MAPPING OF POTENTIAL JOKULHLAUP SOURCE AREAS IN KHUMBU HIMAL

Khumbu Himal, of all the high mountain areas of the Central Himalaya, is probably the best known and most extensively studied. Information sources include air photographs, satellite imagery, ground photographs, topographic maps, and the published results of natural science research. This reinforces the choice of the study of the Langmoche *jokulhlaup* as a test programme for *jokulhlaup* hazard mapping and related glaciological research.

Much of this material on Khumbu Himal is comparatively easily available: for instance, the Schneider maps scale 1: 50,000, and associated ground photo-theodolite coverage; the National Geographic Society air photography of December/January, 1983/84, scale 1:30,000; the SpaceLab metric camera ESA/Earthnet imagery of 2 December, 1983; various Landsat images; the UNU/Nepal MAB Mountain Hazards Mapping Project map, field survey, and related ground photographs; the hand-held air and ground photography by Dr. Victor Galay in 1985 and 1986 (35 mm and 60 x 60 mm) ; the October, 1985, survey of Langmoche and the Bhote Koshi - Dudh Koshi (Vuichard and Zimmermann 1986, 1987 in press); the glaciological and geomorphological research undertaken by Muller (1958), Higuchi (1976-80) and colleagues, Heuberger (1956, 1974), Khule (1986), and others. In addition, there is an enormous number of ground photographs taken by mountaineers and trekkers. While the last-mentioned material is much more diffuse and difficult to obtain, some useful photographs of ice and moraine-dammed lakes and related glaciological features might be obtainable.

These materials, and especially the results of stereoscopic analysis of the National Geographic Society's air photography, can be used as the basis for compilation of a reconnaissance map of glaciological hazards. The Schneider map, **Khumbu Himal**, scale 1:50,000, would provide a suitable cartographic base. A proposed legend is given in Table 3.

The two specific (Mingbo and Langmoche glaciers) and two or three additional glacier tongues should be selected for long-term monitoring during "ground-truthing" of the reconnaissance map in the field. Sketch maps on smaller scales (1:500/1:2,500) should be made of these small areas and permanent photograph stations should be installed.

Table 3 Proposed Glaciological Hazards Map Legend

Scale 1:50,000-Topography, E.Schneider

- Ice and permanent snow cover
- Ice-dammed lakes (min.size 0.1km^2)
- Moraine-dammed lakes (min. size 0.1km^2)
- Supra-glacial lakes (individual min. size 0.1km2) - groups of small lakes by symbol
- Debris - covered glacier tongue
- Neo-glacial end and lateral moraines
- Older and lateral moraines
- Hollows below glacier snouts that may become sites for new lakes if glaciers advance
- Streams and rivers
- Other topographical features from the Schneider map as required (e.g., vegetation cover)
- **Geomorphic Features**
  stripped bedrock
  high lake shorelines
  spillways
  recent alluvium
  debris flows (landslides)
  giant blocks in river channel
  condition of river channel
- Mingbo Glacier and site of 1977 jokulhlaup
- Langmoche Glacier and site of 1985 *jokulhlaup*

Some glacier details of the sections of the Schneider map are not accurate, or conditions have changed since the ground photogrammetry was completed (see discussion on the age and development of Dig Tsho). Where possible, detailed corrections should be effected by reference to the more recent photographs. The

map should also include all settlements, bridges, trails, and other elements of human infrastructure.

The final step in this phase of the proposed programme should be a remote-sensing comparison between the National Geographic Society air photography, the SpaceLab metric camera imagery, and selected Landsat images. This would facilitate an estimation of the loss of detail and accuracy with increasingly unfavourable scales of the imagery. Thus an impression would be gained of the form that a reconnaissance map would take showing a much larger section of the Himalaya, dependent upon interpretation of Landsat imagery.

The final document of a Khumbu-Himal glaciological hazards mapping exercise should include the following:

- reconnaissance map, selectively field-checked, scale 1:50,000;
- comprehensive report of glacier, snow and avalanche conditions;
- Photographic file.

It would be valuable for the following reasons:

- it would provide a benchmark upon which data derived from a monitoring project could be evaluated;
- it would provide the H.M.G. Water and Energy Commission and the Small Hydel Development Board and other agencies with a basic glaciological hazard document to be used in conjunction with any future site study for proposed hydro-electric and other engineering works in the Khumbu region;
- it would serve as a prototype for expansion to other areas.

For each lake identified the following data should be obtained:

- lake geometry and volume;
- estimation of the likelihood of a similar drainage triggering mechanism to Dig Tsho;
- assessment of the possibility of remedial measures, for example, artificial draining.

In addition, installation of stream gauging instrumentation at selected localities would be important for the eventual accumulation of long-term hydrologic records.

The Arun River Basin and its Hydro-Electric Potential

There is a potentially highly valuable intermediate step that can be inserted between the proposed Khumbu Himal scheme and the general Himalayan survey using Landsat imagery. This relates to on-going discussions for a co-operative survey of the nearby Arun catchment, which is also included on the outstanding SpaceLab metric camera images.

Since a very large and expensive cascade of hydro-electric power installations is being planned for the Arun River, and since there are on-going discussions between Nepalese and Chinese scientific and survey teams (much of the upper Arun catchment lies in the Xizang Autonomous Region), these activities should be supplemented by remote sensing and field checking of dangerous ice-dammed and moraine-dammed lakes in this area.

From a preliminary examination of the SpaceLab metric camera imagery, there is evidence of at least 50 ice-dammed and moraine-dammed lakes, most of them located in Chinese territory. It is highly recommended that an exhaustive investigation be undertaken to determine the potential hazard posed by these and other lakes before any final decisions are made concerning engineering works on the Arun River.