ASSESSMENT OF HIGH FLOOD DISCHARGE IN A POST-FLOOD SCENARIO – A CASE STUDY FROM UTTARAKHAND

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ABSTRACT

In a catastrophic post-flood scenario, estimating the flood that passed can be challenging due to damages to the data-collection infrastructure, physical impossibility of measurement during the actual passage of the flood, etc. Moreover, long term historical data, by which the element of uncertainty is tackled in a predictive scenario is of little use in this case. The June 2013 flood in Uttarakhand had GLOF (Glacial Lake Outburst Flood) also as a component. Some recent developments in technology offer the possibility of increasing the confidence level of assessment in such situations. Near real-time current rainfall data by the Tropical Rainfall Measuring Mission (TRMM) and developments in GIS technology are worth mentioning in this regard. Application of these developments integrated with traditional data and methods in assessment of the catastrophic June 2013 flood that passed through the under-construction Singoli-Bhatwari Hydro Electric Project in Uttarakhand are discussed in this paper.

INTRODUCTION

Hydrology as a science has a risk management aspect which is predominant in the planning, design and operation of a hydroelectric project. In the planning and design stage, and during construction, this aspect is generally concerned with development of methods and tools for prediction of high flood events that are likely in the future. In the operational stage, prediction of low flow periods may gain prominence for assessment of the hydrological risk from financial considerations. But there are occasions when assessment of a high flood discharge in a post-flood scenario also becomes important. The June 2013 flood in Uttarakhand which ravaged through and caused severe damages to a number of hydroelectric power projects, big and small, is a case in point. In both the predictive and post-flood scenarios, lack of observed data may be the main hindrance. In a catastrophic post-flood scenario, however, the problem is compounded due to damages to the data-collection infrastructure, physical impossibility of measurement during the actual passage of the flood, etc. Moreover, long term historical data, by which the element of uncertainty is tackled in a predictive scenario is of little use in this case. The June 2013 flood in Uttarakhand had GLOF (Glacial Lake Outburst Flood) also as a component. Some recent developments in technology offer the possibility of increasing the confidence level of hydrological assessments in such situations. Near real-time current rainfall data (TRMM), globally available topographical data (SRTM, ASTER), GIS techniques etc. are worth mentioning in this regard. These developments integrated with traditional data and methods have been applied in assessment of the catastrophic June 2013 flood that passed through the under-construction Singoli-Bhatwari Hydro Electric Project in Uttarakhand.

THE SINGOLI-BHATWARI HYDRO ELECTRIC PROJECT

The Singoli-Bhatwari HEP, presently under construction, is located on the Mandakini river in Uttarakhand. The catchment of Mandakini, a sub-basin of the Alakananda basin is sandwiched between the catchments of Bhagirathi and Alakananda rivers. Figure-1 shows the location of the project site with reference to the two adjoining basins, along with a few important places. The project comprises of a 22 m high barrage, an 11.87 km long HRT with a design drawl of 59.6 cumecs and a surface power house at Bhatwari proposed to house a 99 MW installation. The project construction commenced in 2008. As on during the June 2013 flood incident, the barrage was 50% complete with 3 bays constructed out of 5. The barrage has not suffered any major structural damage except scouring on the right flank. However the rock ledge on which the right abutment would be founded is intact. The HRT was 60% complete. Construction of the power house structure was going on which got substantially silted up during the flood event.

