Chapter 9
Glacial Lake Outburst Floods and Damage in the Country

9.1 INTRODUCTION

Periodic or occasional release of large amounts of stored water in a catastrophic outburst flood is widely referred to as a **jokulhlaup** (Iceland), a **debacle** (French), an **aluvión** (South America), or a **Glacial Lake Outburst Flood** (GLOF) (Himalaya). A **jokulhlaup** is an outburst which may be associated with volcanic activity, a **debacle** is an outburst but from a proglacial lake, an **aluvión** is a catastrophic flood of liquid mud, irrespective of its cause, generally transporting large boulders, and a GLOF is a catastrophic discharge of water under pressure from a glacier. GLOF events are severe geomorphological hazards and their floodwaters can wreak havoc on all human structures located on their path. Much of the damage created during GLOF events is associated with the large amounts of debris that accompany the floodwaters. Damage to settlements and farmland can take place at very great distances from the outburst source, for example in Pakistan, damage occurred 1,300 km from the outburst source (WECS 1987b).

9.2 CAUSES OF LAKE CREATION

Global warming

There is growing concern that human activities may change the climate of the globe. Past and continuing emissions of carbon dioxide (CO_2) and other gases will cause the temperature of the Earth's surface to increase—this is popularly termed 'global warming' or the 'greenhouse effect'. The 'greenhouse effect' gives an extra temperature rise.

Glacier retreat

An important factor in the formation of glacial lakes is the rising global temperature ('greenhouse effect') which causes glacial retreat in many mountain regions.

During the so-called 'Little Ice Age' (AD 1550–1850), many glaciers were longer than today. Moraines formed in front of the glaciers at that time nowadays block the lakes. Glaciation and interglaciation are natural processes that have occurred several times during the last 10,000 years.

As a general rule, it can be said that glaciers in the Himalayas have retreated about 1 km since the Little Ice Age, a situation that provides a large space for retaining melt water, leading to the formation of moraine-dammed lakes (LIGG/WECS/NEA 1988).

Röthlisberger and Geyh (1985) conclude in their study on 'glacier variations in Himalaya and Karakorum' that a rapid retreat of nearly all glaciers with small oscillation was found in the period from 1860/1900–1980.

Causes of glacial lake water level rise

The causes of rise in water level in the glacial lake dammed by moraines that endanger the lake to reach breaching point are given below.

- Rapid change in climatic conditions that increase solar radiation causing rapid melting of glacier ice and snow with or without the retreat of the glacier.
- Intensive precipitation events
- Decrease in sufficient seepage across the moraine to balance the inflow because of sedimentation of silt from the glacier runoff, enhanced by the dust flow into the lake.
- Blocking of ice conduits by sedimentation or by enhanced plastic ice flow in the case of a glacial advance.
- Thick layer of glacial ice (dead ice) weighed down by sediment below the lake bottom which stops subsurface infiltration or seepage from the lake bottom.
- Shrinking of the glacier tongue higher up, causing melt water that previously left the glacier somewhere outside the moraine, where it may have continued underground through talus, not to follow the path of the glacier.
- Blocking of an outlet by an advancing tributary glacier.
- Landslide at the inner part of the moraine wall, or from slopes above the lake level
- Melting of ice from an ice-core moraine wall.
- Melting of ice due to subterranean thermal activities (volcanogenic, tectonic).
- Inter-basin sub-surface flow of water from one lake to another due to height difference and availability of flow path.

9.3 Bursting Mechanisms

Different triggering mechanisms of GLOF events depend on the nature of the damming materials, the position of the lake, the volume of the water, the nature and position of the associated mother glacier, physical and topographical conditions, and other physical conditions of the surroundings.

Mechanism of ice core-dammed lake failure

Ice-core dammed (glacier-dammed) lakes drain mainly in two ways.

- through or underneath the ice
- over the ice

Initiation of opening within or under the ice dam (glacier) occurs in six ways.

- Flotation of the ice dam (a lake can only be drained sub-glacially if it can lift the damming ice barrier sufficiently for the water to find its way underneath).
- Pressure deformation (plastic yielding of the ice dam due to a hydrostatic pressure difference between the lake water and the adjacent less dense ice of the dam; outward progression of cracks or crevasses under shear stress due to a combination of glacier flow and high hydrostatic pressure).
- Melting of a tunnel through or under the ice
- Drainage associated with tectonic activity
- Water overflowing the ice dam generally along the lower margin
- Sub-glacial melting by volcanic heat

The bursting mechanism for ice core-dammed lakes can be highly complex and involve most or some of the above-stated hypothesis. Marcus (1960) considered ice core-dammed bursting as a set of interdependent processes rather than one hypothesis.

A landslide adjacent to the lake and/or subsequent partial abrasion on ice may lead to overtopping as the water flows over, the glacier retreats, and the lake fills rapidly, which may subsequently result in the draining of ice core moraine-dammed lakes.

Mechanisms of moraine-dammed lake failure

Moraine-dammed lakes are generally drained by rapid incision of the sediment barrier by outpouring waters. Once incision begins, the hustling water flowing through the outlet can accelerate erosion and enlargement of the outlet, setting off a catastrophic positive feedback process resulting in the rapid release of huge amounts of sediment-laden water (Figure 9.1). The onset of rapid incision of the barrier can be triggered by waves generated by glacier calving or ice avalanching, or by an increase in water level associated with glacial advance (examples include an ice avalanche from Langmoche Glacier on 4 August 1985 and another on 3 September 1998 from Sabai Glacier).

