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Glacier Lake Outburst Floods in Nepal

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ABSTRACT

The most active glaciers of Nepal, and adjoining Tibet in China, are located in the eastern part of the region. There are numerous occurrences of glacier lakes in this region. There are evidences that Glacier Lake Outburst Floods (GLOFs) have occurred throughout the Himalaya. However there is no detailed catalogue of the number and location of these past events. Most of the known cases occurred on the major rivers in the Kosi basin. The transport of sediment during GLOFs can be exceptionally high, with suspended sediment concentrations as high as 350,000 mg/l. The vertical and lateral erosion of the stream channel has the potential to destabilise talus slopes, former debris flows and landslides and to initiate new ones.

The impacts of GLOFs downstream are extensive loss of human lives and cattle, loss of infrastructures, destruction of land, and interruption of tourism in mountainous areas. The GLOF on 11 July 1981 from Zhangzanbo Lake destroyed the diversion weir at the Sun Kosi Hydro Project in Nepal. The GLOF on 4 August 1985 from Dig Tsho lake along the Bhote-(Dudh) Kosi destroyed the nearly completed Namche Small Hydel Project. Even the very small GLOF of Chubung on 12 July 1991, destroyed six houses and a long stretch of river banks in Beding village, in the Rolwaling Valley.

Compilation of the inventory of glaciers and glacier lakes using remote sensing technology is the first step in identifying the occurrence of GLOF prone areas. Mitigating the impact of a GLOF surge can be done by reducing the volume of water in the glacier lakes in order to reduce the peak surge discharge. This can be achieved by: controlled breaching; construction of an outlet control structure; pumping out of a lake; and construction of a tunnel through the moraine barrier, or under an ice dam. Preventive measures, such as blasting masses of loose rock and ice, can be applied to ensure against avalanches into lakes.

INTRODUCTION

There are more than 6,000 streams and rivers in Nepal and most of them are snow-fed, originating from the High Himalaya. About 14% of the country is covered by snow and ice. At present, numerous active glaciers in the High Himalaya of Nepal are retreating in the most part and contributing to discharge downstream. The catastrophic discharge of large volumes of water is characteristic of many mountain regions, and especially the glaciated areas.

Most mountain glaciers reached the Little Ice Age (Neoglacial) and built up prominent end moraines at that time (Sugden and John 1990). Due to the pronounced climatic amelioration of the first half of the twentieth century, the majority of mountain glaciers thinned and retreated. Thus, in many glacier frontal situations, a lake was formed as the glacier continued to retreat. Glacier lakes can be broadly classified into three categories: (1) Moraine damed lake, (2) Glacier ice-dammed lake (sometime referred to as glacier dammed lake), and (3) Ice-core moraine dammed lake.

CAUSES OF GLOF

The water level in the glacier lake may rise due to climatic conditions and the other natural processes in the glacier and lake area, causing to reach the breaching point. The bursting of the moraine dam can take place by progressive erosion of dam material or by the sudden removal of a portion of dam material. The erosion of dam material can be caused by overtopping of the dam due to the progressive rising of lake levels; by the creation of a surface wave, either by landslide, rockfall, or icefall; by glacier ice supplying the upper end of the lake; or by wind waves. Breaching can also be caused by piping through the dam material. Flood caused by the sudden bursting of a glacier lake, which is either ice-dammed or moraine-dammed, is called **Glacier Lake Outburst Flood (GLOF)**. Moraine-dammed lakes generally breach by overtopping or by piping, whereas ice-dammed lakes drain underneath the ice.

GLOF EVENTS

The most active glaciers of Nepal, and adjoining Tibet in China, are located in the eastern part of the

