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DAM Break Analysis USING HEC-RAS: A CASE SUTDY of Proposed Koshi High Dam

Gyawali, D. R., and Devkota, L. P.
[1]Nepal Development Research Institute (NDRI), Pulchowk, Lalitpur
Email: dheeraz@gmail.com

Abstract

Nepal has been bestowed upon with tremendous water resources potential. However, only a small fraction of it has so far been used in different sectors. For year round irrigation facilities to increase agricultural productivity, to meet the peak hour electricity demand and dry season deficit, Nepal needs to develop storage projects from long term development perspective. Proposed Koshi High Dam project is one of them. The proposed dam project, though may provide a number of benefits ranging from water supply to flood control, recreation, hydropower and irrigation, catastrophic flooding can occur when a dam breaks as the magnitude of the discharge in such events far exceeds all other floods. Advancing knowledge is, thus, beneficial to reduce the potential threats of the dam failure. The Hydrologic Engineering Center's River Analysis System (HEC-RAS) was used with HEC-GeoRAS to develop a dam failure model for the Koshi High Dam. HEC-RAS model was run under unsteady flow to assess the magnitude of flood and stage and the timing of high flood arrival. These dam failure models can be used as a preliminary assessment tool for the resulting catastrophic floods.

Keywords: Dam break, HEC-RAS model, Koshi high dam, unsteady flow simulation

Introduction

The total average annual runoff from the Nepalese rivers is about 225 billion cubic meters i.e. 225 cubic km (NWP, 2005). Internally renewable water resource of Nepal has been estimated to be 198 cubic km, which is about 0.45% of the world's available fresh water reserve of 44,000 cubic km. Per capita water available of a country should be above 2,000 m^3 per year in order to be in comfortable from availability point of view (Sharma, 2006). A country is said to be in water stress state if the per capita water available in that country falls below 1,700 m^3/year. If it is less than 1,000 m^3/year, the situation is considered to be "highly stressed" (Revenga, 2000). The consequences of such water scarcity can be much more severe, leading to problems with local food production and economic development. Current per capita water availability of Nepal is 7,100 m3/year which is close to the world average of 7200 m3/year. It is more than double to the average of Asia and 6/7 times higher than the average of SAARC. Having 0.45% of total global fresh water in a country with a land area of only 0.1%, having very high ratio of independency (94%) as well as having sufficient amount of per capita water availability (> 7,000 m3 per year), Nepal can definitely be said as a rich country in water resources. Even after 40 years per capita water availability would remain quite high (~ 4,000 m3) for Nepal. Analyzing these criteria as discussed, it can be concluded that Nepal would be in comfortable position even in the future from the perspective of water resources availability.

Although Nepal has been bestowed upon with tremendous water resources potential, only a small fraction of it, about 15 cubic km, has so far been used in these different sectors (NWP, 2005). The total agricultural land in Nepal is about 2.640 million ha. The irrigable land with year round irrigation facility is only about 15% (DOI, 2009) while the rest of area is not irrigated in the dry season due to the water scarcity. Although Nepal has huge hydropower potential; more than 50% of the total population of Nepal has yet to receive electricity at their homes. The total installed capacity of the hydropower plants of the country has reached to 718 MW, out of which storage hydropower projects has a mere capacity of 92 MW (DOED, 2015). The rest of the projects are run off the river types which generates around one third of its installed capacity during the dry months of the year. To attain the food security, agricultural production and productivity must be increased. It is only possible through year round irrigation facilities. To meet the peak hour electricity demand and dry season deficit, Nepal needs to develop storage projects. Task force of 2009 has recommended various such storage projects for country's long term development perspective (TF, 2009). Proposed Koshi High Dam project is one of them.

Koshi High Dam, which was envisioned in 1937 to effectively "cure" the flooding problem, has once again come forward as revitalized issue for flood control, irrigation and hydropower generation. Koshi High Dam, a concrete dam of 269 m height, is proposed to be constructed in Barahkshetra (near Chatara) with live storage of 4,420 million cubic meters (mcm) and gross storage of 8,500 mcm. The expected benefit from the dam is irrigation of 66,450 ha of land in Nepal and millions of ha in India, flood control and 3,489 MW of hydropower (NDRI, 2015). As such, Nepal (the upper riparian), India (middle riparian), and even Bangladesh (lower riparian of the Ganga River Basin) have shown interest in the construction of the high dam. Recently, the sixth meeting of the India Nepal Joint Ministerial Commission on Water Resources (JCWR), held in November 2011 at New Delhi agreed to expedite the completion of Detailed Project Report of Koshi High Dam Multipurpose Project. Similarly, the meeting of the JCWR held in January 2013 at Kathmandu decided to continue the feasibility study of the Dam (MoEn, 2014).

