Natural Disaster Preparedness for Hydropower Projects in High Mountain Environments

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1. Introduction

Geologically young and dynamically-active high mountain regions such as the Himalayas experience high levels of tectonic seismicity. Moderate to large magnitude earthquake can trigger rock and ice avalanches as well as multiple landslides. Heavy rainfall during the summer monsoon, compounded by cloudbursts, can also lead to landslides and mudslides and debris flows, all of which can wreak havoc on downstream communities and infrastructure. It is possible that changing climate is altering precipitation patterns as well as resulting in rising temperatures, especially within the High Himalayas. This is affecting glaciers and snowfields and melt-water run-off, which in turn impacts on river flow volumes, both during peak flood and low-flow periods. Thawing high-altitude permafrost is thought to result in more destabilisation of steep mountain flanks, which gives rise to catastrophic mass movement as seen by landslide activity. Mass-movements from mountain flank destabilisation can produce rock and ice avalanches that can impact into glacial lakes resulting in potentially highly-damaging Glacial Lake Outburst Floods (GLOFs).

Large-scale landslides, whether initiated for instance by earthquake activity or cloudbursts, can dam river valleys leading to impoundment of upstream river flow and the inundation of river-side communities and infrastructure. Should a landslide dam fail, severe flooding (Landslide Dam Outburst Flood, LDOF) can ensue with catastrophic consequences for many tens of kilometres downstream. Such torrents are not respecters of international borders and international co-operation is required to manage and mitigate such natural disasters.

Currently there is a significant amount of hydropower development being planned (>100 GW) and under construction to boost the generating capacity across the Himalaya-Hindu Kush-Karakoram region. However, as will be discussed below, many hydropower installations have been affected badly by natural disasters resulting in very significant economic losses, measured in the hundreds of millions of US dollars. Yet the hydropower industry has been remarkably slow in reacting to these issues, preferring either to ignore the risks or to hope that any damage can be managed under a maintenance programme. This is to completely ignore the possibility that such extreme physical events can lead to large-scale damage if not total destruction.

In February 2014, the Japanese Government and The World Bank launched a $20million/year, five-year *Program for Mainstreaming Disaster Risk Management in Developing Countries* in response to the *Sendai Report* published in 2012 (The World Bank, 2012). This major new initiative has come about following both the Great East Earthquake and Tsunami of 11th March 2011 that so badly affected Japan, and the rising trend in highly costly natural disasters across the globe. Of particular interest in this presentation is disaster risk management with respect to hydropower developments across the Himalaya-Hindu Kush-Karakoram region.

This presentation provides an introduction and broad-scale overview of some of the issues affecting the siting, design and construction of and long-term risk management for hydropower projects being developed in high mountain regions such as in the Himalayas-Hindu Kush-Karakoram region. It provides some recommendations for consideration by hydropower developers, their investors and funding bodies and national governments.

2. Background

On Monday 12th May 2008 a magnitude-8 earthquake struck in the Sichuan area of China resulting in the deaths of 69,125 people with more than 18,000 missing and 4.8 million people made homeless. The earthquake triggered over 40 valley-blocking landslides of which the most significant was that which occurred at Tangjiashan. The main landslide blocked the river and a lake formed behind it. Downstream two smaller landslides occurred and also blocked the river just upstream of the town of Beichuan, which had borne the brunt of the devastating earthquake. When the landslide dam breached the resulting flood swept downstream and impacted on a small hydroelectric power facility; the central sluice gates were swept away although the ones on the edge of the channel survived (Figure 1; Petley, 2009).

Figure 1: Remnants of the small hydropower structure downstream of the Tangjiashan landslide dam near Beichuan, Sechuan Province, China. The central sluice gates were swept away. (Photo courtesy of Dr Dave Petley).

On Saturday 5th May 2012, flash flooding in the Kaski district of northwestern Nepal resulted in the deaths of more than 30 people, including four Russian tourists, left dozens more missing and wreaked havoc along the downstream reaches of the river. It is thought that the source of the flood was an outburst flood from a landslide-dammed lake upstream in a tributary of the Seti River. This tragic event highlighted, yet again, the lack of awareness of some local communities. Early recognition of the dramatic unseasonal reduction of the river flow due to the landslide dam blocking the river upstream should have alerted local people to take immediate action to evacuate the riverbank areas.

In June 2013 in Uttarakhand in Northern India, 300 mm of rain fell in 60 hours triggering landslides, debris flows and at least one Glacial Lake Outburst Flood (GLOF) resulting in the loss of over 5,000 lives and massive damage over a very wide area. The sacred Hindu shrine at Kedarnath was destroyed (Figure 2). The $648 million Vishnugad-Pipalkoti Hydro-electric power scheme on the Alaknanda River also suffered damage. Investigations into the disaster are still ongoing with respect to gaining a better understanding of the physical event itself, the responses of the affected communities, and local authorities and responsible agencies. The implications of this, and potentially similar events, on the Vishnugad-Pipalkoti Hydropower Plant on the Alaknanda River are currently being reviewed.

Figure 2: The remains of the Kedarnath shrine after the June 2013 floods. The scar from the Glacial Lake Outburst Flood upstream of the town can be seen in the upper left of the photograph. A second debris flow struck from the other side (to the right of the shrine). (Photo courtesy: www.saharasamay.com).

