

Photographic Feature

Glacial hazard assessment at Tsho Rolpa, Rolwaling, Central Nepal

John M. Reynolds

Reynolds Geo-Sciences Ltd, The Stables, Waen Farm, Nercwys, Mold, Flintshire, CH7 4EW, UK

Recession of glaciers throughout the Himalayas is resulting in the development of a growing number of high-altitude proglacial lakes that are retained behind natural moraine dams. Some of these have failed catastrophically and the consequential Glacier Lake Outburst Floods (GLOFs) have resulted in substantial damage and loss of life downstream. With growing populations in remote valleys coupled with the demand for substantial growth in the capacity for hydro-electric power for export, the risk of further disasters is increasing. Accordingly, His Majesty's Government of Nepal has undertaken a series of studies since 1985 to investigate the risks associated with such glacial lakes. This photofeature encapsulates aspects of the work undertaken between 1994 and 1997 at Tsho Rolpa, which is thought generally to be the largest and most dangerous glacial lake in Nepal. The present project at Tsho Rolpa is the first of its kind in Nepal and represents the first time that such detailed glacial hazard assessment has been undertaken through to the development of a full remediation scheme in Nepal.

Tsho Rolpa lies about 110 km north east of Kathmandu at the eastern end of the Rolwaling Valley

(Fig. 1) and immediately south of Gauri Sankar (7146 m). The lake (Fig. 2) is about 3.5 km long by 0.5 km wide and is up to 135 m deep. It is fed by Trakarding Glacier (Fig. 3) to the southeast which is itself a composite glacier supplied by several glaciers from among the peaks to the east and south east of Tsoboje (6689 m). The north-western end of the lake is dammed by a terminal moraine complex (Fig. 4). This is up to 150 m high and is partly cored by stagnant glacier ice of unknown thickness. The lake currently holds about 80 million cubic metres of water; it is thought that a Glacier Lake Outburst Flood could occur at some time in the near future with a potential volume of up to 30 million cubic metres of water.

At Khimti, 80 km downstream from Tsho Rolpa, a new hydro-electric power (HEP) scheme is being built. Subject to financing provisions, it is anticipated that, at the height of construction, some 1500–2000 workers will be housed in a camp adjacent to the river and might be at risk from a possible GLOF. It has been estimated by the plant managers that serious GLOF damage could cost in excess of \$22 million and put the construction project back by two or more years. More details of the

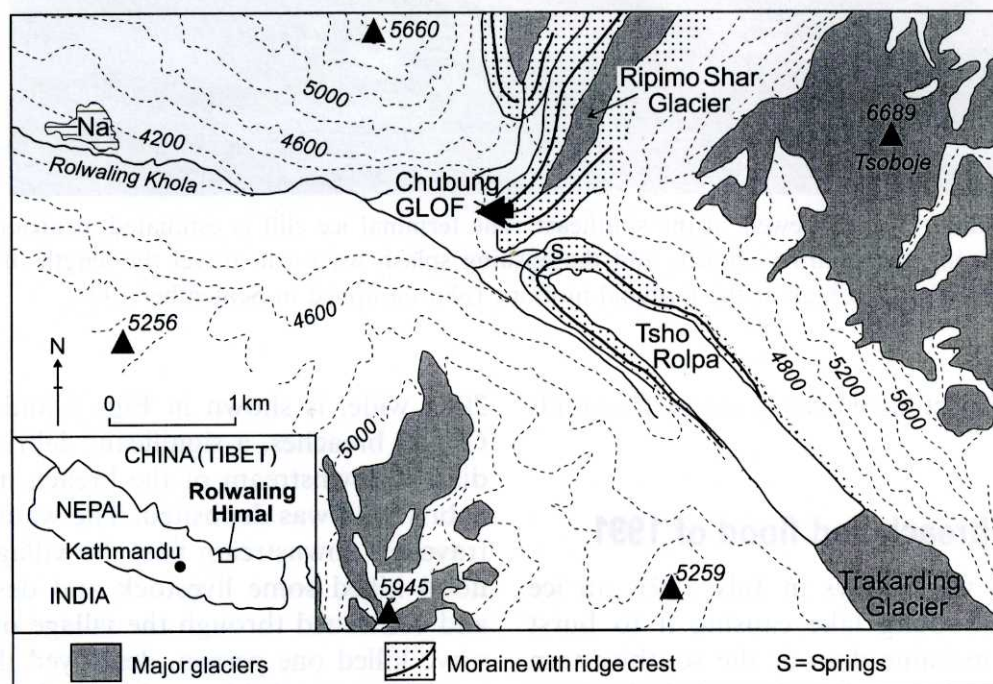


Fig. 1. Summary map of the Tsho Rolpa area with a location map of the Rolwaling Himal (inset).

