A Hydrological Approach to Environmental Impact Assessment in the Himalayan Rivers: A Case Study of the Khimti River in Nepal

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Introduction

Water is Nepal's greatest natural resource. In a drive to utilise this resource, the 60 MW Khimti *Khola* Hydroelectric Project is being constructed. Using a gross head of 684m and a total length of 10km of tunnel, the intake will be of the low diversion weir type with limited pondage.

The Khimti basin is 443sq.km in area, and drains parts of the High and Low Himalayas. Extreme seasonal variations in river discharges will significantly affect the amount of water diverted at the diversion weir site for ultimate power development. Optimal use of the weir will require increased power generation in the monsoon period to take advantage of the large monsoon discharges and to compensate for the flow that is diverted during the low flow period to sustain the various water uses. The Khimti Valley has a biologically diverse and rich ecosystem, including some rare species. Construction of the weir could significantly affect these species.

The tributaries of the Khimti River do not contribute enough water to the Khimti during the low flow period to sustain various water uses. Therefore, there will be considerable effects on water users in the areas below the proposed diversion weir site.

One of the greatest challenges has been to assess the effects of flow regulation scenarios on fisheries, irrigation, and various other water uses downstream of the intake and, based on this to describe the needs, recommend design features of engineering or socioeconomic mitigation measures, and draw up a monitoring programme for the construction phase and early stages of the operational phase.

The Natural Resources of the Khimti Basin

The Khimti River basin lies within the three physiographic regions of the High Himalayas, Lesser Himalayas, and Middle Hills. A small portion of the basin lies in the High Himalayas, about one third in the Lesser Himalayas, and about half in the Middle Hills. The Khimti *Khola* drains the southern flank of the Himalayan Range, originating in the High Himalayas, and flowing south-westerly until it joins the Tama Koshi at Khimti Besi.

The Khimti is a very steep river, particularly in the upper reaches, but has a slightly flatter gradient in the middle reaches. For about 20km above the gauging station at Rasnalu, the gradient varies from 1.5 to 3.5 per cent. From Rasnalu it is about 4.6km to the intake site at Palati *Khola*, and the average gradient is 6.5 per cent. A similar gradient continues for about 9-10km and then flattens out at Khimti Besi near the confluence with the Tama Koshi. Figure 1 shows a longitudinal profile of the middle and lower reaches of the Khimti *Khola*.

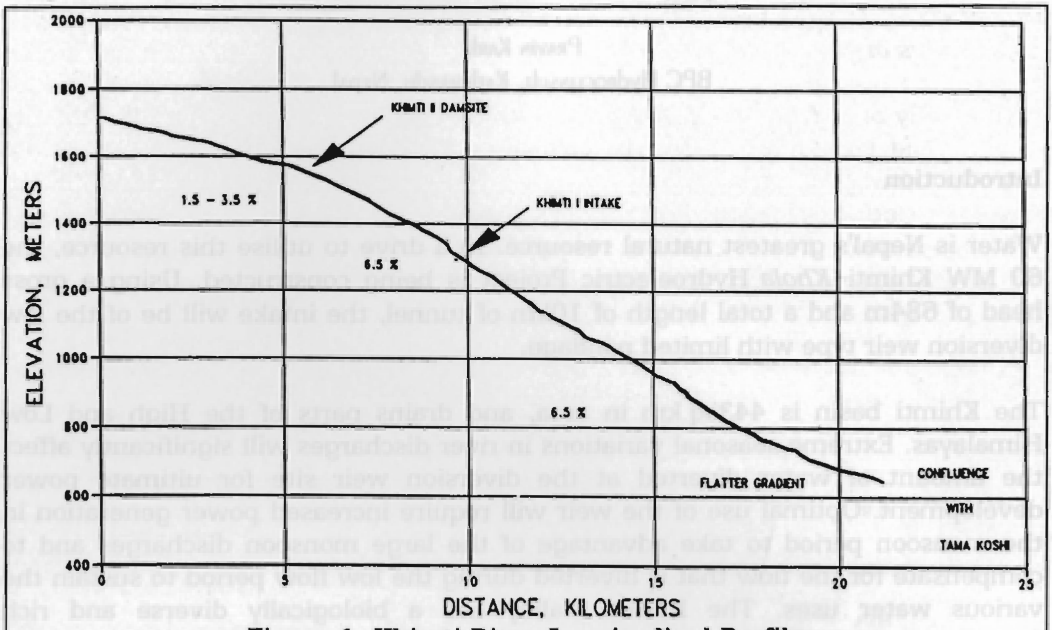

Figure 1: Khimti River Longitudinal Profile

The Khimti basin is comprised of numerous tributaries. There are high gradient seasonal streams, with a mean slope of about 12 per cent. Gradients are usually less steep as they enter the Khimti *Khola*. To a great extent the tributaries are commonly observed to be dry in the pre-monsoon period, while some continue to flow, probably being spring-fed. The catchment areas of the tributaries lying between the intake and the confluence of the Khimti and Tama Koshi rivers vary from large (Haluwa 22sq.km.) to very small (Chahare 1.2sq.km.).

Surveys of the fish fauna in the Khimti *Khola* system have revealed the presence of 45 species belonging to 12 families. The various reaches of the Khimti *Khola* provide habitats for fresh-water fish, ranging from cold water snow trout to catfish.

The physiography of the Khimti Valley precludes irrigation close to the main river channel, since most of the agricultural land is situated well above the river. An exception to this is the area around the confluence of the Khimti with the Tama Koshi River.