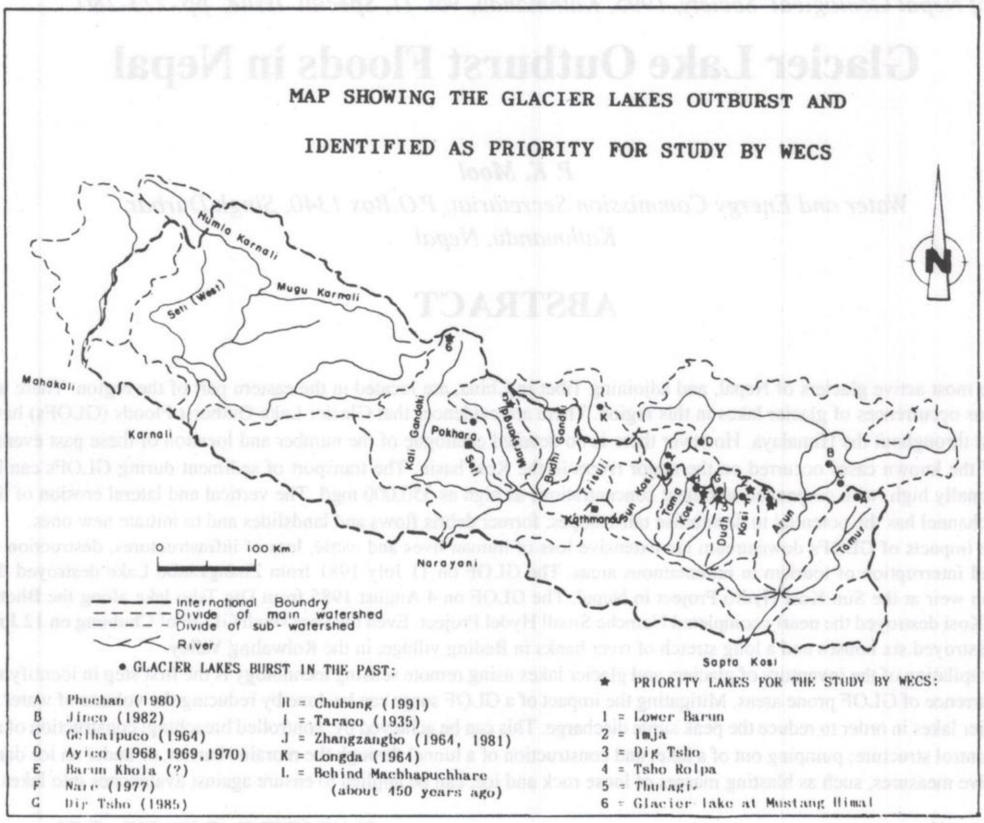


Fig. 1 Map showing the glacier lake outbursts and priority for study by WECS

region. There are numerous occurrences of glacier lakes in this region. The frequency and extent of GLOFs in the Himalaya is not yet adequately documented. Only in the last decade the phenomenon has drawn scientific attention after the Zhangzangbo GLOF on 11 July 1981 (XuDaoming 1985) and the Dig Tsho GLOF on 4 August 1985 (WECS 1987, wIves 1986, Vuichard and Zimmerman 1986, Zimmerman et al. 1986). But there are evidences (primarily in the form of extensive deposits in side valleys and breached terminal moraines) that GLOFs have occurred throughout the Himalaya (Yongjian & Jingshi 1992, Qinghua 1991,WECS 1986), however, to date, there is no detailed catalogue of the number and location of these past events. Few cases are reported (see Fig. 1). Most of the known cases occurred on the major rivers in the Kosi basin (in Nepal and Pumqu basin in Tibet, China). Some of the recorded events are:

- Historical GLOF in Pokhara Valley, about 450 years ago;
- Taraco GLOF in the Targyaling gully of the Poiqu basin (in Tibet, China) and Sun Kosi basin (in Nepal) in1935
- GLOF from Gelhaipuco Lake (Tibet) along the Arun River (Nepal) in 1964;
- GLOF of Longda at the source of the Trisuli River in Tibet in 1964
- GLOF of Ayaco on the northern slope, west of Mt.Sagarmatha (Mt.Everest), in Pumqu basin (Tibet, China), in 1968, 1969 and 1970,
- GLOF of Nare glacier lake (south slope of Mt.Ama Dablam in Nepal) in 1977,
- GLOF from Phuchan glacier lake along the Tamur River (Nepal) in 1980,
- destructive GLOFs along the Bhote-(Sun) Kosi in Nepal from Zhangzangbo Lake (Boqu River in Tibet, China) in 1964 and 1981;

- Jinco GLOF along Yairuzangbo River of the Pumqu basin (Tibet, China) (Arun Basin) in 1982
- GLOF along the Bhote-(Dudh) Kosi in Nepal, from Dig Tsho Lake on 4 August 1985,
- Chubung GLOF at the end of the Ripimo Shar Glacier in the Rolwaling Valley of Nepal on 12 July 1991.