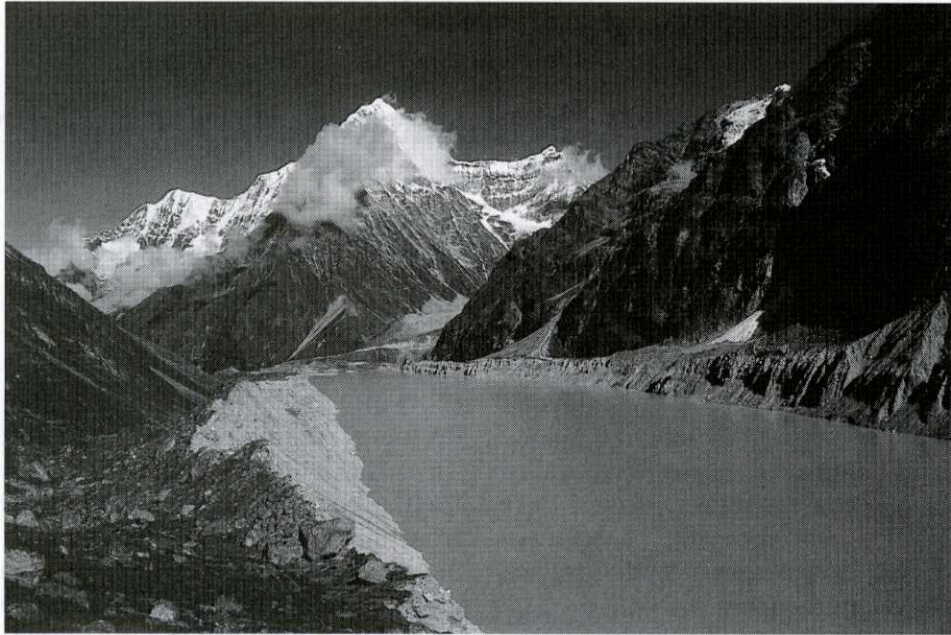


Fig. 2. Tsho Rolpa glacial lake viewed towards the northwest. The eroding lateral moraine is over 80 m high (photographed in September 1994).



Fig. 3. Snout of Trakarding Glacier viewed to the southeast. The terminal ice cliff is estimated at around 40 m high. The ice cliff calves most days during the summer months and the ensuing splash wave can travel the length of the lake. The largest wave recorded to date is over 1.3 m high at the terminal moraine (photographed in September 1997).

background to this project have been given by Reynolds (1995, 1998*a,b*).

The Chubung breach and flood of 1991

Following three very warm days in July 1991, an ice avalanche fell into Chubung lake causing it to burst through its terminal moraine dam at the southwestern end of Ripimo Shar Glacier (Fig. 1) and drain completely. The breach, estimated as being 15 m deep and

20 m wide, is shown in Figs 5 and 6. As is typical of GLOF breaches, a significant debris fan formed immediately downstream of the breach in which the coarser debris load was deposited. The water and finer material travelled downstream past the village of Na, where the flood killed some livestock and destroyed one bridge, and continued through the village of Beding. The flood wave killed one person, destroyed three flour mills and several potato fields, and caused great alarm amongst the inhabitants.

