

## 9. Recommendations

To control the potential risks of the destructive impacts on human activities and the fragile Himalayan environment caused by GLOF, further GLOF studies are recommended here.

### 9.1 For the Future GLOF Studies

Abatement of the impact of the inevitable GLOF phenomena is highly desirable and necessary. The following investigations of a glacier lake as a source of GLOF should be promoted to fill the data gaps in our knowledge and insight into the glacier lakes and related phenomena :

- 1) to complete the inventory work of glacier lakes and their mother glaciers in the Nepal Himalaya and also in the Tibetan drainage basin upstream of the Bhote Kosi by using vertical aerial photographs with a help of time series satellite imageries,
- 2) to evaluate potentially dangerous glacier lakes by flight observations and by field visits,
- 3) to monitor the potentially dangerous lakes by satellite imageries and / or a flight observations,
- 4) to study the mechanism of quick formation of a glacier lake : melting mechanism of a debris covered glacier, a supra-glacial pond formation and its expansion mechanism to form the lake.

Once the potentially dangerous lakes are found, we should undertake continuous monitoring of their growing processes and changes in general features, carefully, for detecting any signs of degradation. If the formation mechanism of a glacier lake could be understood clearly, we may be able to predict the future tendency of glacier lake development in the Himalaya with reasonable accuracy. Before implementing civil engineering intervention on a potentially dangerous glacier lake, the following studies should be carried out :

- 5) preparation of the vertical aerial photographs around the lake and along the river channel downstream as basic data for planning,
- 6) detailed topographical mapping of the lake and its related areas such as the moraine-dam, the valleys between the lateral moraines and the mountain slopes etc.,
- 7) bathometric mapping of the lake, especially the downlake area near the end moraine-dam in detail and to estimate volume of stored water,
- 8) meteorological data collection at least one year,
- 9) discharge measurement through the outlet of the lake to obtain the annual amount and seasonal variation of discharge,
- 10) physical survey of the buried (dead) ice in the moraine to reveal its accurate distribution and to clarify the moraine-dam structure,
- 11) to examine and to evaluate possible technology for lowering the lake level,
  - 11-1) test of siphon system,
  - 11-2) feasibility study of micro-hydropower generation for electrically pumping out lake water,
- 12) to examine and to evaluate possible technology for excavating spillway on / in the moraine,

- 13) to examine and to evaluate practical possibility for the introduction of heavy duty construction machines,
- 14) to examine the logistical issues such as transportation and living condition of engineers and workers.

As for item 11-1, the siphon system, the pipe diameter of 13.8 cm, has been installed and tested from May 1995 at Tsho Rolpa glacier lake by Holland-Nepal Friendship Association on a trial basis. Water has been drained out at the rate of about 63 L/s, which is estimated by the velocity of 4.2 m/s measured in May 1996 (Yamada, 1996). The system has been successfully functioning for over a year without any maintenance. It was found that the joints of the siphon pipes had been disjointed by settlement forces of snow overburden during winter but the siphon itself was still operating in May 1996 as shown in Photo 35. The problem may be easy to solve technically.



**Photo 35 :** Trial siphon system in May 1996, which being installed in May, 1995.

Since mitigation work requires large funds, its cost effectiveness should be carefully analyzed in the light of not only economic benefit but also the welfare of the vulnerable inhabitants and the conservation of the Himalayan environment. This is the responsibility of not only the scientists and engineers but also the politicians with high insight into the decision making processes. Now the mitigation work belongs to high political issues.

## **9. 2 For the Glaciology in the Nepal Himalaya**

The development of the country was initiated from the midlands and the Terai because of their dense population and relatively easy accessibility. The high Himalayan regions, consisting of brilliant white peaks decorated by snow and glaciers under sub-polar climate, had remained as the hallowed abodes of the Gods and Goddesses in Hindu mythology located in the remote areas far

from the Hindu society. The Himalayan regions have recently been worthwhile to develop not only for water resources but also their attraction for the tourism industry and a valuable scientific field for the study of the earth sciences. The high Himalaya is believed to be a valuable new frontier in Nepal. Further development would be heartily expected in the coming 21st century.

Snow, glacier and permafrost induced disasters will clearly and surely appear in the near future as serious problems if socio-economic development is to progressively enter into the deep Himalayan regions. It should be recognized that the GLOF problem is only one of them. When development results in the proliferation of expensive infrastructures and facilities for the tourism industry etc. accompanied by population growth in the Himalayan regions, the disasters will arise due to snow, ice and rock avalanches, landslides, frost heaving due to the cold climate, cutting off the transportation due to blockages by heavy snowfall and so on. To prevent, to avoid and to mitigate those potential natural disasters and environmental problems in the Himalaya, we have to make a sincere effort to obtain and to collect basic glaciological, hydrological, meteorological and environmental data, information and knowledge relating to snow and glaciers in the Himalaya.

Human resource development and supply system are urgently required in Nepal for the glaciology sector. It should be promoted as one of the important national policies of His Majesty's Government of Nepal, first by positively accepting any support of foreign glaciologists by means of all governmental and non-governmental channels available.

It is obvious that one set of vertical aerial photographs, topographical maps, meteorological and hydrological data as well as the data of population density and land use in the high Himalayan regions are the most fundamental and basic tools for any kind of planning for the socio-economic development of the Himalaya. Some of them are still not sufficient. Furthermore, the above mentioned data should be easily accessible for effective use to all earnest research and development personnel.