Chapter 6

Early Warning Systems and Mitigation Measures

Early warning systems aim to detect impending GLOFs in sufficient time to relay a warning to people who might be affected so they can move to safer ground. Mitigation measures aim to reduce the risk by intervening to somehow change the physical structure. Different types of early warning systems and mitigation measures are in place in Nepal and Bhutan. Examples of early warning systems and mitigation measures from the Tsho Rolpa and Bhote Koshi valleys of Nepal, and Lunana region of Bhutan are described.

Early warning systems

Early warning systems in the Tsho Rolpa and Tama Koshi Valleys, Nepal

Tsho Rolpa is one of the most extensively studied glacial lakes and has received extensive media coverage. The Department of Hydrology and Meteorology Nepal (DHM) installed an early warning system in the villages of the Tama Koshi valley to warn people living in downstream areas. The GLOF early warning system, installed in April–May 1998, consists of two main components: a GLOF sensing system and a GLOF warning system.

GLOF sensing system

The sensing system detects the occurrence of a GLOF and transmits relevant information to the transmitter station to initiate the warning process. Six water level sensors are installed at the river channel (immediately downstream of the lake outlet) at Sangma Kharka to detect the onset of a breach. The sensors are connected by armoured and shielded cables to a transmitter station (Figure 6.1) located at a higher elevation within a distance of 80m from the sensors. In the event of a GLOF, the system detects and immediately relays the information. The information is received by all warning stations located downstream within two minutes of initiation of the flood. The warning system is fully automated, redundant and requires no human intervention.

The remote station at Naa village has the dual function of forming part of the GLOF sensing system and providing local warning to the residents of Naa. The warning system is functioning, but there have been a few minor occurrences of false alarms due to shorts caused by moisture in the electrical system.

Figure 6.1: The transmitter station of Sangma Kharka outside Lake Tsho Rolpa receives signals from sensors and transmits to other remote warning stations.

GLOF warning system

A series of 19 GLOF warning stations and relay stations are installed at the 17 villages in the Rolwaling and Tama Koshi valleys (Naa, Bedding, Jyablu, Gongar, Jagat, Totalabari, Bhorle, Singati, Pikhuti, Nagdaha, Nayapul, Sitali, Kirne, Khimtibesi, Haldibesi, Manthali and Rajagaon) (Figures 6.2, 6.3, and 6.4). In addition, a meteor-burst master station has been installed in the city of Dhanagadhi in western Nepal. The master station provides a communication link between remote stations located in the Rowaling and Tama Koshi valleys and the system monitoring station located in Kathmandu.

The GLOF warning systems are based on Extended Line of Site VHF radio technology (Bell et al. 2000). An early warning signal is triggered automatically when a GLOF is detected. Each village has an Meteor Communication Corporation (MCC) 545-transceiver unit mounted on a 4.67m self-supporting standard galvanized iron power pole. The master station has a phased array of four receiver antennas and one transmitter antenna. It receives signals from and sends signals to the remote stations via signal-reflected off-ionised meteor trails in the upper atmosphere. The operation of this component of the communication system is equipped with a computer. The station is connected to the local AC power supply with automatic switchover to and between two backup diesel generators.

An antenna is mounted on an extension to the pole and approximately 5m above the ground. Also mounted on the pole are a lightning rod and a solar panel. The MCC 545 unit, battery, and relay for the horn are mounted inside a sheet metal box with a lockable shelter attached to the pole (Figure 6.5). All cables are protected by a plastic conduit, covered by galvanised sheet metal and strapped to the pole. An air-powered horn is backed-up by an electric horn. The air horn is designed to operate off a charged air cylinder for a period of two minutes with a reserve for an additional one to two minutes in the event. The electric back-up horn will operate for four minutes. The air horn provides a sound of 80dB up to a minimum distance of 150m under the most adverse conditions (Bridges 99, 2001).

Figure 6.2: Early warning system installed at Gongar village. The systems consist of a solar panel, battery, antenna and amplifier with siren.