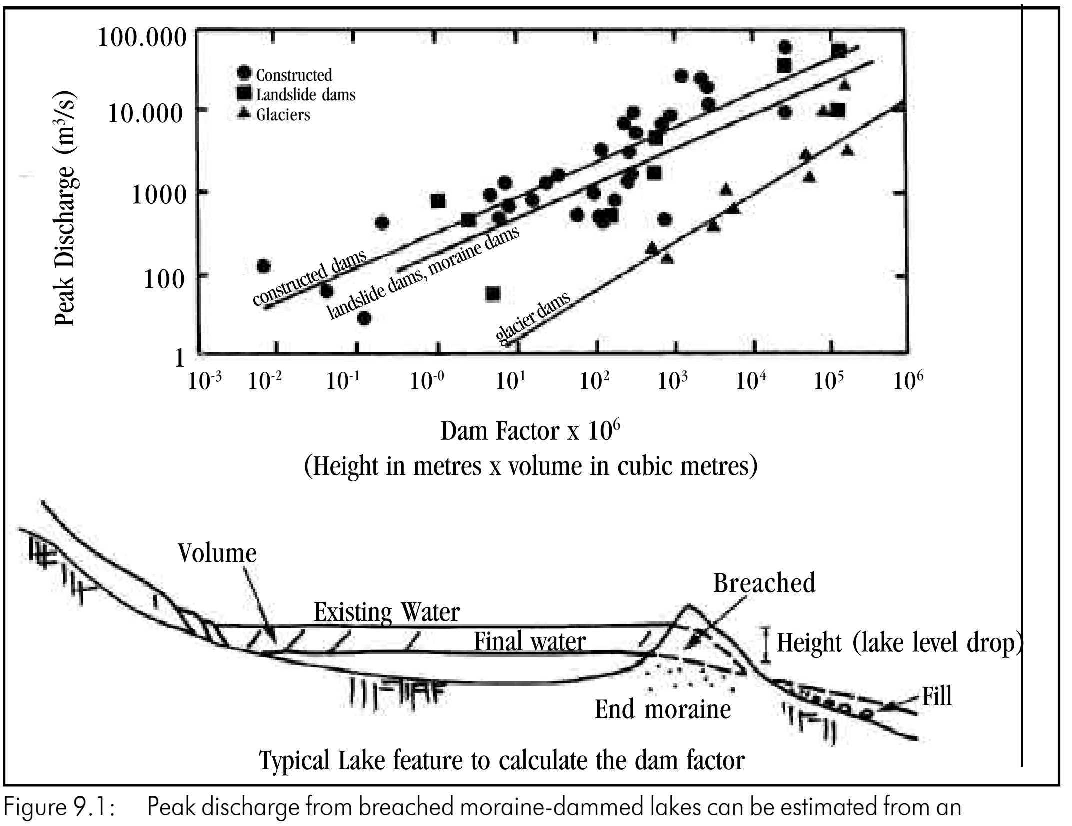

Figure 9.1: Peak discharge from breached moraine-dammed lakes can be estimated from an empirical relationship developed by Costa (1985)

Dam failure can occur for the following reasons:

- melting ice core within the moraine dam,
- rock and/or ice avalanche into a dammed lake,
- settlement and/or piping within the moraine dam,
- sub-glacial drainage, and
- engineering works.

Melting ice-core

The melting of impervious ice core within a moraine dam may result in the lowering of the effective height of the dam, thus allowing lake water to drain over the residual ice core. As the discharge increases with the melting of the ice core, greater amounts of water filter through the moraine, carrying fine materials. Eventually, the resulting regressive erosion of the moraine dam leads to its ultimate failure.

Overtopping by displacement waves

Lake water is displaced by the sudden influx of rock and/or ice avalanche debris. The resultant waves overtop the freeboard of the dam causing regressive and eventual failure.

Settlement and/or piping

Earthquake shocks can cause settlement of the moraine. This reduces the dam freeboard to a point that the lake water drains over the moraine and causes regressive erosion and eventual failure.

Sub-glacial drainage

A receding glacier with a terminus grounded within a proglacial lake can have its volume reduced without its ice front receding up-valley. When the volume of melt water within the lake increases to a point that the formerly grounded glacier floats, an instantaneous sub-glacial drainage occurs. Such drainage can destroy any moraine dam, allowing the lake to discharge until the glacier loses its buoyancy and grounds again.

Engineering works

One of the main difficulties in changing water levels or dam structures artificially is that this can unintentionally trigger a catastrophic discharge event. For example, in Peru in 1953, during the artificial lowering of the water level, an earth slide caused 12m high displacement waves, which poured into a trench, excavated as part of the engineering works and almost led to the total failure of the moraine dam.

9.4 Surge Propagation

As GLOFs pose severe threats to humans and man-made structures, it is important to make accurate estimates of the likely magnitude of future floods. Several methods have been devised to predict peak discharges, which are the most erosive and destructive phases of floods. The surge propagation hydrograph depends upon the type of GLOF event, i.e. from moraine-dammed lake or from ice-dammed lake (Figure 9.2). The duration of a surge wave from an ice-dammed lake may last for days to even weeks, while from a moraine-dammed lake the duration is shorter, minutes to hours. The peak discharge from the moraine-dammed lake is usually higher than from ice-dammed lakes.

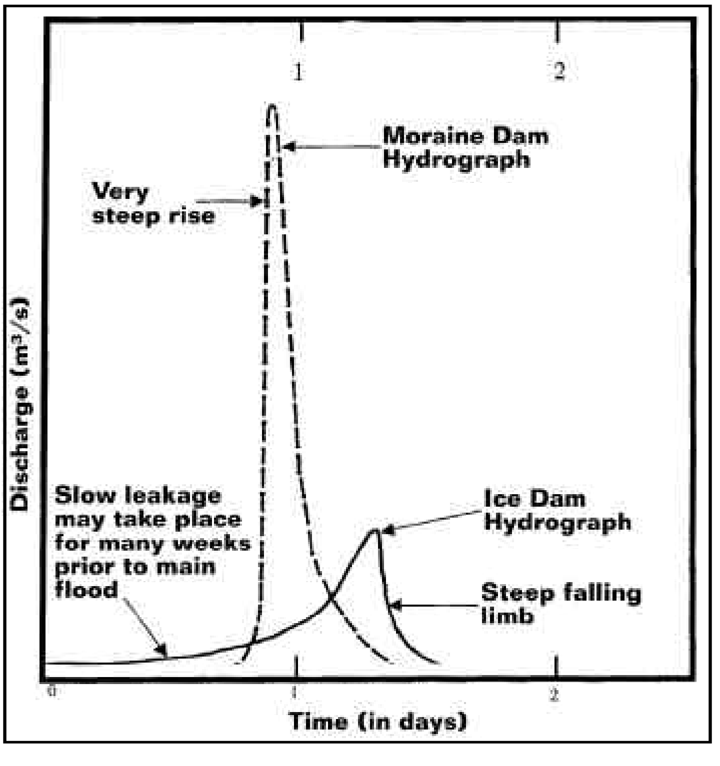

Figure 9.2: Difference in release hydrograph between moraine- and ice-dammed lakes (WECS 1987A)

The following methods have been proposed for estimation of peak discharges.