Though, these storage dams provide a number of benefits that ranges from water supply, flood control, recreation, hydropower and irrigation, catastrophic flooding occurs when a dam breaks as the magnitude of the resultant flood in such event far exceeds all other floods. These dam failures may arise from different reasons: seepage, piping (internal erosion), overtopping due to insufficient spillway capacity or insufficient free board and settlement due to slopes slides on the upstream shells and liquefaction due to earthquakes (SoC, 2010, Xiong, 2011). Early warning is thus, very important and necessary to save the lives and property during the dam break event (Alghazali and Alhadrawi, 2012). Total number of dam failures even in USA from 1975 to 2011 is 656, out of which overtopping was the most common cause of dam failure followed by piping (FEMA, 2013). Simulation of dam break events and the resulting floods are, thus crucial to characterizing and reducing threats due to potential dam failures (Xiong, 2011). HEC-RAS model has the capability of simulating the dam break event and has been used in many past researches (Xiong, 2011, Bjerke, 2011, Alghazali and Alhadrawi, 2012, FEMA, 2013).

The beneficial aspects of the Koshi High Dam are promising; advancing knowledge is beneficial to reduce the potential threats of the dam failure. With this backdrop, dam break simulation study was carried out to assess the magnitude of flood and stage and the timing of arriving high flood at different location below the proposed dam site under different breach modes using HEC-RAS model.

Study Area

The Koshi River Basin covers three ecological zones of Nepal within the transverse length of about 150 km (Figure 1). The variation of altitude in this short reach is quite sharp i.e. from 95 m to 8848 m. The Koshi River Basin covers the area of 2,000 km2 in the Terai region of Nepal before entering into India and these regions are densely populated. The Koshi River has three main tributaries viz. Tamor in the eastern part, Arun in the middle and Sunkoshi in the western part of the basin. The Sunkoshi River consists of 5 major tributaries: the Indrawati, the Bhote-Koshi, the Tama Koshi, the Likhu and the Dudh Koshi (Figure 1). Sub-basins Sun-Koshi, Arun and Tamor meet at Tribeni-ghat, flow through Barahkshetra gorge, location of proposed Koshi dam, for a length of about 15 km and enters into the Terai Region of Nepal at Chatara. Immediately after emerging from the gorge at Chatara, Koshi River flows in a much wider channel through the Terain plains towards India. The abrupt change in gradient of Koshi has periodically proved catastrophic in nature with flooding, aggradations of the river bed due to sedimentation and river bank erosion, as frequent occurrences.

The study area lies within a tropical climatic regime with the annual rainfall of about 2000 mm (NDRI, 2015). However, variability in the annual precipitation is quite high for a given location. The Koshi River has an annual average flow of 1,540 m3/s measured at Chatara (DHM, 2008). However annual variability even in the average flow is significant: 2,070 m3/s in 1999 and 1,230 m3/s in 1982. The annual hydrograph of 2000, clearly illustrates the flow dominancy in the four monsoon months (Figure 2). Also the maximum and minimum flow occurs in the month of August and March respectively. The daily maximum and minimum flows at this station in 2000 are respectively 294 m3/s and 7,540 m3/s, showing great variation in the flow within a year. It thus suggests the importance of the water impounding structure for the better management of the water resources of the river and to mitigate the water induced disasters.

