THE NAMCHE SMALL HYDEL PROJECT, KHUMBU HIMAL

Decision Making, Project Design, and Site Characteristics

In April 1976 His Majesty's Government of Nepal requested the technical and financial assistance of the Austrian Federal Government for the construction of a small hydroelectric power station to service Namche Bazar and a number of neighbouring villages. The basis of this request was the rapid growth in trekking tourism and mountaineering in Khumbu Himal and the progressive transformation of the Sherpa economy as it adjusted to the disruption of its traditional pattern which was based in large part on open trade links with Tibet (Furer- Haimendorf 1964, 1984).

The number of tourists and mountaineers passing through Namche Bazar each year had exceeded the total Sherpa population by the early 1970s and had nearly doubled again by 1981. Guest houses and tea houses were constructed, especially along the trekking route from Lukla to Mount Everest base camp, and in Namche Bazar itself.

Rapid growth in demand for construction timber, together with the great increase in the use of fuelwood for cooking, hot water, and camp fires for trekking parties was perceived as a threat to the local mountain forests. Despite the establishment of Sagarmatha (Mount Everest) National Park, and increasing efforts to enforce the regulations against tree-felling within the park, this threat was perceived to be continuing unabated. Thus, the desire to harness local water energy was a rational government response.

The Austrian Federal Government granted the request in principle, and planning and site studies were undertaken by the Hydrology Department of the Universitat fur Bodenkultur, Wien, and the Verbund-Plan Ges. m.b.H., a group of Austrian consulting engineers. Various negotiations, site visits, and planning sessions led to the selection of a site near Dramo on the Bhote Koshi River. This is situated about six kilometres upstream from the confluence of the Bhote Koshi River and the Imja Khola to become the Dudh Koshi, " as clearly the most favourable possibility ".

Various design modifications, primarily to adjust to significant increases in estimated costs, and to reduce the amount of cement needed in the construction, were effected. Excavation began in October 1978, with initial scheduled completion by September 1982.

The plant design included a weir, intake, and headrace canal to a surge basin and penstocks, giving a vertical displacement to a power house and tailrace 35 metres below. From the intake the headrace canal extended for 285 metres across the lower slopes of a debris fan. Thus excavation was primarily in colluvium, alluvium and probably some till. The facility was designed for a minimum water flow capacity of $2m^3/sec$ -- this figure apparently derived from a hydrologic study of the Imja Khola (1971-1975) despite the fact that its course was in a somewhat different micro-climatic environment to the Bhote Koshi.

The site itself, the lower slopes of a debris fan, was sparsely vegetated in contrast to valley slopes both upstream and downstream which carried a fairly complete cover of forest (including *Abies spectabilis, Betula utilis, Rhododendron spp.*), and shrub forest, except where debris flow tracks and torrents cut down to the river from the steeper slopes above.

The hydro-plant debris fan is marked by several conspicuous debris flow deposits and small torrent channels. The possibility of mudslide and soil creep occurrence was taken into account in the project design. Ground photographs, however, show that sections of the debris fan toe were being undercut by the Bhote Koshi prior to excavation and quite extensive undercutting is apparent in a November 1984 photograph when the excavation work was nearly complete (Plate 5, A & B).

The lowest point of the project, the power intake, is at 3,300m.a.s.l.; the altitude of Namche Bazar is 3,440 metres. Thus the project site lies well within the High Himalaya belt and has a severe, mountain-attenuated monsoon climatic regime. The total catchment of the Bhote Koshi is 444 km^2 and the power intake controls 88 percent of this. Several mountain peaks along the rim of the catchment exceed 7,000m with a maximum altitude of 7,532m.