1) Clague and Mathews formula

Clague and Mathews (1973) were the first to show the relationship between the volume of water released from ice-dammed lakes and peak flood discharges.

$$Q_{max} = 75(V_0*10^{-6})^{0.67}$$

where
Q_{max} = peak flood discharge ($m^3 s^{-1}$)
V_0 = total volume of water drained out from lake (m^3)

The above relationship was later modified by Costa (1988) as the peak discharge yielded from the equation was higher than that measured for Flood Lake in British Columbia that occurred in August 1979:

$$Q_{max} = 113(V_0*10^{-6})^{0.64}$$

Later Desloges et al. (1989) proposed:

$$Q_{max}=17V_0*19(0^{-6})^{0.64}$$

This method of discharge prediction is not based on any physical mechanism, but seems to give reasonable results.

2) Mean versus maximum discharge method

If the volume of water released by a flood and the flood duration are known, the mean and peak discharges can be calculated. Generally the flood duration will not be known in advance. Hence, this method cannot be used to determine the magnitude of future floods. Observations of several outburst floods in North America, Iceland, and Scandinavia have shown that peak discharges are between two to six times higher than the mean discharge for the whole event.

3) Slope area method

This method is based on measured physical parameters such as dimensions and slope of channel during peak flood conditions from direct observations or geomorphological evidence.

$$Q_{max} = vA$$

The peak velocity is calculated by the Gauckler–Manning formula (Williams 1988)

$$v = r^{0.67} S^{0.50}/n$$

where
v = peak velocity
S = bed slope for a 100m channel reach
n = Manning's roughness coefficient
r = hydraulic radius of the channel

$$r = A/p$$

where
A = cross-sectional area of the channel
p = perimeter of the channel under water

For sediment floored channels, bed roughness is mainly a function of bed material, particle size, and bed form or shape and can be estimated from:

$n = 0.038D^{0.167}$

where
D = average intermediate axis of the largest particles on the channel floor.

Desloges et al. (1989) compared the results from all the three methods for a jokulhlaup from the ice-dammed Ape Lake, British Columbia. All the methods gave comparable results.

- The Clague and Mathews method gave a calculated peak discharge of 1,680 ± 380 $m^3 s^{-1}$.
- The mean versus maximum discharge method gave 1,080–3,240 $m^3 s^{-1}$.
- The slope area method gave 1,534 and 1,155 $m^3 s^{-1}$ at a distance of 1 and 12 km from the outlet respectively.

These general relationships are useful for determining the order of magnitude of initial release that may propagate down the system. However, to predict the magnitude of future floods, the first method should be applied, because volume of lake water can be estimated in advance.

Attenuation of a peak discharge of 15,000–20,000$m^3 s^{-1}$ has been reported for the Sun Koshi River in Tibet within a distance of 50 km (XuDaoming 1985) (Figure 9.11). The propagation of surge waves can be numerically modelled using the dam-break flood-forecasting model.

9.5 Sediment Processes During a Glacial Lake Outburst Flood

During a GLOF, the flow velocity and discharge are exceptionally high and it becomes practically impossible to carry out any measurement. Field observations after a GLOF event have shown a much higher sediment concentration of rivers than before the GLOF event (Electrowatt Engineering Service Ltd 1982; WECS 1995a). WECS (1995a) calculated the volume of scoured sediment as $22.5*10^4$ m^3 after the Chubung GLOF in 1991. A high concentration of 350,000 mg^{-1} during a GLOF in the Indus River at Darband in 1962 is reported by Hewitt (1985). Hypothetical illustrations showing discharge and variation in sediment concentration (WECS 1987a) are shown in Figure 9.3.

The total sediment load is generally accepted as the wash load, which moves through a river system and finally deposits in deltas. In Nepal, no measurements have been taken of total sediment during GLOF events, however, rough estimates of total load during torrents can be made assuming a high sediment concentration (WECS 1987b). During a GLOF event, stones the size of small houses can be easily moved (WECS 1987b). The relationship between flow velocity and particle diameter can also be used to calculate the size of boulders that can be moved during such events.

9.6 Socioeconomic Effects of Glacial Lake Outburst Floods

The impact of a GLOF event downstream is quite extensive in terms of damage to roads, bridges, trekking trials, villages, and agricultural lands as well as the loss of human lives and other infrastructures. The sociological impacts can be direct when human lives are lost, or indirect when the agricultural lands are converted to debris filled lands and the village has to be shifted. The records of past GLOF events show that once every three to ten years, a GLOF has occurred in Nepal with varying degrees of socioeconomic impact. Therefore, proper hazard assessment studies must be carried out in potentially problematic basins to evaluate the likely economic loss and the most appropriate method of mitigation activities.

The 1981 GLOF from Zhangzangbo in Tibet (China) brought a lot of destruction in Tibet (China) and Nepal. It even caused severe damage to sections of the Nepal–China Highway including the Phulping and Friendship bridges in Nepal. The road was rebuilt at a cost of US $3 million. The present road level is now above the historic 1981 GLOF.

