Section 3

Discussion, Recommendations and Conclusion

Monjo village downstream of Imja Tsho, 1 June 2009

10 Monitoring, Early Warning and Mitigation

Risk results from a combination of the actual hazard and the vulnerability of people and their environment (United Nations 2006). Thus a risk can be minimised by lowering the level of hazard as well as by reducing vulnerability. Mitigation is the word used to describe actions to reduce the hazard and risk level.

A detailed discussion of mitigation is beyond the scope of this publication. But some of the major points and actions taken in Nepal are summarised in the following to indicate the possibilities. Some mitigation measures in Nepal have been described in Ives et al (2010).

Mitigation measures can be structural and non-structural. Measures include monitoring to provide an early indication of changes, early warning systems (EWS) to provide downstream residents and owners of infrastructure time to take avoidance action, and mitigation measures to physically change the situation and reduce the hazard and risk.

Nepal has made considerable progress in GLOF risk knowledge, risk assessment, monitoring, and early warning as well as some progress in mitigation measures. Some glacial lakes in Nepal are being monitored; early warning systems have been developed and installed in the Tsho Rolpa and Tama Koshi valleys as well as in the Upper Bhote Koshi area. Structural mitigation activities for GLOF risk reduction were carried out for Tsho Rolpa, but such measures are very expensive and it is unlikely that this approach could be utilised in the case of all 21 glacial lakes in Nepal that have been identified as potentially posing a risk of a GLOF.

Monitoring

Monitoring GLOF hazard levels requires a multi-staged, interdisciplinary approach using multi-temporal data sets. Key indicators include changes in the lakes and their impoundments which should be observed using different data sets at varying time scales to evaluate glacier hazard and stability of moraine dams. A considerable amount of information can be derived using remote sensing approaches to identify changes in lake size, and flight observation with small format cameras to observe lakes more closely. Monitoring of critical lakes may require direct periodic observation. To be effective, this should be carried out in cooperation with all stakeholders: communities, government departments, institutions, agencies, and broadcasting media, and others.

An automated monitoring system has been set up for Imja Tsho in partnership with DNPWC in Nepal, AIT in Thailand, and Keio University in Japan as a test for developing an early warning system (see Ives et al. 2010).

Early Warning

Early warning is defined as: "The provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid or reduce their risk and prepare for effective response" (United Nations 2006). For an early warning system to be effective, it must integrate four elements: knowledge of the risk, a monitoring and warning service, dissemination and communication, and response capability.

Early warning systems need to be technically sound, simple to operate, easy to maintain or replace, and reliable so that accurate and timely warning can be given. The human communication networks must be capable of relaying the warning to the appropriate authorities. Maximum effectiveness would most likely be achieved if the warning systems are placed in the hands of the local communities. The systems tested in Nepal have met with mixed success.

A manual early warning system was set up in the Tsho Rolpa area and downstream in 1997, when the army and police in the area were provided with communication sets, following considerable awareness raising activities. In 1998, a fully functional automatic system was put in place before mitigation work commenced on Tsho Rolpa (Reynolds 1999; Bajracharya et al. 2007). However, by 2002 the system was no longer operating, in part because local residents assumed that the lake had been lowered to a safe level. Damage also appeared to have incurred during the recent period of political unrest and as a result of new developments such as roads (Ives et al. 2010).

An early warning system was also installed in the upper Bhote Koshi valley near the Friendship Bridge on the Nepal-China border in eastern Nepal in 2001. This was intended to protect the Upper Bhote Koshi Hydroelectric Project. This system, however, has a lead time of only six minutes as the stations are all within the Nepal part of the catchment. To be really effective, sensors need to be installed in the Tibet Autonomous Region to cover the upper catchments. The system was still functioning in 2009, presumably because of the interest of the hydropower project (Ives et al. 2010).

Mitigation

There are several possible methods for mitigating the impact of GLOFs. The most important mitigation measure is to reduce the volume of water in the lake, thus reducing the magnitude of the possible peak discharge at the time of breach. Structural mitigation measures can also be applied downstream to protect infrastructure from peak floods.

The volume of water can be reduced by means of one or more of the following: controlled breaching of the moraine dam; construction of an outlet control structure; pumping or siphoning the water from the lake; and tunnelling through the moraine barrier or under an ice dam.