The engineering report estimated that 34 percent of the catchment was covered by permanent ice and glaciers. The largest glacier, Nangpa Glacier, which descends from the Nangpa La (5,716 metres) on the border with Tibet (People's Republic of China), is about 18km in length. It has several tributary glaciers, the largest being the Sumna Glacier, which is almost 8km in length. The source of the Bhote Koshi originates from the indefinite and debris-covered terminal zone of this complex of glaciers. The Bhote Koshi also receives several west-bank tributaries draining from a series of valley glaciers and cirque glaciers that originate high on the western rim of the catchment. One of the more important of these drains from a series of glaciers into the Langmoche Valley which is confluent with the mainstream about 6km above the project site. Another tributary enters the Bhote Koshi about 2.5km above the site which drains the glaciers and ice-fields of the Trashi Labtsa Pass. Many of these glaciers are partially nourished by massive snow and ice avalanches which fall from the spectacular mountain wall above. Large rockfalls are also an obvious component of the suite of geomorphic processes.

Most of the glaciers in Khumbu Himal have been thinning and retreating for several decades. This process has led to an increase in the area of debris-covered and apparently stagnant ice, characteristic of the lower reaches of many of the larger Himalayan glaciers. Another feature of the recent glacier thinning and retreat has been the development of many small lakes dammed between the innermost end-moraines and the glacier margins. Lakes are also apparent in supra-glacial positions on many of the larger glaciers, and there are also ice-dammed lakes lateral to the main trunk glaciers. In 1977 one of these lakes, a moraine-dammed lake in the Imja Khola catchment (Fushimi *et al* 1985, see above), drained catastrophically causing much damage and destroying all the bridges for 35km downstream. Vuichard and Zimmermann (1986) reported that oral tradition among the Sherpa communities indicates the probable occurrence of four or five similar *jokulhlaup* over the previous forty years.

No evidence was obtained from the available Namche Small Hydel Project documents to the effect that any special attention was paid to the possible occurrence of catastrophic geomorphic events, despite the fact that the project was being sited in one of the highest and most precipitous mountain regions in the world. Even the Engineering Report (DRG. No. 1.01, n.d.) provides only an abbreviated overview of the terrain and a very unbalanced view of the climate, making the surprising claim, for instance, that the mean annual air temperature for Namche Bazar is 11°C (actual m. a. a. temp. is 6.4°C).

Construction Phase and Restraints

"The planned Namche Bazar Hydropower Station can be regarded as an extraordinary engineering project in every respect " (DRG. No. 1.01, n.d., p. 9). This is because of the high altitude and severe climate at the site and its extreme difficulty of access. Access in the late 1970s involved a 12 to 15 day walk from the nearest point on the China Road, a three day walk from the STOL airstrip at Lukla on the Dudh Koshi, or a three hour walk from the Pilatus STOL landing strip at Syangboche. Thus, from an economic as well as an environmental impact point of view, maximum use was to be made of local materials and the overall design was established to consume an absolute minimum amount of cement. The original design called for the transport of 900 tons of cement to the site within a three-year period. This was deemed impractical and to reduce the amount required still further (to 300 tons) "certain operational safeties, which under normal circumstances would be required as a matter of course, were dispensed with..." (DRG. No. 1.01, n.d., p. 9). It was planned that the necessary structural steel and mechanical equipment, such as turbines, generators, and transformers, would be flown in by helicopter.

In addition to the power plant itself, several construction auxiliaries were required. These included an all-weather foot-bridge across the Bhote Koshi, a cable crane installation at the weir, a power distribution system so that the villages of Namche Bazar, Khumjung, Khunde, and Thamo could be supplied with electricity and sundry support buildings.

The project met with a number of construction delays and a change in engineering consultants. A site inspection report dated 29 May 1985, revealed that most of the civil engineering construction had been completed, excavation for the foundations of the power house prepared, and some on-site modifications had been made. Plans were in hand for the design, fabrication, and delivery of the generators, turbines, and transformers, and the power house was scheduled for construction during October/November, 1985. Installation of the penstocks and hydroelectric structures was planned for completion prior to the 1985/86 winter. It should be noted that during a heavy flood in 1984 -- presumably normal summer monsoonal peak -- the river bank above the power house was eroded, necessitating the construction of a stone protection wall.

