Section 1

Introduction to the Study

Imja Tsho with Mt. Ambulapcha in the background, 14 October 2010

1 Introduction

Background

For as long as historic records have been available, evidence has been documented that glaciers and glacial lakes have been a hazard to people and property located downstream. During the so-called 'Little Ice Age' (about AD 1500 – 1900), glaciers thickened and advanced and, in many instances, blocked side valleys causing river and meltwater to accumulate against an ice barrier. In some instances, as these glacial lakes grew, increasing hydrostatic pressure eventually caused the ice dam to lift or burst. In other instances, the lake level simply rose to overtop the ice dam. In either case, when the lake drained, either partially or entirely, the water which was released suddenly was destructive to anything in its path. This phenomenon was repeated at intervals as the glacier dam re-formed following the outbreak.

In regions such as the European Alps, Scandinavia, and Iceland such catastrophic events have been recorded for several hundred years, often in great detail. Comparable disasters have doubtlessly occurred in other mountain areas where they were either not recorded, or took place in areas that were uninhabited. Such hitherto unrecorded major events are now being detected by modern geo-scientific research.

The sudden drainage of ice-dammed lakes attracted scientific interest from the mid-19th century as the natural sciences developed rapidly. Some of the earliest attempts to relate such events to atmospheric warming and sea-level rise (post-Little Ice Age) were undertaken by Swedish and Icelandic scientists and this gave rise to the colloquial Icelandic term 'jökulhlaup' (glacier leap) entering the scientific literature (Thorarinsson 1939; Ahlmann 1948). Another, even more dramatic, form of glacier outburst which results from sub-glacial volcanic activity is also common in Iceland (Thorarinsson 1953; Björnsson 2009a, 2009b). Individual historic events (for example, the 1727 eruption of Öraefajökull), in conjunction with peak glacial activity during the Little Ice Age, were sufficiently catastrophic to threaten the very existence of Iceland.

After the mid-19th century, the world climate began to change. The maximum advance of glaciers occurred at different times in different parts of the world, ranging from the early 19th century to as recently as 1905. After this time, mountain glaciers globally began to experience overall thinning and retreat, with several decadal reversals and regional contrasts. This behaviour of glaciers so intrigued scientists that in the first half of the 20th century individual glaciers were selected for continuous annual mass balance and climatological study: included were several glaciers in Europe such as the Kårsa glacier in Arctic Sweden (Wallén 1949); somewhat later, the Peyto glacier in the Canadian Rockies (Østrem 1966, 2006; Østrem and Brugman 1991); and others in the Canadian High Arctic (Axel Heiberg Island, Fritz Müller). Fritz Müller's world glaciological vision led to the establishment of the International Inventory of Glaciers (Müller et al. 1977).

Many studies which systematically record glacier terminal positions have been carried out annually without a break until the present day. This large and growing bank of data provides vital information for critical determination of the impacts of current climate change. It is universally recognised by glaciologists and climatologists, however, that the number of 'indicator' glaciers is very small and that many mountain ranges have no adequate representative data sets. Furthermore, observations that are restricted to an annual recording of the position of glacier termini provide a very limited tool.

As a result of the fact that the world's glaciers are at present thinning and retreating, associated meltwater lakes are increasing in size and new lakes continue to be created. These lakes differ from the ice-dammed lakes which attracted scientific attention earlier, because they are predominantly supra-glacial and moraine-dammed rather than dammed by advancing glaciers. This type of lake is characteristic of many of the glacial lakes found in the Himalayas and they constitute the major topic of this report.

Despite the lack of systematic glaciological and climatological research, since the 1970s it has become increasingly apparent that, although there are conspicuous exceptions, the majority of glaciers throughout the Hindu Kush-Himalayan region have been thinning and retreating. Today it is generally accepted that this is a consequence of the atmospheric warming that is affecting glaciers worldwide. It is important to note, however, that overly close comparisons between the response of Himalayan glaciers and those in the European Alps, where long-term data sets are available, are not always productive. The major differences between the two types of glaciers are (1) the extremely high altitude of the glacial region of the Hindu Kush-Himalayas; (2) many of the longer glacier tongues are mantled by a heavy cover of rock debris for several kilometres upstream of their termini and have very low gradients – these characteristics are very significant in terms of glacial mass balance and the manner of wasting; (3) knowledge about the meso-scale and local (micro-scale) climatology of glacial environments is inadequate due to the scarcity of data from high-altitude meteorological and hydrological observations; and (4) despite a large amount of selective glaciological research, there are virtually no systematic, long-term records of mass balance in the Hindu Kush-Himalayan region.