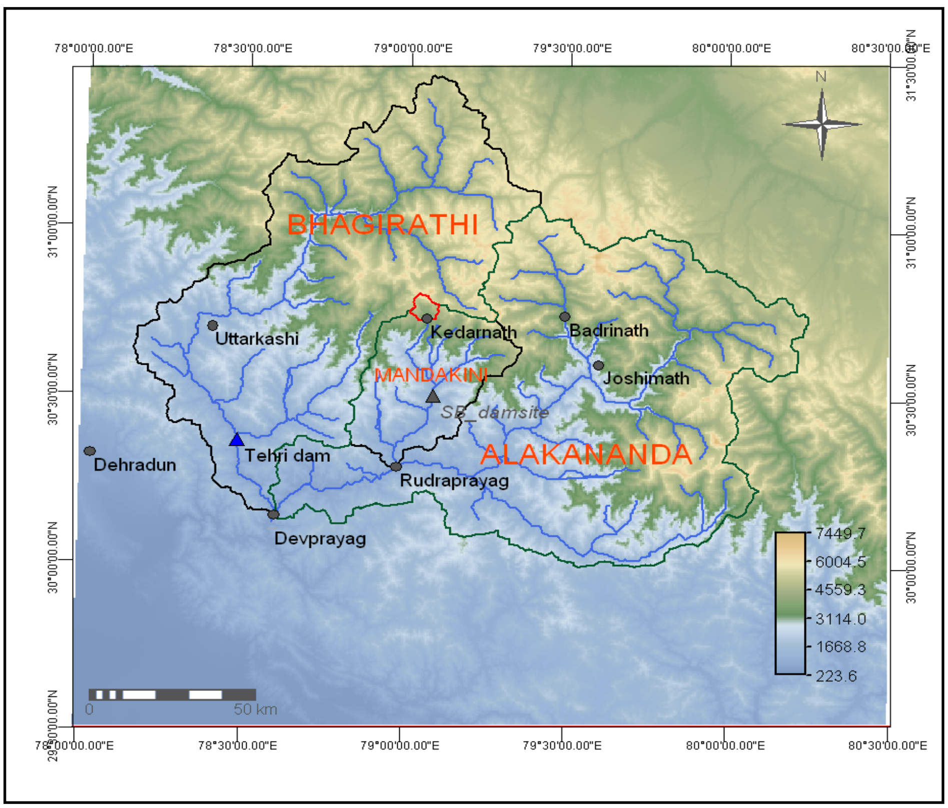

Fig. 1: Location map showing the flood-affected basins

THE JUNE 2013 FLOOD

The Uttarakhand flood disaster of June 2013 will be remembered for the havoc it wrecked by way of inflicting massive human suffering along with tens of thousands of deaths. The untimely and unprecedented event also dealt a severe blow to the infrastructure development effort of the government in the Alakananda, Bhagirathi and Mandakini sub-basins. In particular, the hydropower sector was badly affected. Along with the many already constructed and under-construction projects, the floods caused considerable damages to the under-construction Singoli-Bhatwari HEP of L&T in Mandakini sub-basin also. Incessant rainfall which started from the morning of 15 June till 17 June coupled with numerous landslide events in the project catchment were partly responsible. The major damage was caused by a flood of huge magnitude that passed through the project area between 8:30 AM to 9:00 AM on 17 June. It is now well known that this flood of huge magnitude was the combined result of incessant rain coupled with the outburst of a glacial lake called Chorabari, upstream of Kedarnath township.

ASSESSMENT METHODOLOGY

As the flood was unprecedented, actual flow measurements were not possible. Water level records at some places of the project area e.g. barrage site and power house site are available, but out-flanking of the river at barrage site, and the dynamic bed conditions prevailing during that time due to the carriage of large-scale debris from the landslides and moraine materials from the burst glacial lake in general, and at the power house site, in particular, prevent a proper estimation of the flood that passed. However, there is one location between the barrage site and the power house site, viz. the Baswara bridge site 7.4 km downstream of the barrage site where a hydraulic estimation is possible due to the confined river cross-section at this location. From a hydrologic viewpoint, the flood was composed of two components – a rainfall component and a GLOF (glacial lake outburst flood) component. Accordingly, the flood assessment is carried out by both hydraulic and hydrologic methods. The floods assessed by these two methods are compared so as to obtain a reasonable estimate of the unprecedented flood that passed through the Singoli-Bhatwari project area on 17 June 2013.

