Analysis of Artificial Lake formed on river Phutkal, J&K and Management of Outburst Flood at Nimmo-Bazgo dam

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ABSTRACT

The landslide lakes are temporary lakes in the river valleys formed by landslide debris and commonly form in mountains of high relief and mass movement activity such as Indian Himalayas. Breaching of such temporary lakes with huge amount of accumulated water and sediments can create devastating floods in the downstream areas. On 31 December 2014, a large landslide in the Zanskar Himalayas, India created a 50m high natural blockade on the Phuktal river, a tributary of Zanskar which is further a tributary of Indus river, resulting in formation of around 15 km long impounded lake upstream of blockade. NHPC has a hydroelectric power project, namely Nimmo-Bazgo power station (45 MW) in the downstream on Indus river about 220 km from Phutkal and about 20 km d/s of Indus-Zanskar confluence. After the blockade a study was carried out for possible landslide breach to estimate the flood peak, its travel time and rise in river water level at various locations along the reach upto Nimmo-Bazgo project. The landslide dam finally breached on 7^{th} May 2015 and in this study, a comparison of simulated and actual event parameters have been presented. Results of the study indicate that parameters estimated through hydrodynamic simulation using river cross-sections from open source DEM provided a reasonable assessment of the situation which helped in formulation of effective reservoir operation plan for passing the flood safely in the downstream.

1.0 INTRODUCTION

The combination of extremely high mountains, high seismic activity, and steep slopes in the Himalayan region causes a wide range of natural hazards, including landslides, flash floods, avalanches etc. Landslide dam lakes are created as a result of a broad range of mass movements in different geomorphologic settings. Dams form most frequently as a result of rock and earth slumps and slides, debris and mudflows, and rock and debris avalanches in areas where narrow river valleys are bordered by steep and rugged mountain slopes. A lake then forms behind the dam as a result of the continuous inflow of water from the river. This type of activity is common in geologically active areas such as the Himalayas. These areas contain abundant landslide source materials such as sheared and fractured bedrock materials. The lakes formed as a result of such damming of the river can breach at timescales varying from days to years after their formation (Li et al., 1986), producing some of the largest known catastrophic floods (O'Connor et al., 2013). The resulting dam geometry and the hydrogeomorphic characteristics of the upstream catchment area are primary factors determining the stability and longevity of landslide dammed lakes.

A large landslide on 31 December 2014 blocked the Phuktal river (a tributary of Zanskar river which is further a tributary of Indus river) in Leh district, Jammu and Kashmir state of India. Blockage of Phuktal river gorge by the landslide created a temporary lake behind the accumulated debris thereby reducing the flow of river in the downstream.

2.0 STUDY AREA

Leh district is a part of union territory of Ladakh which lies between 32^0 17'N to $36^0$15' N latitude and 75^0 15' E to 80^0 30' E longitude and is one of the remotest district in India. It has got land route connectivity only during summer whereas during winter because of heavy snow fall in Zozilla Pass and Rohtang pass, it remain cutoff from rest of the world with only aerial route available as connectivity. The region is bounded in north and east by Tibet and on the north-west by Pakistan. Ladakh is cut diagonally by Indus river forming a huge basin. The Indus River rises from the lofty mountains of Himalayas around Mansarovar Lake in Tibet at an elevation of 5,182 m. The total length of Indus from origin to its outfall in Arabian Sea is 2,880 km, out of which 1,114 km flows through India. It follows a north-westerly course through Tibet and enters the Indian Territory. The main tributaries of Indus are Zanskar, Shyok, Nubra and Hunza. The study area is shown in Figure-1.