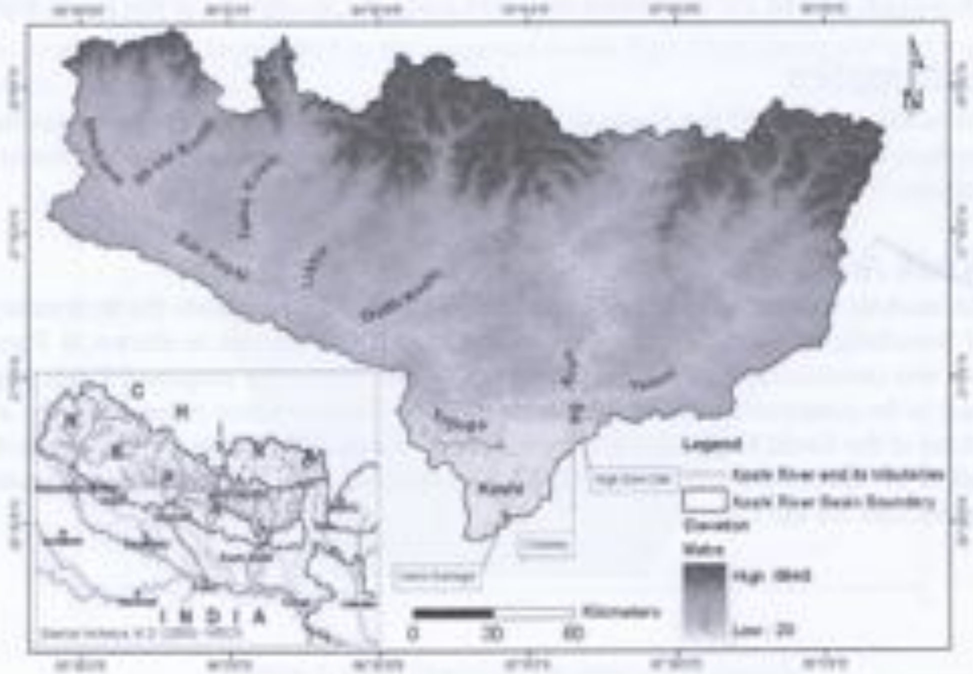
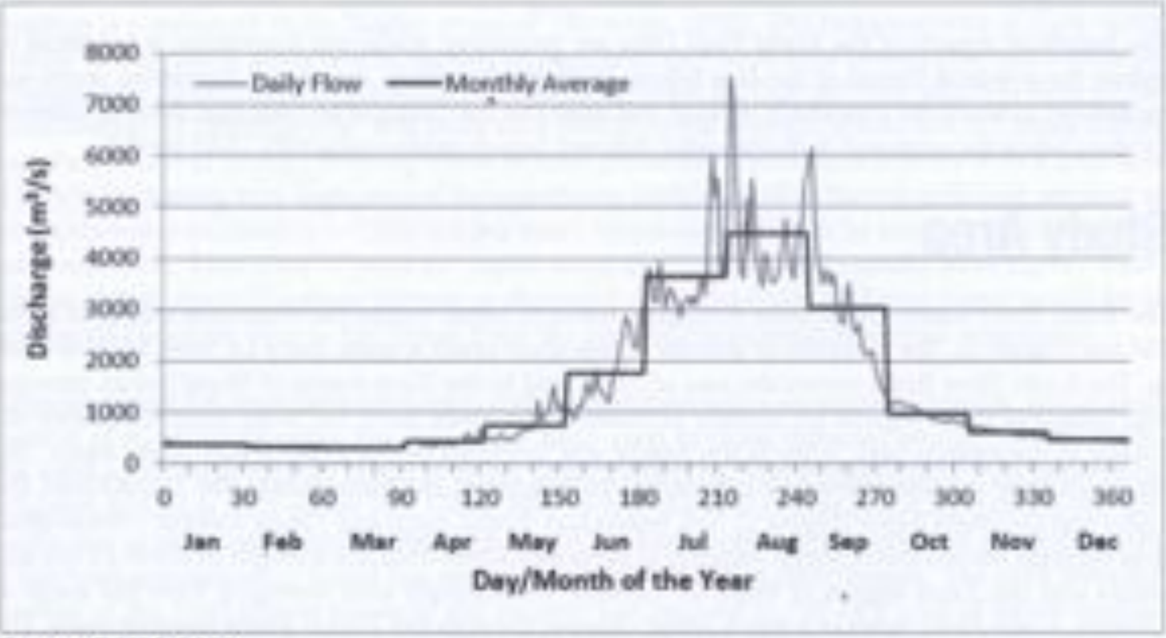


Figure 1. Koshi River Basin in Nepal



Source: DHM, 2008

Figure 2. Hydrograph of Chatara (2000)

Methodology

The dam break simulation study conducted in this study consists of following steps:

DEM Preparation

Due to inadequacy of national level contour and spot height dataset at the required scale, topographical surveyed data (DWIDP, 2012) was obtained to derive a more realistic river cross section using the ArcGIS 9.3 environment. National level contour and spot height data was used along with ASTER GDEM V2[1] to prepare the DEM along the floodplains of the Koshi River.

River Schematics

Due to the braided nature of the Koshi River in the Terai plains, the river schematics including river centerline, banks, flood plains as well as embankments were extracted from the recent Google Earth Imageries.

Dam Break Analysis

Dam break analysis was carried out using the HEC-RAS model to simulate the hydraulic process in case of breaching of the Koshi High Dam. The simulation domain is shown in Figure 3. A model dam was constructed in the Koshi River at Chatara where the proposed Koshi High Dam is supposed to be constructed. The model dam has the characteristics resembling the available specifications of the Koshi High Dam along the proposed axis. While doing this analysis, the dam was placed as an inline structure in the HEC- RAS environment and piping was assumed as a trigger mechanism for the breach.

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1 ASTER GDEM v2.0 is the property of METI and NASA.