HYDRAULIC METHOD

The Baswara Bridge over Mandakini River is located 7.4 km downstream of the barrage site, almost midway between the barrage and power house sites. The cross-section of the river at this site and the maximum water level achieved during the passage of the unprecedented flood of 17 June, 2013 (EL 903.83 m) are available. The deck level of the bridge is EL 911 m. The minimum river bed level at this cross-section is EL 894.842 m giving a maximum water depth of 9 m during the maximum flood. Also available is the long-section of the river from the barrage site to the power house site. The hydraulic parameters are calculated from the cross-section and long-section data. The results are very sensitive to the assumption of Manning's 'n'. Manning's 'n' for mountain streams having bed of cobbles with large boulders can range from minimum 0.04, normal 0.05, to maximum 0.07 (Chow, 1959). From 15 December onwards, the situation was extra-ordinary with very large amounts of sediment flowing. With such heavily sediment-laden water, Manning's 'n' could be in the higher range. Channel slope is also a very sensitive parameter. During the high flood days of 15-17 June, a lot of debris resulting from the numerous landslides coupled with the GLOF event must certainly have led to a temporarily degraded condition causing a reduction in channel slope. The complete sedimentation of the Power House site of SBHEP is a proof of this fact.

It may be mentioned that the root cause of this huge flood was the outburst of the Chorabari lake. It is reported that the Chorabari lake outburst occurred at 6:45 AM on 17 June (*Dobhal et.al., 2013*). The peak flood passed through Singoli-Bhatwari project area between 8:30 AM to 9:00 AM. The travel time can be calculated and the velocity of flow in turn comes out to be 6.68 m/s. With 6.68 m/s mean velocity through the cross-sectional area of 588.42 m^2, the discharge is 3930.5 m^3/s. Considering the average channel slope as 0.013, the Manning's 'n' comes out to be 0.063, which is reasonable. Thus, the maximum discharge that passed through the Baswara Bridge as estimated by hydraulic method can be said to be 3931 m^3/s.

HYDROLOGIC METHOD

As stated already, the flood was composed of two components – a rainfall component and a GLOF (glacial lake outburst flood) component. The rainfall component is computed following standard hydrologic procedure (unit hydrograph method) and the GLOF component is computed employing empirical models. The final flood is the total of the floods due to rainfall component and the GLOF component.

ASSESSMENT OF FLOOD

Estimation of flood due to rainfall component

A unit hydrograph for the Singoli-Bhatwari HEP approved by CWC is available in the DPR of the project. Applying the maximum 24-hour rainfall during 15-17 June, 2013, we can get the maximum discharge due to rainfall. There is only one raingauge station (SRRG) at Ukhimath maintained by IMD within the Mandakini sub-basin, but data is not available after 17:00 hours of 16^{th} June, whereas the maximum flood passed through the Singoli-Bhatwari project area in the morning of 17^{th} June. Thus, rainfall data from other sources becomes inevitable for arriving at a reasonable estimate of the flood. In such a situation, data available from TRMM (Tropical Rainfall Measuring Mission) proved to be a helpful source. A number of data products including near real-time rainfall estimates are available for download. One such data product providing 3-hourly average aerial rainfall over a 15' grid area is selected for our purpose. Analysis of the TRMM data shows that maximum rainfall occurred in the Kedarnath-Ukhimath area (which is just upstream of Singoli-Bhatwari HEP) on all the 3 days viz. 15, 16 & 17 June, 2013. The TRMM data is found to be in general agreement with the IMD data. It can be seen from both data sources that the maximum daily rainfall occurred on 16 June 2103. Although average aerial rainfall over a $15^{/}$ grid area cannot be strictly compared with point data, a comparison is attempted for validation purposes. IMD data at Ukhimath is available at hourly interval, whereas TRMM data is available at 3-hour interval for the $15^{/}$ grid where Ukhimath falls viz. latitude 30.5^0 – 30.75^0 E and longitude 79^0 – 79.25^0 N. The validation is quite acceptable when we compare the data graphically as shown in Figures 2(a) and 2(b).

The $15^{/}$ grid between latitude 30.5^0 – 30.75^0 E and longitude 79^0 – 79.25^0 N matches the project catchment of Singoli-Bhatwari HEP. Therefore, it is proposed to use the TRMM aerial average rainfall of this grid to find out the 24-hour rainfall. The maximum 24-hour rainfall was 148 mm at 15:00 hrs on 16 June. This rainfall is applied on the unit hydrograph to obtain the peak flood which is found to be 2435 cumecs. Our interest is the flood due to rainfall at 09:00 hours on 17^{th} June. The 24-hour rainfall at 09:00 hours on 17^{th} June is 115 mm. The corresponding flood is found to be 1912 cumecs.