Preventative measures can also be carried out around the lake to secure against potential threats such as loose rocks or snow/ice avalanches that could trigger displacement waves.

Infrastructure downstream (diversion weirs, intakes, bridges, or river bank settlements) can be protected against a possible surge through proper construction that allows sufficient space for the flow of water and avoids damming. Bridges should have appropriate flow capacities at elevations higher than expected GLOF levels and the spans of piers should not be obstructed by uprooted tree trunks. Land use zoning should also be considered as an effective approach to mitigation by reducing the structures and elements at risk. Among others, settlements should not be built on or near low river terraces within the GLOF hazard zones. River banks with potential or old landslides and scree slopes near settlements should be stabilised and appropriate warning devices installed.

Tsho Rolpa is the only glacial lake in Nepal that has been subjected to mitigation measures. A siphon system installed in 1995 had only limited success. It was followed by cutting of an open channel through the moraine dam; the four metre deep artificial spillway completed in 2000 succeeded in lowering the lake level by three metres.

Awareness Raising

Besides monitoring lakes, it is essential to raise local awareness, and increase knowledge about how to respond. Community and local government bodies should focus on monitoring the lakes, mitigating their vulnerability to GLOF, and preparing to cope with such events should they occur: early warning begins with disaster preparedness. This involves raising awareness about glacial lakes, their characteristics, level of hazards, and the required responses during and after GLOF events.

11 Guidelines for GLOF Risk Management and Strategy in Nepal

Introduction

Glacial lakes in the Nepal Himalayas have been categorised and mapped systematically; nevertheless there are prevailing risks. Increased human pressure in high mountain areas in Nepal and growing socioeconomic vulnerability mean that GLOF risk management is needed.

Risk management in the broadest sense is defined as "the creation and evaluation of options for initiating or changing human activities or (natural and artificial) structures with the objectives of increasing the net benefit to human society and preventing harm to humans and what they value; and the implementation of chosen options and the monitoring of their effectiveness" (IRGC 2005).

In October 2009, a 'National Strategy for Disaster Risk Management' was approved by the Nepal Home Ministry. A qualitative change is visualised in this strategy document based on realisation of the need to mainstream disaster risk management into development activities and to shifting the emphasis from relief to preparedness. The document also proposes an organisational set up for a 'National Authority for Disaster Risk Management (NADRM)' under the Ministry of Home Affairs for implementation of disaster risk management plans. In addition, a 'Disaster Management Act 2009' was drafted and is in the process of promulgation.

The Government of Nepal adopted a 'National Action Plan on Disaster Management in Nepal' on 18 February 1996 in view of 1990-2000 being declared the 'International Decade of Natural Disaster Reduction' (IDNDR) by the United Nations General Assembly (Resolution 44/23622 December 1989). This has improved understanding and capacity in hazard assessment and mapping of recurring disasters and a component on disaster risk reduction has been included in national development plans. The Tenth Five Year Plan (2002-2007) and Three-Year Interim Plan (2007-2010) incorporated disaster risk reduction (DRR) and preparedness and mainstreaming of DRR components. Nepal has also ratified the Hyogo Framework for Action (HFA) 2005-2015, adopted at the UN World Conference on Disaster Reduction, Kobe, in 2005.

Other documents related to disaster preparedness and its policies in Nepal include the following:
- Natural Disaster Relief Act, 1982
- National Action Plan for Disaster Management in Nepal, 1996
- Tenth Five Year Plan (2002-2007)
- National Water Plan, 2005
- Water Induced Disaster Management Policy, 2006
- National Policy and Strategy for Disaster Risk Management, 2007
- National Strategy for Disaster Risk Management, 2009
- Disaster Management Act (draft)

Essential Components of GLOF Risk Management

The National Strategy for Disaster Risk Management (2009) refers to disasters in general: it includes GLOF risk but does not address it distinctively. National strategies and approaches to disaster risk management pay little attention to GLOF risk management, perhaps because information about it is inadequate. It is essential to develop short- and long-term action plans and programmes.