Figure 6.3: The early warning system installed at Bhorle village

The remote stations are powered by a 12V battery charged by a solar panel. The power for beyond the 'line-of-site' VHF signals as well as system configuration guarantees that any particular warning station can receive or transmit signals to the two immediately upstream and two immediately downstream stations. This ensures that a temporary failure at any particular station does not interrupt the transmission of warning signals to other villages. The system is automatically monitored hourly for battery voltages, forward and reverse transmit power, and sensor status from data monitoring stations at Khimti and in Kathmandu.

Figure 6.4: The early warning system installed at Jagat village

The master station has a phased array of four receiver antennas and one transmitter antenna. It receives signals from and sends signals to the remote stations via signal-reflected off-ionised meteor trails in the upper atmosphere. The operation of this component of the communication system is equipped with a computer. The station is connected to the local AC power supply with automatic switchover to and between two backup diesel generators.

A somewhat different and more intensive warning system is needed either during those short time periods when construction projects are taking place or for other reasons when greater risk is identified. For example, during the 1997 construction of the Tsho Rolpa GLOF Risk Reduction Project (TRGRRP), which aimed to lower the lake level by 3 metres, such early warning systems were installed in the Rolwaling and Tama Koshi valleys. These were housed at the army camps (lakeside) and at the police posts of the Naa and Bedding villages. Each army camp and police post was provided with a high frequency (HF) radio transceiver, and the army post at Naa had a backup set as well. The police posts and the army camp in Naa were in regular radio contact with their respective headquarters in Kathmandu. The army posts were also provided with satellite telephones. The army post at the lakeside used one of the phones to contact the Disaster Prevention Cell at the Home Ministry twice a day to deliver status reports. In the event of a GLOF, Radio Nepal, the national broadcaster, would broadcast a warning. (Radio Nepal was a natural choice since its signal is received in most at-risk places along the valley.) After completion of the first phase of the TRGRRP, the HF radio transceiver was removed from all the army camps and police posts.

Figure 6.5: An MCC 545 unit with 12 V batteries, air cylinder, and MCC-545A RF modem for relay, mounted inside a lockable shelter

Figure 6.6: GLOF Sensor and early warning system in the Bhote Koshi, (a) Sensor at River Level, (b) Sensor at Friendship Bridge, (c) Early warning system siren

Early warning system in the Upper Bhote Koshi valley, Nepal

The early warning system installed in the Upper Bhote Koshi Hydroelectric Project (UBKHEP) is similar to the one that is part of the TRGRRP. There are two remote sensing stations with data loggers near the Friendship Bridge designated to receive, analyse, and transmit data from sensors. When the water level increases significantly, the system transmits evacuation warning signals to the warning stations installed at the intake and the powerhouse (Figure 6.6). The fully redundant warning systems consist of seven GLOF detection sensors at the Friendship Bridge, one ultrasonic water level measuring device, and six float type water level switches (Figure 6.7). It operates on short-burst VHF radio signals using meteor burst technology. As a result, warning sirens are set off from compressed air horns, which transmit the sound of 127 dB at a minimum distance of 100 feet. There are five such stations along the river.

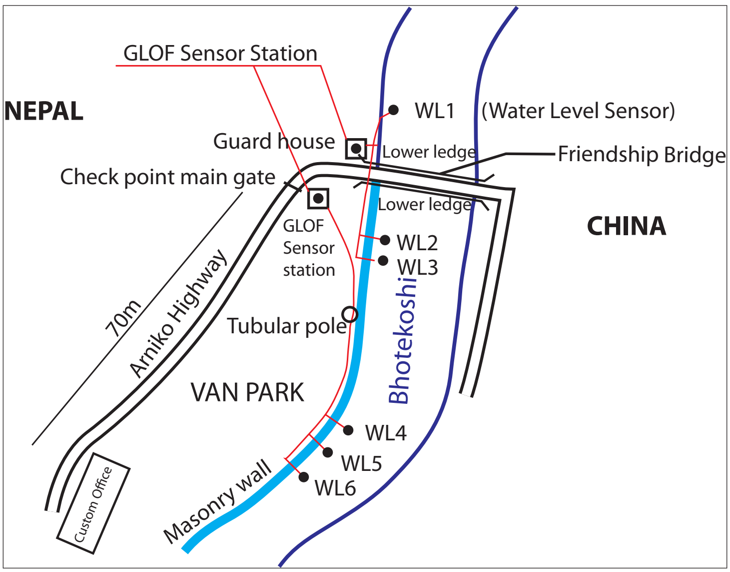

Figure 6.7: Location map of the GLOF sensor stations installed in the Bhote Koshi valley