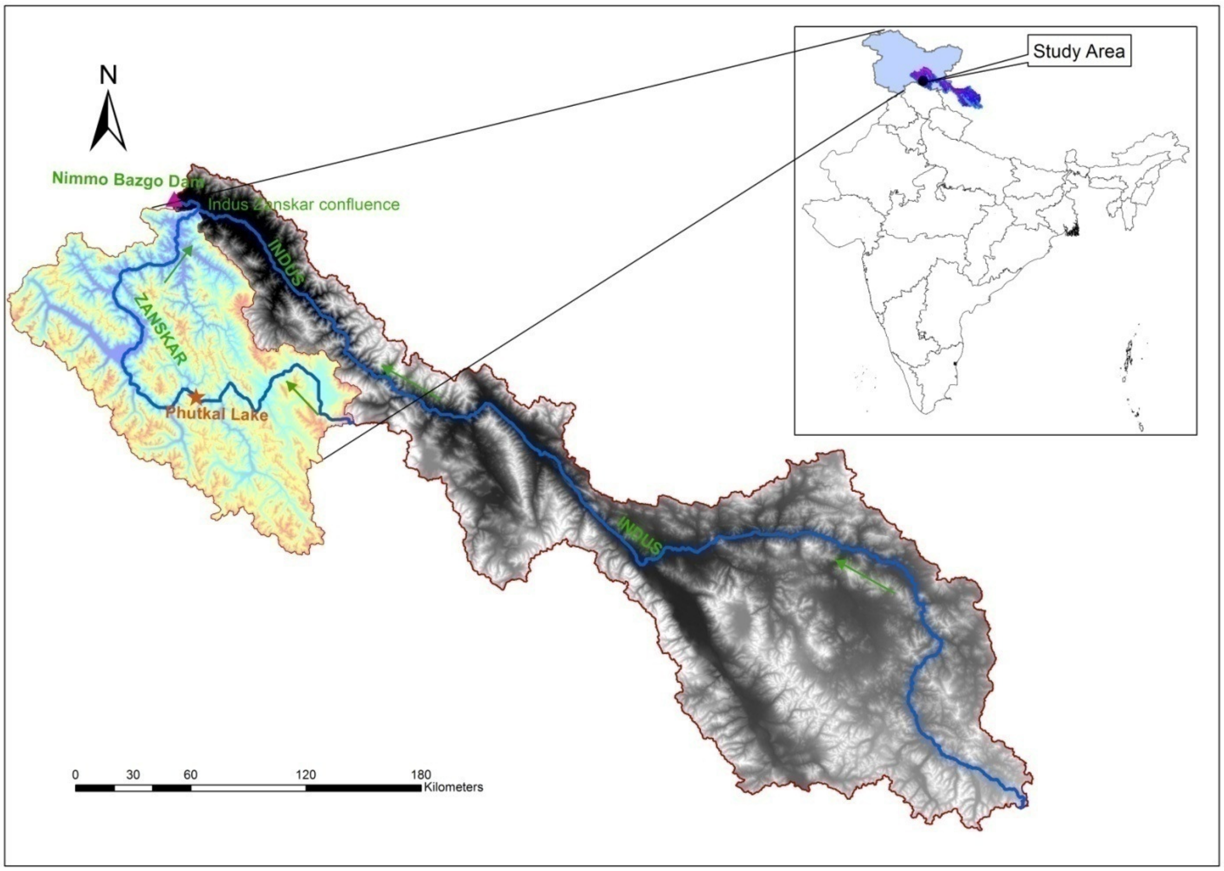

Figure-1: Study Area of the Landslide

2.1 Brief Description of the event

An artificial lake was formed on River Phutkal a tributary of River Zanskar due to landslide about 200 km upstream of Indus-Zanskar confluence probably on 31st Dec 2014. The slide debris thereafter blocked the flow of Phutkal and Zanskar river due to natural damming of the river. The latitude and longitude of land slide blockage is about 33^0 17' 57" N and 77^0 17' 23" E respectively.

Discharge of river Phutkal and further of river Indus suddenly decreased on 31st Dec 2014 and subsequently it came to the notice of Kargil district administration that the flow of river Phutkal has reduced due to the landslide over the river near village Marshum. The location of landslide is shown in Figure-2. A pre and post landslide image as per NRSC satellite data is shown in Figure-3.

