DAM BREAK MODELLING OF PHOUPHONG DAM, LAO PDR AND FLOOD INUNDATION MAPPING OF POST DAM BREAK SCENARIO

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ABSTRACT

In recent years, the problem of dam break has perhaps received enormous attention by the developers, stake holders, and associated authorities; it is also evident from the past records of Lao PDR that flood has become an event causing devastation of life and property (Ref. Department of Water Resources, Ministry of Natural Resources and Environment, Lao PDR). The consequences of an unalarmed flood hit are often detrimental delivering havoc in such situations, which becomes potential hazard to virtually everything downstream. A dam break event could be as devastating as any other natural flood hazard that propagates downstream depending upon the impounded volume of flow. The two major reasons of dam break are overflow and piping failure. In both the cases, the breach is developed either instantaneously or at intervals. The modelling of dam breaching due to either or both of these causes is of fundamental importance to development of dam-safety programs.

Phouphong Dam is an integral structure of the Namphak Hydropower Project (Namphak HPP), located at the south-western corner of Bolaven Plateau; approximately 10 Km south west of Paksong in the southern region of Lao PDR. The project is planned to collect the runoff from a number of streams on the plateau that flow generally north-west and south-west and convey this via two diversions to the Phouphong reservoir. The project is a run-of-river scheme with generating facility sited on the banks of Houay (River) Namphak at the base of the plateau escarpment and has a total installed capacity of 150MW. A one-dimensional hydraulic/numerical model study of Phouphong River with Phouphong Dam as inline structure has been carried out with a dam break event of Phouphong Dam to analyze the consequence of the said event from the derived flood attenuation chart, thereby presenting the inundation or incision caused due to the event in the form of flood inundation map.

Keywords: *Dam break, HPP, one-dimensional, attenuation, inundation, mapping, houay, reservoir.*

1. INTRODUCTION

Dams are planned and constructed to gain multiple advantages of power generation, water supply, irrigation network, and many others. While listing out the advantages, the impact of damage is often least considered to verify that even if the dam has been designed efficiently for a design flood and structurally, the dam is sound, the dam breaks may or may not have lead to catastrophes. The impact is, in general, left out to be a part of the environmental study in some countries. Unpredicted natural hazards have been observed as major causes of dam breaks. The flood wave propagating downstream due to dam break often leads to a catastrophe as the flood inundates brutally causing heavy damages to lives and properties before it dissipates. Therefore, the influence zones need utmost attention. If a natural structure or a man-made structure or a dam impounding a gigantic pool of water breaks, the flood wave may have the potential to submerge and destroy power plants, dwellings, and bridges; may disrupt irrigation, navigation, transportation, and socio-economic activities, which are located downstream; may damage the natural river morphology, spoiling of agricultural land, and may result in adverse ecological and environmental impact.

The Namphak Hydropower Project (Namphak HPP) is located at the south-western corner of Bolaven Plateau, approximately 10 Km south west of Paksong in the southern region of Lao PDR, and takes advantage of a 700m difference in elevation between the plateau and the plains to the south. The project collects the runoff from a number of streams on the plateau that flow generally north-west and south-west and convey this via two diversions to the Phouphong Reservoir. The project is a run-of-river scheme with generating facility sited on the banks of Namphak River at the base of the plateau escarpment and has a total installed capacity of 150MW. On the immediate downstream of the Phouphong Dam, the Phouphong River joins the Bangliang River; Phouphong River is a tributary of Bangliang River. A dam-break scenario of Phouphong Dam has been modeled to analyze the consequence of the said event on the downstream of the dam covering both the Phouphong River and the post confluence Bangliang River by using 1-dimensional numerical model, HEC-RAS. From the inferences of the model results; the flood inundation map of the post dam break event has been displayed to highlight the potential flood extent.

