DAM BREACH ANALYSIS: CASE STUDY OF PHUKOT KARNALI (480 MW) HYDROELECTRIC PROJECT IN NEPAL

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ABSTRACT

The design and construction of dams in Nepal is getting pace and consequently the challenges are coming to the surface. Dam breach is one of the major challenges that may create a huge disaster due to instantaneous outbreak of high discharge from the reservoir. Thus, design of dam should assure the safety of life and properties at the downstream valleys where population density is increasing due to inland migration. This paper presents the dam breach analysis of dam for Phukot Karnali Hydroelectirc Project (PKHEP) in western Nepal. The dam height and reservoir volume are 107 m and 70.78 Mm^3 respectively. HEC-RAS is used for prediction of outflow hydrograph at various river station and to get peak discharge, velocity, maximum water elevation and travel time. The different scenario analyzed; included a complete collapse and partial breach on geometry recommended by National Weather Commission (NWS). The inundation map is generated for the downstream tail reach. The results obtained from this study can be used in dam safety emergency response plan.

Key Words *: Gravity Dam, Hydraulic Model, Flood, Emergency Plan*

1. INTRODUCTION

1.1 General

Nepal is very rich in water resource which is stored in the form of snow covers, rivers, springs, lakes, and groundwater (WEPA, 2016). The study for construction of dam across the major rivers to impound water for the purpose of flood control, water supply, irrigation, hydropower, navigation and recreational advantages has been increased. These dams should assure safety of life and properties at downstream valleys.

Hundreds of dam failure events were reported the past centuries and still today structures breach every year due to high water levels, often with catastrophic consequences (Steininger, 2014). Dam failure can take several forms, including a collapse of or breach in the structure. Catastrophic flash flooding occurs when a dam is breached and the impounded water escapes through the breach into the downstream valley. Failure of dams retaining small water volume have few or no remarkable consequence. But for high dams storing large amount of water results in generation of massive amount of flood wave inundating downstream reaches of dam. These catastrophic floods caused by dam failures always lead to a great amount of property damage like buildings, crop land, roads, railways, forest and even loss of human and wild life (Saikia, 2007).

This study is presented with hydraulic model of dam breach analysis of Phukot Karnali Hydroelectric Project (PKHEP) for preparation of inundation mapping. The peak outflow discharge, flow depth and travel time of peak discharge at downstream of dam axis is predicted. Moreover, an emergency action plan from the result of dam breach analysis is summarized.

1.2 Review of Previous Studies

Dam are considered as installations containing dangerous forces. Dam failures are comparatively rare, but can cause immense damage of life and properties when it occur. The majority of historic dam failures have occurred in embankment dams (ICOLD, 1995) and bulk of research into breach geometry has been focused on embankment dam failures (ASCE, 2011). In comparison, there is relatively little guidance regarding breach parameters for gravity dams.

MacDonald C.T. et al., (1984) have analyzed data collected on several historical dam failures and presented a relationship for predicting breach characteristics developed for erosion type breaches. The data provides a basis for selecting a breach shape and calculating the breach size and the time for breach development. A relationship was also developed for estimating peak outflows from dam failures. The relationship can be used to verify the methodology and the results of dam safety guides.

2. STUDY AREA

The Karnali River is a perennial trans-boundary river originating on the Tibetan Plateau near Lake Manasarovar. It cuts through the Himalayas in Nepal and joins the Sharda River at Brahmaghat in India. Together they form the Ghaghara River, a major left bank tributary of the Ganges. The proposed RCC dam of PKHEP is located at 29°12'38.40" N and 81°37'25.57" E in western Nepal. The location of dam with respect to the distance from the Nepal India boarder at an elevation of 200 masl is presented in Fig. 1. The longitudinal profile of the Karnali River with PKHEP dam is presented in Fig. 2.