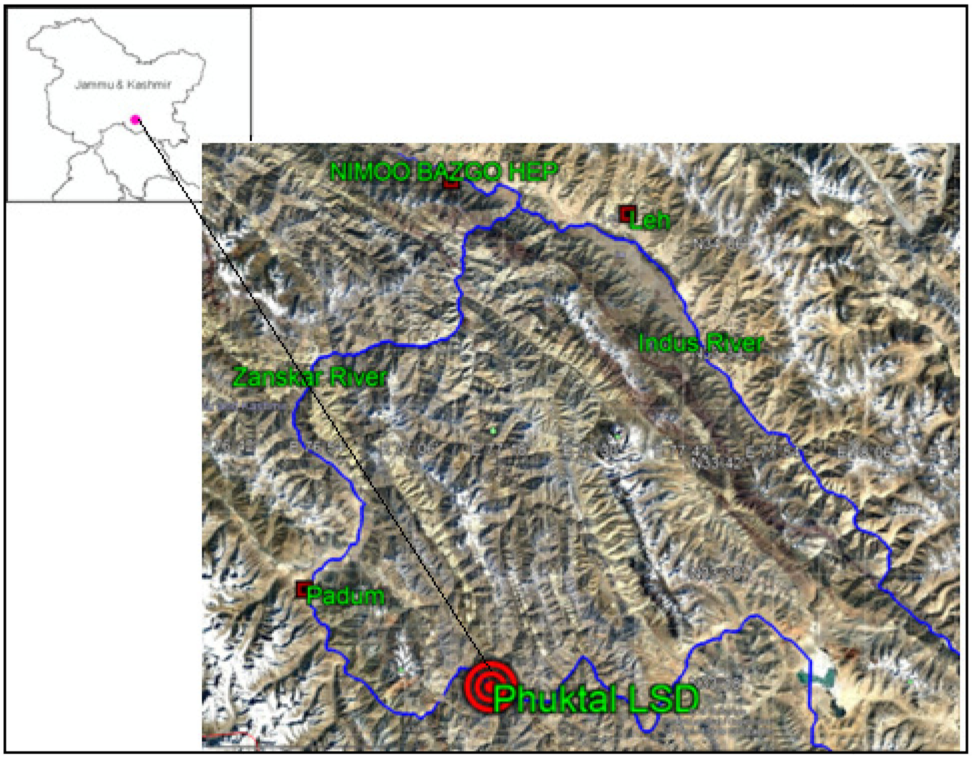

Figure-2: Location map of the Landslide

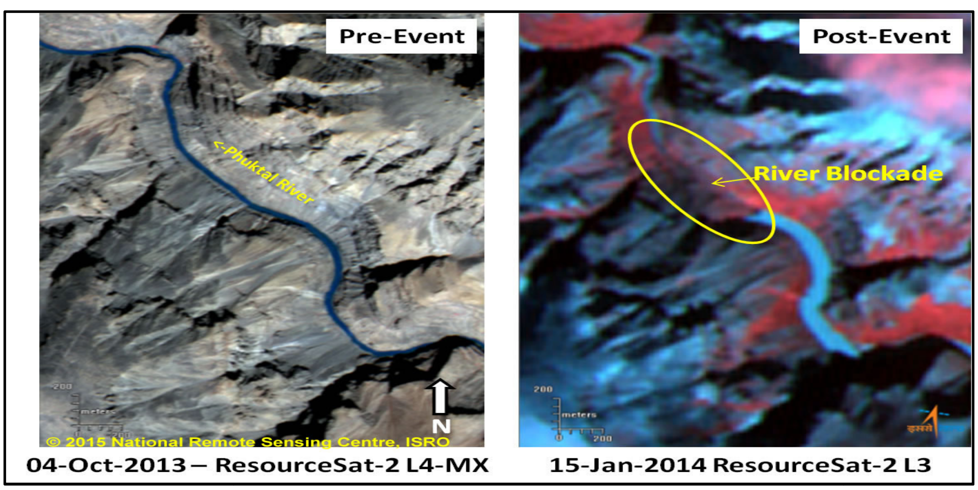

Figure-3: Pre and post landslide image of the Zanskar river

2.1.1 Dimensions of Landslide

Using multi date satellite data, NRSC provided necessary information on the landslide to the concerned government authorities. NRSC analyzed the high resolution (1 m) CARTOSAT-2 data of 20th January 2015 along with the DEM data of CARTOSAT and provided the satellite image of the landslide area. A High resolution satellite image showing detailed view of landslide and water impoundment is shown in Figure 4. The dimensions and some features of the landslide as well as impounded area are mentioned below and shown in Figures-5 (a) to 5(d):

- The landslide scar is observed and the length of the blockade created has a length of about 600 m and width of about 60 m .
- The length of the lake formed due to impoundment of water as per initial information was about 15 km with a surface area of about 55 Ha. Surface of the artificial lake formed was completely frozen.

As per preliminary analysis based on the dimensions of blockade coupled with differential discharge at Nimmo-Bazgo dam site due to blockade, the estimated volume of the artificial lake was worked out as 40 Mcum during Jan 2015.