1.1 Salient Features

The ray diagram of the rivers under study has been displayed below:

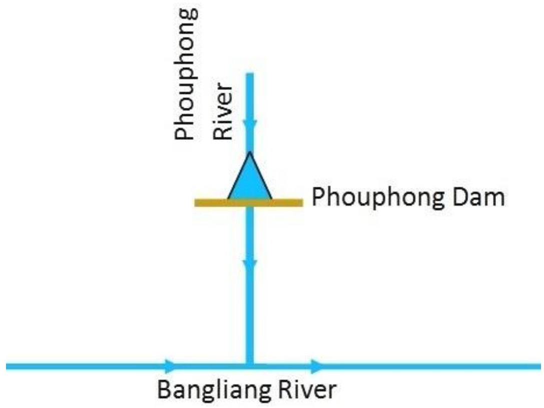

Figure 1. Ray diagram showing Phouphong River and Bangliang River

The salient features of the project have been summarized in the following tables:

Table 1. Features of Phouphong Dam

Particulars	Name/Coordinates
Country	Lao PDR
Stream	Phouphong/Katan
Latitude	15° 08' 30"
Longitude	106° 06' 10"

Table 2. Phouphong Dam Characteristics

Particulars	Values/Type	Unit
Dam Type	Rockfill	--
Crest Elevation	914.5	m a.s.l.
Stream Bed (Thalweg) Level	863	m a.s.l.
Embankment width at crest	6	m
Embankment length at crest	230.668	m
Upstream slope	2:1	[H:V]
Downstream slope	2:1	[H:V]

Table 3. Phouphong Reservoir Characteristics

Particulars	Values	Unit
Full Supply Level/FSL	909	m a.s.l.
Minimum Drawdown Level/MDL	905	m a.s.l.
Maximum Water Level (PMF Level)	912.5	m a.s.l.
Total Storage Volume	22.66	MCM
Live Storage Volume	12.36	MCM
Dead Storage Volume	10.30	MCM

2. MODELLING THEORY AND MODEL DESCRIPTION

The physical laws which govern the flow of water in a stream are expressed mathematically in the form of partial differential equations:

Conservation of mass (continuity) equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_1 = 0 \quad (1)$$

Conservation of momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \quad (2)$$

where:

Q = discharge,
A = total flow area,
q_1 = lateral inflow per unit length,
x = distance along waterway,
t = time,
V = velocity,
g = acceleration due to gravity,
z = water surface elevation, and
S_f = frictional slope.

These differential equations also describe the transport of sediment, salinity and other constituents. The software, HEC-RAS is designed to perform one-dimensional hydraulic computations numerically for a full network of natural and constructed channels. The HEC-RAS model comprises two major components; steady flow and unsteady flow. The software, HEC-RAS is designed to perform one-dimensional hydraulic computations for a full network of natural and constructed channels. HEC-RAS software can model inline structures, such as dams, weirs, spillways, and structures with sluice gates, radial gates, and overflow gates. The HEC-RAS model comprises two major components; steady flow and unsteady flow. In the present study, the steady and unsteady flow component of HEC-RAS has been used to model the dam break. The steady component has been used to calibrate the model, whereas the unsteady fully hydrodynamic model has been used to model the dam break scenario. The flowchart describing the dam break modelling mechanism has been presented below:

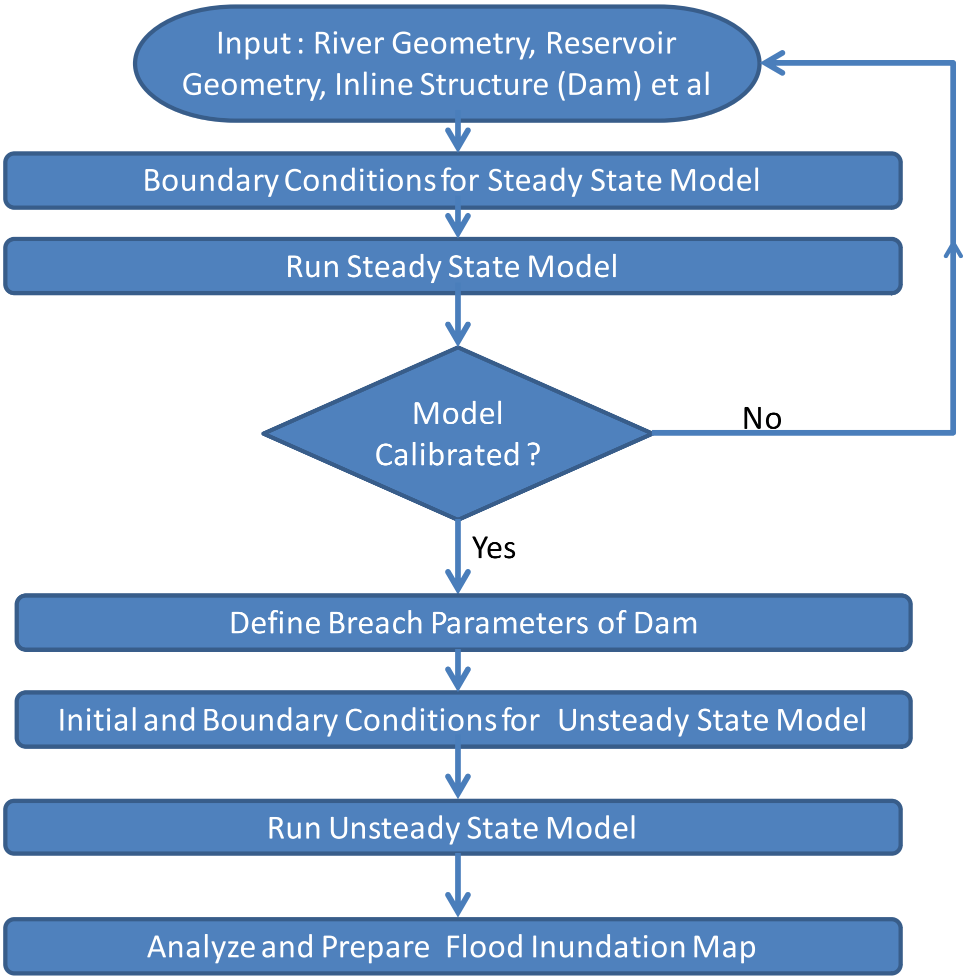

Figure 2. Flowchart of dam break modelling with particular reference to the present study

4. DATA ORGANIZATION

The river geometry data and the input data for model set up have been organized as indicated below:

4.1 River Geometry

The river cross-sections data to define the geometry of the river have been listed in the table below:

Table 4. Cross-sections of Phouphong River

Chainage of River Cross-sections (m)	River	Remarks
0.00	Phouphong	Phouphong Dam at Ch 0.00
0.00 to 4250.00	Phouphong	Cross-sections interval 250m to 500m. Confluence of Phouphong River and Bangliang River at Ch 4250.00
4250.00 to 46391.00	Bangliang	Cross-sections interval 250m to 500m. Confluence of Phouphong River and Bangliang River at Ch 4250.00

4.3 Storage-Area Curve of Reservoir and PMF Hydrohraphs.

The capacity area data and the PMF hydrographs have been displayed below:

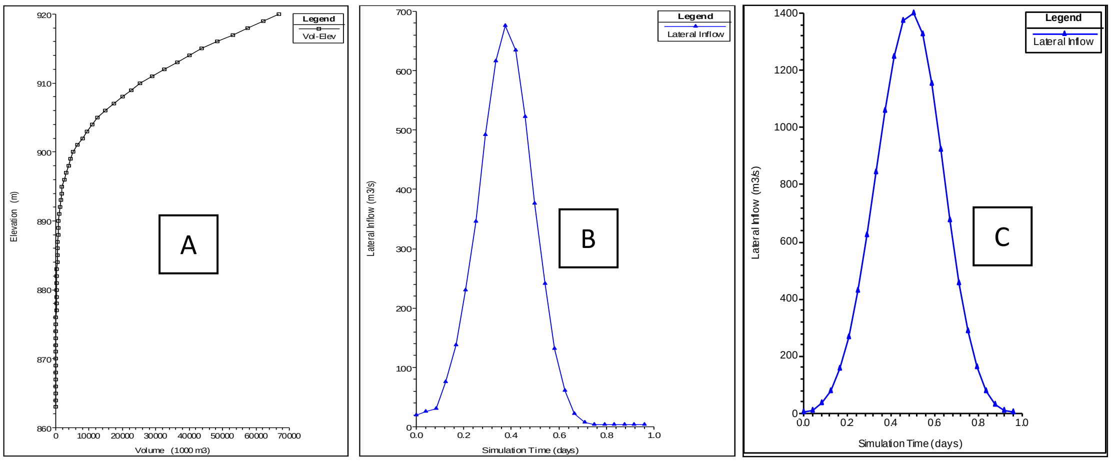

Figure 3. Input Data for model set up: Plot with Box A - Storage area curve of Phouphong Reservoir, Plot with Box B and C - PMF hydrographs at Phouphong Dam Site and at confluence with Bangliang River on the downstream, respectively.

5. MODEL SET UP

The following sub-sections describe the setting up of the model.

5.1 Convention Adopted

The adopted convention to create a dam break scenario is to make the model simpler to represent the river networks.