The original planning called for a facility with an annual power output of 6,350,000 kWh at an estimated cost of NRs 24.13 million. Some years of delay ensued and final cost estimates increased to NRs 45 million. Nevertheless, the prospect was for the provision of reliable and very cheap power to the neighbouring communities. A diesel power plant, for instance, would entail fuel costs alone exceeding by six times the total energy costs of hydropower (DRG. No. 1.01, n.d., p.35).

On 4 August 1985, the Dig Tsho moraine-dammed lake in front of the Langmoche Glacier overtopped and burst its dam.

The Namche Small Hydro Project was virtually destroyed.

Destruction of the Namche Hydel Project

Comparison of two sets of ground photographs, one set from the north side of the Bhote Koshi looking directly across the river onto the debris fan, and the other set taken from the Namche Bazar trail looking upstream, clearly demonstrate the extent of the damage. The first set was photographed by Dr. Victor Galay in November 1984, and after 4 August 1985 ; the second set was photographed by Daniel Vuichard on 4 April 1985, and 19 October 1985 (Vuichard and Zimmermann 1986, p. 93, Figures 5 and 6). These are reproduced as Plates 2, 3, 4, and 5.

The debris fan underwent extensive undercutting, erosion, and transport, with most of the erosion occurring in three distinct areas :

- The vicinity of the weir and intake to the headrace canal;
- The central tract of the toe;
- The downstream tract in the vicinity of the power house site and tailrace.

Much erosion also took place on the north side of the stream. This erosion resulted in the total destruction of the weir and headrace intake, the upstream half of the headrace canal, the lower half of the penstock channel, the foundations for the power house, the tailrace, and the helicopter landing pad. In addition, the river channel, or flood plain, was extensively widened and heavily aggraded with three to seven metres of large-diameter debris. The character of the Bhote Koshi channel in this section, as well as that of the debris fan, has been totally changed. This has probably made the site unsuitable for any salvage or reconstruction action, even if it is assumed that the draining of Dig Tsho was a unique event and that there is no likelihood of future *jokulhlaup* occurring from any alternate source within the Bhote Koshi catchment. The latest report from the Small Hydel Development Board is that the feasibility of constructing several micro-power stations away from the main stream is being explored.

Thus ended nine years of negotiations, planning, construction, and comparatively heavy expenditure, and nine years of anticipation on the part of four or more Sherpa villages that eventually they would receive a hydroelectric power supply.

A number of compelling questions demand attention :

- What was the viability of the decision to respond to a perceived need for hydroelectric power in the Khumbu in the first place ?
- Why was there no investigation of the hydro-glaciology of the Bhote Koshi catchment prior to site selection, espe-

Plate 2. Site of the Namche Small Hydel Project looking upstream from the Namche Bazar trail. Photographed on 4 April 1985, by D. Vuichard.

Plate 3. Nearly identical view to Plate 4, photographed after the *jokulhlaup*, 19 October 1985, by D. Vuichard. Note the extensive erosion to the debris fan and the massive accumulation of coarse alluvium in the now much widened riverbed.

cially to locate possible ice-dammed and moraine-dammed lakes ?

- Once seepage from Dig Tsho and a degree of overtopping was noticed in August, 1984, why were no steps taken to partially drain the lake, or at least to set up a monitoring and early warning system, or to review the design and site selection parameters ?

These questions may well be dismissed as excellent hindsight and of purely academic importance. They are certainly not intended as criticism for its own sake ; rather they are posed to set the stage for demonstrating the need for integration of glaciological reconnaissance and research with future planning, design, and construction of waterpower (and other) projects in glaciated areas of the Himalayan region.

Plate 4. Panoramic view of the Namche Small Hydel Project site by Dr. Victor Galay in November 1984. The photographs are taken from the north side of the Bhote Koshi looking onto the debris cone. The headrace canal cuts conspicuously sub - horizontally across the fan. Undercutting of the fan has occurred during the preceding summer monsoon at (a) and (b).

Plate 5. **The Bhote Koshi after the 4 August 1985,** ***jokulhlaup*** **showing aggradation and extensive bank undercutting and a large landslide.**
Photograph by Dr. Victor Galay.