years it occurred the flood in the downstream area. For avoiding the flood damage and get the benefit of the electricity production from this river. Therefore, in the year 1971 The NNG1 HPP was built and begun the electricity production. However, Nam Ngum River only could not avoid the flood in downstream area. NNG2 HPP project was started on October 2010, it is located the upstream of NNG1 HPP. The project was finished in 2011. This paper demonstrates the effectiveness of cascades reservoir for flood control operation and electricity production in the Nam Ngum River. The reservoir management of both hydropower plants difficulty operated because owner and power grid connection of both hydropower plants are different that load demand in the each period is different. Which is reasonable the reservoir management problem of these hydropower plants.
NNG 2 HPP is located in Vientiane province, central part of Laos, and about 90 km north from Vientiane Capital. Total installed capacity is 615 MW, annual electricity production is 2,310 GWh. Transmission line of NNG 2 HPP connected with the power grid at Oudone 2 substation in Oudonethany province, Thailand. This hydropower plant is operated and managed by Namngum 2 Power Company Limited, which will be following the load demand of EGAT, Thailand. [1]

NNG 1 HPP, located the downstream of NNG 2 HPP about 35 km across the reservoir. Total installed capacity is 155 MW, annual electricity production is 1,025 GWh. Transmission line of NNG 1 HPP connected with the power grid at Phontong substation in Vientiane capital. The NNG 1 HPP is operate and manage by EDL-Generation Public Company. The technical data shows in table 1 as below. [7]

| Description                  | Units | NNG 1 HPP | NNG 2 HPP |
|------------------------------|-------|-----------|-----------|
| Reservoir                    |       |           |           |
| Catchment Area               | km    | 8,460     | 5,640     |
| Average Annual Inflow        | MCM   | 382.00    | 6,305     |
| Maximum Flood Level          | masl  | 213.00    | 378.75    |
| Full Supply Level            | masl  | 212.30    | 375.00    |
| Reservoir Area at MFL        | km    | 370       | 107       |
| Storage at MFL               | MCM   | 7,030     | 4,886     |
| Dead Level                   | masl  | 196.00    | 345.00    |
| Storage at MOL               | MCM   | 2,330.00  | 2,269.00  |

**Literature review.** In recent years, many researchers have presented the methods and principle for flood control operation and electricity production. The short-term operation of flood management was studied by U Gokcen [2], the purpose of the study is to maximize of water supply, and flood mitigation at the downstream. Software used is HEC-ResSim and RTC-Tools package of Deltares for simulating the reservoir operation, which base on water balance equation and dynamic system for the approach optimization. M. Hosseini [3] had been study the multi-objective optimization model for the flood control operation. The objectives are to select the control point for reducing the flood damage at downstream and to maximize electricity production. The theory in this paper is the multiobjective particle swarm optimization algorithm. The study used the VENSIM software to simulate the reservoir operation for the flood control, which base on dynamic programming. The flood mitigation operation of
multi-reservoir was researched by O. Prakah [4]. The objectives are to minimize the sum of water flow at a control point, to flood mitigation at the control point and to maximize the electricity production. The theory used is non-dominated sorting genetic algorithm-II (NSGA-II). A. Jung Min [5] had been study the evaluation of dam and weirs operation for water resource management, which considered the water supply capacity, electricity production and flood damage at downstream. Software used is the Streamflow Synthesis and Reservoir Regulation (SSARR) model to estimate the natural flow and HEC-ResSim for simulating the reservoir operation.

2. Reservoir Operational Management

The HEC-ResSim software was used in this study, which is developed by US Army Corps of Engineers. The software is used for the reservoir simulation. The main equation in the software is water balance equation, which important to operate the flood control and electricity production. The changing of storage volume depends on the inflow and the outflow, which are the variables in the equation. Fig 2 shows the schematic representation of the NNG1 and NNG2 reservoirs. [2][5]

![Figure 2. Schematic representations of NNG 1 and 2 HPPs](image)

From the schematic, we can be written the equations for of NNG2 reservoir as the following:

In that $V_{2,t+1} = V_{2,t} + (I_{2,t} - Q_{2,\text{outflow},t})$ \hspace{1cm} (1)

$Q_{2,\text{outflow},t} = Q_{2,t} + S_{2,t} + E_{2,t} + B_{2,t}$ \hspace{1cm} (2)

The outflow of NNG2 HPP is main inflow to NNG1 HPP. Therefore, water balance equation can be written as.