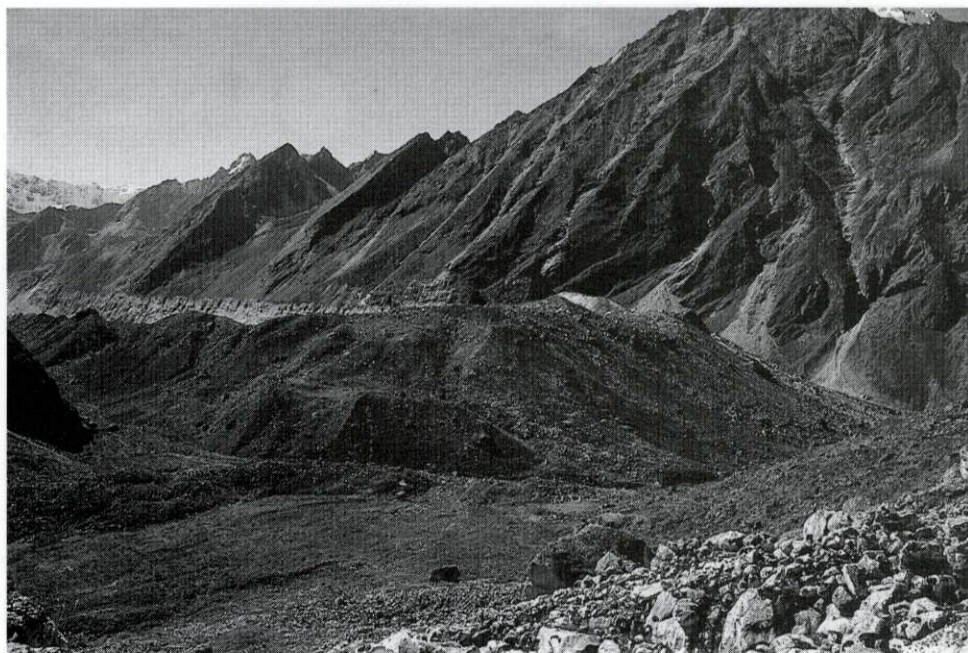


Fig. 4. The terminal moraine of Tsho Rolpa viewed from the Ripimo Shar moraine complex (photographed in September 1994).



Fig. 5. The Chubung breach of July 1991. Some of the boulders in the foreground fan deposit weigh in excess of 400 tonnes (photographed in September 1994).

Previous work

Following the July 1991 GLOF from Ripimo Shar, the villagers of Beding and Na within the Rolwaling Valley sought outside help as they perceived a serious risk of a future GLOF from Tsho Rolpa, a lake many times the size of Chubung. The present author received an invitation in 1993 to help with the problem at Tsho Rolpa from the Water and Energy Commission Secretariat (WECS), Ministry of Water Resources, His Majesty's Government of Nepal, Kathmandu. Although WECS had undertaken some preliminary

observations in the Rolwaling valley and around Tsho Rolpa in 1993 in association with some Japanese researchers (Mool 1995; Yamada 1993), little was known about the potential hazard risk. Given the immediacy of the problem, the author was financed by the Emergency Aid Department of the Overseas Development Administration (now the Department for International Development) to visit Tsho Rolpa and to assess the situation. As a result of this work, it was realized that the moraine complex that dammed Tsho Rolpa was probably cored with ice (Reynolds 1998*b*). This, in conjunction with observed seepage

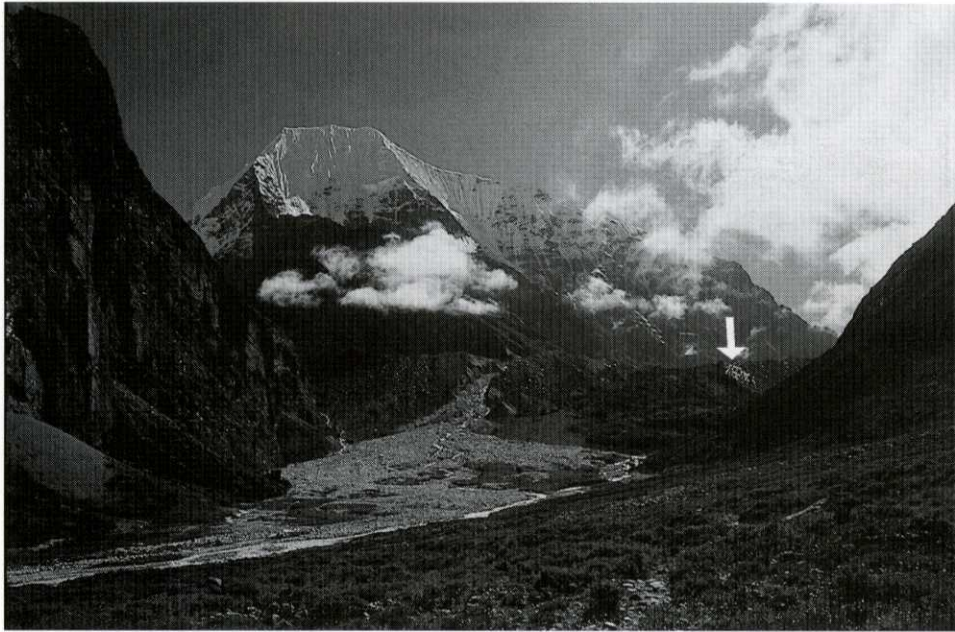


Fig. 6. The view towards the eastern end of Rolwaling Valley from Na, showing the Chubung breach and fan deposits, and the spillway from Tsho Rolpa (arrowed). The base of this valley lies at an altitude of 4200 m and the main snow-capped peak shown is Tsoboje (6689 m). This peak also marks the boundary with Tibet (China) (photographed in September 1994).