Following assumptions have been made:

1) Dam break scenarios at the dam are hypothesized at PMF event as well as at stage flowing over dam conditions.
2) The river network has been established to represent the entire reaches of the river as Phouphong River and Bangliang River.
3) The confluence network is replaced by introducing additional boundary condition applied at the cross section just at the confluence to represent the flow of Bangliang River to the defined reach of the river and also the flow of Phouphong River to the defined reach of the river.
4) As the catchment characteristics of Phouphong River and Bangliang River are similar, it is assumed that the occurrence of PMFs at the confluence (being in the proximity of the Phouphong Dam) and at the Phouphong Dam would be simultaneous.
5) Failure of dam is due to overtopping.
6) Time series data chosen for hydrographs starts from 1 June 2014 1200hours to 2 June 2014 1100hours, which is merely relative of flood event and universally applied for the simulation.

5.2 Calibration

The Manning's roughness coefficient for different reaches of Phouphong River has been initially set as n = 0.04 considering the river beds with boulders and rocks of hilly terrain, and vegetations on the overbanks. (Ref. Open Channel Hydraulics, V.T.Chow). However, a steady state model has been tested applying the same value of (n) to check the model response against the known water surface elevation values for given discharges on downstream near the confluence of Bangliang River and Phouphong River. The model is observed to be approximate, thereby validating the considered roughness value. Hence, the n=0.04 has been applied in the dam break model.

5.3 Initial and Boundary Conditions

The project elements which constitute to set up the Phouphong dam break model are initial conditions, boundary conditions and breach parameters. Model is developed for PMF event and termed as Model1. The event and the conditions have been tabulated below:

Table 3. Initial and boundary conditions for Phouphong dam break and flood scenario

Model No.	Flood routing event description	Initial condition		Flow (m^3/sec)	Boundary condition	
		Stage Elevation Upstream (m)	Reservoir Min Elevation (m)		Upstream End	Downstream End
Model 1	Dam break at PMF or at Overtopping Stage	909	909	676	PMF hydrographs, Elevation-Storage Curve	Normal depth

5.4 Critical Condition for Phouphong Dam Break

The critical condition for a dam break study is when the reservoir is at FRL and design flood hydrograph (PMF) is impinged. Accordingly, in the present study first the reservoir routing has been carried out by impinging the PMF into the reservoir, assuming that the water level in the reservoir is at FRL of 909 m. However, the maximum water level in the reservoir routing does not reach the top level EL 914.5 of the dam. It may be concluded that even the initial level of Phouphong Reservoir is at FRL, the reservoir being higher in capacity, the rise in flood level does not let dam to be overtopped. Therefore, impinging a PMF hydrograph at a level higher than FRL has been selected based on optimization and the dam breach has been initiated when the dam is overtopped.

Model 1 is simulated with this critical condition. These results are discussed in the later section of the report.

5.5 Breach Parameters for Phouphong Dam Break

The breach plan data has been specified at dam location attached to the cross section just downstream of the reservoir. The Phouphong dam is represented in HEC-RAS as inline weir structure of rockfill embankment type with 2:1 embankment slopes. With an advent of the aforesaid, the breach parameters are defined with assumptions. The inline structure of Phouphong represented in HEC RAS below:

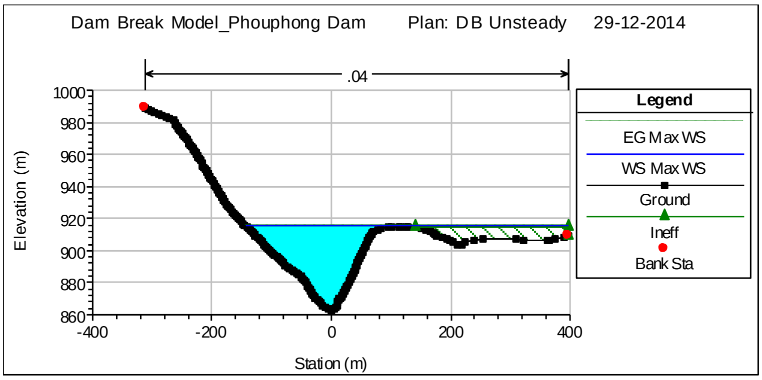

Figure 4. Phouphong Dam Representation in HEC-RAS

As per the U.S. Bureau of Reclamation (1988), for earthfill dams, the ultimate width of a rectangular dam breach shape equals three times the initial water depth in the reservoir measured to the breach bottom elevation assumed to be at the stream bed elevation. This relationship has been used as a guideline in the National Weather Service Simplified Dam Break Model (SMDBRK).

$$B_{avg} = 3H_d$$

where,
B_{avg} is the ultimate average breach width and H_d is the water depth in the reservoir initiating the failure.