In that $V_{1,t+1} = V_{1,t} + (I_{1,t} - Q_{1,\text{outflow},t})$ \hspace{1cm} (3)

$Q_{1,\text{outflow},t} = Q_{1,t} + S_{1,t} + E_{1,t}$ \hspace{1cm} (4)

$I_{1,t} = L_{t} + Q_{2,\text{outflow},t}$ \hspace{1cm} (5)

Where $V_{i,t}$ is the storage volume of reservoir $i$ in $t$ period, $i=1$ for NNG1 HPP and $i=2$ for NNG2 HPP; $I_{i,t}$ is the water inflow of reservoir $i$ in $t$ period; $L_{i,t}$ is the local water inflow of reservoir $i$ in $t$ period; $Q_{i,t}$ is the water released of reservoir $i$ in $t$ period; $S_{i,t}$ is the spillway discharge of HPP of reservoir $i$ in $t$ period; $E_{i,t}$ is the evaporation of reservoir $i$ in $t$ period, and $B_{i,t}$ is the button outlet of reservoir $i$ in $t$ period.

Water release passes turbine converts the mechanical energy to electrical energy as below: [6][7]

$$P_{t,t} = \rho \eta g H_{t} Q_{t,t}$$ \hspace{1cm} (6)

$$E = max \sum_{t=1}^{N} \sum_{j=1}^{N} P_{t,t} \Delta_{t}, \hspace{0.5cm} n = T \hspace{0.5cm} \Delta_{t}.$$ \hspace{1cm} (7)
Where \( P_{i,t} \) is the Power of generator unit \( i \) in \( t \) period; \( E \) is the total electricity production; \( H_t \) is the gross head in \( t \) period; \( g \) is the gravitational acceleration \( (m/s^2) \) and \( \rho \) is the water density \( (~ 1000 \text{ kg/m}^3) \).

1. Reservoir level constraint
   \[ Z_{t,\text{min}} \leq Z_t \leq Z_{t,\text{max}} \]  

2. Gross head constraint
   \[ H_{t,\text{min}} \leq H_t \leq H_{t,\text{max}} \]  

3. Power generation constraint
   \[ P_{t,\text{min}} \leq P_t \leq P_{t,\text{max}} \]  

4. Turbine discharge constraint
   \[ Q_{t,\text{min}} \leq Q_t \leq Q_{t,\text{max}} \]  

### 2.1. Calibration equation of software simulation result

The calibration equation is to compare the simulation results and the actual recorded data for reliability of the software, which follows the each equation as below. \([6][7]\)

a) Root mean square error (RMSE)

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{\text{obs},i} - X_{\text{model},i})^2}{n}}
\]  

Where \( X_{\text{obs}} \) is the actual recorded data \( i \); \( X_{\text{model}} \) is the simulation results data \( i \) and \( n \) is the data number.

b) Pearson correlation coefficient \( (r) \)

\[
r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}}
\]  

Where \( x_i, y_i \) are the actual recorded data \( i \) and the simulation results data \( i \), respectively. \( \bar{x}, \bar{y} \) are the average values of actual recorded data and simulation results data.

c) Efficiency index \( (EI) \)

\[
EI = 1 - \frac{\sum_{i=1}^{n}(X_{\text{obs},i} - X_{\text{model},i})^2}{\sum_{i=1}^{n}(X_{\text{obs},i} - \bar{X}_{\text{obs}})^2}
\]  

Where \( X_{\text{obs}} \) is the actual recorded data \( i \); \( X_{\text{model}} \) is the simulation results data \( i \) and \( \bar{X}_{\text{obs}} \) is the average values of actual recorded data.

### 3. Methodology

The simulation framework for the effectiveness of cascades reservoir is shown in Fig 3. The model in HECResSim software was configured the conservation rule as same the conventional operation. Then the calibration equations was used for the reliability of the model. How procedure the model as below.

**Step 1:** Inputted the physical data of hydro plant and water inflow to the software.

**Step 2:** Initialize the reservoir level.

**Step 3:** Configured the operation set such as conservation operation.

**Step 4:** Used the equation (15), (16), and (17) for checking the percentage error between the actual data and simulation results, if the value is not unacceptance, it returns to step 3.
4. Methodology

Inflow data collection of NNG2 HPP is 34 years between 1982-2016. The flood year was selected for the study cases, which are 1994, 1995, 2002, 2005, 2008 and 2011. [1]

![Flowchart of simulation model](image)

**Figure 3.** Flowchart of simulation model

![Inflow data of NNG2 HPP](image)

**Figure 4.** Inflow data of NNG2 HPP

The NNG1 HPP have been operated the power generation between1971 to present. Which counted for 45 years, as well as the data can be collected and summarized such as, water inflow, outflow, elevation level, and electricity production.
5. Methodology
The effectiveness of cascades reservoir was considered two cases studies which are case of with and without NNG2 HPP. However, NNG2 HPP is added into simulation. The simulation results for the case of without NNG2 HPP are shown the flooding days and cumulative flow at flood control point, which are close to the actual recorded data as show in table 2. The electricity production of certain year is not close to the actual recorded data because the NNG1 HPP in simulation model use the latest power installed capacity, which is 155 MW as show in table 6.