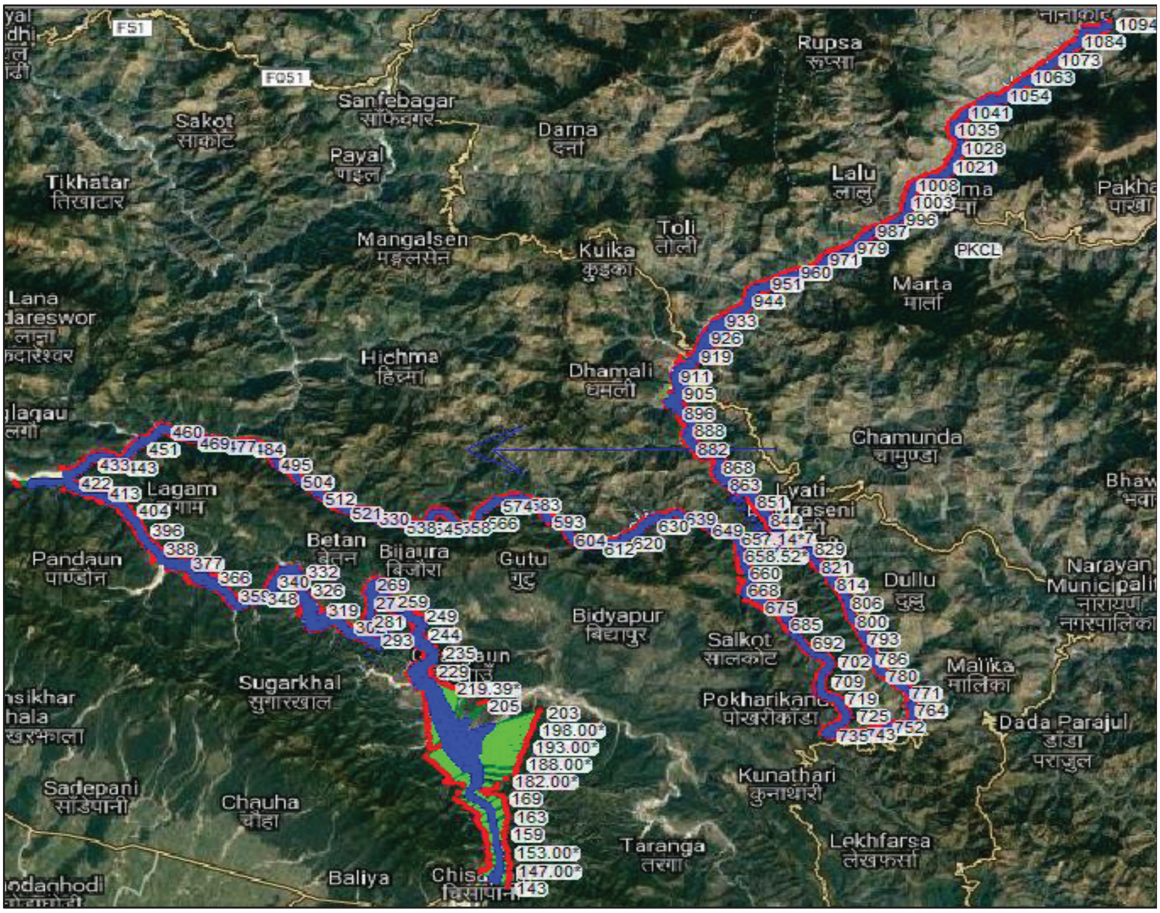

Figure 1 : Study Area

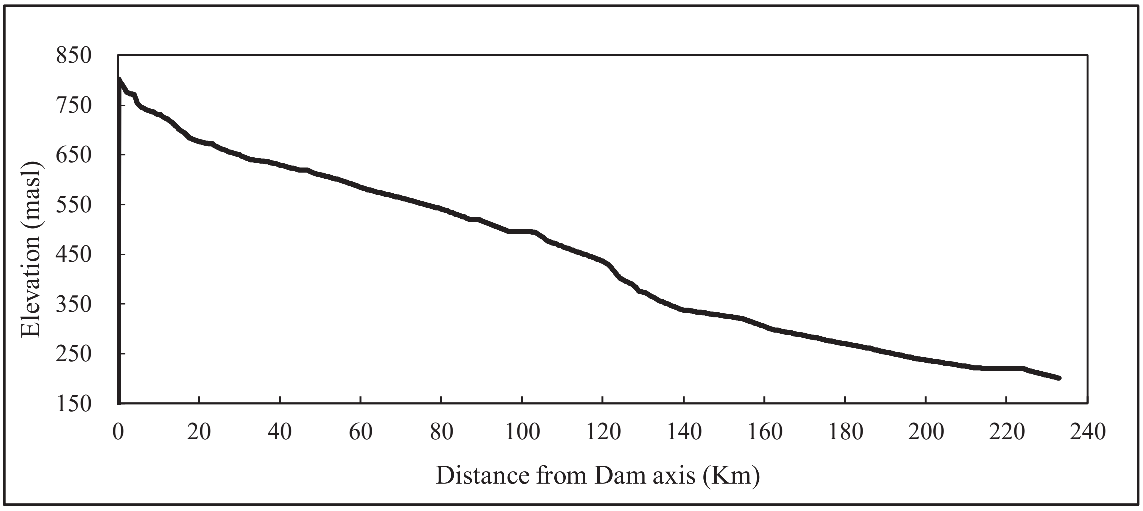

Figure 2 : Longitudinal Profile of Karnali River

The PKHEP comprises a high concrete gravity dam with Crest elevation at 915 masl. The proposed 109.00 m high (from riverbed) Roller Compacted Concrete (RCC) dam stores significantly large volume of water after impounding with live storage volume 37.00 Mm^3 .Three overflow spillways with radial gates and three breast wall spillways are proposed to safely spill the design flood of 15600 Cumec.

3. METHODOLOGY

Dam break flood modelling is accomplished by hydraulic modelling in combination with the GIS analysis. The required topographic and hydrological data were collected from the Detail Engineering Design Report of PKHEP. Tools and techniques within ArcGIS, AutoCAD Civil 3D and HEC-RAS were utilized in order to simulate the flood and consequent inundation pattern. Civil 3D was used for pre-processing of geographic data to determine stream centerline, cross sectional cut lines and bank line etcs.

HEC-RAS was then used for hydraulic data processing and analysis. The modelling process was as presented in Fig.3. The geometry file was imported to HEC-RAS and the hydraulic data, dam breach parameters and boundary conditions were provided as an input. Then 1-D unsteady simulation was done. The result and output tables were exported to ArcGIS for inundation mapping and damage assessment.

3.1 Dam Break Modelling Process