As per the UK Dam Break Guidelines and U.S. Federal Energy Regulatory Commission (FERC) Guidelines, in the case of earthfill/rockfill dams, breach development time should be taken about 0.2-0.5 hour.

On the basis of above guidelines, the breach parameters are defined with following rational assumptions:

i) the breach side slope of Phouphong Dam is zero
ii) the breach development time is 0.2 hour for instantaneous failure.

To model the realistic nature of breach, two cases of breach width and height are analysed for the models, Model 1(Case1) and Model 1(Case2). The input breaching parameters for these models have been tabulated below:

Table 4. Breach parameters of Phouphong dam for different cases

Case No	Breach level (m)		Breach width (m)		Breach slope	Breaching time (hr)	Remarks
	Initial	Final	Initial	Final			
Case 1	914.5	897.3	120	120	0	0.2	Breach to start from EL 914.5 in the proximity of left overbank down to EL 897.3
Case 2	914.5	863	154.5	154.5	0	0.2	Breach to start from EL 914.5 in the proximity of left overbank down to EL 863

6. RESULTS AND DISCUSSION

A comparative analysis of the models developed and the flood wave propagation downstream of Phouphong River and Bangliang River has been made. The results have been displayed below:

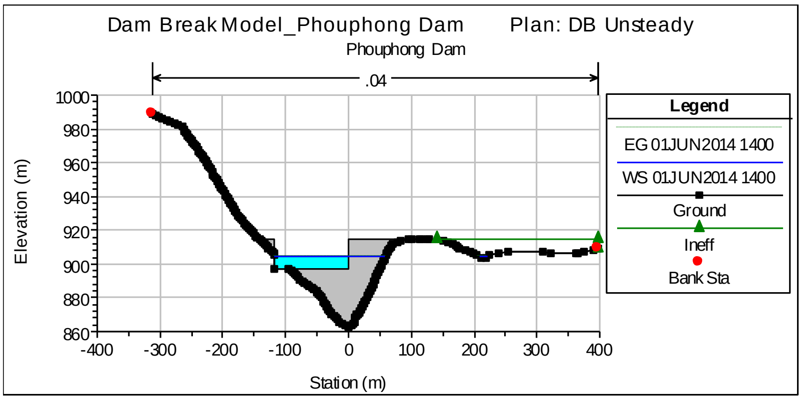

Figure 5. Partial Breach of Dam (Case 1)

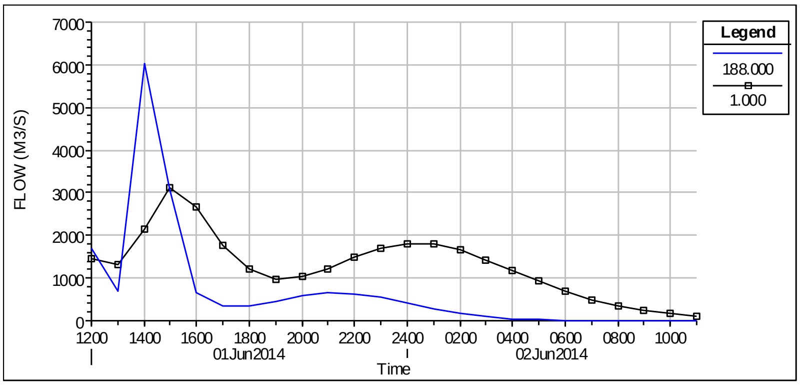

Figure 6. Results of hydrodymanic flood routing with dam break event (Case 1)