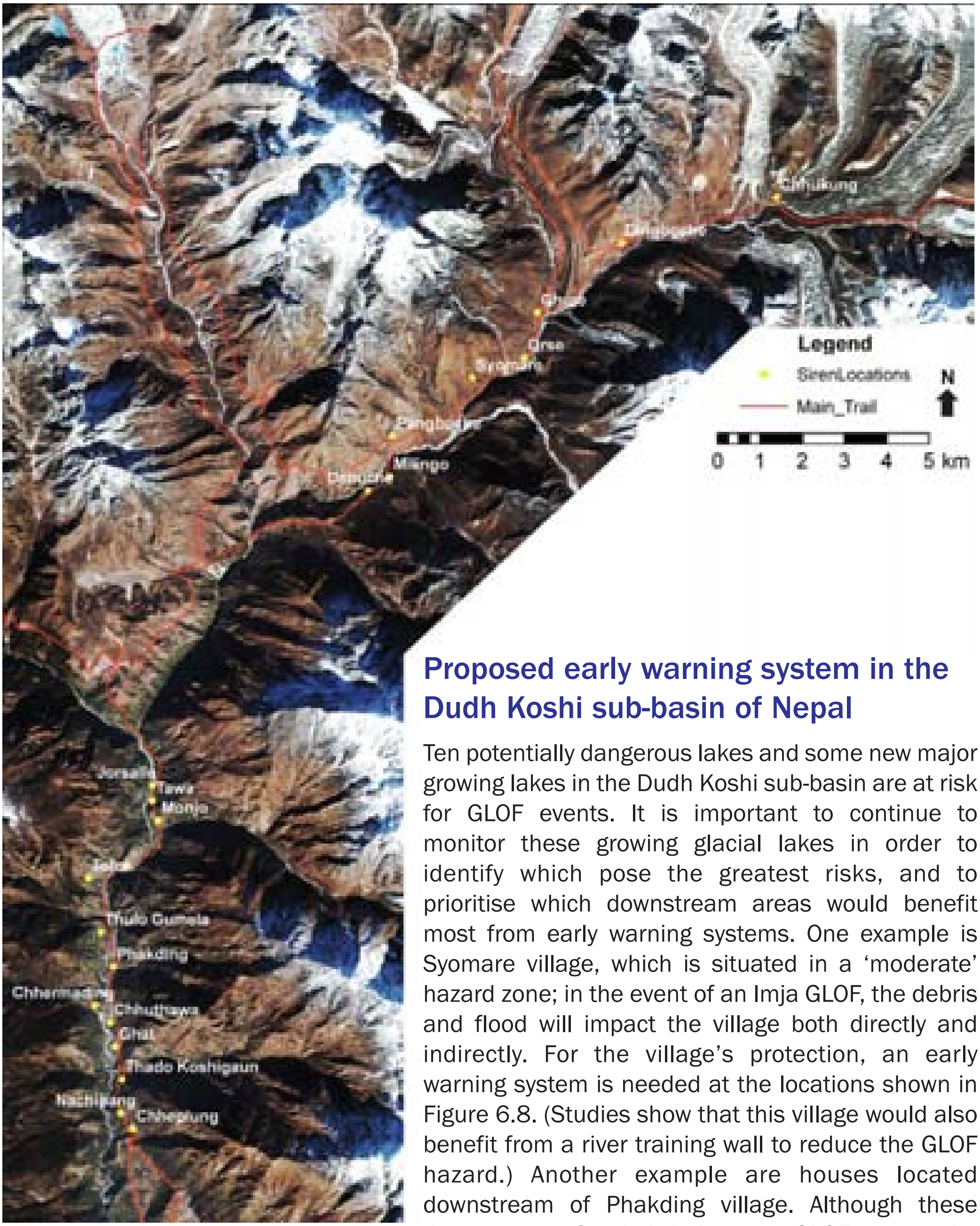

Figure 6.8: Proposed locations of early warning system in the Dudh Koshi valley

Proposed early warning system in the Dudh Koshi sub-basin of Nepal

Ten potentially dangerous lakes and some new major growing lakes in the Dudh Koshi sub-basin are at risk for GLOF events. It is important to continue to monitor these growing glacial lakes in order to identify which pose the greatest risks, and to prioritise which downstream areas would benefit most from early warning systems. One example is Syomare village, which is situated in a 'moderate' hazard zone; in the event of an Imja GLOF, the debris and flood will impact the village both directly and indirectly. For the village's protection, an early warning system is needed at the locations shown in Figure 6.8. (Studies show that this village would also benefit from a river training wall to reduce the GLOF hazard.) Another example are houses located downstream of Phakding village. Although these houses were flooded during past GLOF events, the number of houses and other buildings in the area continues to increase, despite local awareness that it is a flood-prone area, because Phakding is located on a major tourist trekking route. Houses located on lower terraces (mostly in Benkar, Phakding, and other low-lying areas) are prone to floods and secondary events such as lateral erosion, which extends to upper terraces. As an absolutely minimum measure, at least villages that were previously subjected to flooding and overtopping during the Dig Tsho GLOF, and which are known to be at risk, should be equipped with early warning systems.

Regular temporal monitoring using RADAR dataset in Nepal