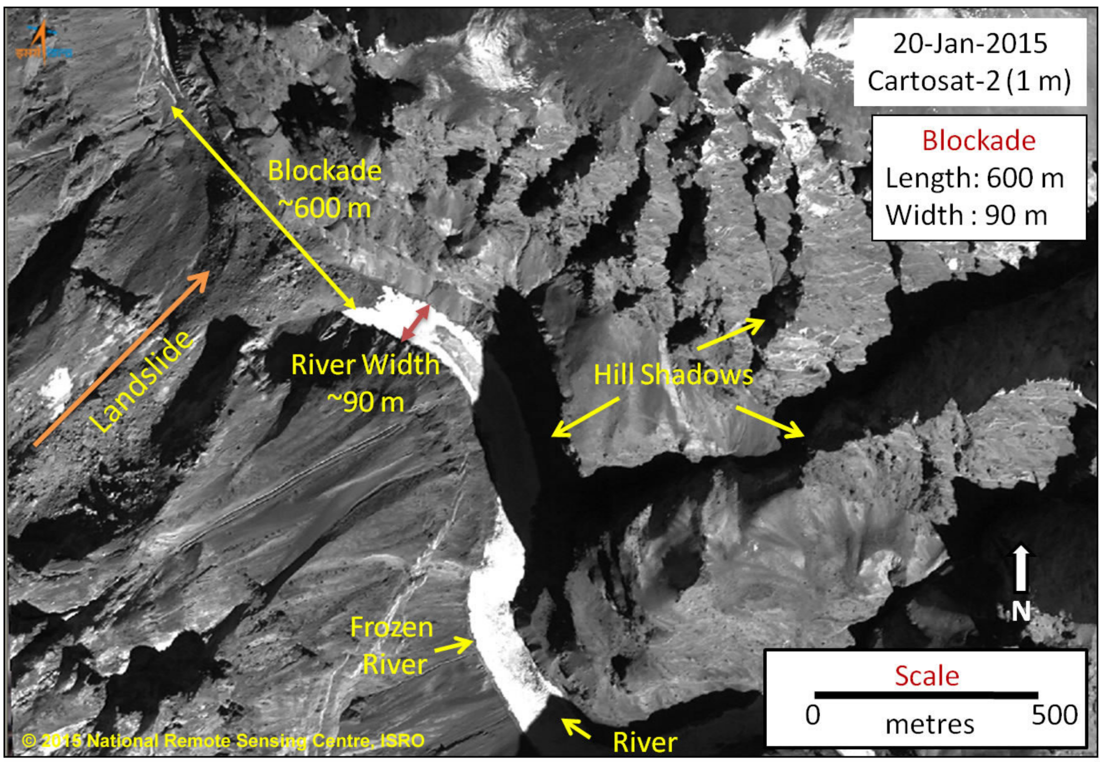

Figure-4: Satellite image showing detailed view of Landslide

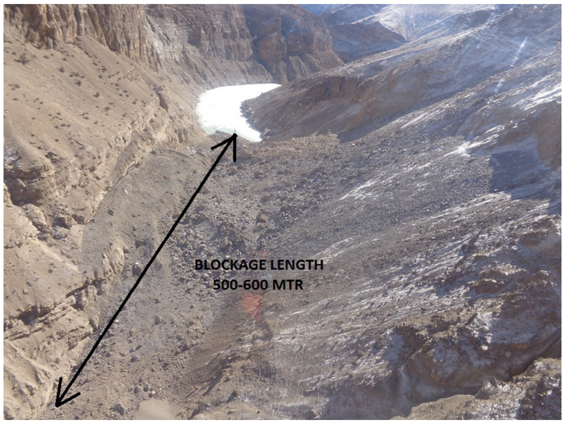

Figure-5 (a)

Figure-5 (b)

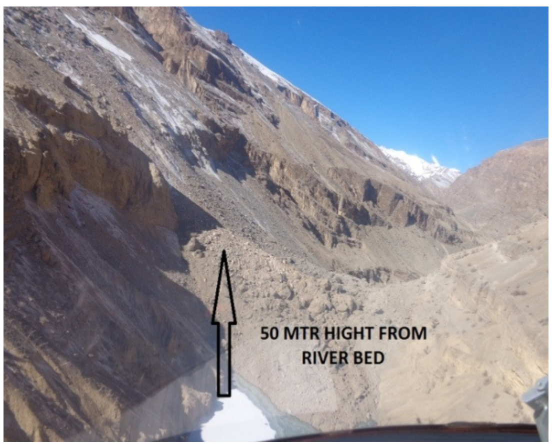

Figure-5 (c)

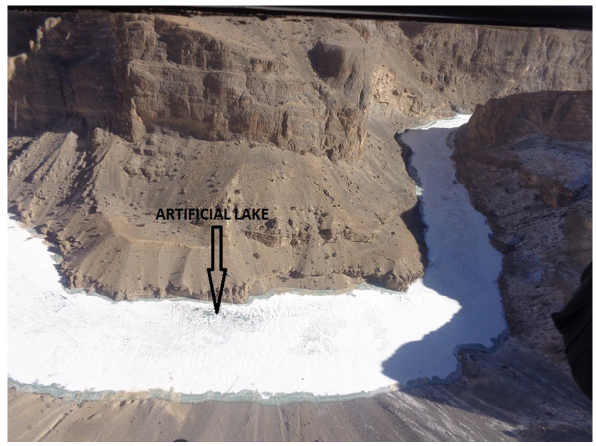

Figure-5 (d)

Figures 5(a) to 5 (d): Dimensions of the blockade and artificial lake formed

2.2 Breach Analysis

For the estimated volume of 40 Mcum in Jan 2015, the possible critical landslide breach analysis was generated to estimate the flood peak, its travel time and possible rise in river water level at various locations along the reach. Zanskar river meets Indus river at about 200 km d/s of the location of artificial lake and NHPC has a hydroelectric power project, namely Nimmo-Bazgo power station (45 MW) in the downstream on Indus river about 220 km from Phutkal and about 20 km d/s of Indus-Zanskar confluence. A preliminary study was carried out considering the following input data and limitations:

(i) The cross-sections along Zanskar river have been developed using 30m ASTER DEM from site of landslide upto Indus-Zanskar confluence at an interval of 4 km.