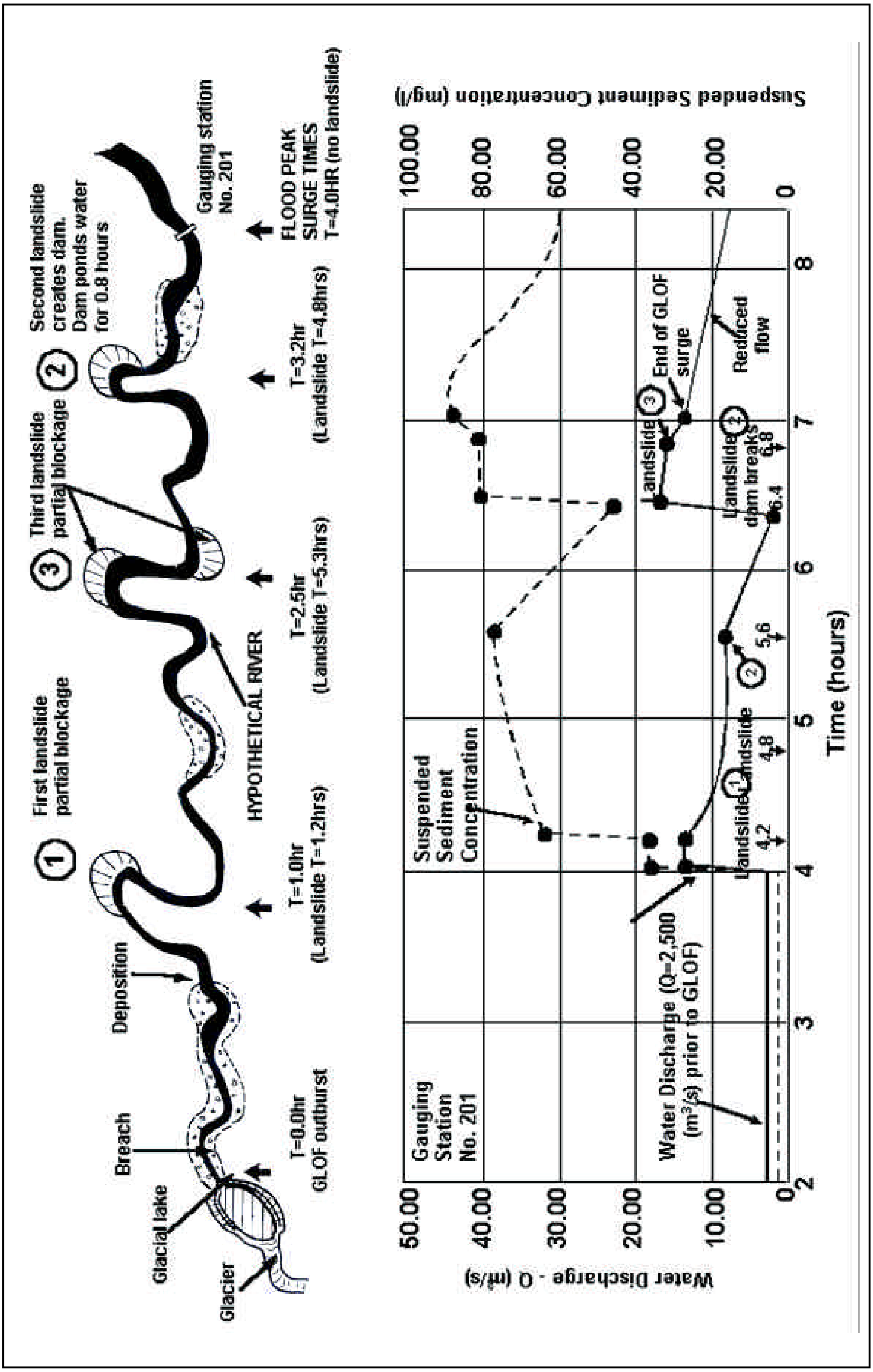

Figure 9.3: Hypothetical illustration of GLOF showing discharge and variation in sediment concentration (WECS 1987a)

The 1985 GLOF from Dig Tsho in the Dudh Koshi Basin damaged Namche hydropower station (US $1.5 million), 14 bridges, cultivated lands etc. (Vuichard and Zimmerman 1987). The hydropower plant has been rebuilt at another site. The sociological cost of lost lives and dwellings to communities was enormous. The study shows that this glacial lake is refilling again and possibly engineering a greater risk of a GLOF occurrence in the same basin. This and many more GLOF events indicate that before any major project is undertaken in the basin, in-depth cost and benefit analyses have to be carried out for deciding on the most appropriate alternative that will enable project financiers to assess their risks from a GLOF. The assessment of tangible benefits in respect to mitigation of GLOFs is, however, difficult. Reduced damage is considered a benefit and can be quantified, but the frequency of the reduced damage is difficult to ascertain due to lack of data. One cannot simply predict the timing and occurrences of GLOFs. It is extremely difficult to simulate numerically the flood level and velocities at a particular place.

At this stage, from brief studies of GLOFs throughout the world, it appears that there are no simple direct means of estimating the recurrence of GLOFs.

9.7 Brief Review of Glacial Lake Outburst Flood Events and Damage Caused

GLOF events have been reported most frequently within the last three decades. The reported GLOF events are given in Table 9.1 and shown in Figure 9.4. Some of the events have been disastrous for Tibet (China) as well as for Nepal. The GLOF event of the Barun Khola is not known, but the accumulation of the debris along the river valley is the indication of the GLOF event along the Barun Khola. The damage caused by the GLOF event of Jinco and Tara-Cho is not well known. The first GLOF event was experienced on 25 August 1964, when the Longda GLOF took place in the headwaters of the Trishuli River in Chinese territory. Most of the damage occurred in Chinese territory and a large debris flow was experienced in Nepal. In the same year, another Gelhaipuco GLOF was experienced along the Arun Valley. Severe damage and heavy economic losses occurred in Chinese Territory. The Zhangzangbo-Cho GLOF event at the headwaters of the Sun Koshi River on 11 July 1981 destroyed the Friendship Bridge of the China–Nepal Highway and the diversion weir at the Sun Koshi hydropower plant in Nepal, causing serious economic losses for Nepal. Dig Tsho GLOF, on 4 August 1985, destroyed the nearly completed Namche hydropower plant, cultivated land, and other infrastructures and caused the loss of many lives. Similar events have been reported from time to time. The most recent GLOF event is that of Tam Pokhari (Sabai-Tsho) on 3 September 1998 at the headwaters of the Inkhu Khola, one of the tributaries of the Dudh Koshi River.