Remote sensing has transformed the field of earth observation but it is not without its own inherent problems. Clouds can be a major hindrance to satellite imaging (particularly during the monsoon season) in the visible and infrared remote sensing range. Information missed due to cloud cover cannot be retrieved and is then accessible only by field observation. An alternative solution is microwave remote sensing. Since microwave sensing can penetrate cloud cover it is independent of weather conditions and is thus suitable for year-round monitoring of glacial lakes.

Radio detection and ranging (RADAR) is a system that operates in the ultra high-frequency (UHF) or microwave part of the radio frequency spectrum. Synthetic Aperture Radar (SAR) and Advanced Synthetic Aperture Radar (ASAR) aboard ENVISAT are two of the RADAR sensors operated by the European Space Agency (ESA). In a feasibility study, ICIMOD (with support from ESA) is looking at regular temporal RADAR monitoring of Lake Imja Thso. Since 2007, SAR and ASAR data are being used to monitor the growth of Imja Tsho and its vicinity. Although highly simplified, the growth pattern and activities at the glacier snout indicate a possible GLOF hazard. The rate of change can be particularly significant, and RADAR can be used to monitor as often as monthly.

Differences in the surface area of the lake are observed by examining colour composite images. A colour composite image is produced by superimposing images collected at different times where each time frame is assigned a colour. Figure 6.9 shows a composite image of Lake Imja Tsho produced by superimposing data from three different years.

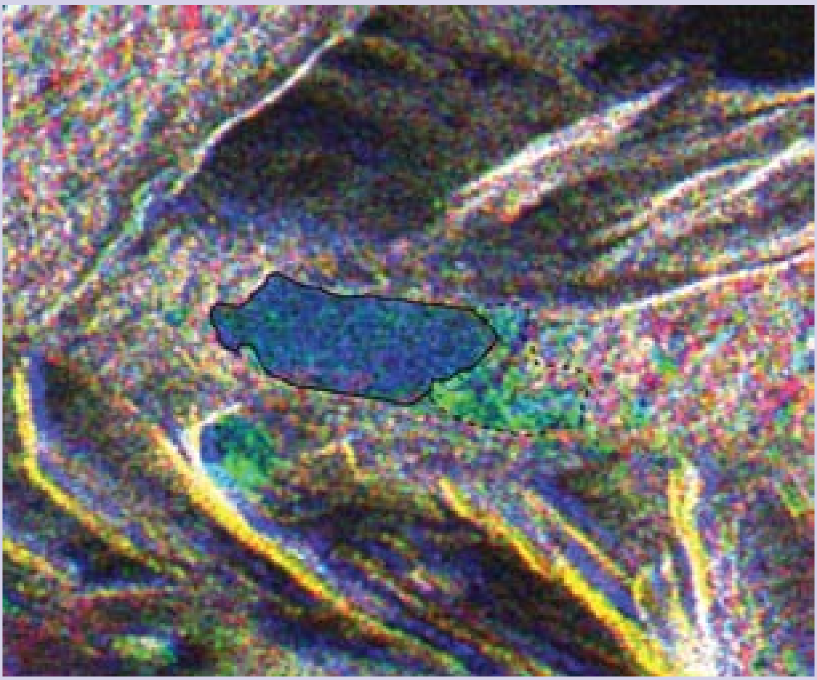

Figure 6.9: A colour composite image obtained by superimposing the RADAR images of Lake Imja Tsho taken in 1993 (red), 1996 (green), and 2005 (blue). The unbroken polygon represents the lake area in 1993 while the dashed polygon represents the increase in the lake area by 2005.