### Table 2. Flood days and cumulative flow at flood control point for the case without NNG2 HPP

| Year | Volume MCM | Flood Period Day | Volume MCM | Flood Period Day |
|------|------------|-----------------|------------|-----------------|
| 1994 | 16,724.48  | 3               | 16,724.43  | 1               |
| 1995 | 20,973.98  | 23              | 20,693.95  | 24              |
| 2002 | 15,696.62  | 2               | 15,738.83  | 0               |
| 2005 | 17,776.27  | 3               | 17,819.99  | 3               |
| 2008 | 17,661.17  | 8               | 17,602.41  | 7               |

For the calibration is used EI, r² and RMSE. Which input the elevation reservoir and electricity production of NNG1 HPP. The results show that, the calibration is acceptable ranges and the value is in the limit of calibration equation, the calibration result is summarized in the table 3 and the Fig 6 shown the comparison of model and actual of the year 1994.

### Table 3. Calibration result of NNG1 HPP

| Year | RMSE | r²  | EI   | RMSE | r²  | EI   |
|------|------|-----|------|------|-----|------|
| 1994 | 0.01 | 1.00| 1.00 | 0.03 | 0.80| 0.58 |
| 1995 | 0.01 | 1.00| 1.00 | 0.03 | 0.80| 0.36 |
| 2002 | 0.02 | 1.00| 0.99 | 0.02 | 0.86| 0.59 |
| 2005 | 0.03 | 1.00| 0.99 | 0.03 | 0.78| 0.58 |
| 2008 | 0.02 | 0.99| 0.99 | 0.03 | 0.85| 0.63 |
The simulation result for the case of with NNG2 HPP demonstrate the flooding days, which is decreased as compared to the case of without NNG2 HPP. Due to the cumulative flow at flood control point was reduced. Because the NNG2 HPP can be saved the max flow which flow to the NNG1 HPP in wet season on July to October as shown in table 4. For the electricity production of the NNG1 HPP is increase as compared to the case of without NNG2 HPP because the inflow is increased between from January to May as shown in table 7 and 8.

**Table 4. Flood days and cumulative flow at flood control point for the case of with NNG2 HPP**

| Year | Simulation Volume MCM | Flood Period Day | Actual Volume MCM | Flood Period Day |
|------|-----------------------|------------------|-------------------|------------------|
| 1994 | 14,928.59             | 0                | 16,724.43         | 1                |
| 1995 | 19,598.49             | 13               | 20,693.95         | 24               |
| 2002 | 15,236.37             | 0                | 15,738.83         | 0                |
| 2005 | 16,746.58             | 0                | 17,819.99         | 3                |
| 2008 | 16,646.10             | 2                | 17,602.41         | 7                |
| 2011 | 18,374.69             | 8                | 18,672.75         | 7                |
### Table 5. Comparison of flooding days and cumulative flow for the case of both case study

| Year | Case of with NNG2 HPP | Case of without NNG2 HPP |
|------|-----------------------|--------------------------|
|      | Volume MCM | Flood Period Day | Volume MCM | Flood Period Day |
| 1994 | 14,928.59 | 0 | 16,724.48 | 3 |
| 1995 | 19,598.49 | 13 | 20,973.98 | 23 |
| 2002 | 15,236.37 | 0 | 15,696.62 | 2 |
| 2005 | 16,746.58 | 0 | 17,776.27 | 3 |
| 2008 | 16,646.10 | 2 | 17,661.17 | 8 |

**Figure 8.** NNG2 HPP switching curve for the case of with NNG2 HPP

**Figure 9.** NNG 1 HPP switching curve for the case of with NNG2 HPP
Figure 10. Comparison of NNG1 HPP switching curve of 1994 year

Table 6. NNG1 HPP simulation results for the case of without NNG2 HPP.

| Year | Inflow  | Energy | Outflow |
|------|---------|--------|---------|
|      | MCM     | Simulation | Actual | Diff | Percentage Diff | Turbine | Spillway |
|      |         | MCM | GWh | GWh | GWh | % | MCM | MCM |
| 1994 | 12,531.10 | 1,057.90 | 1,032.47 | 25.43 | 2.46% | 10,114.50 | 2,213.50 |
| 1995 | 11,148.47 | 1,032.40 | 965.70 | 66.70 | 6.91% | 10,088.28 | 1,312.28 |
| 2002 | 13,890.42 | 1,208.46 | 1,153.05 | 55.41 | 4.81% | 11,866.75 | 2,110.75 |
| 2005 | 14,356.66 | 1,174.09 | 1,127.28 | 46.80 | 4.15% | 11,814.85 | 2,688.85 |
| 2008 | 14,249.94 | 1,153.79 | 1,145.78 | 8.01 | 0.70% | 11,143.69 | 2,620.45 |