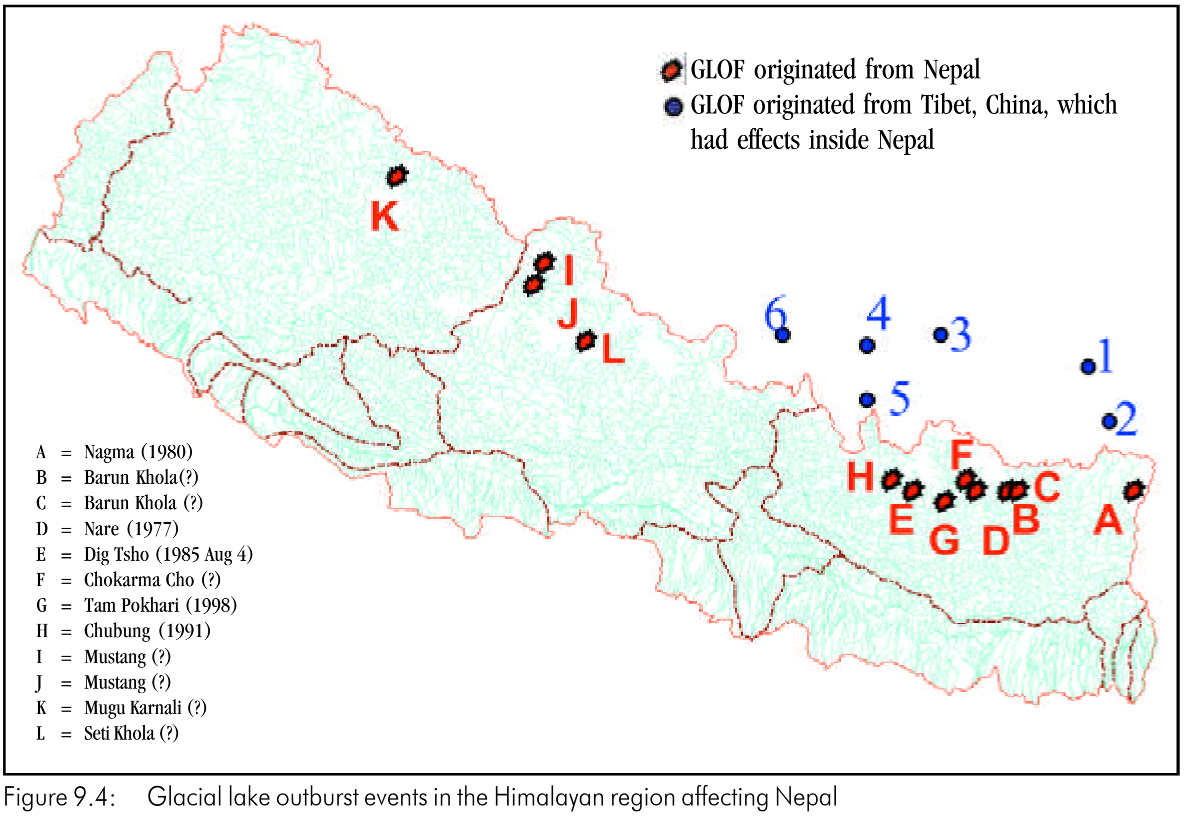

Figure 9.4: Glacial lake outburst events in the Himalayan region affecting Nepal

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Pokhara valley

The 50–60m thick sediments at the floor of the Pokhara Valley are an indication of the debris flow in the past. It is estimated that the valley has suffered from a GLOF event that occurred 500 years ago. The source of the debris deposited in the Pokhara Valley floor is the Machhapuchhre area.

Barun khola

There is evidence of a GLOF in the Barun Khola Valley as shown in Figure 9.5, and this is indicated by the debris along the Barun Khola. The source of the GLOF is the Barun Pokhari. The dates and other details are not available.

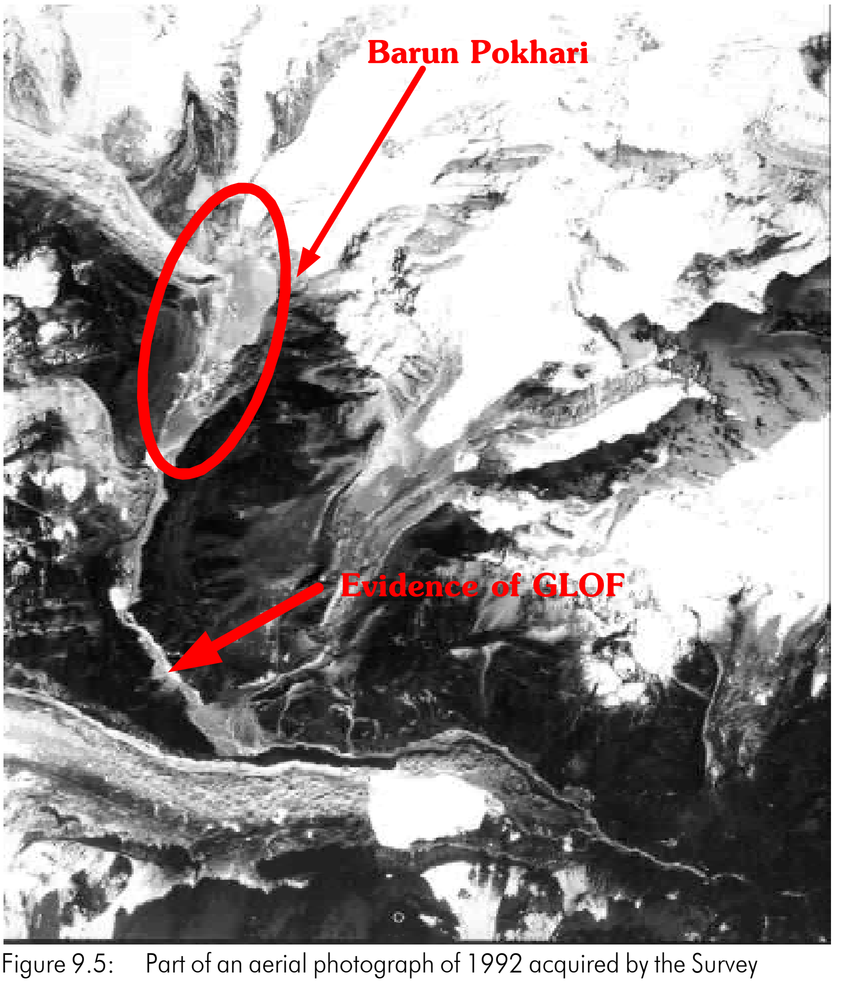

Figure 9.5: Part of an aerial photograph of 1992 acquired by the Survey Department of His Majesty's Government of Nepal (HMGN) showing the Barun Pokhari and evidence of a GLOF from the Barun Pokhari (Aerial Photo 53-35)

Tara-Cho

The Tara-Cho Lake is located in the Targyailing Gully of the Boqu Basin (Tibet [China]) and the Bhote Koshi Basin (in Nepal) situated at latitude 28° 17' N and longitude 86° 08' E at an elevation of 5,240 masl. It is a moraine-dammed lake. The lake is 1.0 km long, occupies an area of 0.224 sq.km, and is dammed by a moraine 50m thick.