(ii) The breach parameters i.e. breach depth, breach width and breach time have been assumed on basis of some dimensions given by NRSC and also as per committee visit at site and others as used in similar studies. The breach depth, breach width and breach time have been estimated as 40 m, 60 m and 1 hour respectively.

Based on the above data dam break study was carried out to estimate the possible discharge reaching in the downstream reaches and expected water levels corresponding to those discharges using 1-D mathematical model MIKE-11. In this tentative study, it was estimated that in case of outburst of this artificial lake a discharge of about 1460 cumec shall be reaching at Indus-Zanskar confluence (approx near tail end of Nimmo-Bazgo reservoir) after a lag of about 11 hours. Thus it was expected that Nimmo-Bazgo power station may experience a discharge of 1460 cumec in addition to regular discharge coming from river Indus. The approximate depth of water along travel reach would vary from 2.0 m to 15 m depending upon the river geometry along the reach. A plot showing the travel time and possible rise in water level with respect to distance from blockage site is shown in Figure-6.

After two months in Mar 2015, the analysis was revised considering some increase in lake volume as the lake had not breached by that time and the water level behind the lake was increasing. Breach analysis considering the volume of lake as 50 Mcum was carried out and it was estimated that in case of outburst, a discharge of about 2142 cumec shall be reaching at Indus-Zanskar confluence after a lag of about 10 hours.

In the eventually of outburst of this artificial lake, there would have been sudden increase in discharge at Nimmo-Bazgo power station and therefore, suitable reservoir operation guidelines were being followed at the power station. The FRL and MDDL of Nimmo-Bazgo power station are EL 3093.0 m and EL 3090.0 m respectively and the live capacity of the reservoir as per Sep 2014 survey was 9.67 Mcum. The flood hydrograph reaching at Indus-Zanskar confluence due to outburst of artificial lake was routed through the reservoir for passing the flood safely in the downstream. Power station was advised to maintain the reservoir level at MDDL and for carrying out reservoir routing, the flood hydrograph was impinged at MDDL i.e. EL 3090.0 m and the spillway outflow curve was assumed in such a manner so as to contain the maximum water level within FRL i.e. EL 3093.0 m. As a precautionary measure, NHPC along with local administration had been monitoring the water level at various locations enroute Zanskar river, ever since the news of blockage first appeared.

In the month of February, an expert committee having members from CWC, SOI, NHPC, SASE, BRO & local administration was constituted under the aegis of National Disaster Management Authority (NDMA) who decided on a creation of a channel through the landslide blockade to drain out water from the artificial lake in a controlled manner. In March 2015, after a series of blasting and manual digging the team NDMA was able to create a narrow channel which resulted in controlled release of impounded water in the downstream. However, in Apr 2015, the flow through channel was reduced due to marginal collapse of debris into the created channel.