GLOF risk is difficult to predict and it is impossible to guarantee absolute safety, hence GLOF risk management is needed to minimise the loss of lives and property. For effective GLOF risk management, it is essential to define components and their relevant issues so that appropriate strategies can be established. The main components that need to be addressed are outlined in the following section.

Knowledge about risks

It is essential to know the GLOF risk in order to manage it properly. Thus continued assessment of GLOF hazard and vulnerability is an integral part of risk management; it requires the following:

a) Detection – mapping and classifying glacial lakes and ranking them using remote sensing and aerial photographs
b) Field visits to the potentially critical lakes to determine the GLOF hazard
c) Assessment of GLOF hazards in terms of magnitude and frequency, including mapping of GLOF hazard and flooding zones
d) Vulnerability assessment in the hazard zones; assessment of environmental and socioeconomic impact is essential for this
e) Risk mapping through an analysis of the possible interaction of a GLOF hazard and vulnerability

Monitoring risk

Effective monitoring is important for disaster preparedness and should involve use of remote sensing, aerial observations, and field study; it requires the following:

a) Regular repeated mapping of lakes using remote sensing and monitoring of key indicators of glacier and GLOF hazards
b) Regular investigation of the development of hazards and risk in a periodic manner including regular evaluation of the effectiveness of any mitigation measures implemented
c) Field-based monitoring of GLOF hazard and risk in critical lakes in the field
d) Regular monitoring of seepages, ice cores, and slope instability in the end moraine complex and of the stability of the natural moraine dam
e) Regular monitoring of exceptional input of drainage as discharge and debris from side valleys into the lake as well as discharge from the lake
f) Monitoring of lake storage volume, bottom of the lake, and shape
g) Regular monitoring of surroundings of lakes, e.g., hanging glaciers, for changes in snow mass, position, and slope instability to evaluate possibility of triggering

Preparedness

Preventative and precautionary measures are needed to minimise human and economic vulnerability. Prevention entails adapted use of space by trying to avoid hazards. Where this is not possible, structural, technical, or biological measures should be taken to minimise the intensity of the natural process (www.planat.ch, accessed 20 July 2010).

Early warning should provide information in time for response. The preparedness strategy should address as a minimum, but not only, the following:

a) Ensure that hazard maps are prepared of potentially dangerous lakes and their flow paths.
b) Land-use planning should determine development planning.
c) Structural mitigation measures should be undertaken to eliminate protection deficiencies.
d) Establishment of early warning systems is essential: one related to communicating changes in water level in the lake with community participation, and another in the form of a mechanical system with sirens.
e) Provisions must be made in legislation and policies so that infrastructure developers, especially private hydropower developers, are engaged in GLOF early warning and risk reduction activities.
f) GLOF risk reduction should be considered as a national as well as a local priority.

Community participation in risk reduction

Dissemination and communication of GLOF risk information and early warnings to individuals and communities threatened by hazards is an essential part of risk management. Decentralisation of risk management activities to communities and local authorities will encourage their ownership and participation at all levels. The following actions are necessary to ensure community involvement:

a) Communicate and disseminate at least the key findings of GLOF hazard and vulnerability mapping and risk assessment to key stakeholders at different levels – the community, VDC, DDC, and nationally.
b) Awareness creation programmes should be developed and implemented.
c) Community leaders should be trained on what to do, how to do, where to do, and when to do before, during, and after GLOF disasters. Training manuals should be prepared accordingly.
d) Put communities in charge of early warning systems so that they are properly maintained.

Transboundary dimensions

Impacts of GLOF are not limited within the borders of a country. In the past, many GLOF events that originated in the Tibet Autonomous Region of China caused heavy damage in the territory of Nepal. Hence, it is necessary to address transboundary dimensions of GLOF.

a) It is essential to ensure that the regional and international collaboration for GLOF risk mitigations deals with cross-border problems.
b) Mechanisms for inter-governmental collaboration in sharing data and information are essential: different levels of collaboration should be explored.

Institutional arrangements

Organisational arrangements should be made for appropriate GLOF risk management clarifying the roles of the key government agencies involved. A National GLOF Risk Reduction Fund should be established for research, awareness creation, design, implementation, and monitoring of mitigation and adaptation measures. For this, the following are necessary:

a) An institutional basis should be established to implement GLOF risk reduction activities.
b) Research to improve hazard management and capacity building should be promoted.