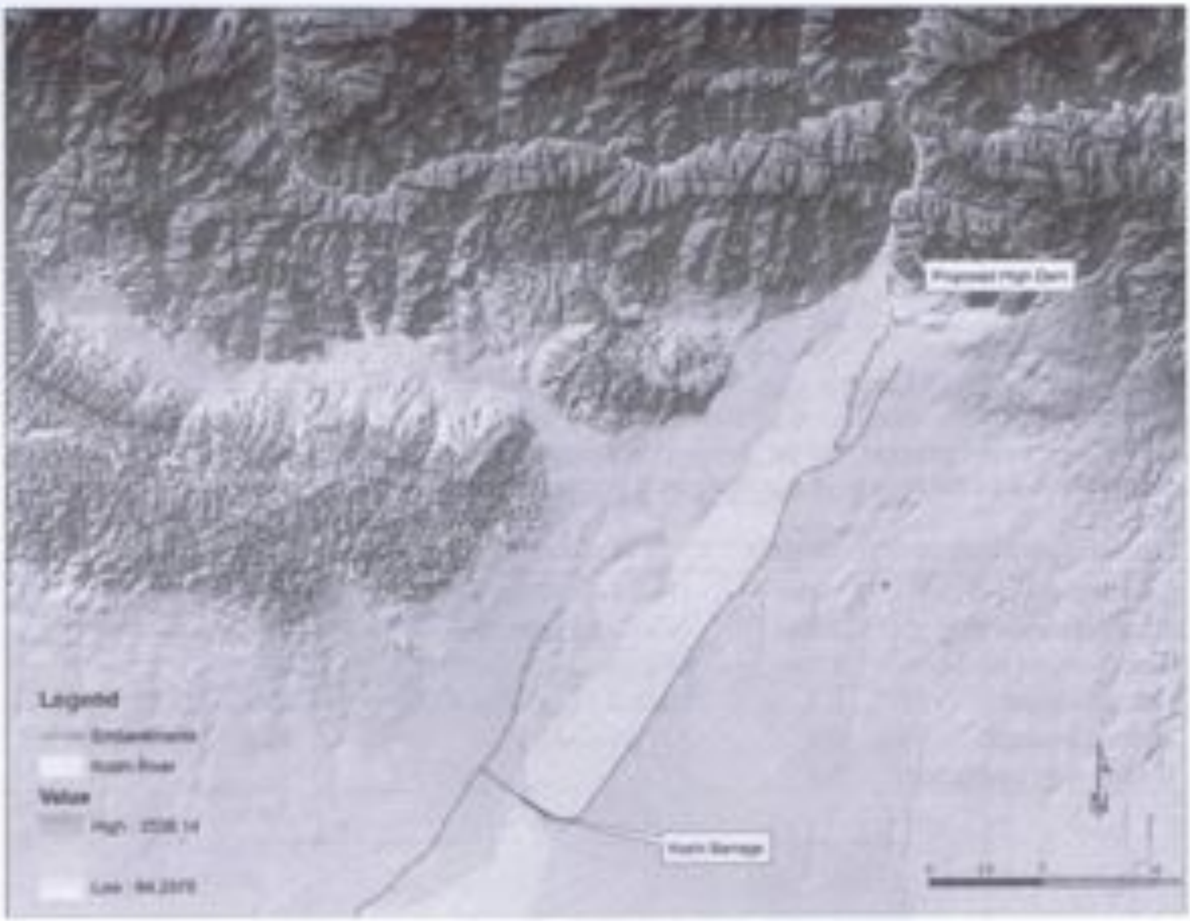


Figure 3. Simulation Domain

Dam Parameters

Specifications of Dam

Figure 4 and Table 1 shows the specifications of dam used in the model. A storage area of about 8.5 billion cubic meters (equivalent to the proposed Koshi High Dam Gross storage) was assumed for analysis.

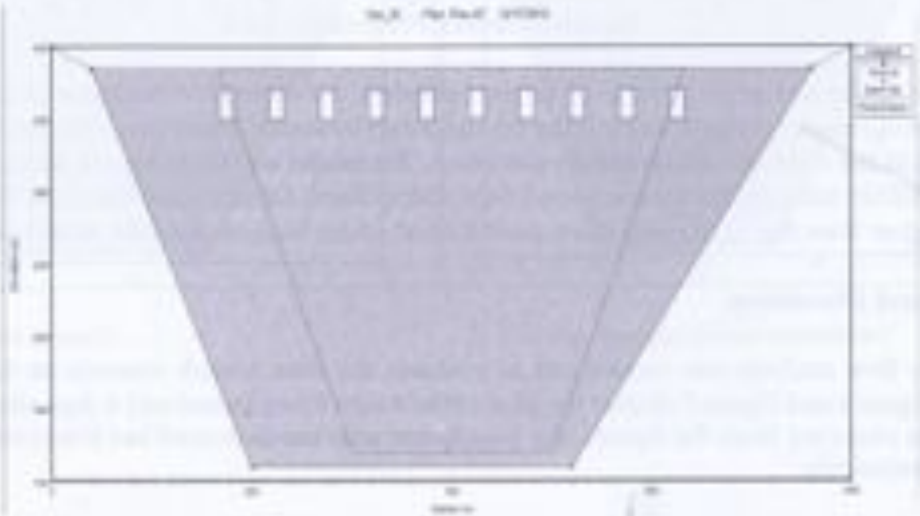


Figure 4. Dam Specification used in the model

Table 1. Dam Specification used in the model

Dam Specification	Dam Height	269m	Gate Specification	Type	Sluice
	Deck width	15m		Numbers: 10	Size: 20mx15m
	Weir Crest Shape	Broad crested		Sluice discharge coefficient	0.6
	u/s side slope	0		Invert	350m
	d/s side slope	2:1		Weir shape	Broad crested weir

Breach Specification

Piping was considered as the triggering mechanism for the dam breach. Full formation hours for the breach were considered as 5 hours and a half sine wave breach progression was used for the simulation process. **Error! Reference source not found.** and **Figure 5** show the breach specification and the breach progression plot respectively.