Supra-glacial lakes often appear to merge with moraine-dammed lakes, or may develop contemporaneously as composite forms. In addition, their end moraines may be underlain by masses of dead ice which are remnants of earlier glacial expansion. Permafrost may also be present. Buried dead ice and permafrost strengthen the end moraines and reduce the risk of glacial lake outbursts to a great extent. Nevertheless, the current atmospheric warming also affects buried ice and permafrost. In any event, as these lakes increase in size and deepen, the presence of open water in contact with the glacier terminus further accelerates glacial retreat and thinning and may give rise to increasing instability.

Meltwater lakes are potentially unstable; the sudden catastrophic release of water from such a lake is known as a glacial lake outburst flood (GLOF). In Nepal, little attention was paid to this phenomenon until the sudden outburst of the Dig Tsho (Tsho = lake), a glacial lake in the western section of the Sagarmatha (Mt Everest) National Park, Khumbu Himal, on the 4th August, 1985.

When the end moraine dam of the Dig Tsho collapsed, the water from the lake drained into the valley downstream over a four-hour period, wreaking destruction as it went. This sudden outburst destroyed the nearly completed Namche Small Hydel facility, some 11 km downstream and caused other losses as far as 50 to 60 km downstream. Somewhat ironically, Dig Tsho was not typical of the large glacial lakes that have formed supra-glacially, but was one of the smaller 'clean-ice' glacial lakes. The outburst event was triggered by a large ice and rock avalanche that cascaded into the lake from a steep glacial surface: when it splashed into the lake it produced a surge wave. The surge overtopped the end moraine and caused it to collapse, discharging an estimated 6 - 10 million cubic metres of water into the valley below. The outbreak of Dig Tsho caused more than three million dollars worth of damage and disrupted the downstream community of Khumbu for several months. The alarm bells sounded by this outburst event put in motion a plethora of scientific investigations, including, surveys, research, and preliminary estimates of downstream vulnerability among others. The Water and Energy Commission Secretariat (WECS) of the Nepal Government, the International Centre for Integrated Mountain Development (ICIMOD), and the United Nations University (UNU) collaborated in the work that eventually produced the first detailed assessment of a GLOF event in Nepal (WECS internal report 1987; Ives 1986; Vuichard and Zimmermann 1986, 1987).

The Dig Tsho event showed that it is not necessarily the largest lakes that are the most dangerous, and that even small lakes may cause serious damage, especially if there are populated areas and infrastructure located near the hazard source. In the decade after 2000, several outburst floods from small lakes were reported in the western part of the Teskey Ala-Too range, Tien Shan, Kyrgyzstan. In this region most glacial lakes are small. For example, Zyndan Lake in the Tong District of Ysyk-Köl Oblast, Kyrgyzstan, formed rapidly over two and half months (from early May to late July 2008), and with an area of only 0.0422 sq.km, burst on 24 July. The GLOF from this small lake killed three people and numerous livestock, destroyed infrastructure, and devastated potato and barley crops as well as pastures (Narama et al. 2010). Such disasters highlight the fact that the downstream vulnerability might be as important, or more important, than the actual volume of water released.

After the initial flurry of scientific activity that immediately followed the Dig Tsho event, there was a partial hiatus in GLOF-related investigations in Nepal until the late 1990s, when it was noticed that Tsho Rolpa, a large glacial lake at the terminus of the Trakarding glacier in Rolwaling Himal could be close to overtopping and destabilising its end moraine. This led to mitigation efforts that included the construction of an artificially reinforced channel which was cut through the end moraine to allow the level of the lake to be lowered by three metres (Rana et al. 2000, Richardson and Reynolds 2000). This also marked the beginning of a determined response to the threat of GLOF activity in Nepal.

Other, non-structural measures, such as remote sensing, were started and led to region-wide identification and mapping of the glaciers and glacial lakes that seemed to be forming in large numbers (Mool et al. 2001a; 2001b). At the outset, this work focused on Nepal and Bhutan. Subsequent work in collaboration with various institutions within ICIMOD's member countries led to completion of a preliminary inspection of the entire Hindu Kush-Himalayan region (Mool and Bajracharya 2003; Bhagat et al. 2004; Sah et al. 2005; Roohi et al. 2005; Wu Lizong et al. 2005).

In a next step, supported by The World Bank Global Facility for Disaster Reduction and Recovery (GFDRR), and with additional support from the Swedish International Development Cooperation Agency (Sida) and the Norwegian Ministry of Foreign Affairs, a detailed multistep risk assessment methodology for glacial lakes was developed and used in collaboration with national partners to assess the hazard posed by glacial lakes in Nepal. This publication provides a detailed account of the results of the study; additional material, including the GIS database, is provided on a DVD included in the back pocket. Some preliminary results were also provided in Ives et al. (2010).

