6 Establishment of an Inter-country Regional GLOF Risk Monitoring Network

Many types of glacial lake have formed in the past in various parts of the world. In regions where mountain farming populations have lived for centuries and where accumulation of documentary records was customary, a long history of the dangers associated with the occasional outburst of such lakes has been preserved. Thus there are at least sporadic records of catastrophic events emanating from regions such as the European Alps, Scandinavia, and Iceland, going back several centuries. Most of these lakes, however, had formed as a result of advancing glaciers that blocked tributary, ice-free valleys. They are best classified as 'ice-dammed lakes'. They are quite distinct from the glacial lakes being considered here, but the accumulated knowledge of their development and periodic drainage is quite well known and relevant. More recently (late 19th and 20th centuries) glacial lake outburst floods have been documented in Alaska, British Columbia, and the Andes. Investigation of many of these occurrences has added to the volume of knowledge concerning this destructive phenomenon.

As the science of glaciology developed after about 1880, such ice-dammed lakes became objects of academic study (e.g., Ahlmann 1948; Thorarinsson 1939, 1940, 1943; Björnsson 2009). Iceland has experienced a special form of glacial lake outburst resulting from volcanic activity beneath several of that country's ice caps, especially Vatnajökull (Thorarinsson 1953; Björnsson 1974). Some of these 'jökulhlaups' have produced immense volumes of water estimated to exceed the flow of the River Amazon in full flood.

With the onset of climate warming about 1850-1905 (generally considered as the end of the Little Ice Age), glaciers in many parts of the world began to thin and their termini to retreat. Thus another form of meltwater lake became increasingly common – the frontal, supra-glacier, and/or moraine-dammed lake. The continued trend in climate warming, despite certain reversals (1960s and 1970s), has resulted in the formation of an increasing number of moraine-dammed lakes. This pattern either was not noticed or did not occur to any significant extent in the Himalayas until well into the second half of the 20th century. Although Kenneth Hewitt long ago recorded the occurrence of glacial lake outburst floods in northern Pakistan, these were ice-dammed lakes (Hewitt1982).

By the 1970s, there had been a number of outbursts from the supra-glacial/ moraine-dammed type of lake in the central and eastern Himalayas. They caused appreciable damage to people and property living in downstream lower lying areas. Despite this, there was no concerted government response. For Nepal, at least, 1985 proved a critical turning point, although even then wide appreciation of the significance of climate warming and the debate over its cause did not arise.

The 4 August 1985, catastrophic drainage of the moraine-dammed lake (Dig Tsho) that had formed behind the end moraines of the retreating and thinning Langmoche glacier in the eastern section of Sagarmatha (Mt Everest) National Park proved a pivotal event. Eleven kilometres downstream of Dig Tsho, an Austrian Aid hydro-electric facility (Namche Small Hydel Project) that was nearing completion was totally destroyed within minutes of the outburst. Over a distance of 60 kilometres, fourteen bridges, more than two dozen homes, and much agricultural land, were destroyed or damaged. That only four or five lives were lost was in part because the outburst flood coincided with traditional/religious celebrations so that few of the local people were near the affected river. The timing of the catastrophe also coincided with the summer monsoon hiatus in the trekking season (much of the Dudh Kosi drainage below the confluence of the Bhote Kosi and Imja Khola rivers carries long sections of the popular trekking route to the Mt Everest base camp – it would be instructive to complete a retrospective worst case assessment of potential loss based on the assumption that the outburst occurred at the height of the trekking season).

Nevertheless, serious local losses occurred for many months after the actual event due to continuing instability of sections of the valley slopes affected by passage of the flood/debris flow.

Coincidental with the Dig Tsho outburst flood, a United Nations University mountain hazards mapping project in the Khumbu (Ives and Messerli, project coordinators) was nearing completion. This project was operating in association with ICIMOD and included the field training of several young Nepali scholars (Ives and Messerli 1981). It ensured that a first-hand examination of the impacts of the outburst flood could be undertaken by two of the Swiss graduate student team members (Vuichard and Zimmermann). Much assistance was also provided by Dr Victor Galay, who at that time was serving as a consultant to WECS, Government of Nepal.

The extent of the damage and the overall shock of the Dig Tsho outburst prompted Dr Colin Rosser, then Director General of ICIMOD, to invite Ives to undertake an assessment of the event and to prepare a report for publication (Ives 1986). This was supplemented by scientific papers prepared by Vuichard and Zimmermann (1986, 1987).