IMPACTS OF GLOF

The transport of sediment during GLOFs can be exceptionally high, with suspended sediment concentrations as high as 350,000 mg/l (Indus River at Darband, Pakistan) (Hewitt 1983). Large quantities of material are eroded from terraces, valley walls, river banks and previous fluvial deposits. The vertical and lateral erosion of the stream channel has the potential to destabilise talus slopes, former debris flows and landslides and to initiate new ones. These processes leave an extensive series of unstable slope sections, which are subject to intermittent movement, and become sources of river sediment over several years following the GLOF. The surge during GLOFs could be of a devastating scale with a discharge of about 16,000 cum/sec (Zhangzangbo GLOF,1981, which occurred 23 minutes after the burst). The main flood of the Zhangzangbo GLOF (1981) lasted about 60 minutes and the burst water volume was estimated at 19 million cubic metres with about 4 million cubic metres of mixed materials joining the debris flow process (XuDaoming 1985). The bulk density of Jelhaipuco GLOF (1964) was about 1.45 tons per cubic metre and the total burst water volume was about 23.36 million cubic metres, which affected long stretches downstream along the Arun River in Nepal (LIGG/WECS/NEA 1988). During the Dig Tsho GLOF on 4 August 1985 along the Dudh Kosi, it was estimated that a volume of 6 to 10 million cubic metres of water had drained from the lake within four hours, giving an average dis-

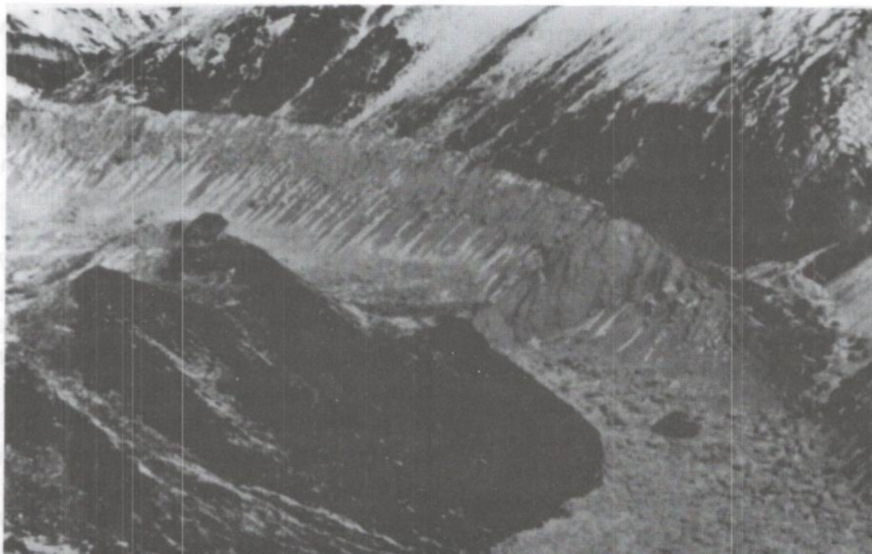


Fig. 2 A view of the breached end moraine of the Dig Tsho lake after the 4 Aug 1985 GLOF event. The lake has been almost completely drained. (photo source: WECS)