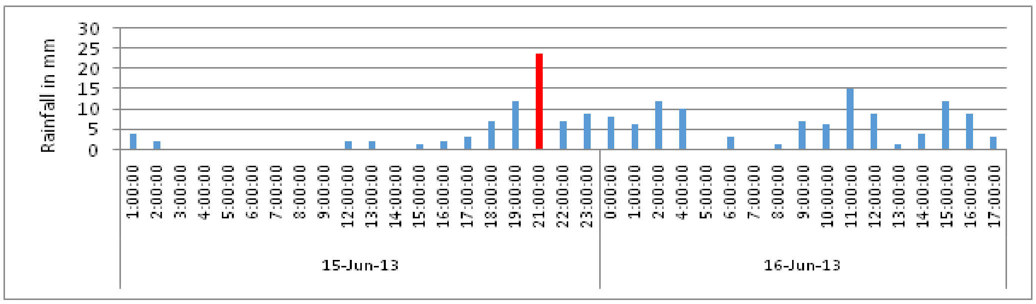

Fig. 2 (a): Hourly rainfall recorded at Ukhimath SRRG of IMD

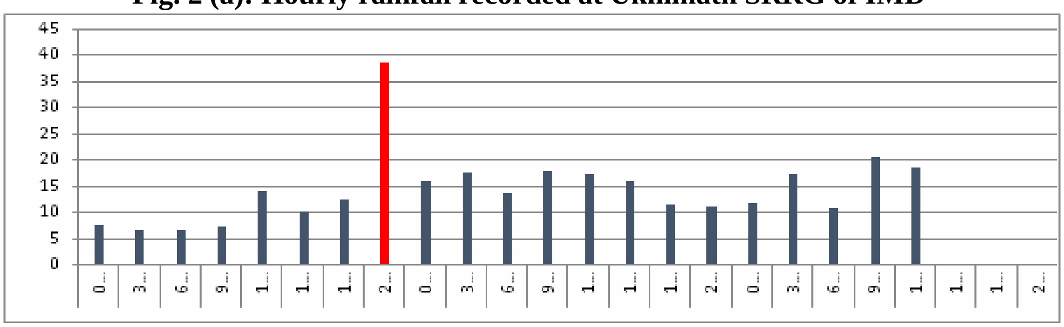

Fig. 2 (b): 3-hourly rainfall from TRMM at Ukhimath area

Estimation of GLOF Component

The Chorabari Taal (EL 3960 m), also known as the Gandhi Sarovar is a snowmelt and rainfed lake, located at the snout of the Chorabari glacier, about 2 km upstream of Kedarnath town. Rapid melting of snow/ice and heavy rainfall resulted in bursting of this lake which not only caused devastation of the Kedarnath township, but also caused damages downstream due to the traveling outburst flood. The bursting of this lake led to its complete draining within 5-10 minutes as reported by the watch and ward staff of the Wadia Institute of Himalayan Geology (WIHG). The Chorabari lake is visible and measurable in Google maps and the area is found to be 31,062 m^2. However, the Google maps are based on satellite imageries of earlier dates. The WIHG has reported the lake size to be 400 m long and 200 m wide i.e. having an area of 80,000 m^2 and the depth of the lake to be 15-20 m. These information are sufficient to employ available empirical formulae or models to arrive at the glacial lake outburst flood (GLOF) that occurred on 17 June.

The variables in the empirical equations are lake volume (V), potential energy (P_E) of the water reservoir, and duration of the outburst (t). There is no feasible way to directly derive lake volume, but it has been found that plots of volume against area usually show very high coefficients of determination forming the basis of an acceptable empirical relationship. Such a relationship given by Huggel et.al. in 2002 is as follows –

$V = 0.104A^{1.42}$ where V=lake volume, A=lake area

The potential energy (P_E) of the water reservoir is expressed as the product of dam height, volume, and the specific weight of water. In the instant case, WIHG has reported that the depth of the lake is 15-20 m. So, 20 m can be considered as the dam height while computing $P_{E.}$

In Haeberli's relation, the lake volume is divided by a time constant. The time constant value is based on experience and 1000 s has been found to be a characteristic value. In the case of Chorabari lake outburst, it is reported by the watch and ward staff of WIHG that the duration of the outburst was 5-10 minutes. Accordingly, 10 minutes i.e. 600 s is considered as't'.