Table 2. Specification of the Breach

Center Station	400m	Full Formation Time (hrs)	5
Final bottom width	200m	Failure Mode	Piping
Final bottom elevation	120m	Piping Coefficient	0.5
Left side slope	0.5	Initial Piping elevation	250
Right side slope	0.5	Trigger failure at	25th August, 2006
Breach weir coefficient	2.5		

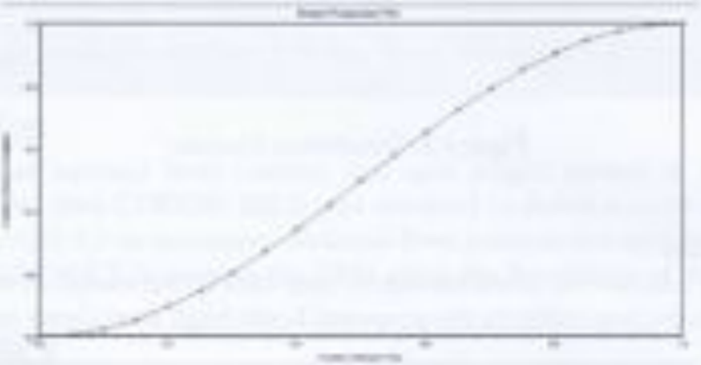


Figure 5. Breach Progression Plot

Elevation controlled gates were used as the boundary condition for the inline structure (dam). Flow hydrograph for August was used as the upstream boundary condition whereas normal depth was used as the downstream boundary condition. The model was set to breach under the extreme flood of 69758 m3/s (100yr return period ECHAM05 flood, Devkota and Gyawali, 2015) which is much higher than the 1000 year return period flood under historic data (i.e. 47444 m^3/s).

Results and Discussion

Unsteady flow analysis was carried out to evaluate the dam breach scenario in the HEC-RAS model. Figure 6 and Figure 7 display the plan of the Koshi River, before and 4 days after the breach. As can be observed from the figures, the inundation area has increased but it is contained within the embankments.

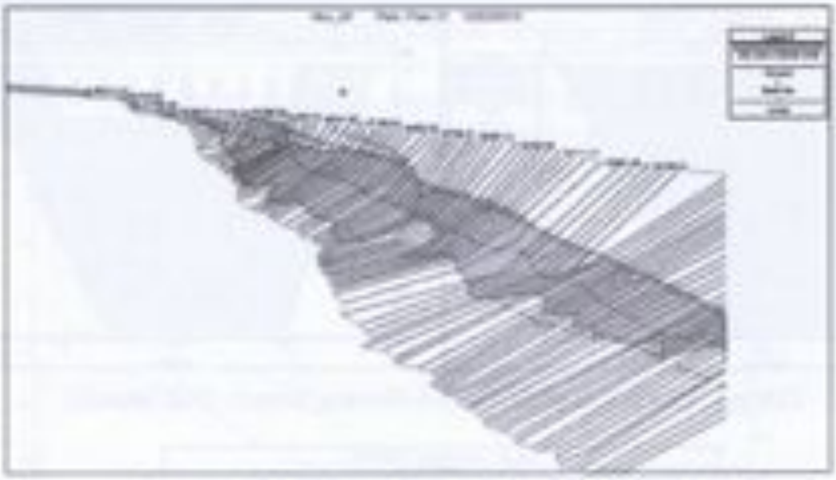


Figure 6. Plan Prior to breach (24th August, 24:00)