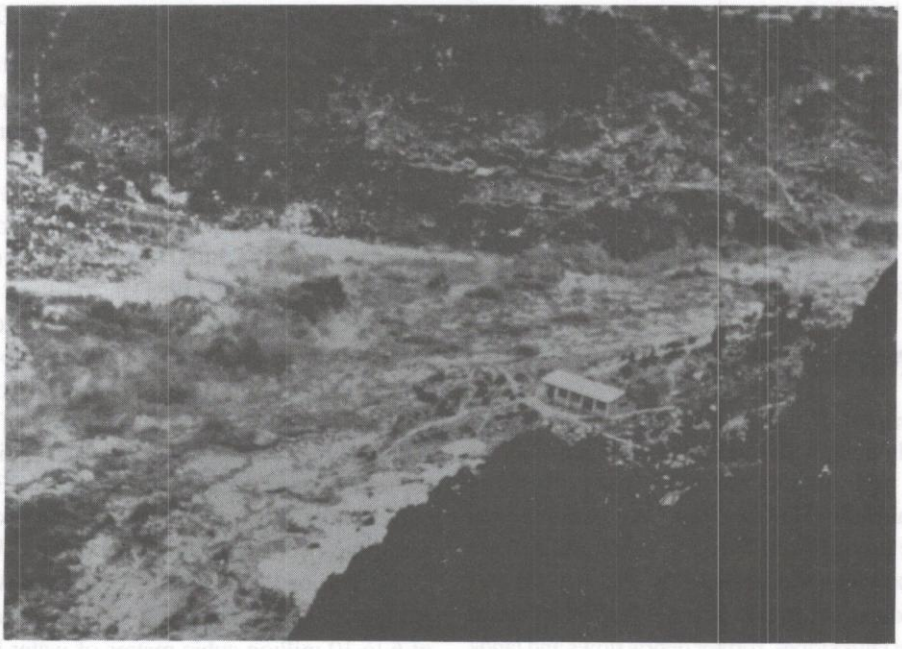


Fig. 3 Surge wave from GLOF of Dig Tsho glacier lake (4 Aug 1985) eroding right bank of Bhote-Dudh Kosi at Namche Small Hydel Project. Shock waves of 5 to 10 m in height were developed at obstructions such as river banks, constrictions, bends and boulders. Velocities were exceptionally high. Namche Small Hydel Project was completely destroyed by the GLOF (photo source: WECS).

charge of 500 cum/Sec, the initial peak discharge possibly exceeding 2,000 cumecs (Vuichard and Zimmerman 1987).

The main impact of GLOFs downstream is extensive loss of human lives and cattle, loss of infrastructure, destruction of land which cannot be reclaimed for several years, and interruption of tourism in mountainous areas. The GLOF on 11 July 1981 from Zhangzanbo Lake at Boqu (Bhote-Sun Kosi) River in Tibet (China) destroyed the diversion weir at the Sun Kosi Hydro Project (Nepal), two bridges, and tore out extensive sections of the Arniko Highway (highway linking Nepal and China) resulting in damage amounting to US$ three million. The GLOF on 4 August 1985 from Dig Tsho lake (Fig. 2) along the Bhote-(Dudh) Kosi (Fig. 3) destroyed the nearly completed Namche Small Hydel Project (at an estimated cost of US$ one and a half million), numerous footbridges, and trekking trails, as well as took many lives. Even the very small GLOF of Chubung on 12 July 1991, destroyed six houses and a long stretch of river banks in Beding village, in the Rolwaling Valley.

INVESTIGATION AND MITIGATION

For the prediction of GLOFs, identification of the GLOF prone areas as well as investigation of possible (actual) occurrences and their consequences, are necessary (Bjornsson 1992, Reynolds 1992, Ives 1986, Young 1980, Lliboutry et al. 1977a, 1977b, 1977c, Muller 1970). The accuracy of prediction of GLOFs may range from a high degree of reliability to a level of uncertainty. Compilation of the inventory of glaciers and glacier lakes using remote sensing technology is the first step in identifying the GLOF prone areas. Remotely sensed data, such as satellite data and aerial photographs, and exiting maps are very useful in the study of GLOFs (Mool 1993, WECS 1993a,1993b,1986, ,Yamada 1992,1991, Kulkarni 1991). Careful monitoring of climatic changes, glacier behaviour, mechanical condition of dam material and surroundings, subsurface hydrology in and around the lake area, as well as seismic and tectonic activity of the region is needed.

Mitigating the impact of a GLOF surge can be done by reducing the volume of water in the glacier lakes in order to reduce the peak surge discharge. This can be achieved by: controlled breaching; construction of an outlet control structure; pumping out of a lake; and construction of a tunnel through the moraine barrier, or under an ice dam. Protecting infrastructures against the destructive forces of the GLOF surge, and monitoring systems prior to, during, and after construction of infrastructures and settlements, are necessary. Preventive measures, such as blasting masses of loose rock and ice, can be applied to ensure against avalanches into lakes.

After the incidence of 1985 Dig Tsho GLOF, the phenomenon of GLOF in the Nepal Himalaya drew the attention of many organisations, leading to the initiation of various studies. In this context, the Water and Energy Commission Secretariat (WECS) of His Majesty's Government of Nepal started the first ever systematic GLOF study, which is still continuing. In 1987, a joint Nepal-China study team successfully conducted a field research on glaciers and glacier lakes in the Arun and Bhote-(Sun) Kosi basins within Tibet (China). Within Nepal, field inves-