The mathematical model is used to demonstrate the dam break phenomena. This is most cost effective and approximately solves the governing flow equations of continuity and momentum by computer simulation (Wahl, 2010). Mathematical modeling of dam breach floods can be carried out by either one dimensional analysis or two dimensional analysis (USACE, 2014). In one dimensional analysis, the information about the magnitude of flood, i.e., discharge and water levels, variation of these with time and velocity of flow through breach can be studied in the direction of flow. In case of two-dimensional analyses, the additional information about the inundated area, variation of surface elevation and velocities in two dimensions can also be forecasted. One dimensional analysis is generally accepted when valley is long and narrow and the flood wave characteristics over a large distance from the dam are of main interest (Scott, 2007). On the other hand, when the valley widens considerably downstream of dam and large area is likely to be flooded, two dimensional analyses is necessary. In our case due to narrow valley at mountainous region one dimensional analysis has been carried out.

The basic theory for dynamic routing in one dimensional analysis consists of two partial differential equations originally derived by Barre De Saint Venant in 1871 (Bartholomew, 1989). The equations are:

Conservation of mass (continuity) equation

$$(\partial Q/\partial X) + \partial (A + A0) / \partial t - q = 0 \tag{1}$$

Conservation of momentum equation

$$(\partial Q/\partial t) + \{\partial (Q2/A)/\partial X\} + gA ((\partial h/\partial X) + Sf + Sc) = 0 \tag{2}$$

Where;

Q = Discharge, A = Active flow area, A0 = Inactive storage area, h = Water surface elevation,

q = Lateral outflow, x = Distance along waterway, t = Time, Sf = Friction slope, Sc=Expansion contraction slope