The lake burst due to dam piping and released a 6.3 million m^3 volume of water breaching at a depth of 10m. According to local, old residents' descriptions, the lake burst abruptly one night in August 1935. It happened during the wheat harvest season. Nearly 66,700m^2 of wheat field at the outlet of the gully were destroyed and several livestock including yaks were lost. A huge amount of debris was deposited on the terraces of the Targyailing Gully. Now there is no cultivation in the affected area due to the thick accumulation of stony debris. According to the description of local old men, there was water oozing from beneath the dam before the burst. It is understood that the burst was probably caused by the collapse of part of the dam due to seepage. There is a cirque hanging glacier behind the lake, with an area of 2.46 sq.km and length of 1.5 km. Now the terminus of the glacier is 0.3 km away from the lake. If the glacier moves forward again, there is still the possibility of another burst, but the scale and damage degree would not be as big as in 1935.

Longda

The Longda Glacial Lake burst on 25 August 1964. The outburst flood washed out a huge amount of sediment which created a debris blockage 800m long, 200m wide, and 5m deep, on average, along the Gyirongzangbo River, the source of the Trishuli River.

Gelhaipuco

Gelhaipuco is an end moraine-dammed lake located in the headwaters of the Gelhaipu Gully (Natangqu River Basin), east of Riwo, Dinggye County, Tibet (China). Its geographic position is latitude 27° 58' N and longitude 87° 49' E. The lake burst abruptly due to an ice avalanche at 2 pm, on 21 September 1964. According to an investigation by Chengdu Institute of Geography of the Chinese Academy of Sciences, from the middle of March to the end of September 1964, there was a large precipitation in the Natangqu River Basin, which caused the glacier of the Natangqu River to slide (LIGG/WECS/NEA 1988). Huge amounts of ice slid into the lake resulting in the generation of a shock wave and water level increase. Finally, the lake water overflowed through the moraine dam and breached the 30m steep valley through the dam.

The flood, with a huge amount of debris, damaged Chentang-Riwo Highway and 12 trucks transporting timber were washed away. The debris flow rushed down to the lower reaches of the Arun (Pumqu) River of Nepal and caused heavy economic losses. Based on flood trace marks and sediment deposits on the river bed, it was concluded that it was a turbulent debris flow with a bulk density of about 1.45 t m^{-3}.

Before the burst, Gelhaipuco Lake was 1.4 km in length and 0.548 sq.km in area with water reserves of about 25.45 million m^3. The water level of the lake dropped by 40m after the lake burst in 1964 and released about 23.36 million m^3 of water. The slope of the exposed lake bed is 0.6% and it is 0.2 km away from the glacier margin. The present condition of the lake indicates stability. But if the glacier advances forward again, the possibility of another burst cannot be ruled out.

The LANDSAT TM and field photographs of Gelhaipuco Lake are given in Figures 9.6, 9.7, and 9.8 respectively.

Figure 9.6: LANDSAT TM of 22 September 1988 (the Gelhaipuco Glacial Lake area is shown in the circle)

Zhangzangbo-Cho

The GLOF event of the Zhangzangbo-Cho Lake at Poiqu (Bhote-Sun Koshi) River in Tibet took place on 11 July 1981. This Little Ice Age moraine-dammed lake is located at the headwaters of the Zhangzangbu Gully (Figure 9.9). The lake burst due to a sudden ice avalanche at midnight. A breach 50m deep and 40–60m bottom width was formed at the moraine. The flood formed a large alluvial fan. According to XuDaoming (1985), the largest burst discharge was about 1,6000 $m^3 s^{-1}$, which happened 23 min after the burst. The main flood lasted about 60 min and the amount of burst water was estimated to be about 19 million m^3. Erosion and sedimentation can be seen along the valley and about 4 million m^3 of debris mixed materials joined the flow process. Before the burst, the end moraine-dammed lake was 1.7 km long and 0.643 sq.km in area. After the burst the length and area were reduced to 1.1 km and 0.265 sq.km respectively. The water reserves of the lake were also greatly reduced. According to an investigation in 1984, there had been a burst in 1964 from the same lake, but the breach was different

Figure 9.7: The field photograph (1987) of Gelhaipuco Glacial Lake shows the lake in contact with the hanging glacier

Figure 9.8: The eroded banks of the Natangchu (tributary of the Arun River in Tibet [China]) after the Gelhaipuco GLOF in 1964 (photograph 1987)

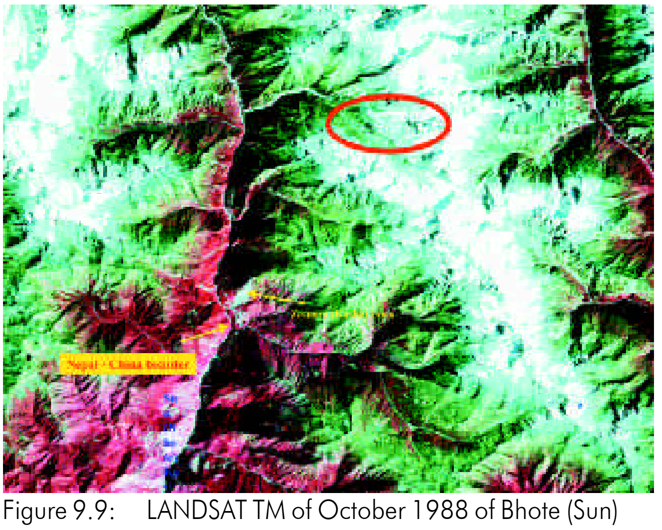

Figure 9.9: LANDSAT TM of October 1988 of Bhote (Sun) Koshi (Poiqu in Tibet [China]) showing Zhangzangbo-Cho

from that in 1981. The burst discharge and the damage caused were smaller. There is a cirque hanging glacier in the Zhangzangbo Gully (Figure 9.9), whose area is 2.47 sq.km, length is 2.2 km, and it ends at the bank of the lake. From 5 to 10 July 1981, there was continuous hot weather. The increased glacier ablation produced a large amount of water seeping into the crevasse of the glacier tongue, which brought the glacier into a critical state and caused part of the glacier to slide. Huge amounts of ice collapsed into the lake, which generated the shock wave that caused the dam burst.

The geomorphological map around Zhangzangbo Glacial Lake (XuDaoming 1985) is shown in Figure 9.10.