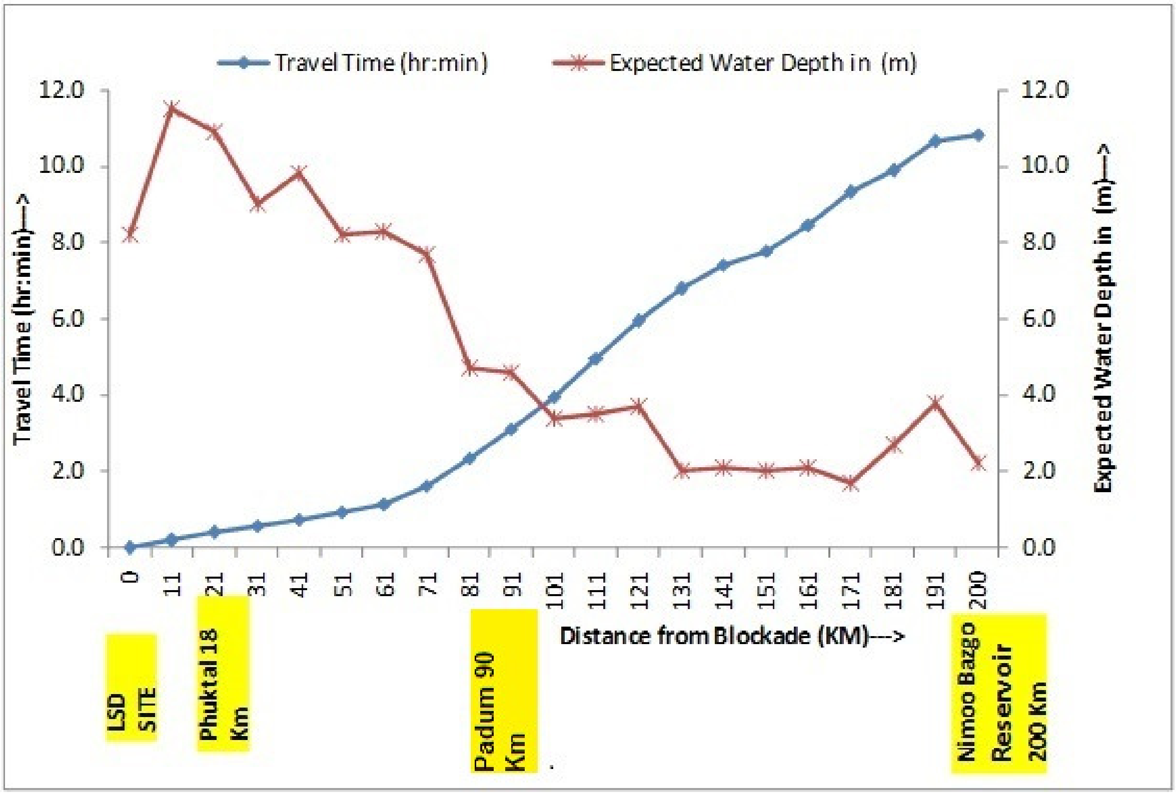

Figure-6: Plot showing the travel time and possible rise in water level with respect to distance from blockage site

3.0 LAKE BURST AND FLOOD MANAGEMENT

During summer, when the temperature started rising to about 15 degree, due to pressure induced by melting of snow, water finally started coming across the channel which was created earlier and on the morning of 7th May (about 5:00 AM) the artificial lake appeared to have busted and water started coming from the lake in an uninterrupted manner. The district administration sounded an alert in the area and villagers were asked to move to safer places in view of the possibility of heavy flow of water from the lake. NHPC also sounded alert in the areas falling in the vicinity of the dam and alerted people living near the banks of the river to move to safer places. Special teams were sent for announcement in nearby downstream area to alert people not to go near the river. A satellite image showing the landslide site before and after lake burst is shown in Figure-7.

