Chapter 13
Conclusions

Databases of the glaciers and glacial lakes of Nepal, based on medium- to large-scale topographic maps, have not been developed prior to the present study. For the glacier inventory the study used the methodology developed by the Temporary Technical Secretary for the World Glacier Inventory (Muller et al. 1977), and for the glacial lake inventory, the methodology developed by the Lanzhou Institute of Glaciology and Geocryology (LIGG) (LIGG/Water and Energy Commission Secretariat (WECS)/Nepal Electricity Authority [NEA] 1988) was used with modification. The present methodology for the compilation of inventories of glaciers and glacial lakes of Nepal is applied using medium-scale maps.

The topographic maps published by the Survey of India in the 1950s–1970s on a scale of 1:63,360, based on aerial photographs and field verification, are the only map series that cover the whole of Nepal on a medium scale. Based on this map series, spatial and attribute databases of glaciers and glacial lakes were developed.

Creating inventories of and monitoring glaciers and glacial lakes can be done quickly and correctly using a combination of satellite images and aerial photographs simultaneously with topographic maps. The multi-stage approach of using remotely-sensed data and field data increases the ability and accuracy of the work. The integration of visual and digital image analysis with a geographic information system (GIS) can provide very useful tools for the study of glaciers, glacial lakes, and Glacial Lake Outburst Floods (GLOFs).

Analysts' experiences and adequate field knowledge of the physical characteristics of the glacier and lake and their associated features are always necessary for the interpretation of the topographic maps, satellite images, and aerial photographs. Evaluation of spectral responses by different surface cover types in different bands of satellite images is necessary. Different techniques of digital image enhancement and spectral classification of ground features are useful for the study of glaciers and lakes. Different spectral band combinations in False Colour Composite (FCC) and individual spectral bands were used to study glaciers and glacial lakes using knowledge of image interpretation keys.

The Digital Elevation Model (DEM) is useful to decide the rules for discrimination of features and land-cover types in GIS techniques and for better perspective viewing and presentations. A DEM suitable for the present study of the whole country is not yet available.

The inventory of glaciers and glacial lakes of Nepal as a whole is divided into four major basins, namely, the Mahakali, Karnali, Gandaki, and Koshi Basins from west to east. Among the basins only 35% of the

Mahakali River Basin lies within the territory of Nepal and comprises 87 glaciers with an area of 143 sq.km and an estimated ice reserve of 10 km^3. The Karnali River Basin consists of 1,361 glaciers 1,740 sq.km area and an estimated ice reserve of 128 km^3. The Gandaki River Basin consists of 1,025 glaciers covering an area of 2,029 sq.km with an ice reserve of 191 km^3. Similarly the Koshi River Basin comprises 779 glaciers with an area of 1,410 sq.km and an estimated ice reserve of 152 km^3. There are 3,252 glaciers altogether, which cover an area of 5,322 sq.km with approximately 481 km^3 of ice reserves within the territory of Nepal. The largest glacier found is Ktr 193 located in Tamor Sub-basin. It has an area of 94.52 sq.km and is of the valley type.

Prior to the present study, there was hardly an inventory of lakes of the country. In the present study, lakes at an elevation higher than 3,500 masl are considered as glacial lakes. Some of the lakes inventoried are isolated and far behind the ice mass, which may or may not be the glacial origin. The Mahakali River Basin within the territory of Nepal consists of 16 lakes, the Karnali River Basin consists of 907 lakes, the Gandaki River Basin consists of 338 lakes, and the Koshi River Basin contains 1,062 lakes. Altogether 2,323 glacial lakes were identified in Nepal. The largest glacial lake found is (Kbh_gl 10) (Phoksondo Tal) located in the Bheri Sub-basin. It has an area of 4.528 sq.km and is of the valley type.

Altogether 21 GLOF events were identified by the present study, of which nine events occurred in the Tibetan catchment of rivers flowing into Nepal. Dates of only 14 GLOF events are known. Out of these, five GLOF events occurred inside Nepal. The 14 GLOF events were described and in some of them damage was also quantified.

The study of glacial lakes in Nepal started in 1985 after the outburst of Dig Tsho Lake on 4 August 1985. So far six lakes have been studied, of which Tsho Rolpa Glacial Lake is the only one where detailed study and mitigation measures have been carried out.

The characteristic features of the identified potentially dangerous lakes in general are:

- moraine-dammed glacial lakes in contact or very near to large glaciers,
- merging of supraglacial lakes at the glacier tongue, such as Tsho Rolpa Lake of Tama Koshi River Basin and West Chamjang Lake in the Dudh Koshi River Basin,
- some new lakes of considerable size formed at glacier tongues such as Lower Barun Lake,
- lakes rapidly growing in size, and
- rejuvenation of lakes after a past glacial lake outburst event.

All these potentially dangerous lakes have been classified into the following three categories.

Category 1: Potentially dangerous glacial lakes without a record of past GLOF events

Category 2: Potentially dangerous glacial lakes with past outburst events

Category 3: Potentially dangerous glacial lakes identified in the inventory but posing no danger at present based on GLOF events in the past

It was found that 16 lakes belong to category 1, three lakes to category 2, and seven lakes to category 3. Out of these, three lakes have been found with known outburst events, and six GLOF events were seen in satellite images. Two more outburst events (Nare and Chubung) were noted in satellite images that were not formed or mapped during topographic mapping in the 1960s.

Altogether 20 glacial lakes are identified as potentially dangerous; and these include 16 glacial lakes in category 1, 3 glacial lakes in category 2, and 1 glacial lake (Lower Barun) not shown in the topographic map tabulated in the 1960s. It is recommended that these lakes are subjected to further field survey and investigation.

Among the potentially dangerous lakes, the only lake for which mitigation measures are taken is Tsho Rolpa. As a mitigation measure, an appropriate method for lowering the water level was chosen. For the mitigation work at Tsho Rolpa Lake, the major funding is from the Netherlands Government (US $2,988,625) and His Majesty's Government of Nepal (HMGN) contributes US $115,414. Mitigation of a Tsho Rolpa GLOF will be achieved only when the lake level is lowered by a total of 20m, phase-wise, i.e.

by discharging 35 million m^3 of water through gated canal openings. In its first phase the lowering was planned for 3m through a gated canal 3m deep and 70m long along the moraine dam. The first phase of mitigation work was completed by the end of June 2000.

There are several possible methods for mitigating the impact of GLOF surge, for monitoring, and for early warning systems. Careful evaluation by detailed studies of lakes, mother glaciers, damming materials, and the surrounding conditions are essential in choosing the appropriate method and in starting mitigation measures.