This debris flow damaged the highway sections between the outlet of Zhangzangbo Gully and the Sun Koshi Power Station in Nepal. It destroyed the Friendship Bridge of the China–Nepal Highway and the diversion weir at the Sun Koshi hydropower plant in Nepal, causing serious economic losses to Nepal. It also destroyed two bridges and tore out extensive road sections of the Arniko Highway of Nepal amounting to losses of US $3 million. The peak discharge attenuation downstream due to the GLOF is shown in Figure 9.11, the remnant pier of the old bridge damaged by the 1981 GLOF and new bridge at Phulping is shown in Figure 9.12, and the washed out portion of the Kodari Highway is shown in Figure 9.13.

Ayaco

Ayaco is located at the headwaters of the Zongboxan River in the Pumqu Basin (Tibet) on the northwestern slope of Mount Everest. The geographic position of the lake is latitude 28° 21'N and longitude 86° 29'E. According to an investigation by Chengdu Institute of Geography of the Chinese Academy of Sciences, there were three burst events recorded in mid August 1968, 1969, and 1970 (LIGG/WECS/NEA 1988). A huge fan-shaped mass of debris was deposited at the confluence of the lake drainage channel and the main river course. The estimated sediment deposit is about 4.59 million m^3. At present the lake is only 1.2 km long and 0.35 sq.km in area, which is much smaller than its size before the burst. The distance from the glacier to the lake is 0.5 km. If the glacier advances again, there is the possibility of another burst, but the intensity may not be as strong as during the period from 1968–1970. The flood damaged the highway and concrete bridges of Desha No.1 in Tibet (China). The damage on the Nepal side is unknown.

Nare

Nare is situated in the Dudh Koshi watershed boundary at the southern slope of Mount Ama Dablam in Nepal. The lake was formed due to damming of the ice cored moraine. The GLOF event of 3 September 1977 damaged a mini hydro plant, a road, bridges, and farmland in Nepal. The lake is not present in the map studied.

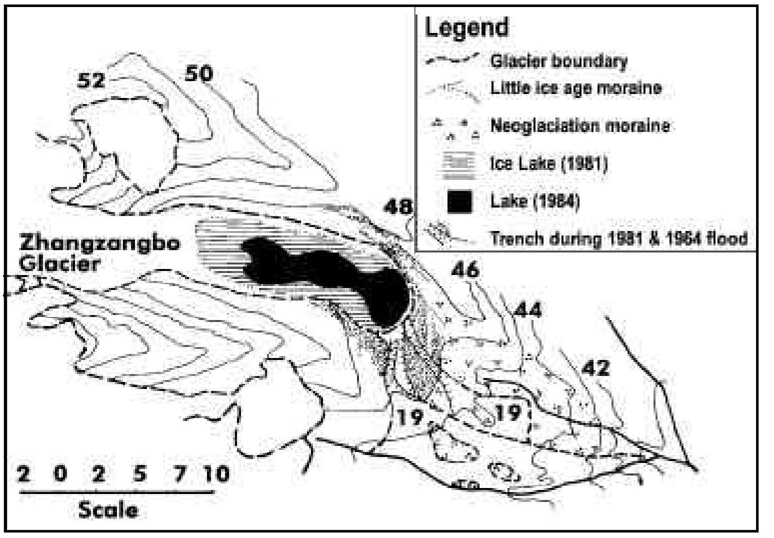

Figure 9.10: Geomorphological map of Zhangzangbo Glacial Lake area, Tibet (China) (XuDaoming 1985)

Nagma

Nagma (Punchan) is situated at the Tamor watershed. Due to the GLOF event of 23 June 1980, one village was completely destroyed and the villagers had to migrate to other places. The eroded banks of the Tamor River after the Nagma GLOF of 1980 is shown in Figure 9.14, while the 1992 aerial photographs of Nagma Glacial Lake and Chhechen Pokhari formed after the Nagma GLOF are shown in Figure 9.15 and 9.16 respectively.

Jinco

Jinco Lake is located at the headwaters of the Yairuzangbo River of the Pumqu Basin (Tibet) and the Arun Basin in Nepal. It is an end moraine-dammed lake. The Jinco GLOF happened at 5 pm on August 27 1982 and formed a huge amount of debris flow. At 7 pm the flood peak arrived at Sar. The summer of 1982 was dry and hot. The outburst might have been the result of a strong glacier ablation that seeped melting water into the glacier bed and made it slide. The ice blocks collapsed into the lake and the generated shock wave damaged the dam, thus causing the burst.