Issues and Activities of GLOF Risk Management

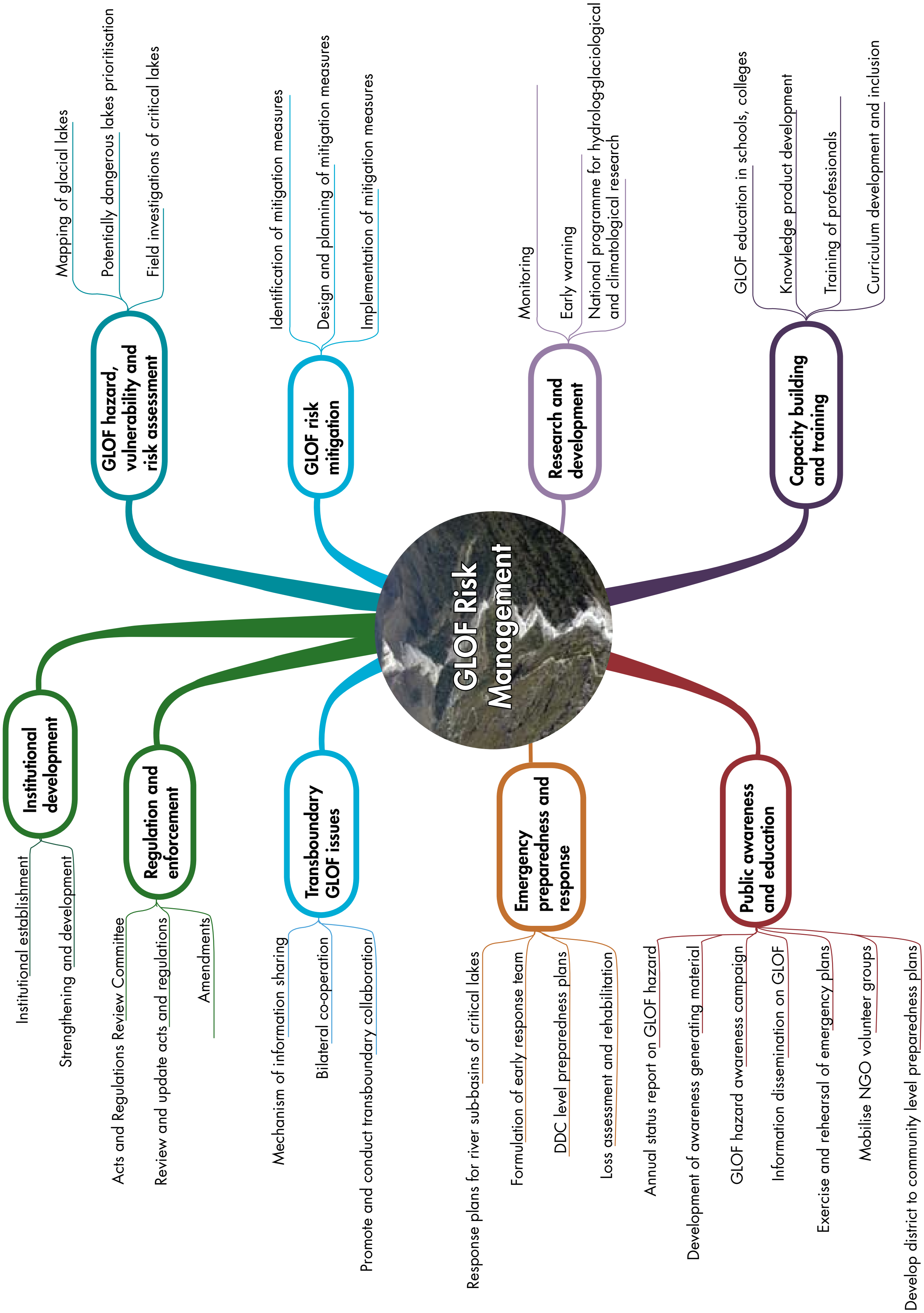
Issues ranging from knowledge of risks to institutional arrangements are required as a guideline for strategy development, including the following:

1. GLOF hazard, vulnerability, and risk assessment
2. GLOF risk mitigation
3. Research and development
4. Capacity building and training
5. Public awareness and education
6. Emergency preparedness and response
7. Transboundary GLOF issues
8. Regulation and enforcement
9. Institutional development

The systematic and coordinated activities related to these issues are illustrated in Figure 11.1. It is envisaged that the activities related to the components and issues will serve as guidelines for GLOF risk management strategies. Risk management is a continuous process and periodic evaluation of the dynamic processes of glacial lake formation and their expansion has to be monitored continuously. With the institutional development, the activities suggested here should be carried out in a five- or ten-year cycle and should include updating the inventory or mapping of lakes.