Fig. 7. This 34 m wide thermokarst hole in the northwestern terminal moraine had developed by May 1997 from a 3 m diameter depression that had been observed in October 1996. The resultant ice cliff shown here was 11 m high and the pond was over 3 m deep. Between May and September 1997 this feature had doubled in size and had reduced the moraine dam width by a further 30 m (photographed in May 1997).

through the outer flank of the moraine, indicated that the moraine was deteriorating structurally. Furthermore, increased ice avalanche activity from the ice cliff at Trakarding Glacier, coupled with greater avalanche magnitudes, observed between 1994 and 1997, were also cause for concern. Displacement waves, caused by ice avalanches from the terminal ice cliff at Trakarding Glacier, were observed in 1997 to reach in excess of 1.3 m in amplitude at the terminal moraine. Conse-

quently, the risk due to waves overtopping the moraine dam and causing regressive erosion on the distal side was also increasing with time.

It was felt that, unless appropriate remediation works were undertaken, the moraine would fail and Rolwaling Valley would be inundated. This would cause widespread loss of life and serious damage to local infrastructure including potential damage to the Khimti HEP water intake.

emergency strategic measures in June 1997 to provide a manual early warning system for the local villagers and the Khimti hydro-power installation. A small detachment of army personnel established camps at the terminal moraine and at Na where a small police post was also installed. Observations of the moraine were made regularly and reports were radioed to Kathmandu three times daily throughout the period from May to September. Furthermore, a local pipe manufacturer was commissioned to supply pipes similar to those produced by WAVIN Overseas B.V. and a further 5 siphons were installed in June 1997 (Fig. 9). In late August/early September 1997, the site was revisited by the author with colleagues from the Department of Hydrology and Meteorology, Kathmandu, as part of a review of the possible remediation schemes. It was found that the exposed ice cliff had increased in height to 19 m and the melt pond at the foot of the ice cliff had deepened to over 5 m. This represented more than a doubling by volume of the melt feature and indicated a significant further deterioration of the moraine.

In May 1998, a series of remote sensors was installed along the Rolwaling Khola as part of an Early Warning System funded by the World Bank. The sensors were placed so that if a flood wave of a certain height was recorded by a specific number of sensors, sirens would sound in the villages downstream to alert the local inhabitants.

A revised proposal for remediation of Tsho Rolpa was submitted by His Majesty's Government of Nepal to the Dutch Government in December 1997. Funding worth \$2.9 million was granted in March 1998 to implement a remediation programme for completion by July 2000. This will involve the construction of a 4 m

deep artificial spillway to lower the lake level by 3–4 m. An additional phase of remediation, currently under negotiation, will be needed to lower the lake by 15–20 m below its present level before the potential hazard can be considered to have been successfully remediated.

Acknowledgements. The author is very grateful to His Majesty's Government of Nepal for the opportunity to work in Rolwaling and for collaboration with staff from the ministries of Water Resources and of Science and Technology, Kathmandu. Thanks are also due to the Emergency Aid Department (now the Conflict and Humanitarian Affairs Department) of the Department for International Development, London, for funding the three field visits made by the author, and generally for supporting this ongoing work. The author is also indebted to the continued support of His Excellency, the British Ambassador, and his staff at the British Embassy in Kathmandu.

References

- MOOL, P. K. 1995. Glacier Lake Outburst Floods in Nepal. *Journal of Nepal Geological Society*, **11**, 273–280.
- REYNOLDS, J. M. 1995. Glacier-lake outburst floods (GLOFs) in the Himalayas: an example of hazard mitigation from Nepal. *Geoscience and Development*, **2**, 6–8.
- 1998a. Managing the risks of glacial flooding at hydro plants. *Hydro Review Worldwide*, **6**(2), 18–22.
- 1998b. High-altitude glacial lake hazard assessment and mitigation: a Himalayan perspective. In: MAUND, J. & EDDLESTON, M. (eds) *Geohazards in Engineering Geology*, Geological Society, London, Special Publications, **15**, 25–34.
- YAMADA, T. 1993. *Glacier Lakes and their Outburst Floods in the Nepal Himalaya*. Water and Energy Commission Secretariat, Kathmandu, Nepal.

Received 2 June 1998; accepted 2 October 1998