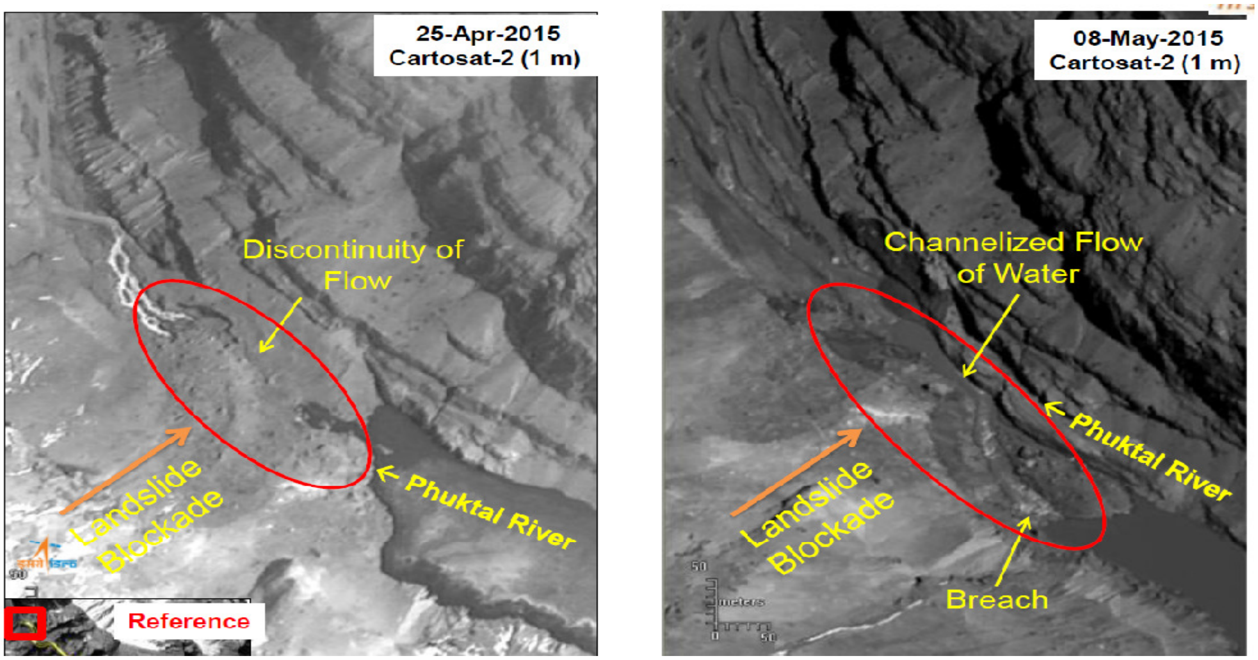

Figure-7: Satellite image of landslide location before and after lake burst

3.1 Flood Management at Nimmo-Bazgo dam

The inflow of water in the river was closely monitored at our Dam Control Room round the clock taking information from various locations in Padam, Chilling, Sangam and at dam site area. It was informed that water level at some locations rose upto 10 m due to sudden burst of lake. Accordingly, as a precautionary measure, reservoir level was kept low so as to accommodate the water coming from Zanskar river. The Power station was shut down at 2:00 PM and the complete system was kept on backup. The discharge kept on rising and the water reached Chilling (about 40 km upstream of the dam) at 4 PM where the water depth was about 6 m. Severe damage was caused to bridges and buildings in the upstream of Zanskar area and some motorable bridges were also washed away in flash flood.

Keeping in view the estimated volume of the lake and a lead time of about 11 hours, it was decided to lower down the reservoir level at Nimmo-Bazgo dam by 3 m below MDDL, which provided a capacity of about 16 Mcum. The peak inflow of about 2757 cumec received at Nimmo-Bazgo dam was moderated to around 1650 cumec which did not cause much damage in the downstream area. Since our initial estimates were based on volume stored over a period of about one month, the estimated figures of volume and peak discharge were on a little lower side. However, at the time of actual event as the water level was continuing to rise at a much faster pace it was decided during the rising limb of the hydrograph, which was very sharp, to increase the outflow through the dam in comparison to that envisaged earlier, so as to avoid the overtopping thereof. A plot showing the outflow hydrograph, reservoir levels and normal river discharge at Nimmo-Bazgo dam during the flood event is shown below in Figure-8.