Ives's report made a number of pertinent recommendations:

1. To identify and map other potentially dangerous lakes in the Khumbu
2. To apply currently available remote sensing technology to search for such lakes over a wider area as a response to the extreme difficulty of terrain access
3. To attempt the mapping of areas downstream of such lakes that would potentially be at risk as a basis for possible control on future land use
4. To undertake detailed field surveys of lakes that were thought to be especially dangerous
5. To develop an archive of replicated photographs as a means of providing a visual record of glacial lake development; it was recommended that permanent photo stations be incorporated into this process

An exploratory inspection of available air photographs and ERTS (Earth Resources Technology Satellite)/LANDSAT imagery led to the identification of an expanding supra-glacial lake on the surface of the Imja glacier a few kilometres south of Mt Everest. By chance, Ives had acquired photographs from the collection of his then deceased colleague, Professor Fritz Müller, who had taken several hundred photographs of the glaciers and glacial landforms during his participation in the 1956 Swiss Everest/Lhotse expedition. Several of them demonstrated that in 1956 no lake existed on the lower tongue of the Imja glacier, only several small melt ponds. In contrast, by 1985 it could be shown that a large lake had formed in the intervening period with a surface area of about 0.6 sq.km. This led to the first efforts to plot the development of what has since become known as Imja Tsho (or Imja lake), today identified as potentially one of the more dangerous lakes in the Himalayas (Figure 10).

In this manner, ICIMOD, in collaboration with WECS, became a lead institution in the Himalayan region to identify with the problem of glacial lake outburst floods. Due to lack of government interest and shortage of funds, there followed a period of reduced activity. Nevertheless, strong university interest persisted. Thus, graduate students who were working with Ives, and in particular, Ms June Hammond (1988), University of Colorado, USA; Dr Teiji Watanabe, now with Hokkaido University, Japan (Watanabe et al. 1994); and Dr Alton Byers, now senior scientist with The Mountain Institute, West Virginia, USA (Byers 2007), continued independent research on the progressive development of Imja Tsho. Much additional research has also been undertaken by Nagoya University, Japan (Fujita et al. 2009).

Revival of interest occurred with the realisation that the glacial lake Tsho Rolpa, situated in the watershed to the west of the Khumbu (Rolwaling Himal), was expanding rapidly and the lake level had risen so that it was draining across the lowest point on the glacier's end moraine. This led to a great amount of activity that had an effect on the economy of the lower valley. For example, some hundreds of people were temporarily evacuated. Because no lake outburst occurred, an attitude of disbelief and disinclination to take the situation seriously is reported to have emerged. Eventually, with foreign aid (Government of the Netherlands), a reinforced channel was constructed through the moraine dam, the lake level was lowered by three metres, and a small hydroelectric station and an early warning system were installed (see Chapter 4). Tsho Rolpa has remained semi-stable until this day; it is now classified as one of the potentially dangerous glacial lakes in the Nepal Himalaya.

Figure 10: **Repeat Photography of Imja glacier and lake, Nepal, at an interval of 50 years**

Imja glacier 1956 (Photo: Fritz Müller, archives of Alton Byers, The Mountain Institute, courtesy Jack Ives)

Imja glacier 2007 (Alton Byers, The Mountain Institute)

In addition, Dr T. Yamada and several of his Japanese colleagues undertook extensive field and airborne investigations in association with WECS (Yamada 1998a).

It is only during the last decade or so that there has been an understanding, at least at a generalised level, that there is probably a causal connection between contemporary climate warming and the creation of new glacial lakes and their sometimes very rapid expansion. During this period, ICIMOD has undertaken a series of investigations, deploying both field teams and employing increasingly sophisticated remote sensing. This work, discussed in the previous chapters, has produced extensive glacier and glacial lake inventories, originally for the the Nepal and Bhutan Himalaya (Mool et al. 2001a and 2001b), and subsequently, in collaboration with institutional partners, preliminary regional reports for most sections of the Hindu Kush-Himalayas. Concomitantly, a significant cadre of staff members has received training in the application of remote sensing techniques, together with a growing amount of fieldwork experience.

During the same period, the issue of potential catastrophe from the sudden outburst of glacial lakes has begun to receive extensive attention by the news media. Unfortunately, much of this news release has led to excessive claims of a doomsday nature, coupled with other melodramatic accounts of the deleterious impacts of climate warming on the Himalayan glaciers at large. Ives (2004, 2005) has published criticisms of several of these gross exaggerations. These exorbitant claims create a potential for significant damage – social, economic, and especially political. It therefore becomes even more urgent that a firm scientific base be created so that rational response policies can be put in place. Such responses need to be: prevention, in terms of reducing the potential for catastrophic glacial lake drainage (engineering interventions); installation of early warning systems; and collaboration with local people to ensure the best possible responses to early warning and mitigation activities and to adaptation. However, while steps can be taken immediately to approach these various objectives, it is vital that a much fuller scientific base be established so that the relationships between climate warming and glacier response be more completely understood. Consideration should be given to broadening the GLOF risk assessment approach to include analysis of the hydrological implications of climate warming as they relate to snow and glaciers and the supply of water downstream (Alford et al. 2009; Armstrong et al. 2009). Similarly, continual refinement in remote sensing techniques and their application are needed. All of these aims will require accelerated training of highly qualified applied scientists and technicians; enlargement of a long-term data base in hydrology, meteorology, and glaciology; specialised engineering; incorporation of local communities into the assessment and response systems; and development of partnerships amongst the many engaged institutions and universities across the region.