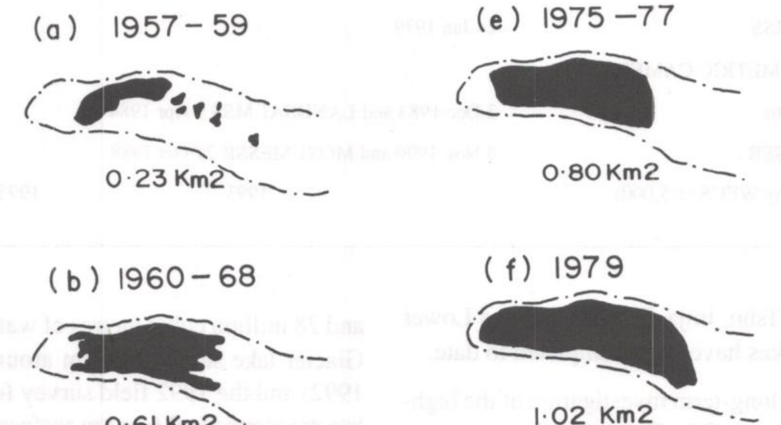


Fig. 4 Development of the Tsho Rolpa Glacier Lake

Table 1. Development of the Tsho Rolpa Glacier Lake

Source	AP/Images	Survey	Published	Area, Km^2
a) Survey of India Toposheet (1:63,360)	1957 - 59	1963	1974	0.23
b) Schneider Map (1:50,000)	?	1960 - 68	1981	0.61
c) ERTS (LANDSAT) MSS	14 Dec 1972			0.62
d) Nepal/China Boarder map (1:50,000)	1974	1978 - 79	1980	0.78
e) LANDSAT MSS	2 Nov 1975 and 20 Mar 1977			0.80
f) LANDSAT MSS	24 Jan 1979			1.02
g) SPACELAB METRIC CAMERA				
color IR photo	3 Dec 1983 and LANDSAT MSS 9 Apr 1984			1.16
h) MOS1 MESSER	9 Nov 1990 and MOS1 MESSR 21 Oct 1988			1.27
i) Field survey by WECS (1:5,000)		1993	1993	1.37

tigations of Dig Tsho, Imja, Tsho Rolpa, and Lower Barun glacier lakes have been completed to date.

Detailed and long-term investigation of the high-potentially dangerous Tsho Rolpa Glacier lake in the Rolwaling Valley was started in 1993 and is considered as a model lake for study and mitigation. Based on available maps, satellite imageries, field surveys, the development of this lake was studied. The Tsho Rolpa Glacier lake has developed from 0.23 sq km (1959) to 1.37 sq km (1993) in area (Fig. 4 and Table 1) . Although there is difference in the time span within the periods, it can be concluded that the rate of area increase has been accelerated. The Tsho Rolpa Glacier lake might have started forming around 1950. The present maximum depth of the lake is 132 m with 71 million cubic metres of water.

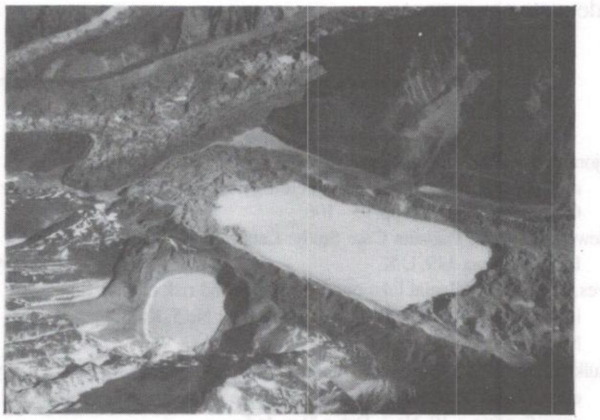
Like the Tsho Rolpa Glacier lake, other glacier lakes (Fig. 5) also have similar trend of accelerated growth. Some examples are worth mentioning here. No lake is shown on the Lower Barun Glacier in the topographic map published in 1967, but the systematic study of satellite imageries and the field survey in 1993 revealed that the glacier lake was developing on the glacier tongue with surface area of 0.6 sq km and 28 million cubic metres of water. Similarly Imja Glacier lake started to form around 1963 (Yamada 1992) and the 1992 field survey found that the lake has developed to 0.6 sq km surface area with 28 million cubic metres of water. Thulagi Glacier lake located southwest of Mt. Manaslu, upper most reach of the Dhana Khola a tributary of Marsyangdi river, has reached 2 km length (based on 24 January 1990 MOS1 MESSER Satellite imagery) from 0.6 km (based on 1960 published toposheet).