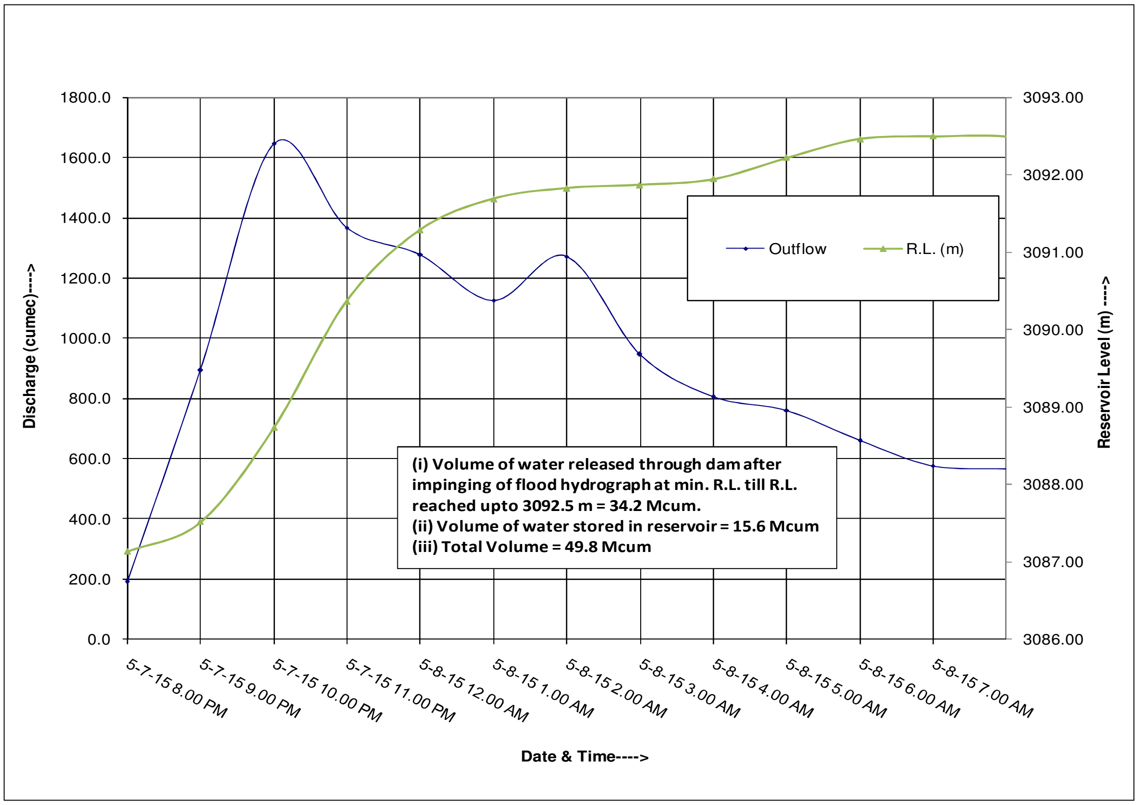

Figure-8: Plot of outflow hydrograph, reservoir level and normal river discharge

As per the above hydrograph, the total amount of water that was released by the artificial lake worked out to be around 49 Mcum upto 8:00 AM on 8th May where as the volume of water released through the dam after impinging of the flood hydrograph till the reservoir level reached upto EL 3092.5 m was about 34.2 Mcum. Timely action by NHPC by regulating the water level and round the control monitoring by our staff at various locations averted the major disaster and saved various villages and downstream areas. The flood volume was absorbed effectively by the reservoir such as the maximum outflow downstream reduced to 1648 cumec.

3.2 Effectiveness of advance disaster management plan at Nimmo Bazgo dam site

- Due to regular monitoring and advance warning systems in place there was no casualty. No loss of human life has been reported.
- Only inevitable damage was reported to low and small bridges and few small buildings near the river banks.
- Nimmo Bazgo dam helped in absorption of flood volume to an extent so as to pass a safe discharge in the downstream areas.
- It is worthwhile to mention here that during the cloud burst of August 2010 in Leh, a discharge of almost similar magnitude (around 2500 cumec) was observed at Nimmo-Bazgo dam site during its construction and it caused widespread devastation in the areas around the project. The debris and mudflows generated during this cloudburst caused extensive damage to life, property and infrastructure.
- During the lake breach event also, the mudflows and debris flows accumulated boulders, trees as the flow travelled along the Indus river and caused major destruction rather than the flooding itself in the reach between lake breach site and

Nimmo-Bazgo dam. Severe damage was reported to bridges and buildings in upstream of dam.

- By absorbing the flood volume at Nimmo-bazgo dam, a major portion of the accompanying debris and mudflow was also accumulated in our reservoir at the cost of loss in reservoir storage capacity, thereby averting a major disaster in the downstream areas and villages.

4.0 CONCLUSION

Landslide lakes are temporary lakes in the river valleys formed by landslide debris blocking the natural flow of river. Breaching of such temporary lakes with huge amounts of accumulated water and sediments can create devastating floods in the downstream areas. To reduce risk posed by breaching of such landslide dams, it becomes important to monitor the impounded lake continuously and assess parameters such as accumulated volume of the lake and maximum discharge released in the downstream along with its corresponding travel time. Due to presence of Nimmo-Bazgo dam it was possible to report the sudden decrease in the river flow at dam site and the same was brought to the notice of Kargil district administration and subsequently the occurrence of landslide in upstream reaches of Zanskar river was reported. Remote sensing techniques using satellite images were helpful in monitoring of this landslide dammed lake and estimating the lake width near the blockade, length and area of the impounded lake. Flood peak due to landslide lake burst and its travel timed estimated through 1-D hydrodynamic simulation using river cross-sections from open source DEM provided a reasonable assessment of the situation in case of lake burst which helped in formulation of effective reservoir operation plan for passing the flood safely in the downstream. The estimated peak discharge by NHPC of about 2200 cumec at Nimmo-Bazgo dam site after a lag of about 10 hours was reasonably close to the actual discharge observed at Nimmo-Bazgo dam after the lake burst. Regular monitoring and advance warning systems helped in reporting the breach of landslide dam as sudden increase in water level was reported along the river. Proper co-ordination by the project authorities among different agencies and regular monitoring of the landslide area made it possible to take timely action to avoid any serious disaster. Nimmo-Bazgo dam also accommodated the large inflow released due to lake burst by absorbing about 30% of the flood volume and 40% reduction in flood peak majority of the mud and debris flow which could cause much of the destruction more than that due to flooding. The discharge downstream of the dam was regulated through dam gates in a controlled manner and the river water level was closely monitored so as to avert damages to the life, bridges and houses in downstream areas which are densely populated. Timely action by NHPC by regulating the water level and round the clock monitoring by our staff at various locations averted major disaster and saved villages in the downstream.

5.0 REFERENCES

- Report on the Phutkal blockage flood and effect on Nimmo-Bazgo power station – report submitted to Indus Commission, MoWR by NHPC Ltd.
- Resource Manual of flash flood risk management, Dec 2012, ICIMOD.
- Press Release- Operation Phutkal, May 2015, National Management Disaster Authority.
- Mass movement events in the Himalaya: The impact of landslides on Ladakh, India, Sian Hodgkins, Geology for Global development.