ICIMOD is uniquely placed to meet these demanding targets; to act in the forefront of research and its application; to assist with the training of a cadre of young professionals; and to perform its primary function as a lead partner and go-between amongst the several highly competent institutions and universities of the region, many of whom are already actively involved within their own sectors of the Hindu Kush-Himalayas. Finally, cooperation with the many scientists from beyond the region, who have had experience in relevant research, needs to be encouraged.

It is essential to utilise the most up-to-date methods to identify and to monitor continued development of glacial lakes and their short-term changes across the Hindu Kush-Himalayan region. This implies

1. assessment of latest developments in relevant remote sensing technology and imagery analysis;
2. review of work on glacial lakes completed to date;
3. update the inventory of institutions and individual experts within the region undertaking related studies;
4. recognise the heavy dependence on remote sensing applications because of the vast area involved and the great difficulties of ground access;
5. consideration of what attempts should be made to counter, through the news media and relevant government and international institutions, the dangers of over-dramatisation in current reporting on the assumed imminence of glacial lake outburst floods and their impacts; and
6. archive the latest scientific information to provide a base for national policy makers dealing with GLOF risk management and to share knowledge with the global scientific community.

Point (4) subsumes the critical importance of determining the advantages and limitations of remote sensing applications. It follows that an attempt is needed to produce a ranking of potentially unstable glacial lakes. It is now well established (Hambrey et al. 2008; Fujita et al. 2009; Watanabe et al. 2009) that the rate of glacial lake enlargement alone cannot be regarded as a reliable measure of instability. Thus the ranking proposed above should become a tool for determining the need for detailed field survey. Sufficient is now known about the factors that have a bearing on glacial lake stability that a check list of specific objectives for investigation in the field can be readily prepared:

1. Changing lake level and rate of change
2. Changing lake depth – results both from change in surface level due to increased inflow of meltwater (increase in level) or accelerated outflow due to cutting down of the lake threshold (lowering); melting of sub-lacustrine ice
3. Condition of dam (including soil mechanics, internal temperature – existence of permafrost, buried ice, and determination of rate of melting)
4. Determination of the lake water balance
5. Proximity of possible destabilising 'triggers' for inducing lake discharge, e.g., steep rock walls as sources of rock fall and ice and snow avalanches, condition of glacier terminus and estimated likelihood for collapse of glacier ice into lake; any large scale activity in these categories could cause a surge wave in a glacial lake that may have sufficient force to overcome a moraine dam (e.g., Dig Tsho, 1985)
6. Assessment of the potential danger of glacial lake outburst as induced by earthquake tremor is most likely beyond current competence

The feasibility of establishing an inter-country regional GLOF risk monitoring network is very high. The preceding sections of this report indicate that such a system is beginning to take shape. Bilateral collaboration, even trilateral, is already well advanced. Rapidly growing awareness of the seriousness of the widespread risk of catastrophic glacial lake outburst and the enormous attention that it is attracting from the various levels of the news media will surely accelerate this process.

Preliminary recommendations for future needs in relation to institutional partnerships and capacities for GLOF risk monitoring

ICIMOD is an international organisation with a regional mandate to partner organisations both within and outside government, including, non-government organisations (NGOs) and civil society, the private sector, and other international organisations. It can use its mandate to further cooperative developments across the region in terms of glacial lake mapping and GLOF risk assessment.

ICIMOD has already established significant partnerships with the national institutions of the regional member countries and has also established relationships with the international agencies such as ESA, GLIMS, GlobGlacier, NOAA (National Oceanic Atmospheric Agency), USGS (United States Geological Survey), National Snow and Ice Data Center, University of Colorado, USA, and Keio University. It is noteworthy here that ICIMOD has contributed to the GLIMS global initiative to monitor the world's glaciers by inserting the database of glaciers of Nepal generated in 2001 in the GLIMS database in 2008. ICIMOD has been designated as the regional coordinator of GLIMS.

The following two fundamental priorities have been identified during the 'Regional Consultative Workshop on Remote Sensing of the Cryosphere – Assessment and Monitoring of Snow and Ice in the HKH Region held from 31 May to 2 April in 2009' (ICIMOD 2009a, internal report):

1. To strengthen snow and ice cover mapping and the monitoring and mapping of the regional distribution of glaciers and glacial lakes
2. To establish links with global initiatives NSIDC (National Snow and Ice Data Centre)/GLIMS and WGMS) as well as local cooperation at sub-regional levels.

The inter-country network should ensure that appropriate data collection using satellite imagery is undertaken in a coordinated manner across the region, and the data collected used to develop a regularly updated map of glaciers and glacial lakes. This should be used for identification of risks, detailed studies outlining any mitigation measures that are necessary, and monitoring of changes.

Thulagi glacial lake, Nepal, IKONOS-2 image
from 14 November 2009 overlaid on Google Earth DEM