Objectives of the Study

The present study had two main objectives:
1. to develop recommendations for adaptation to, and mitigation of, GLOF hazards in Nepal, concentrating on a small number of lakes perceived as especially critical, and
2. to assist the Government of Nepal in developing an overall strategy to address possible risks from GLOFs in the future.

This two-fold objective requires both an assessment of the extent to which specific glacial lakes are unstable, and an analysis of the degree to which people and property downstream are vulnerable. The overall approach requires strengthening of partnerships among key stakeholders including local people, major private and community corporations, government agencies, non-government organisations (NGOs), and tourist-oriented businesses, among others. This work will contribute to the development of an overall strategy for GLOF risk management which will include a more precise identification of the hazard as well as early warning and mitigation measures. As the physical attributes of glacial lakes are similar throughout the Hindu Kush-Himalayas, it is hoped that the results of this work can also be applied to other parts of the region.

GLOF Risk Assessment Methodology

A step by step approach has been developed and applied for GLOF risk assessment. A schematic representation of the methodology of this approach is shown in Figure1.1. It begins with the mapping of glacial lakes and the study of the existing inventory.

Once the glacial lakes are mapped, they are then identified as either potentially dangerous or not, based on a set of defined criteria. The labelling of the lakes at this step does not include categorising the vulnerability of the downstream areas.

The next step involves ranking of the potentially dangerous lakes and setting of priorities for further detailed investigation. For this, the physical condition of a lake related to its stability is assessed by taking into consideration its area, the characteristics of the associated glacier, any changes in boundary conditions, and the stability of the surrounding terrain. Downstream socioeconomic parameters must also be obtained (Figure 1.1).

Socioeconomic parameters include settlements, the number and type of bridges and roads, number and capacity of hydropower projects and the distances to these, the area of agricultural land, location of other important infrastructure, and any other activities of economic value. Repeated observation from low-flying aircraft is a rapid reconnaissance tool which provides an overview of changes and assists in the identification of vulnerable settlements and infrastructure to help assign priority to areas at the hydrological basin level. Thus, aerial observation is an important step in the ranking of potentially dangerous lakes.

After ranking, typically only a few lakes will be given high priority for detailed follow-up investigation through either desk-based or field studies.