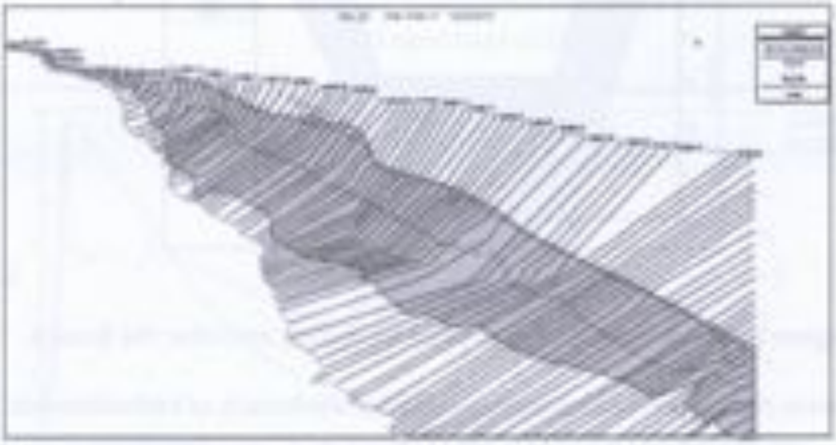
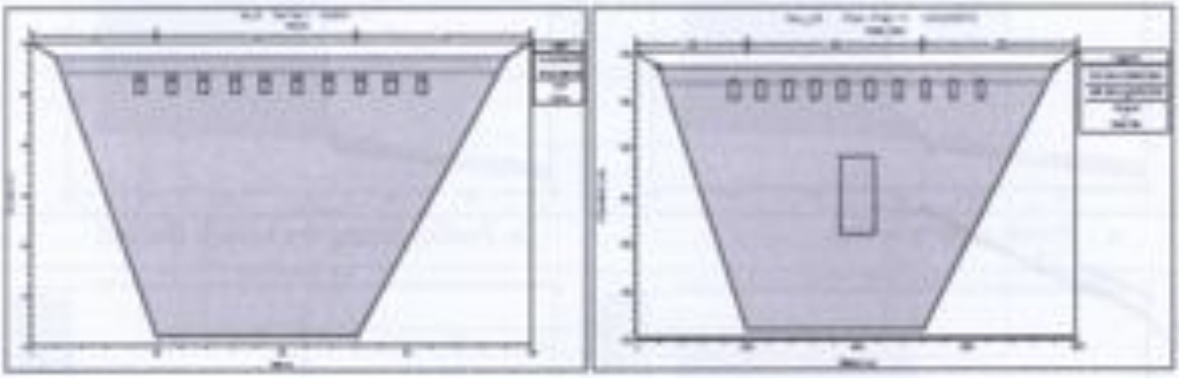


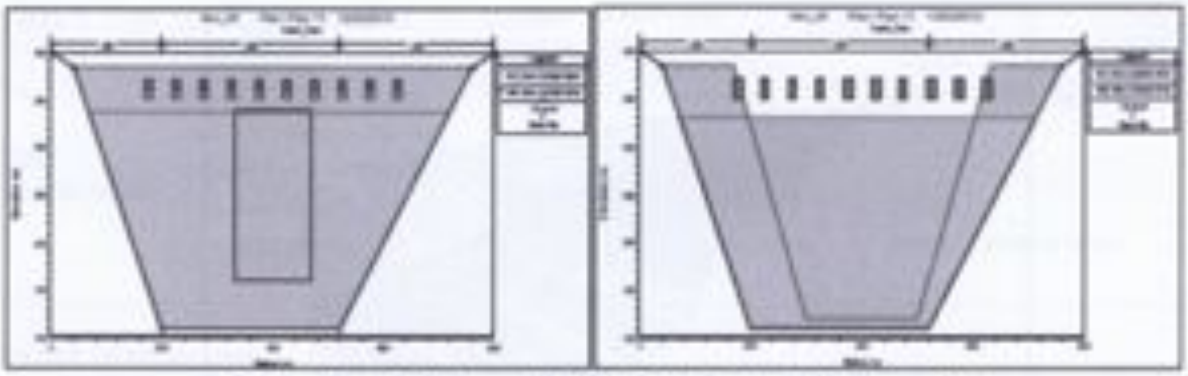
Figure 7. Plan after breach (29th August, 24:00)

Similarly the breach formation at the dam can be seen in Figure 8 (a-e).

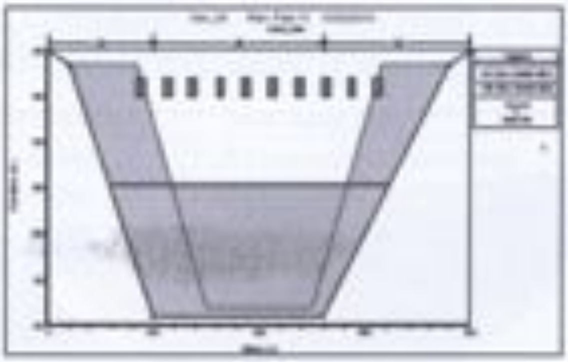


a. Prior to the breach

b. During Breach (breac initiation)



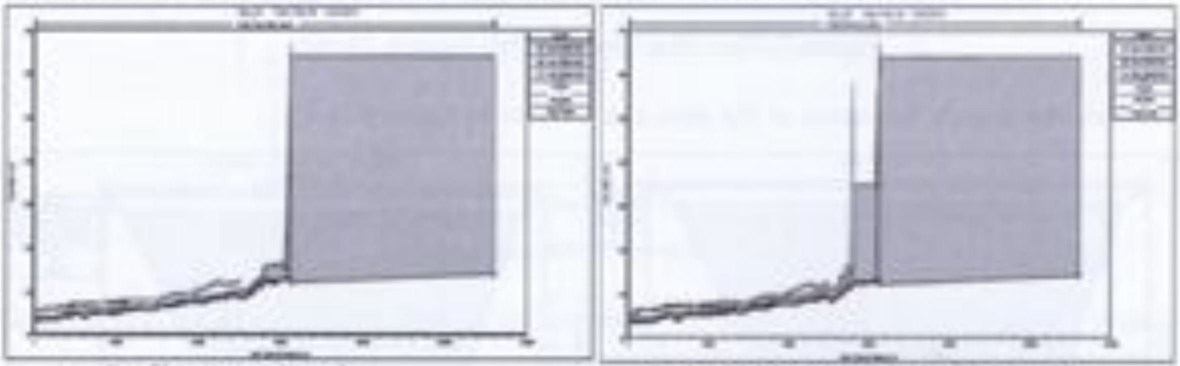
c. During Breach (Intermediate) d. During Breach (Full breach)