In developing the strategy for GLOF risk management, the components and issues mentioned above should not be dealt with in segregation. It is essential to note that these components are inter-linked and should be addressed with an integrated

Figure 11.1: **Issues and activities in GLOF risk management**



approach. The process must be developed such that there will be a feedback mechanism from one component to another. The integrated approach is illustrated with the help of a diagram (Figure 11.2) showing interlinkages and feedback mechanisms between and among all the components.

The GLOF Risk Management Plan should be embedded in the National Disaster Management Plan in accordance with the various disaster-specific guidelines laid down by the Ministry of Home Affairs/Government of Nepal and should incorporate the disaster management plans prepared by the central ministries and /or departments and district authorities for other disasters.

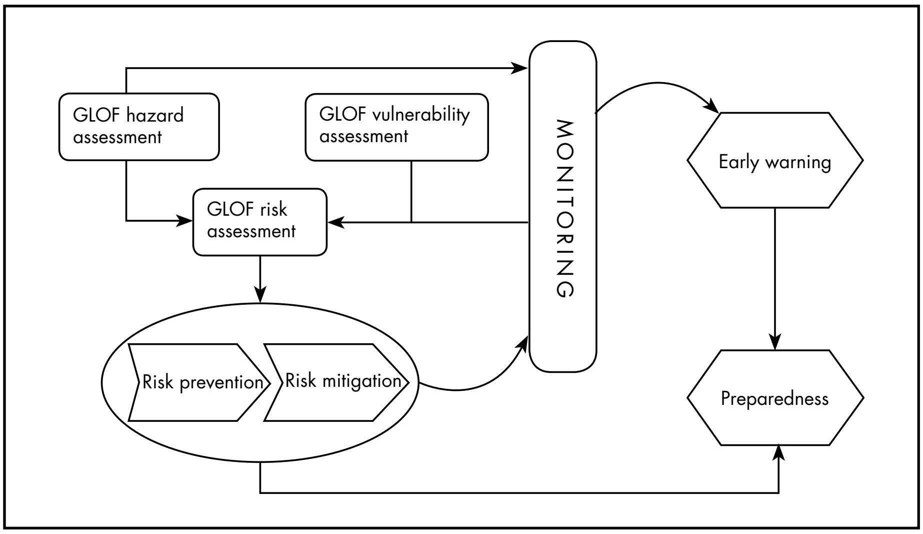


Figure 11.2: **Interlinkages and feedback processes between and among the components of GLOF risk management**
(modified after Stanganelli 2008)

Dona river downstream of Thulagi Lake at the junction with Marsyangdi river, 25 July 2009

12 Conclusions and Recommendations

The GLOF Risk in Nepal

The results in this report illustrate that, given the present state of knowledge, it is not possible to predict even approximate dates of occurrence or magnitude of risk posed by glacial lakes in Nepal. This represents the primary conclusion and leads to the quandary – how to respond to what is certainly a significant hazard? Serious loss of life and property has occurred in the recent past and the potential for future losses is high once a long-term view is assumed. At best, careful monitoring of existing glacial lakes and periodic search for the formation of new ones is essential. Stated without qualification, such a task would be overwhelming. Thus the report's findings, especially the methods employed to classify the existing lakes in terms of degree of perceived threat, is recommended as the most logical approach.

The study took a step-wise approach to ensure that coverage was as comprehensive as possible. At the same time careful deployment of the limited available manpower and financial resources constrained research, especially in the field, to be focused on a small number of the most critical lakes. These were identified during the first stages of the step-wise approach as illustrated in the foregoing chapters. Thus three of the largest existing lakes, Imja Tsho, Tsho Rolpa, and Thulagi Lake, were selected for intensive study. It is also important to emphasise that the three were all originally identified as critically dangerous. The current investigations, together with a survey of the more recent literature, have led to the conclusion that the earlier fears of imminent catastrophe were much exaggerated. This in itself is an important conclusion.