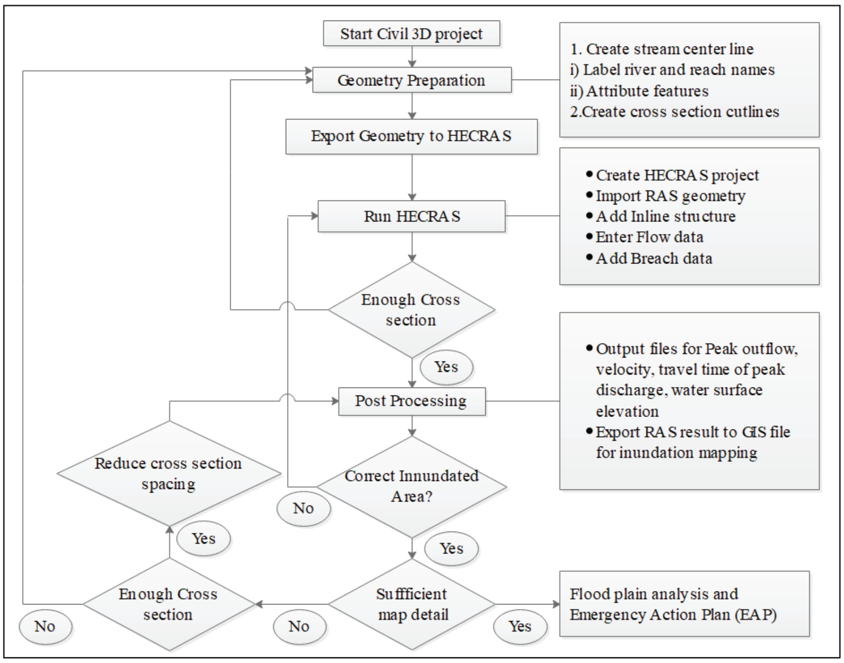

Figure 3 : Methodological Framework

4. MODEL SETUP

HEC-RAS is open source software tool developed by US Army Corps of Engineer. In the present study, unsteady flow simulation model has been used to perform one dimensional hydraulic calculation for dam breach analysis. The unsteady flow simulation system is capable for one dimensional flow through network of open channels, floodplains and alluvial fans.

The geometry data has been prepared in AutoCAD (.dwg file) format. Due to highly unsteady nature of dam break flood, the closely spaced cross-section data at 250 m intervals exceeding over the whole river reach has been prepared. In case of very long and wide reservoirs, the routing of the inflow flood is carried out and hence the reservoir is modeled as cross section at equal intervals. The input data includes the station and elevation coordinates, reach length, channel width at the sections, manning's coefficient and contraction/expansion coefficient. The Probable Maximum Flood (PMF) hydrograph as presented in Fig. 4 is provided as upstream boundary condition and the downstream boundary condition is considered as normal water depth. Initial flow through downstream is given as base flow of the river during wet season.