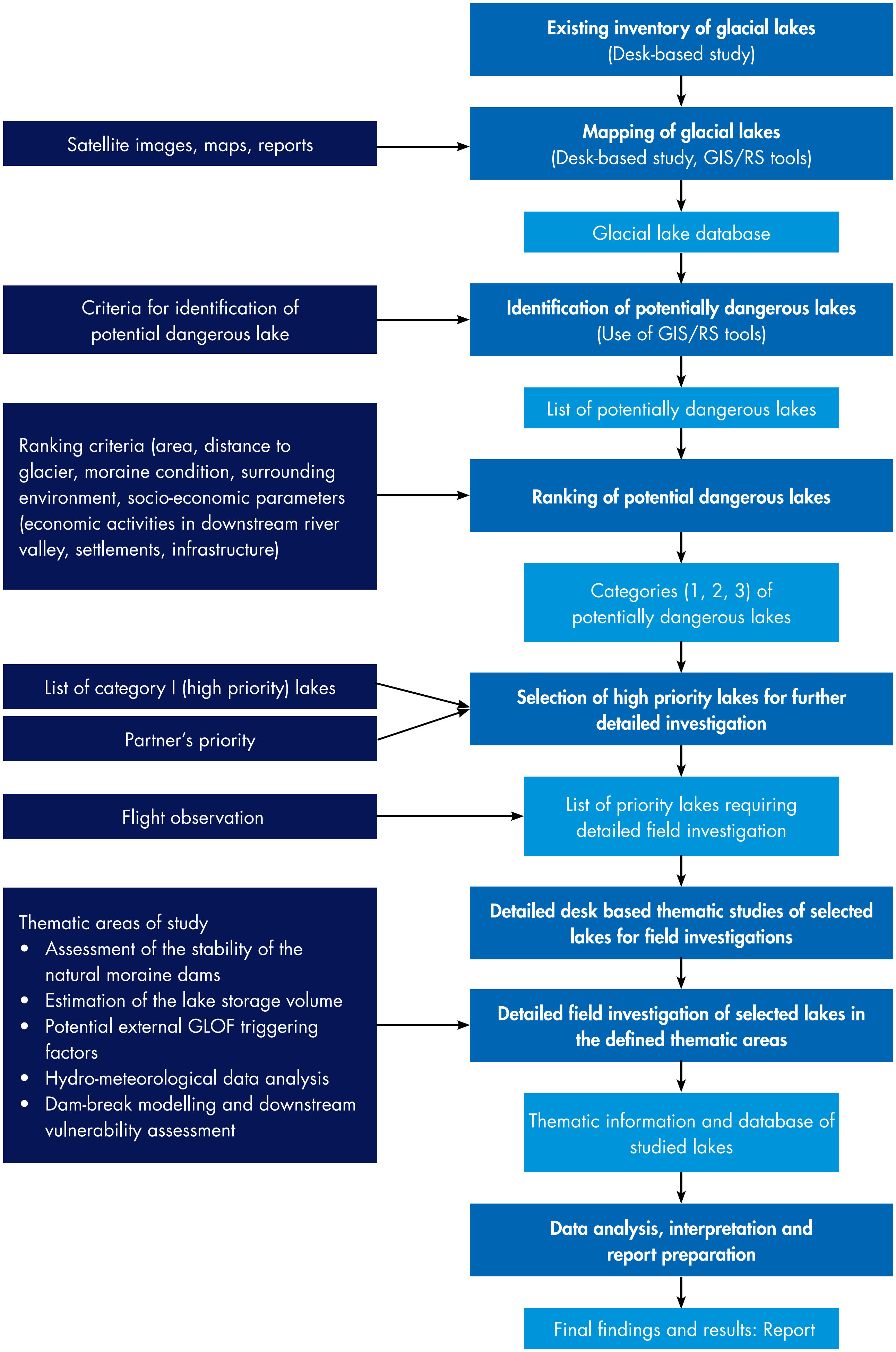

Figure 1.1: **Flow diagram of the step-by-step approach for GLOF risk assessment**

The next step in the risk assessment is the desk-based study of the high-priority lakes selected in order to identify the data gaps and any specific characteristics to be emphasised during the following field study.

The detailed field investigation should focus mainly on the following aspects: estimation of the stability of natural moraine dams; determination of a lake's storage capacity; potential external triggering factors; hydrometeorological data analysis; modelling a potential dam outburst; and carrying out a downstream vulnerability assessment. For overall GLOF risk management, the magnitude of the hazard is directly related to the downstream vulnerability appraisal (Figure 1.1).

Analysis and interpretation of the results obtained from these studies should lead to improved understanding of the overall physical and socioeconomic risks from a GLOF. This will enable recommendations to be formulated for GLOF hazard management and risk mitigation measures.

Design of the Nepal Study

In order to fulfil the objectives outlined above, the step-by-step methodology was applied systematically in collaboration with partners including institutes of the Government of Nepal, academic institutions, international organisations, and other key stakeholders. A Steering Committee was formed on 5 November 2008 to provide overall guidance and support for the project with representatives from Nepal's Department of Hydrology and Meteorology (DHM), Department of Water Induced Disaster Prevention (DWIDP), the Ministry of Home Affairs (MoHA), the Water and Energy Commission Secretariat (WECS), and ICIMOD. An inception workshop was held on 12 November 2008 to formulate the detailed project activity plan. The workshop was attended by representatives of government organisations, academic institutions, international NGOs (INGOs), and private institutes.

As an integral part of the investigation, several workshops and consultative meetings were organised at ICIMOD in Kathmandu. This ensured guidance for project implementation, field planning, and acquisition of equipment, as well as for dissemination of the findings from the field investigations. It also provided guidance for development of a strategy for GLOF risk management. Three workshops were held in the corresponding districts of the three lakes selected for intensive study in order to share information derived from the field investigations. This proved an effective arrangement for obtaining feedback from local communities and stakeholders. Similarly, two national workshops were organised at ICIMOD in order to facilitate dissemination of information on the project progress. The open discussions that ensued served to enhance project performance. Feedback was also obtained from various experts.

Specialised members from partner institutions participated in the field investigations and contributed to the preparation of the technical reports. This helped to reinforce the capacities of the Nepalese institutions. Dissemination of the experience and information gathered during the field investigations to stakeholders, partner institutions, and local communities through a series of workshops and seminars helped to create awareness not only at the grass roots level but also among local government organisations and other stakeholders. Interaction with local communities and local government organisations, such as the district development committees, also helped to create an awareness of the project's findings and draw attention to the fact that glacial lakes also constitute a potential natural resource that should be incorporated into local land-use planning.

The present report was prepared as the final step, summarising different aspects of the findings of the project and the wider implications for dissemination to a broad audience. The report contains a summary of the information on mapping of glacial lakes, databases, field-based investigation information, and issues related to GLOF monitoring, early warning, and mitigation. It also includes general guidelines for the formulation of a strategy with regards to GLOF risk management. With the involvement of the appropriate regional partners, it is hoped that the methodology developed and applied in this project can be extended to similar GLOF-prone areas in other parts of the Hindu Kush-Himalayan region.

Dudh Koshi below Imja lake showing remains of damage from the Nare GLOF event in 1977 and Pangboche village on the right bank of the river, 24 April 2009