Although the three lakes have been evaluated as relatively stable, the possibility for a GLOF to occur sometime in the future cannot be dismissed. More than a dozen significant GLOF events have occurred since 1980 that resulted in serious loss of life and property. It seems likely that such events will occur again, particularly in view of continued atmospheric warming and the associated increase in volume of glacial lakes. Furthermore, expansion of infrastructure in the vulnerable sectors downstream means that the actual risk associated with an individual event is increasing. As with earthquakes, the difficulty lies not in predicting that such an event is likely to take place, rather the problem is that in the current situation it is impossible with any certainty to predict where such an event will occur, and whether this year, next year, or in the remote future. However, because such an event could be imminent, it is vital that steps be taken to mitigate against severe loss of life and property.

Chain reactions and the problem of small lakes

There is a further problem associated with the criteria used to select potentially critical lakes. Very small lakes were excluded from the study as posing little risk, with a recommendation to repeat the inventory at fixed-time intervals (e.g. 5-10 yrs). The recommendations of the Glacier and Permafrost Hazards in Mountains (GAPHAZ) Working Group emphasise that chain reactions and interactions must also be considered when assessing hazards and risk associated with glaciers and permafrost in mountains (GAPHAZ 2007). This applies as much to glacial lakes as to other hazards. The GLOF hazard assessments need to take into account possible interaction of processes or chain reactions as the implications can be complicated and far reaching. One of the many chain reactions that could take place in the Himalayas is that the outburst of a comparably small lake that is situated above another lake or lakes causes a flood and exceptionally large inflow into the other lake or series of lakes, which subsequently burst out. The total discharge of such a chain could be much larger than anticipated from analysing individual lakes only. The triggering lake could even be an erosion lake, considered secure, but squeezed out by an avalanche. This is one of the reasons why smaller lakes can actually pose a large hazard.

One example of this type of lake that has been identified is the Kabung Tshoding lake. The lake is situated about 500 m above the left lateral moraine of Tsho Rolpa. After traversing very long and steep mountain slopes, it drains into the left side valley of Tsho Rolpa. However, the lake does not have large masses of hanging glaciers that might lead to a surge that would overtop the moraine dam.

The Three Lakes in the Study

Each of the three lakes subjected to detailed study formed from the amalgamation of small melt-ponds on the lower sections of the glacier surfaces. Over the last 50 to 60 years, these expanded into large pro-glacial lakes more than a kilometre in length and up to 100 metres deep; some of the original glacier ice may still be present beneath the lakes. Thus immense volumes of water have accumulated. They present a difficult problem: they could cause significant damage should they burst; but they also offer a valuable form of water storage should they be managed appropriately. Of the three, Tsho Rolpa, despite being lowered artificially, is probably the most unstable as a result of its 216 m high and narrow end-moraine dam. However, the overall indication is that none of the three lakes is at immediate risk of bursting out.

All three lakes drain through their end-moraine dams along relatively stable channels, but all three are continuing to expand upstream into the retreating termini of their glaciers. The lake expansion itself is a major factor in the rapid retreat of the three glaciers, in addition to the direct impact of atmospheric warming. The potential for catastrophic outburst of these lakes depends on the stability of the end-moraine dams, and the effect of the slow melting of buried ice and permafrost within them. Seismic activity might also affect dam stability, but such activity is even more difficult to predict, and was not taken into account in this study.