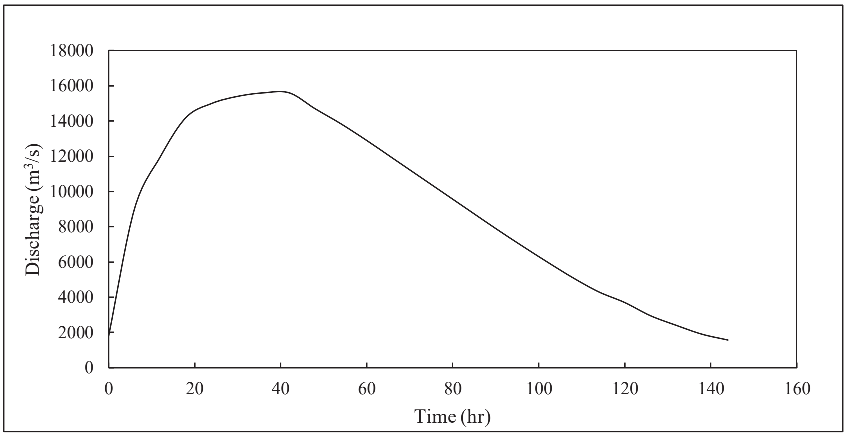

Figure 4 : Inflow Hydrograph

4.1 Dam Break Analysis

Dam break analysis is done for two scenarios; complete collapse and partial collapse of dam to estimate the peak flood. Breach parameter prediction comprises the highest uncertainty of estimating dam break flood. Reference for the ranges of time to failure and breach geometry for concrete gravity dam are taken from the guidelines prepared by NWS, FERC, and USACE. For the modelling of dam failure, dam breach data were entered for the cases under study. The failure mode is selected as overtopping with specified breach formation time. The breach formation process is taken as sine wave progression and trigger mode is set as a time to reach the maximum discharge of inflow hydrograph. The breach parameters taken for modeling is presented n Table 1. The top width of dam is 10 m and the weir coefficient of 1.4 the non-linear breach progression chart is as shown derived is as shown in Fig. 5. The river valley of 232.95 km downstream from the dam axis is considered for the analysis.

Table 1 : Breach Parameters

Breach Parameters	**Complete Collapse**	**Partial collapse**
Breach Geometry Shape	Trapezoidal	Rectangular
Final Bottom width of Breach geometry	60 m	98 m
Final Bottom elevation	805.5 m	820 m
Left Side Slope	1.35 H: 1V	0
Right Side Slope	0.66 H: 1V	0
Breach Formation time	0.25 hr	0.20 hr
Failure mode	Overtopping	Overtopping
Breach Progression type	Non-Linear	Non-Linear

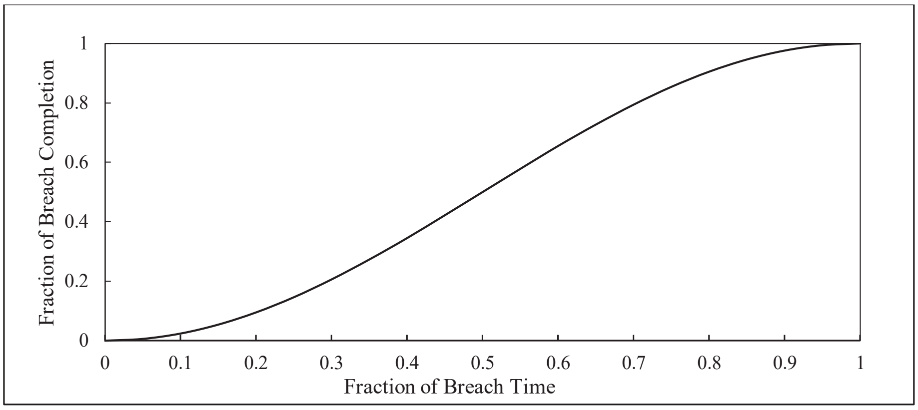

Figure 5 : Breach Progression Plot

5. RESULTS AND DISCUSSION

The following sections describes the result from two scenarios of dam breach (complete and partial collapse of dam body) analysis. The results are discussed and emergency action plan is summarized.

5.1 Results

A detailed output is computed for complete collapse of dam body. The dam breach flood hydrograph is computed. The maximum water surface elevation at dam axis is recorded 915.43 masl just before the dam breach event. The additional head of 5.43 m from Full Supply Level results the hydrological failure of dam. The peak discharge of 91,418.15 m^3/s flows out of dam axis for very short time period. Then, the discharge decreases to 15000 m^3/s at the first 45 min after the failure. After that the flow is synchronized with inflow hydrograph. The maximum velocity is recorded in the stream 0.2 km downstream of dam axis i.e 11.71 m/s due to narrow section. This velocity is sufficient to erode the channel and huge sediment transport will occur in downstream area. The maximum discharge at the lowermost boundary (232.95 km downstream of dam axis), is recorded after 1008.55 min (16.8 hr) after the dam breach event and flow velocity is 3.02 m/s. The attenuation of peak discharge at downstream of dam axis is present in Fig 6. The summary of result for peak discharge, velocity, travel time of peak discharge, and maximum water surface elevation are presented in Table 2 for the case of complete collapse. The inundation mapping for flow depth is prepared showing the headworks area to end river station as shown in Fig 7.