On Saturday 2nd August 2014, a major landslide (Figure 3) crashed down onto a village killing over 150 people and blocked the Sun Kosi River in Sindhupachowk district, about 60 km from Kathmandu in Nepal. The landslide dam impounded the river, the level of which rose rapidly and formed a large lake upstream of the new dam.

Figure 3: The landslide that dammed the Sun Kosi River in Nepal on the 2nd August 2014 (photo courtesy the Nepal Army).

Several villages situated along the river were evacuated. The Sunkoshi hydropower project was shut down as a result of the flooding and a further two power stations downstream were also threatened. The Nepal Army undertook controlled explosions at the landslide dam to relieve the pressure on it but this resulted in high river flows downstream, which also caused damage. In response to the formation of the landslide-dammed lake, the Bihar Government in northern India issued a flood alert over four districts in the Kosi region. Also of concern was the major Kosi River Barrage located just south of the Nepal-India international border. This latest event highlights the need to have international cross-border flood management strategies and action plans so as to manage flood risks effectively.

Each of the examples provided above illustrate the large scale of such physical events, the extent over which the effects can be felt and the huge risks to communities and infrastructure, including hydropower installations. It begs the question: How can the hydropower industry be better prepared for such natural disasters?

3. Flood risk management

The Himalayan region is prone to flash floods that originate from cloudbursts, and failure of landslide- and moraine-dammed lakes from which the co-called Landslide Dam Outburst Floods (LDOFs) and Glacial Lake Outburst Floods (GLOFs) originate. GLOFs tend to occur during the monsoon months whereas LDOFs can be triggered by a variety of mechanisms including meteoric events (cloudbursts) and earthquakes. The occurrence of a GLOF is usually focussed on a single lake source and its downstream run-out. Whereas in the event of an earthquake or cloudburst multiple events can be initiated around the same time, as in the case of the 2008 Sichuan earthquake when over 40 landslides were triggered by the great earthquake. The Uttarakhand cloudburst in June 2013 affected a very wide area of northern India (thousands of square kilometres) simultaneously with multiple events throughout the area. This means that any risk management plans have to be effective at a variety of geographical and geopolitical scales – from dealing with an individual catchment, through to regional, multi-catchment events. Two questions here for the hydropower sector are: (1) How can such possible events be considered when planning, designing, constructing and maintaining high-value infrastructure installations; and (2) how can such disaster risk preparedness planning be incorporated into and made compatible with such plans for whole communities on different geopolitical scales?

Table 1: Triggers and geographic scales of various flooding event types.

Event trigger	Flooding events	Scale
Earthquake	Landslides and Landslide-Dammed Outburst Floods	Regional depending on the magnitude of the earthquake; multiple river catchments, thousands of km².
Cloudburst or exceptionally prolonged heavy rainfall	Landslide-Dam and Glacial Lake Outburst Floods, river and surface-water floods, debris flows, mudslides	Regional depending on the volume and duration of precipitation; multiple river catchments, thousands of km².
Rock-/ice-avalanche	Landslide-Dam or Glacial Lake Outburst Flood	Single catchment, run-out distances hundreds of km.
Ice-dam failure^	Ice Dam Outburst Flood	Single catchment, run-out distances can exceed 1,000 km.

^Ice dam failures can occur when a glacier surges and the rapidly advancing ice mass blocks a river impounding a reservoir upstream. Hydrostatic jacking or mechanical collapse of the ice dam releases very large volumes of flood water with very high peak flow rates. These events have been known to occur in the Hindu Kush-Karakoram region.

The issues associated with identifying the hazards and their triggers, assessing vulnerability and exposure in formulating an overall disaster risk management strategy at various geographical and geopolitical scales will be discussed in this presentation. Examples of assessing and managing glacial hazards in the Himalayan region have been given recently by Reynolds (2014a,b). Furthermore, results from an international workshop on *Glacier, Permafrost and High-Mountain Hazards and Risks*, being held in September 2014 in Turin, Italy, organised by the Glacier and Permafrost Hazards (GAPHAZ) Standing Group of the International Association of Cryospheric Sciences and the International Permafrost Association, will also be presented in this talk.

References

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Prof. John M. Reynolds holds a BSc in Geological Geophysics (Reading University) and a PhD in Glacio-geophysics (CNAA, Reading University and British Antarctic Survey, Cambridge). He has held posts at the British Antarctic Survey (Cambridge), Plymouth Polytechnic (now Plymouth University), and has run his own geological and geophysical consultancy company since 1994. He was appointed as an Honorary Professor at Aberystwyth University in 2005. He is currently a Member of the Advisory Board of the Glacier and Permafrost Hazards in Mountains (GAPHAZ) Standing Group of the International Association of Cryospheric Sciences (IACS) and the International Permafrost Association (IPA). He has been involved in many projects relating to glacial hazards for civil defence, climate change and hydropower projects since the mid-1980s in Bhutan, Chile, India, Kyrgyzstan, Nepal, Pakistan, Peru, and Tajikistan. He is currently Managing Director of his specialist consultancy company Reynolds International Ltd, UK.