CONCLUSIONS

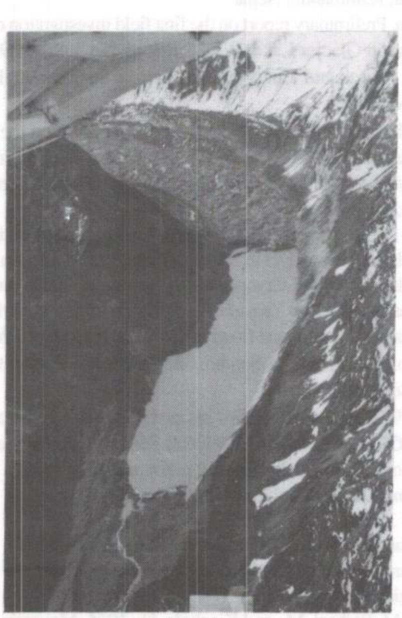
GLOFs are caused by a sudden bursting of glacier lakes which are either ice-dammed or moraine-dammed. Moraine-dammed lakes generally breach by overtopping or by piping while ice-dammed lakes drain underneath the ice. Peak discharge from moraine-dammed lakes are much higher than from ice-dammed lakes because the draining is much faster. The flood surge of GLOF can propagate tens to hundreds of km below the glacier lakes. Sediment loads during a GLOF are exceptionally high. Downstream geomorphic effect (damage) of GLOF is very severe causing great changes along its flow path. The predic-

GLACIAL LAKE OUTBURST FLOOD (GLOF OF 4 AUGUST 1985 DIG TSHO AT LANGMOCHE IN DUDH KOSI BASIN (Photo 25 April 1991)

TSHO ROLPA GLACIER LAKE IN TAMA KOSI BASIN



IMJA GLACIER LAKE IN DUDH KOSI BASIN



THULAGI GLACIER LAKE IN MARSYANGDI BASIN

LOWER BARUN GLACIER LAKE IN ARUN BASIN

Fig. 5 Some important glacier lakes of Nepal (Photo source: WECS)

tion of a GLOF event is very difficult which needs accurate inventories, field investigations and instrumentations to understand the mechanism. Well studied GLOF events are Bhote (Sun) Kosi form Zhangzanbo lake (Poiqu basin in Tibet, China) in 1964 and 1981, Gelhaipuco GLOF of 1964 in Arun Kosi (Pumqu basin in Tibet, China), GLOF on the Bhote (Dudh) Kosi of 1985 August 4. Preliminary study of some of the potentially dangerous glacier lakes (Imja, Lower Barun, Tsho Rolpa) has been done by WECS. It is necessary to carry out detailed field study of glacier lakes as well as associated glaciers in the Nepal Himalaya. There are several other glacier lakes (like Thulagi glacier lake in Marsyangdi basin) still to be studied. Major constraints for GLOF studies in Nepal are availability of fund, field manpower, and lack of adequate equipment.

REFERENCES

Bjornsson H.,1992, Jokulhlaups in Icelands: prediction, characteristics and simulation. Annals of Glaciology, v. 16, International Glaciological Society, pp. 95 - 106.

Hewitt, K., 1885, Pakistan Case Study: Catastrophic Floods, IASH Publication no. 149, U.K.

Ives, J.D., 1986, Glacial lake outburst floods and risk engineering in the Himalaya. ICIMOD occasional paper No 5, Kathmandu, Nepal 42 p.

Kulkarni,A.V., 1991, Glacier inventory in Himachal Pradesh using satellite images. Photonirvachak, Journal of the Indian Society of Remote Sensing, v.19, No.3, Dehra Dun, India.

LIGG/WECS/NEA, 1988, Report on first expedition to glaciers and glacier lakes in the Pumqu (Arun) and Poiqu (Bhote-Sun Kosi) river basin, Xizang (Tibet),China, Sino-Nepalese investigation of glacier lake outburst floods in the Himalaya. Science Press, Beijing, China, 192 p. plus maps.

Lliboutry,L.,Arnao,B.M.,and Schneider,B., 1977a, Glaciological problems set by the control of dangerous lakes in Cordillera Blanca, Peru. I. Historical failures of morainic dams, their causes and prevention. Journ. Glaciol., v.18, no. 79, pp. 239 - 290.