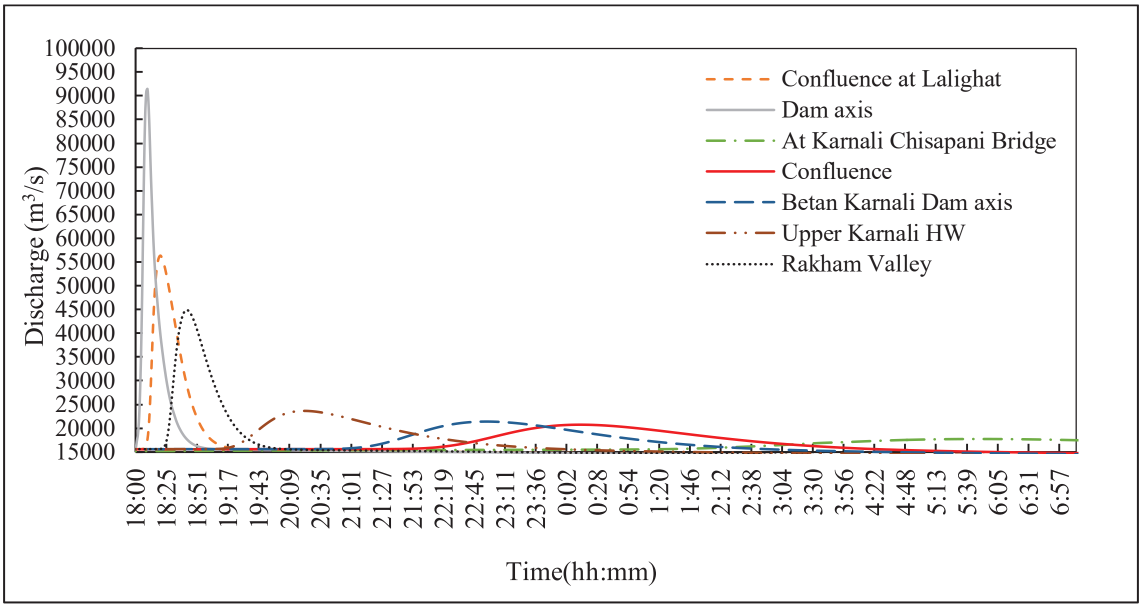

Figure 6 : Peak Outflow Discharge at Different Downstream Stations

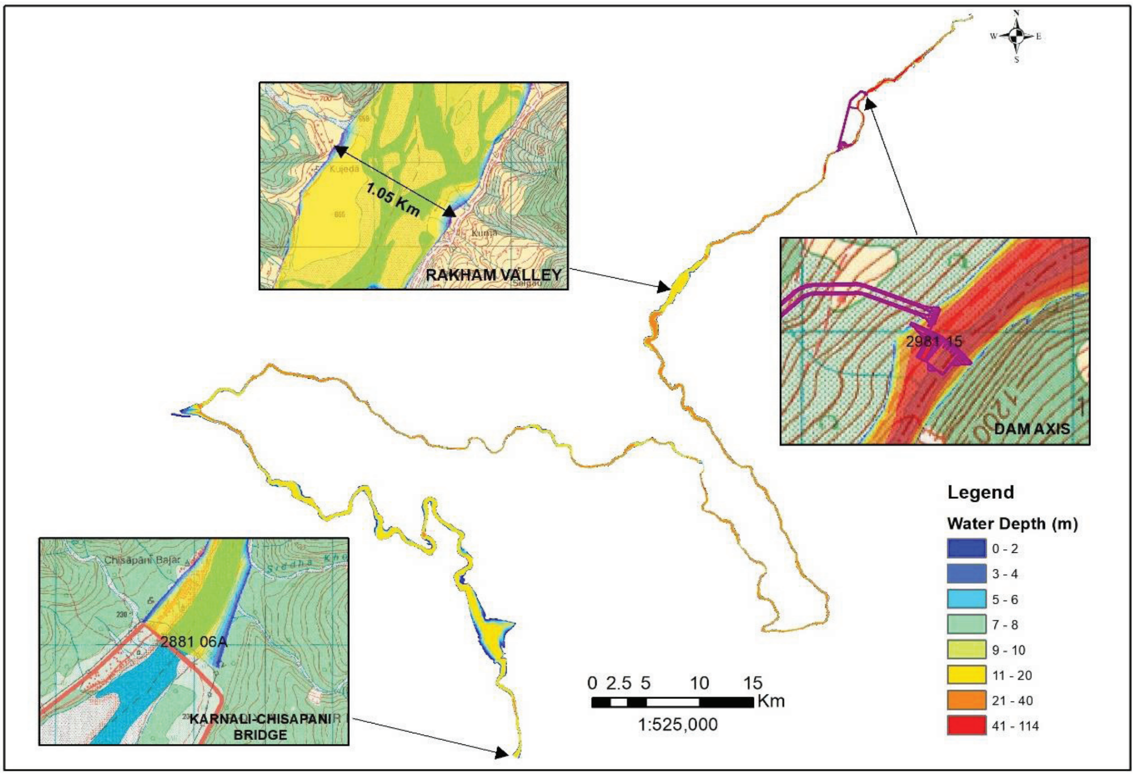

Figure 7 : Inundation Mapping for Complete Dam Collapse

Table 2 : Output at Major River Station Downstream of Dam Axis

Distance from dam axis (Km)	River Station	Travel Time (min)	Velocity (m/s	Discharge (m^3/s)	Bed Level (m)	Max Water Surface (m)	Location
0	1039.8						Dam axis
0.20	1039	-	11.71	91418.15	801.76	857.08	Just D/S of dam axis
9.95	1000	16.87	10.98	55579.48	731.84	771.78	Confluence of Karnali and Tila River
26.20	935	49.09	7.07	44110.74	660.76	676.52	Rakham valley
48.95	844	156.55	3.31	24761.70	612.00	640.88	Upper Karnali Headwork area
125.95	566	394.39	8.58	21402.14	395.00	424.03	Betan Karnali Headwork's area
161.45	424	508.54	0.82	20531.44	300.50	323.17	Confluence of West Seti and Karnali
211.70	223	771.64	2.48	18191.55	222.00	240.34	Ghatgaun
217.95	203	871.78	0.38	17768.80	220.00	239.42	Confluence of Bheri and Karnali
232.95	143	1,008.55	3.02	17730.69	201.00	211.50	Karnali Chisapani Bridge axis

The peak discharge of two scenarios of dam breach analysis is compared. It is found that the peak discharge for complete breach is found 15 % more than the peak discharge from partial breach of dam. The breach velocity is found greater than 10 m/s for both scenarios. The plot of water surface elevation up to 16 Km from dam axis for both complete and partial breach is as show in Fig. 8.