e. After Breach

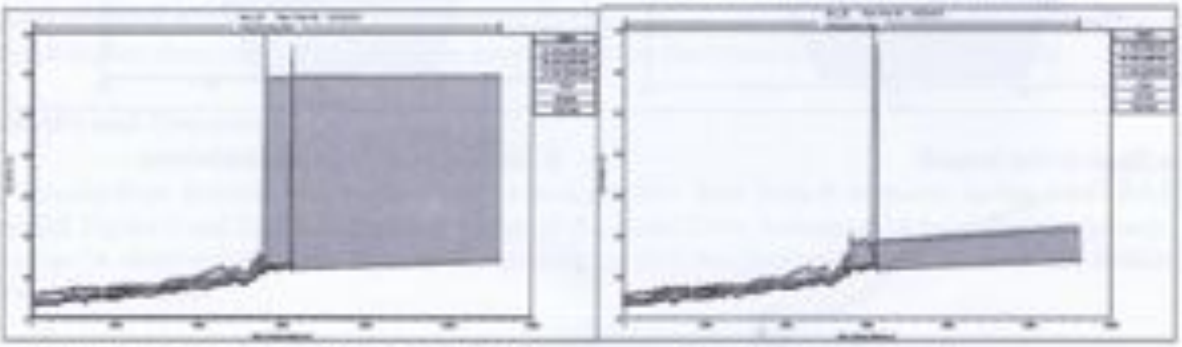
Figure 8. Cross-section of dam prior to, during and after the breach

Figure 9 (a-d) shows the profile before, during and after the breach of embankments.



a. Profile prior to breach

b. Profile during the breach (Initial)

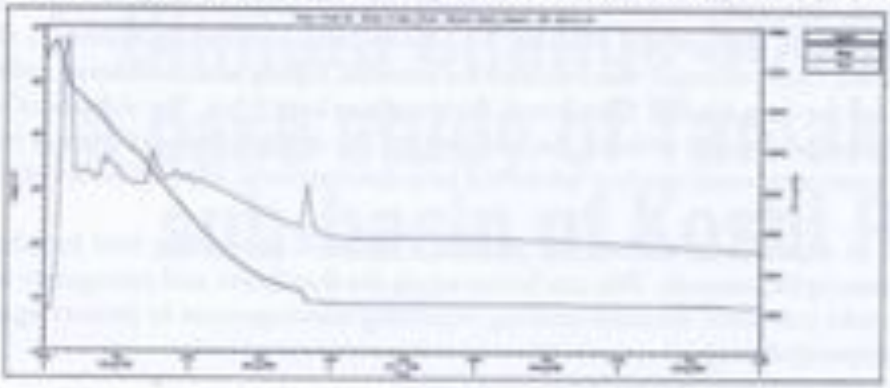


c. Profile during the breach (Intermediate)