Lliboutry, L., Arnao, B.M., and Schneider, B., 1977b, Glaciological problems set by the control of dangerous lakes in Cordillera Blanca, Peru. II. Movement of a covered glacier embedded within a rock glacier. Journ. Glaciol., v.18, no. 79, pp. 255 - 273.

Lliboutry, L., Arnao, B.M., and Schneider, B., 1977c, Glaciological Problems set by the control of dangerous lakes in Cordillera Blanca, Peru. III. Studies of moraines and mass balances at Safund. Journ. Glaciol., v. 18, no. 79, pp. 275 - 290.

Mool, P.K., 1993 Glacier Lake Outburst Floods in Nepal. WECS Bulletin, Vol 4, No 1. A Publication of Water and Energy Commission Secretariat, Kathmandu, Nepal, pp. 8 -11.

Muller, F., 1970, Inventory of glaciers in the Mount Everest region, Perennial ice and snow masses a guide for compilation and assemblage of data for world inventory, UNESCO Technical paper in Hydrology, No.1, pp. 47-45.

Muller, F., Caflish, T., and Muller, G., 1977, *Instruction for compilation and assemblage of data for a World Glacier Inventory.* Temporary Technical Secretariat for World Glacier Inventory, Swiss Federal Institute of Technical, Zurich.

Qinghua, F., 1991, Characteristics of glacier outburst flood in the Yarkiant river, Karakorum Mountains, Geo Journal, 25.2/3, pp. 255 - 263.

Reynolds, J.M., 1992, The identification and mitigation of glacier-related hazards: examples from the Cordillera Blanca, Peru, *in: McCall et al. (eds) chapter 13: Geohazards Natural and man-made,* Chapman & Hall, pp. 143-157.

Sugden, D.E and John D.S, 1990, Short and medium term glacier fluctuations,*in: chapter 6: Glaciers and Landscape A Geomorphological Approach.* Edward Arnord, A division of Hodder & Stroughton, London, pp. 102 - 128.

Vuichard,D. and Zimmerman, M., 1986, The Langmoche flash flood, Khumbu Himal, Nepal. Mountain Research and development, v. 6(1), pp. 90 - 94.

Vuichard, D. and Zimmerman, M., 1987, The 1985 catastrophic drainage of a moraine-dammed lake, Khumbu Himal, Nepal: Cause and consequence. Mountain Research and Development, v. 7 (2), pp. 91 - 110.

WECS,1986, Preliminary study of glacier lake outburst floods (GLOFs) in the Nepal Himalaya: Phase 1 interim report, Report No 4/1/200587/1/1 Seq 252. Water and Energy Commission Secretariat, Kathmandu, Nepal.

WECS, 1987, Dudh Kosi river 1985 GLOF study survey report, Report No 4/3/040587/1/1 Seq 257. Water and Energy Commission Secretariat, Kathmandu, Nepal.

WECS, 1993a, Preliminary report on the first field investigation on the Lower Barun Glacier Lake, WECS Report No 3/4/080893/1/1 Seq 428. Water and Energy Commission Secretariat, Kathmandu, Nepal.

WECS, 1993b, Interim Report on the field investigation on the Tsho Rolpa Glacier Lake , Rolwaling Valley. WECS Report No 3/4/021193/1/1 Seq 436 Water and Energy Commission Secretariat, Kathmandu, Nepal.

XuDaoming, 1985, Characteristics of debris flows caused by outbursts of glacial lake in Boqu river in Xizang, China, 1981. Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, unpublished manuscript, 24 p.Yamada, T., 1991, Preliminary work Report on glacier lake outburst flood in the Nepal Himalayas. WECS Report no. 4/1/291191/1/1 Seq no. 387, Water and Energy Commission Secretariat, 30 p.

Yamada, T., 1992, Report for the first research expedition to Imja lake. WECS Report No 3/4/120892/1/1 Seq no. 412. Water and Energy Commission Secretariat, 20 p.Young, G.J., 1980, Monitoring Glacier Outburst Floods. Nordic Hydrology, v.11, pp. 285 - 300.

Yongjian, D. and Jingshi, L., 1992, Glacier lake outburst flood disasters in China. Annals of Glaciology, v.16, International Glaciological Society, pp.180 - 184.

Zimmerman, M. Bichsel, M., and Kienholz, H., 1986, Mountain hazard mapping in the Khumbu Himal, Nepal with proto type map, scale 1:50,000. Mountain Research and Development, v. 6(1), pp. 29 -40.