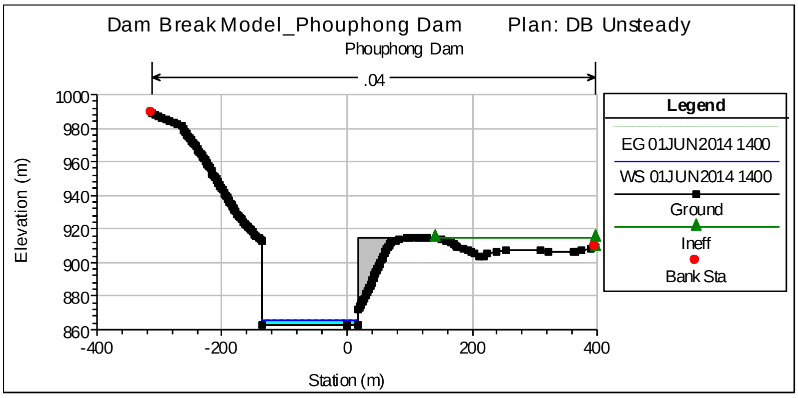

Figure 7. Full Breach of Dam (Case 2)

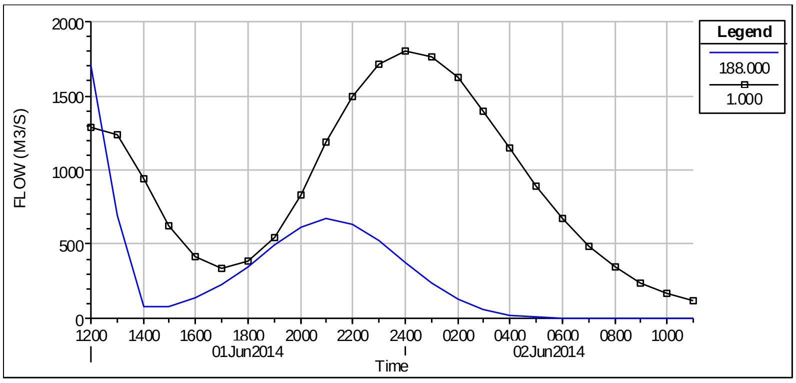

Figure 8. Results of hydrodymanic flood routing with dam break event (Case 2)

As displayed above, the plan numbers are merely names, whereas the simulation time series in graphs are user defined times for a particular event. The inflow hydrograph above is represented by 188.000, whereas the outflow hydrograph has been named as 1.000 in the above plot.

The inflows and outflow curves as shown in the above figures indicate that the magnitudes of the peaks are not varying high comparatively. The simulation resulted above infers that during a dam break scenario the storage behind the dam quickly reduces, thereby having less impact on the normal flow at the downstream end. However, due to intermediate flow boundary conditions, the attenuation in terms of flood peak rise from upstream to downstream have resulted. The dam break analysis of Phouphong starts by describing the model developed for Phouphong dam break due to overtopping. The model results show that the attenuation difference between Case 1 and Case 2 hardly accounts for any major remarks that may reflect the adverse impact of flood wave propagation due to the above applied conditions. The flood inundation map has been prepared by considering the maximum water surface level extent in each cross-section. The same has been displayed below:

Figure 9. Flood inundation map

The inundated flood extent on the contour plan indicates the maximum water surface level that is encountered downstream due to dam break. The downstream reach after the confluence of both the rivers are not significant to create havoc due to Phouphong dam break unless encroachments towards inundated plan are prohibited.

6. CONCLUSIONS

1) The dam break analysis predicts the flood inundation plan, which is vital in resource management and catastrophe management.
2) Based on the flood inundation map prepared for Phouphong River, a flood warning system shall be a necessity as a key source for avoiding loss of human lives, for residents living in the proximity.
3) It would be advisable that a policy to discourage the inhabitation encroachment towards Phouphong River and Bangliang River be endorsed that may also be cost effective for mitigation measures against post dam break flood on the downstream reaches of the project.
4) The modeled breach levels and progressions considered in the model are hypothetical and based on various sources as indicated in the respective se ctions. Therefore, the study is limited to said hypothesis. A deep prognosis of breach progression, however, encourages further research on the topic.

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REFERENCES

Bureau of Indian Standards, IS 14815 (2000) Design flood for river diversion works – Guidelines
LII-KGP (2014). Project hydrology report, Namphak HPP
Abbott, M. B, Pitman Publishing Ltd., London, (1979) Computational hydraulics: Elements of the theory of free surface flows
Chow, V. T. (1959) Open channel hydraulics. McGraw-Hill. New York
U.S. Army Corps of Engineers HEC-RAS (2008) River analysis system hydraulic reference manual. Institute for water resources, Hydrologic engineering center
Zagonjolli, M. and Mynett, A.E.(2006) Dam breaching uncertainty and its effect in downstream areas. Proceedings of the 7th International Conference on Hydro Science and Engineering