Early warning system in the Lunana region, Bhutan

A manually operated early warning system was installed in the Lunana region by the Flood Warning Section (FWS) under the Department of Energy (DoE). In this system, two staff members from the FWS are stationed in the Lunana lake area and are equipped with both a wireless set and a satellite telephone. They use these to report lake water levels on a regular basis and to issue warnings to downstream inhabitants (in the event of any indications of GLOF). A number of gauges have been installed along the main river as well as at the lakes. These are monitored at various stations at different time intervals depending on the distance from the station and base camp. The station is in regular contact with other wireless stations in the downstream areas along the Puna Tsang Chu, including the villages and towns of Punakha, Wangduephodrang, Sunkosh, Khalikhola, and Thimphu (Figure 6.10).

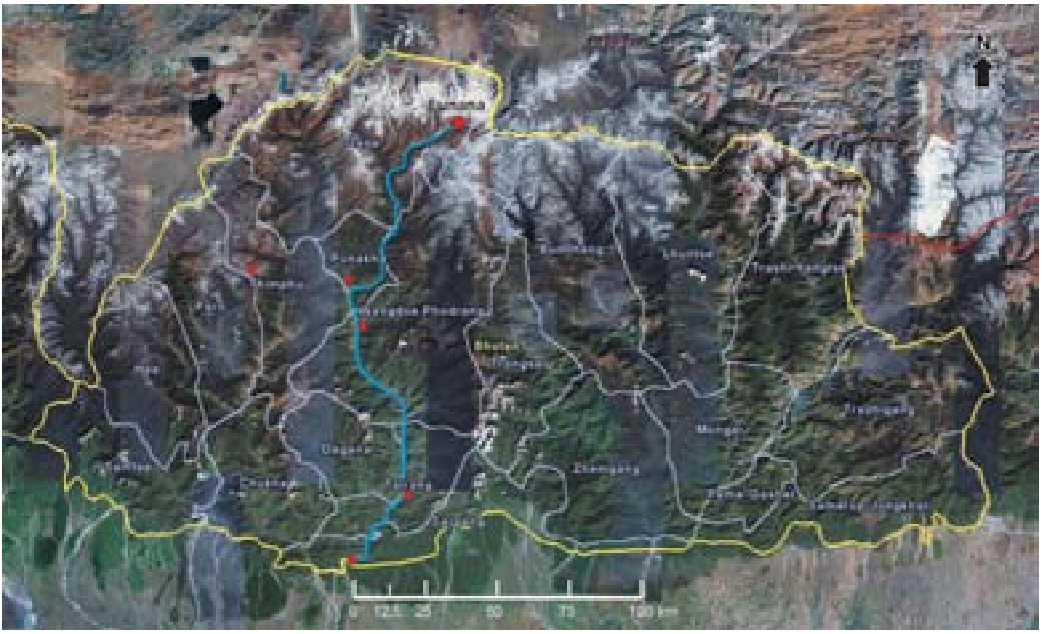

Image: Google Earth 2001

Figure 6.10: Manually operated early warning stations in the Pho Chu valley. Red dot: wireless station; Blue line: Pho Chu River

Mitigation Measures

Various methods and techniques are used to mitigate potential GLOF hazards in the Himalayas. If the environment permits, lowering the level of the lake water is usually considered the most effective mitigation measure. When the lake water level is reduced, the hydrostatic pressure exerted by the water on the moraine wall is correspondingly reduced, ultimately diminishing the risk of outburst from the lake. The lake water level can be reduced by the following methods:

- controlled breaching
- construction of an outlet control structure
- pumping or siphoning out the water from the lake
- boring a tunnel through the moraine barrier or under an ice dam

Examples of the first three of these can be found in Nepal and Bhutan with different rates of success, and are discussed below.