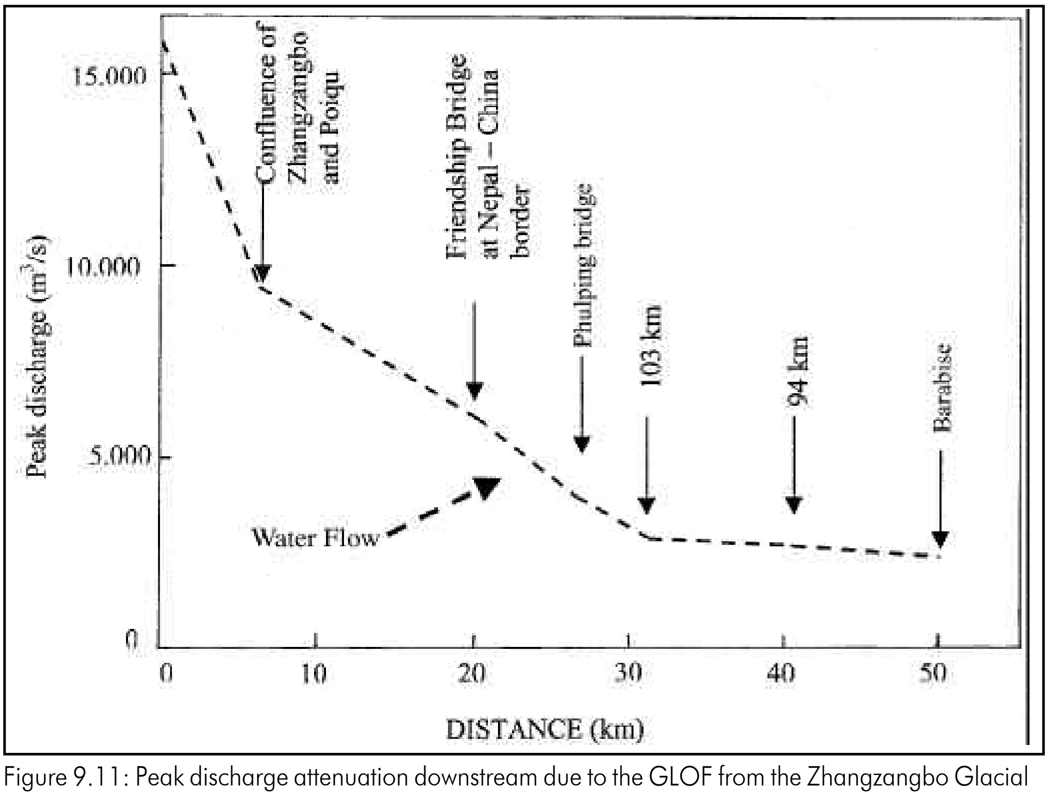

Figure 9.11: Peak discharge attenuation downstream due to the GLOF from the Zhangzangbo Glacial Lake, Poiqu River, Tibet (China) or the Bhote (Sun) Koshi (Nepal) (Xu Daoming 1985)

Figure 9.12: Remnant pier of the old bridge damaged by the 1981 GLOF and the new bridge at Phulping along the Nepal–China Highway

Figure 9.13: The washed out portion of the Kodari Highway (Nepal–China Highway) by the 1981 GLOF

Over 1,600 livestock were lost, about 19 hectares of cultivated field were destroyed, and the houses of eight villages were washed away. Gujing village suffered a different degree of destruction.

Figure 9.14: The eroded banks of the Tamor River after the Nagma GLOF of 1980 (Carson 1985)

Figure 9.15: Part of the 1992 aerial photograph acquired by the Survey Department of HMGN showing the Nagma (Phuchan) Glacial Lake after the GLOF of 1980 (Aerial Photo 53-56).

Dig Tsho

Dig Tsho (Langmoche) Glacial Lake is in contact with the Langmoche hanging glacier in the Dudh Koshi Basin. It burst on 4 August 1985. The GLOF destroyed the nearly completed Namche Hydropower Plant (estimated loss of US $1.5 million), 14 bridges, trails, cultivated land, etc and caused the loss of many lives. The details of the Dig Tsho Glacial Lake are given in Chapter 10. A photograph taken after the GLOF of 1985, showing the remnants of Dig Tsho Glacial Lake and Langmoche Glacier, constitutes Figure 9.17.

Chubung

Chubung is situated in the Tama Koshi Basin at the end of the Ripimo Shar Glacier in the Rolwaling Valley. It is a moraine dam type of glacier, which burst on 12 July 1991 and damaged many houses and much farmland in the upper part of the Rolwaling Valley. Figure 9.18 shows the photograph of the breaching of the moraine dam and fan deposited after the Chubung GLOF of July 1991.

Kali Gandaki

In this basin two lakes identified from the topo-maps are found not to exist at present. Satellite images show evidence of GLOF events. Field interviews indicate that one of these lakes bears the name Tsarang Chu. According to local people the outburst of this lake occurred in May 1995, this has yet to be confirmed.

Tam Pokhari

Tam Pokhari (Sabai Tsho) is situated at the tongue of the Sha (Sabai) Glacier in the headwater of the Inkhu Khola of the Dudh Koshi Sub-basin. It burst on 3 September 1998. Two persons were killed, four suspension bridges and two wooden bridges were damaged, and farmland was buried. The total loss of property is estimated to be worth NRs 150.66 million.

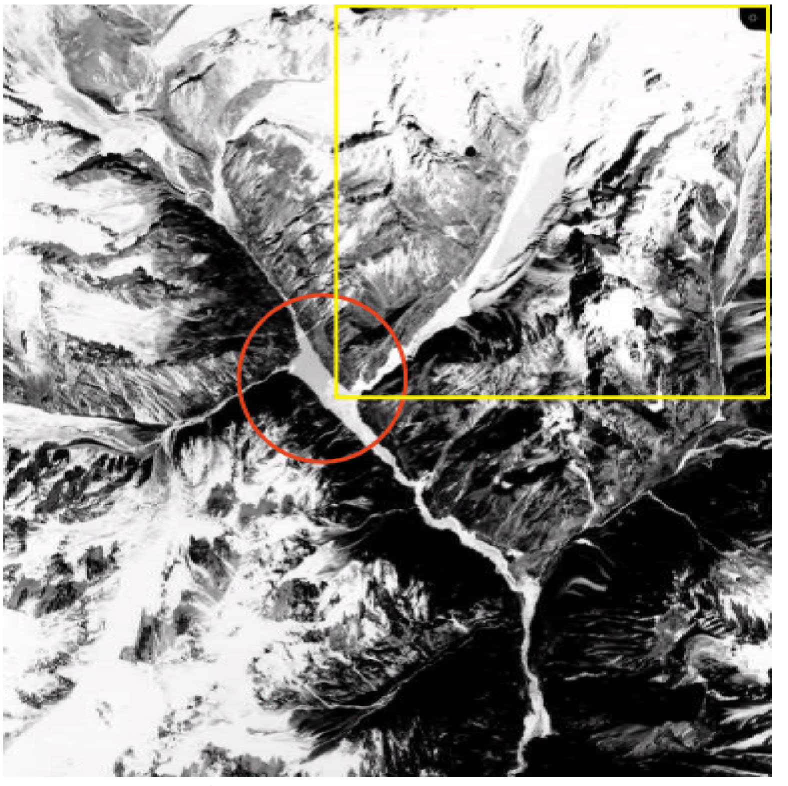

Figure 9.16: Part of the 1992 aerial photograph acquired by the Survey Department of HMGN showing the debris deposited along the gully which blocked the Chhechen Khola to form the Chhechen Pokhari after the Nagma (Phuchan) GLOF of 1980 (Aerial Photo 52-15)

Figure 9.17: Birds-eye view showing the remnants of Dig Tsho Glacial Lake, Langmoche Glacier at the slope and the debris along the gully after the GLOF of 1985 (WECS 1991)

Figure 9.18: The breaching of the moraine dam and fan deposited after the Chubung GLOF of 12 July 1991 in the Rolwaling Valley, Nepal (photograph 1993)