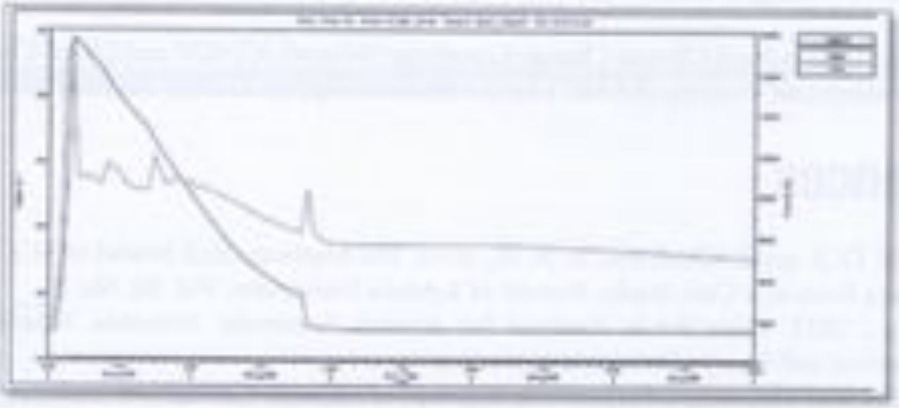
d. Profile after the breach

Figure 9 (a-d). Profile of dam prior to, during and after the breach

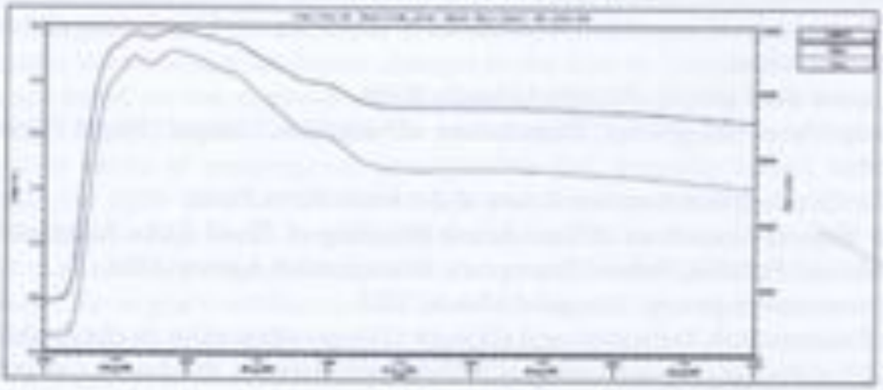
It can be observed from the figures that the volume of water stored behind the dam is flooded within 5 days of breach. Figure 10 (a to c) shows the stage and flow volumes at different locations within the Koshi River. As can be read from Figure 10, the maximum flood wave is transferred to the most downstream cross-section (about 62 kms downstream) after 20 hours of breach.



a. Just upstream of Dam



b. Just downstream of Dam



c. Most downstream cross-section

Figure 10. Stage and Flow at different locations

Conclusions

The beneficial aspects of the Koshi High Dam are promising; advancing knowledge is beneficial to reduce the potential threats of the dam failure. The simulation of potential inundation resulting from a dam failure can provide very relevant and crucial information about the downstream impacts. This exercise requires hydrologic scenarios, the possible dam failure modes, breach parameters associated with failure modes, and the routing and mapping of the consequent discharge hydrograph. The unsteady flow routing model, in HEC-RAS, is used for the simulation of failure of the Koshi High Dam to compute and display downstream impacts resulting from the dam failure. This study assessed the magnitude of flood, stage and the timing of arriving high flood downstream. A storage area of about 8.5 billion cubic meters (equivalent to the proposed Koshi High Dam Gross storage) was assumed for analysis. Piping was considered as the triggering mechanism for the dam breach. Dam break duration was kept 5 hrs. The volume of water stored behind the dam was flooded within 5 days of breach. The maximum flood wave is transferred to the most downstream cross-section (about 62 kms downstream) after 20 hours of breach.

The analysis of dam failure models can provide a scenario generating tool for identifying the resulting catastrophic hazards. This can better equip the floodplain and emergency management authority to take informed decision-making regarding contingencies to protect against the loss of life and property damage.

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References

Alghazali, N. O. S. andd Alhadrawi, D. A. H., 2012. The Mathematical Model of RCC Dam Break, Bastora Dam as a Case Study, Journal of Kerbala University, Vol. 10, No. 3

Bjerke, P. L., 2011, Dam Break Analysis for Aparan Reservoir, Armenia, Norwegian Water Resources and Energy Directorate, Norway.

Devkota, L.P. and Gyawali, D.R.G., 2015: Impacts of Climate Change on Hydrological Regime and Water resources Management of the Koshi River Basin, Nepal, Journal of hydrology: Regional Studies, (Accepted paper)

DHM, 2008: Published and unpublished documents, Department of Hydrology and Meteorology, Kathmandu, Nepal.

DoED, 2015, www.doed.gov.np, Accessed March, 2015.

DOI, 2009: http://www.doi.gov.np/, Department of Irrigation, Lalitpur, Nepal (Visited: October 10, 2009).

DWIDP, 2012. Cross sectional surveyed data of the Koshi River Basin.

FEMA, 2013. Federal Guidelines of Inundation Mapping of Flood Risks Associated with Dam Incidents and Failures, Federal Emergency Management Agency, USA.

MoEn, 2014, www.moen.gov.np, Accessed March, 2015

NDRI, 2015. Disaster Risk Reduction and Climate Change Adaptation in the Koshi River Basin, Nepal. Final Report, Nepal Development Research Institute, Pulchwok, Lalitpur, Nepal

NWP, 2005. National Water Plan, Water and Energy Commission, Kathmandu, Nepal.

Revenga, C., 2000. Will there be enough water? Pilot Analysis of Global Ecosystems: Freshwater Systems (Edited: Greg Mock).

Sharma, K. R., 2006. Newsletter, Department of Irrigation, Lalitpur, Nepal.

SoC, 2011. Guidelines for Dam Breach Analysis, State of Colorado (SoC), Department of Natural Resources, USA.

TF, 2009. Ten Years Hydropower Development Plan, Task Force, Ministry of Energy, Singha Durbar, Kathamndu, Nepal.

Xiong, Y. F., 2011. A Dam Break Analysis Using HEC-RAS, J. of Water Resources and Protection, 3, 370-379.