Example of a chain reaction – Thorthormi and Raphstreng lakes in Bhutan

One of the striking examples in the Himalayas of a chain reaction posing a GLOF hazard is that of the Thorthormi and Raphstreng lakes located in the headwaters of the Lunana area in the Bhutan Himalayas. These lakes were studied in detail by Bhutan's Department of Geology and Mines (DGM) after it was realised that a GLOF resulting from the combination of Raphstreng Tsho and Thorthormi Tsho, which are situated adjacent to each other, would result in the release of 53 million cubic metres of water (Karma et al. 2008). The Raphstreng Tsho and Thorthormi Tsho are interconnected by a 30 m terminal moraine dam, with the Raphstreng Tsho lying 65 m below Thorthormi. Leber et al. (2002) warned that a GLOF resulting from a combined Thorthormi-Raphstreng outburst must be considered as a worst-case scenario. Furthermore, since the Raphstreng Tsho is closely located to the Lugge Tsho, the path of the likely Raphstreng Tsho flood outburst would be similar to the 1994 Lugge Tsho flood outburst.

In contrast to the three cases chosen for intense field investigation, all the recently recorded GLOFs in the Nepal Himalayas have issued from simple moraine-dammed lakes that accumulated behind end moraines of retreating 'clean-ice' glaciers. In each case, release was triggered by a surge wave caused by an ice/rock avalanche hitting the lake surface. The best-documented of these is the 1985 release of Dig Tsho, western Khumbu that destroyed the nearly complete Namche Small Hydel project (see chapter 2 above).

All three of the lakes studied have become tourist destinations. In addition, the access to Imja Tsho involves long stretches of the world-famous trekking route to Mt Everest (Sagarmatha) base camp. Thus, the possible occurrence of a major discharge from Imja Tsho during the trekking season could add several hundred lives to any accounting of the vulnerability of local people and infrastructure.

Awareness Raising

The local community needs to become more aware of GLOF hazards and ways and means to respond to warnings. It is important to continue dissemination of accurate information to the public, and raising of public awareness on glacial lakes and GLOF risk management, through a variety of means such as press reports, TV programmes, radio programmes, news articles, and scientific forums for public awareness.

Materials and knowledge products need to be developed to support awareness generation for different target groups, including school children – for example video films, brochures in local languages, and CD- ROMs. Exercises and rehearsal of emergency plan and programmes on escape, relief, and rescue from GLOF events can also help to raise public awareness.

During the surveys, close contact was maintained with the local people as a first approach to promoting awareness and encouraging future collaboration. The preliminary results of the surveys were discussed with the local communities in public events at each of the three sites, and summary leaflets prepared in Nepali were distributed.

Need for a National Policy

In view of the very high, if unpredictable, hazard involved, it is imperative that a national policy be developed for increasing awareness, early warning, and risk mitigation. This could then be used as a template for application to the entire Hindu Kush-Himalayan region. Furthermore, immediate action is urged along the following lines: increase of public awareness; more extensive vulnerability assessment; routine airborne and satellite monitoring; and more intensive and repeat geophysical survey. There also remains the inherent danger of trans-international border damage that requires international cooperation.

Region-wide cooperation throughout the Hindu Kush-Himalayas should follow, and it is recommended that steps be taken to organise a region-wide planning session for experts and leaders of relevant national institutions to develop a more coordinated approach and begin laying the foundations for a glacial lake outburst risk reduction policy.

Finally, despite the very high, although indeterminate, risks involved, the current tendency for grossly exaggerated reporting, in terms of both the imminence of possible catastrophe and its magnitude, should be severely discouraged.

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Acronyms and Abbreviations

AIT	Asian Institute of Technology
BM	bench mark
CAREERI	Cold and Arid Regions Environmental and Engineering Research Institute
DDC	district development committee
DEM	digital elevation model
dGPS	differential global positioning system
DHM	Department of Hydrology and Meteorology
DNPWC	Department of National Parks and Wildlife Conservation
DWIDP	Department of Water Induced Disaster Prevention
EWS	early warning system
GIS	geographical information system
GLCF	Global Land Cover Facility
GLIMS	Global Land Ice Measurements from Space
GLOF	glacial lake outburst flood
GPR	ground penetrating radar
GPS	global positioning system
ICIMOD	International Centre for Integrated Mountain Development
Landsat	Land Observation Resources Satellite (LANDSAT)
NEA	Nepal Electricity Authority
NGO	non-government organisation
RS	remote sensing
UNU	United Nations University
VDC	village development committee
WECS	Water and Energy Commission Secretariat
WGS 1984	World Geodetic System 1984

About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal
Tel +977-1-5003222 **Fax** +977-1-5003299
Email info@icimod.org **Web** www.icimod.org

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