Mitigation measures in Tsho Rolpa Glacial Lake, Nepal

Tsho Rolpa is the only lake in Nepal where GLOF mitigation measures have been undertaken. Two main attempts both aimed to lower the water level in the lake. The first approach used siphon pipes to drain the water and left the moraine wall intact. The second approach used a channel cut through the end moraine to control the outflow of water.

Siphon pipes

In 1995 the Netherlands-Nepal Friendship Association successfully installed siphons, from the Wavin Overseas Company, the Netherlands (Figure 6.11), which were used to test the mechanisms and materials required to lower the level of Tsho Rolpa Lake. Three separate siphons, specially designed with fittings to increase the flow, were installed at the lake. The system of siphons consisted of about 100 HDPE plastic pipes and couplings, all of which were transported to the site by local people from the endangered villages. These plastic pipes were light enough that 5m sections could be carried by a single porter, flexible enough to accommodate the broken terrain, and rugged enough to withstand the extreme pressure, temperature, and unusually intense UV radiation. Assembly was possible without the need for skilled labour or special tools.

Figure 6.11: Siphon across the end moraine

Figure 6.12: The test siphons lying in an open store in Naa village

The three inlet pipes were submerged 15m below the surface of the lake in the deeper part. Water was carried up over the moraine dam, 1.5m above the surface of the lake, and released at a stable site 200m below. The siphon pipes were 16 ft long and 0.25 inches thick with openings of 5.5 inches, and joint couples 0.8 inches thick. Tests of the trial installation showed that water was being evacuated at a rate of 170 l/sec, but this was not sufficient to have a noticeable impact on the level of the lake. Estimates indicated that an outflow of at least 30 times greater would be required to lower the lake level by 3m. The siphon system worked for 14 months without any maintenance. However, by May 1996, the system was dislocated at three points, and by September 1996 it was out of order. Two months later, for unexplained reasons, the siphon again began to function; however by August 1997 another joint had been broken. The system continued to function under less than optimal conditions (Bridges 99, 2001), and owing to lack of regular maintenance, the joint couplings broke very often. When the water was drained by an open channel outlet, the siphons were removed and distributed to the local people who used them for sewerage management (Figure 6.12).

Open channel

In the second approach, the water level in the Tsho Rolpa glacial lake was lowered by opening a channel through the end moraine. The natural spillway of the lake is located in the centre of the end moraine. An outlet channel (70m long, 4.2m wide, 3m deep) was constructed on the left side of the end moraine (Figures 6.13 to 17).

Mitigation measures of Tsho Rolpa glacial lake to reduce its water level

Figure 6.13: View of the moraine-dammed lake with a natural spillway (left) and an artificial outlet (right)
Figure 6.14: Synoptic view of mitigation measures being implemented at the end moraine
Figure 6.15: Construction of the outlet canal and gates; the canal bed is being covered by geotextile.

Mitigation measures of Tsho Rolpa glacial lake to reduce its water level

Figure 6.16: Completed outlet canal to drain water
Figure 6.17: Spillway of the outlet canal on the moraine

The first phase of mitigation work was carried out by TRGRRP (Figure 6.18) of DHM in June 2000. The major part of the funding was provided by the Government of the Netherlands (US $2,988,625), and the Government of Nepal provided the remainder (US $115,414). The target of the project was to lower the level of the lake by 3m by the end of June of that year. Watermarks on the islands showed that the water level of the lake was lowered to that targeted depth (Figure 6.19).