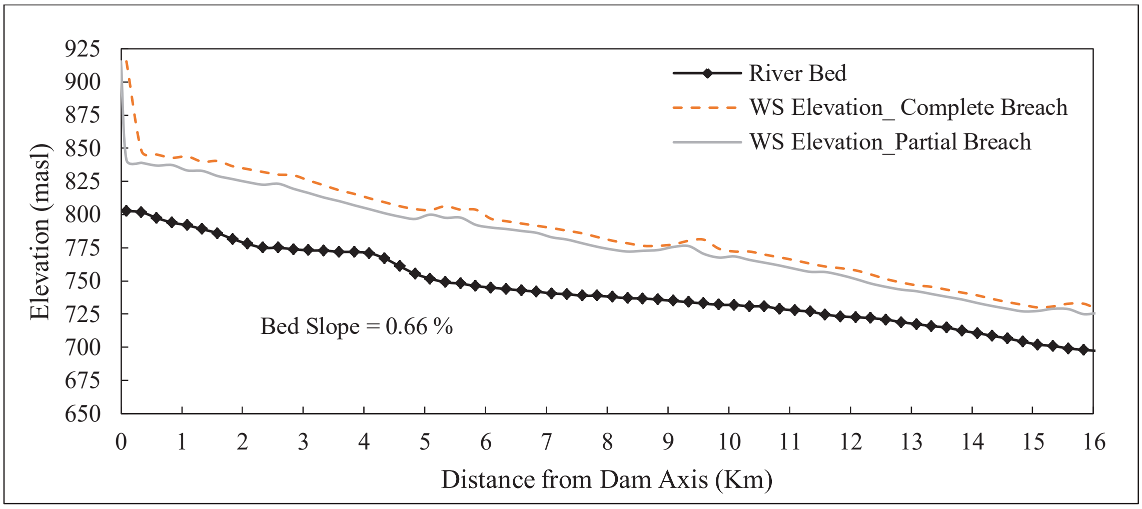

Figure 8 : Comparison of Maximum Water Surface Elevation for Complete and Partial Breach

5.2 Discussion

The order of magnitude of the discharges induced by the dam break of PKHEP is enormous, and the released power will result significant hazard in the downstream of dam. The possibility of massive landslides is high all along the flooded area, and the major erosion will occur from the expected high flow velocities.

The most significant parameters for downstream hazard evaluation are water depths, discharges, and flow velocities. In order to evaluate the risk for downstream populations, the results from water depth and velocity are combined in order to estimate the capacity of a person to move under certain flow conditions. Beyond a flow velocity of 1.5 m/s, or a height beyond 1.5 m, it becomes nearly impossible to an adult in good physical condition to move or swim. After these limits, the risk is considered very high. The calculation showed that the maximum area downstream of PKHEP dam have very high hazard due to flow depth and velocities.

The settlements in the flooded area are expected to destroyed according to the flow characteristic and the flooding duration.15 minutes is considered as the minimum time for populations to reach the secured areas after the emergency alarms. Therefore, the settlements located within the 15 minutes distance i.e., the area where the flood reach within 15 minutes after the dam break, have to be resettled since they don't have enough time to escape in case of failure. This period of 15 min can be extended to longer period to the local site conditions. The peak discharge from PKHEP dam breach will travel 8 Km downstream from dam axis within 15 minutes.

The maximum water depth calculated after the complete breach of PKHEP dam at Karnali Chisapani bridge (near the Indian boarder) axis, about 232.95 KM downstream of dam axis is 10.5 m. According to Department of Hydrology and Meteorology (DHM) of Nepal, the 10 m water depth at Chisapani is marked as warning level and 10.8 m water depth is marked as danger level. Therefore, there is possibility of flood at terrain region at downstream of bridge due to dam breach.

5.3 Emergency Action Plan (EAP)

Indirect impacts from the dam breach are complex and hardly quantifiable. The effect of impacts can extend long time after the dam break. The local economic activities (industrial, agricultural, commercial, etc.) will be interrupted or drastically slowed down in areas not directly flooded and can be extended to dependent regions, and even on the country scale, that will impact the employment in the whole region.

To protect the downstream people and to reduce the impact in the wider region needs an action plan from the dam owner. The action plan also called an Emergency Action Plan (EAP) is a formal document that identifies potential emergency conditions at a dam and specifies pre planned actions to be followed to minimize property damage and life. The early warning system can be planned from the obtained result and flood inundation mapping to minimize the downstream impacts. Further study should be carried to access the safest place near the urban area to relief from immediate impact.

Determining the impacts on the most important infrastructures is also part of EAP. The access road will be crucial for the assistance of mobilization. The hospitals and public services infrastructure such as schools, fire stations, police and military barracks should be located in safe areas in order to allow mobilization and quick implementation of the emergency plan.

6. CONCLUSION

This paper described the details of the water surface elevations, discharges, time reach for peak discharges and flow velocities at different locations of downstream area from the dam axis after the complete and partial breach of 110 m high PKHEP dam. The study showed that the most of the valleys along the Karnali River at the downstream of the PKHEP dam will be severely affected. At the time of the complete breach the discharge level can be at alarming level even at flat plain of Nepal at about 232.95 Km downstream of the dam axis. Emergency action plans are briefly summarized, the settlement which are to be moved are recommended. The major human settlement at Rakham valley need to be evacuated where the peak flood will arrived within 50 minutes of dam breach.

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