Table 7. NNG 1 HPP simulation results for the case of with NNG2 HPP.

| Year | Inflow  | Energy | Outflow |
|------|---------|--------|---------|
|      | MCM     | Simulation | Actual | Diff | Percentage Diff | Turbine | Spillway |
|      |         | MCM | GWh | GWh | GWh | % | MCM | MCM |
| 1994 | 12,522.05 | 1,220.32 | 1,032.47 | 187.85 | 18.19% | 12,148.35 | 304.39 |
| 1995 | 11,513.66 | 1,152.10 | 965.70 | 186.39 | 19.30% | 11,781.02 | - |
| 2002 | 14,062.93 | 1,277.47 | 1,153.05 | 124.42 | 10.79% | 12,523.39 | 1,523.38 |
| 2005 | 15,406.30 | 1,309.74 | 1,127.28 | 182.46 | 16.19% | 13,392.69 | 1,722.06 |
| 2008 | 15,360.07 | 1,324.71 | 1,145.78 | 178.94 | 15.62% | 13,307.90 | 1,568.86 |
| 2011 | 14,984.84 | 1,165.91 | 1,160.66 | 5.25 | 0.45% | 11,536.88 | 2,559.43 |

Table 8. NNG 2 HPP simulation results for the case of with NNG2 HPP.

| Year | Inflow  | Energy | Turbine | Outflow |
|------|---------|--------|---------|---------|
|      | MCM     | GWh | MCM | MCM |
| 1994 | 8,626.33 | 3,093.55 | 7,877.11 | 606.42 |
| 1995 | 7,616.37 | 2,871.57 | 7,535.57 | - |
| 2002 | 7,794.52 | 2,961.47 | 7,578.03 | 76.11 |
| 2005 | 8,410.63 | 3,109.35 | 7,978.70 | 297.61 |
| 2008 | 8,350.06 | 3,102.59 | 7,693.32 | 252.62 |
| 2011 | 8,782.23 | 3,025.37 | 7,512.04 | 1,108.51 |
6. Conclusion
The study used HEC-ResSim3.1 to simulate effectiveness of cascades reservoir for flood control operation and electricity production in the Nam Ngum River. The hydropower plants are Nam Ngum 1 and 2 Hydropower Plants, which are located in Vientiane province, Laos central region. Inflow data used is selected the flood year during 34 years between 1982-2016. The effectiveness of cascades reservoir in Nam Ngum River have efficient for operating the flood control and the electricity production. The results shown the reducing flood days, if NNG2 HPP is incorporated into the simulation, for example in 1995 the flood days reduce from 23 days to 13 days. Direct benefit of water control is the increase of electricity production of NNG1 HPP. The simulation shows that, for the flood years between 1994 to 2011, the electricity production for the case of NNG1 HPP is increased 10.29% if NNG2 HPP is added into the simulation.

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References
[1] TEAM Consulting Engineering and Management Co., Ltd. Rule Curves and Reservoir Simulation Studies for Namngum 2 Hydroelectric Power Project Lao PDR, Bangkok, Thailand, April 2009.
[2] U. Gokcen, A. Bulut, M. Irem Topcu, S. Aynur, and S. Dirk. Comparison of Different Reservoir Models for Short Term Operation of Flood Management, Journal, Procedia Engineering, Vol. 154, No. 1, 2016, pp. 1385-1392.
[3] M. Hosseini, S. Jamshid, A. Ardeshir, and K. Behzadian. Flood Control Operation of a Multi-Reservoir System Using System Dynamic-based Immolation-Optimization Model, Proceedings, International Conference on Flood Resilience, University of Exeter, United Kingdom, September 2011.
[4] P. Om, K. Srinivsan, and K.P. Sudheer. Simulation-Optimization Framework for the Optimal Flood Mitigation Operation of MultiReservoir System, Journal, Civil Engineering and Architecture Research, Vol. 1, No. 5, November 2014, pp. 300-311.
[5] A. Jung Min, L. Sangjin, and K. Taeuk. Evaluation of Dam and Weirs Operating for Water Resource Management of the Geum River, Journal, Science of the Total Environment, Vol. 478, No. 1, February 2014, pp. 103-115.
[6] N. Bangsulin, A. Promwungkwa, and K. Ngamsanroaj. MultiReservoir Operational Management for Optimal Electricity Production of Nam Khan 2 and 3 Hydropower Plants, Proceedings, ASAR International Conference, Bhubaneswar, India, 3 December, 2016, ISBN: 978-93-86291-40-0.
[7] D. Sounanthalath, A. Promwungkwa, K. Ngamsanroaj. HECReSim Model Calibration for Nam Ngum 1 Hydropower Plant, Proceedings, Burapha University International Conference, Bruapha, Thailand, 4-6 July, 2013.