Mitigation measures in Bhutan

Controlled breaching of the Raphstreng Tso, Bhutan

Controlled breaching can be accomplished in different ways, either by using explosives, by excavating, or even by dropping bombs from the air. A successful project of this type was conducted at Bogatyr Lake in Alatau, Kazakhastan, where explosives were used to excavate the outlet channel of the lake (Nurkadiloc et al. 1986). While this method is often effective,

Photo 6.18: Tsho Rolpa GLOF Risk Reduction Project (TRGRRP) of the Department of Hydrology and Meteorology

Figure 6.19: Watermarks on the islands located near the end moraine indicating the lowering of water level

there is always a risk of uncontrolled, regressive erosion of the moraine wall, which could lead to a too rapid lowering of the lake water level. Cases where there has been sudden dumping of huge volumes (6–10 million m^3) of water from a lake have been reported from Peru (Lliboutry et al. 1997a, b, c). In places like Lunana in the Bhutan Himalaya, where several glacial lakes exist adjacent to each other and where their moraine systems are interlinked, the use of explosives is not recommended since too much of the surrounding moraines that dam adjacent lakes in the vicinity may be destabilised.

After the 1994 Luggye Tso GLOF, several studies were conducted in the region to assess the GLOF risk from other lakes. The Raphstreng Tso, a moraine dammed glacial lake in the same area, was found to be in a critical state and immediate mitigation measures were proposed. Subsequently three phases of mitigation work were carried out on this lake from 1996 to 1998. The work was coordinated by the Ministry of Home and Cultural Affairs. The original aim was to reduce the water level by 20m but later this was revised to only about 4m (WAPCOS 1997). Since explosive means were considered too risky, manual excavation of the outlet to widen and deepen the opening was found to be the best option (Figure 6.20).

Controlled breaching, effected by purely manual methods without recourse to machinery or explosives, was considered the most suitable solution for the sensitive site at Raphstreng Tso. A channel, 78.5m long and 36m wide, was constructed at the outlet of this lake. The channel was manually widened and deepened using basic tools such as crowbars, pickaxes, and spades and eventually the lake water level was lowered by approximately 4m. The only drawback is that such manual methods are very labour-intensive and thus rather expensive. Similar mitigation work has already been proposed for the Thorthormi lakes (Brauner et al. 2003).

Figure 6.20: Raphstreng Tso outlet expanded by manually digging through the end moraine in 1998, see Figure 2.9 for location

Pumping or siphoning out water from the Raphstreng Tso, Bhutan

This method of lowering the lake water level was attempted on the Raphstreng Tso during the first mitigation phase in 1996. In total, 9 or 10 water pumps (power tiller heads) were used to pump the water out of the main lake for 24 hours. The team found that pumping has only a minimal effect and was rather expensive, especially since the pumps were operated on fuel that added considerably to overall transport and fuel costs. In fact, it had originally been decided that the pumps were to be used in conjunction with manual excavation work;

however, they were discarded after they were found to be not particularly effective at lowering the water level. Pumps were not used in the later two phases of the work (1997 and 1998) except to pump water out of specific (small) excavation sites.

Other groups have also reported the high costs involved in using pumps for siphoning. See for example Liboutry et al. (1977a, b, c) from Peru and USA. Considering the remoteness of the geographical locations in the Himalayas, pumping as a means of reducing the lake water level is not appropriate. It is difficult to operate the pumps in these places because hydro power is seldom available; the only alternative is fuel, which is expensive and needs to be transported. The earlier inventory reported successfully using smaller and more manageable size pumps on smaller lakes, where they can be quite effective.

Hazard mapping in Bhutan a tool for decision-making

As discussed in the previous chapter for the Imja and Dudh Koshi valleys, hazard mapping can be applied in downstream areas where there are settlements and infrastructures and where people are planning for further development activities. Following the old adage that prevention is better than cure, hazard zonation mapping is relatively inexpensive and can help prevent disasters by making people aware so that they build beyond the reach of GLOF hazard areas. Results on hazard and risk mapping can be shared among relevant stakeholders and planners of development activities to ensure that infrastructure such as roads, buildings, hydropower, and bridges are built well away from high-risk areas.

Being a mountainous country, most of the population of Bhutan is settled along the fertile valley bottoms of major river basins, many of which are vulnerable to GLOFs. During the last phase of the Austrian-Bhutan project, a hazard zonation mapping was carried out along the Pho Chu River from Lunana (lake area) to Khuruthang in Punakha Dzongkhag. The main output from their work was a hazard map delineating areas along the Pho Chu River into different hazard zones. Similar mapping programmes are being proposed for Chamkhar Chu in Bumthang Dzongkhag and the remaining parts of Puna Tsang Chu, downstream from Khuruthang to Kalikhola at the border area.