With the help of the physical characteristics and the empirical formulae, the possible maximum discharges due to breach of Chorabari lake are estimated and shown in the following table:

S. No.	Formulae or models		Max discharge (m^3/s)
1.	Huggel et.al., 2002	$Q_{max}=0.00077V^{1.017}$	928
2.	Costa & Schuster, 1988	$Q_{max}=0.00013P_E^{0.60}$	634
3.	Popov, 1991	$Q_{max}=0.0048V^{0.895}$	1093
4.	Haeberli's corrected, 1983	$Q_{max}=2V/t$	3179
5.	Clague & Evans, 2000	$Q_{max}=0.063P_E^{0.42}$	3027

It can be observed that Haeberli's corrected formula gives the highest discharge of 3179 cumecs. This discharge can be considered to be the most plausible discharge resulting from the lake outburst because of the following reasons –

(i) Haeberli's corrected formula is the simplest of the lot. Given the complex nature of a glacial lake outburst, such a simple approach is no less appropriate than the other non-linear relations.

(ii) Haeberli's corrected formula has lake volume and duration of outburst as the variables. Lake volume is calculated on the basis of the area of the lake. Both lake area and duration of outburst estimates are based on actual observations of the WIHG staff, and not derivatives of remote sensing analysis as usual in case of GLOF studies.

(iii) The relations involving potential energy (Costa & Schuster and Clague & Evans) are dependent on dam height, which is again a variable which is difficult to measure.

With the above considerations, the GLOF due to Chorabari lake outburst is taken to be 3179 cumecs. Now, the Singoli-Bhatwari HEP site is at a distance of 40.7 km from the Chorabari lake. One empirical routing equation was developed by the USBR in 1982 "Guidelines for defining inundation areas downstream from Bureau of Reclamation Dams" which can be used to find out the attenuated GLOF when it reached Singoli-Bhatwari HEP site. The equation follows:

$$Q_r=10^{\log(Q_{max})-0.01x}$$

where:

Q_r =peak discharge in cfs corresponding to distance x.

Q_{max} =peak dam break discharge at the dam in cfs.

X =distance in miles downstream of the dam measured along the flood plain.

Using the above equation, the attenuated GLOF at Singoli-Bhatwari site is found to be 1776 cumecs. Thus, 1776 cumecs can be said to be the GLOF component of the huge flood that passed through the Singoli-Bhatwari project area in the morning of 17 June, 2013.

The combined flood due to rainfall and GLOF

The flood values due to rainfall component and GLOF component are found to be 1912 cumecs and 1776 cumecs respectively. Thus, the estimation of the flood that passed through the Singoli-Bhatwari project site on 17 June 2013 by adding these two components is found to be 3688 cumecs. The maximum discharge from hydraulic estimation Baswara bridge site, 7.4 km downstream, is found to be 3931 cumecs. The results from both the methods are close and validate each other. Therefore, 3688 cumecs can be said to be the maximum flood that passed through the Singoli-Bhatwari project area on the morning of 17 June, 2013.

DISCUSSION OF RESULTS AND CONCLUSIONS

In the Mandakini sub-basin, the maximum rainfall occurred on 16th June but the flood peaked on 17th June due to the addition of GLOF. The peak flood passing through the Singoli-Bhatwari project site would have been 2435 cumecs on 16th June which has a return period of about 500 years as per available records against a 24-hour rainfall of 148 mm. But due to the

GLOF event, the flood peaked up to 3688 cumecs next day against a lesser 24-hour rainfall of 115 mm which is even slightly more than the projected 1000 year return period flood (3661 cumecs) for the project. It is evident that the lakeburst of Chorabari glacial lake was the critical element in the whole catastrophe. From the flood assessment point of view, however, rainfall data becomes critical due to breakdown of the traditional data-collection infrastructure. It is found that TRMM data products can provide an excellent source of rainfall data in such situations.

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