Precipitation

On an average the project site receives about 2,000-2,500mm of annual rainfall, as recorded by the rainfall gauge at Jiri. Approximately 80 per cent of the annual total is accounted for during the monsoon from June September. Winter precipitation in all regions is sparse. There are no rainfall gauges in the upper reaches of the Khimti *Khola* which could indicate the importance of the High Himalayas to the Khimti's flow characteristics.

Streamflows of the Khimti Khola

There is only one gauging station located within the Khimti basin, number 650 at Rasnalu. The period of the record published in 1994 was from 1962 to 1984. Figure 2 shows the mean monthly hydrograph at Rasnalu gauging station. At flows up to about 10 m^3/s, and in the months from October to June, the data appear to be quite reliable. The most stable period is from January to April, which is the significant period for low flows and hence for scheme-sizing optimum flow and determining energy production.

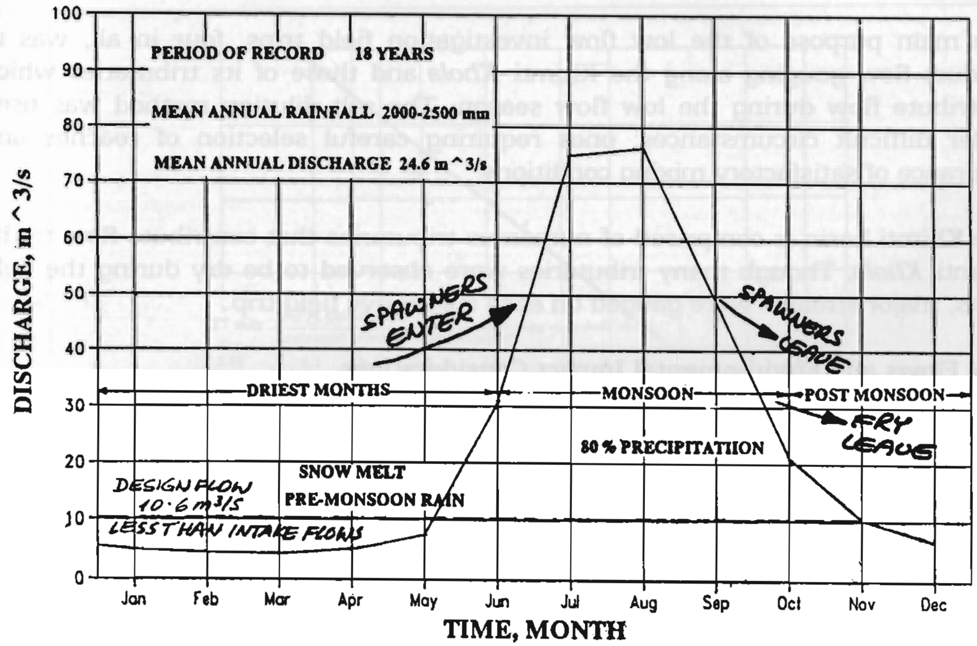

Figure 2: Khimti River Mean Monthly Flow

Tributaries to the Khimti Khola

The flows contributed by the more significant of these tributaries were calculated by three different methods. The lowest calculated flows contributed by the individual tributaries of the Khimti *Khola* are summarised in Table 1, providing a conservative estimate of their importance for Khimti streamflow conditions.

Table 1 : Calculated Flows of the Khimti Khola's Tributaries in l/s

River	Area (km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hanba	5.7	13	9	7	5	9	280	960	1,210	960	420	25	19
Haluwa	22.0	238	204	186	116	218	1,070	3,330	4,130	3,230	1,410	475	308
Khahare	3.3	21	15	11	8	15	160	620	780	620	270	39	29
Pharpu	18.0	169	117	86	62	117	880	2,750	3,410	2,670	1,170	311	233
Chatiune	7.7	10	9	8	9	14	370	1240	1,560	1,230	540	20	13
Other streams	_	22	20	16	17	20	150	600	720	610	250	35	27
Total	-	473	374	314	217	393	2,910	9,500	11,810	9,320	4,060	905	629

Field Investigations

The entire programme concentrated on three fields - low flow hydrology, fisheries, and other water uses — with an objective of providing data complementary to each other.

Low Flow Investigations

The main purpose of the low flow investigation field trips, four in all, was to conduct flow gauging along the Khimti *Khola* and those of its tributaries which contribute flow during the low flow season. The salt dilution method was used under difficult circumstances; ones requiring careful selection of reaches and assurance of satisfactory mixing conditions.

The Khimti basin is comprised of numerous tributaries that contribute flow to the Khimti *Khola*. Though many tributaries were observed to be dry during the field visits, major streams were gauged on each successive field trip.

Low Flows and Environmental Impact Considerations

Hydrological data used for the low flow analysis in 1994 consisted of 30 years of rainfall records from Hydrometereological Station 1103 at Jiri and 17 years of flow data from DHM Gauging Station 650. At the time of the field visit in February 1994, the rainfall recorded in Jiri was 27mm, which has an estimated return period of about five years. Furthermore, analysis shows that the accumulated rainfall from December through February has similar return periods; between five and ten years. The 30-year record shows that February 1994 was a drier than average month.

Low flow data from Gauging Station 650 at Rasnalu were prorated to the proposed intake site, and the driest months in each successive year were taken for purposes of establishing their return periods. Figure 3 shows the frequency curve. During the field visit in February 1994, the Khimti *Khola* was gauged at Palati, the site of the proposed intake site. The flow was $4m^3/s$, corresponding to a low flow return period of five years, similar to the return period of the rainfall recorded in Jiri (Figure 4).

Flow measurements carried out in February 1994 were plotted as accumulated flows along the Khimti *Khola* longitudinal profile. The resulting curve in Figure 5

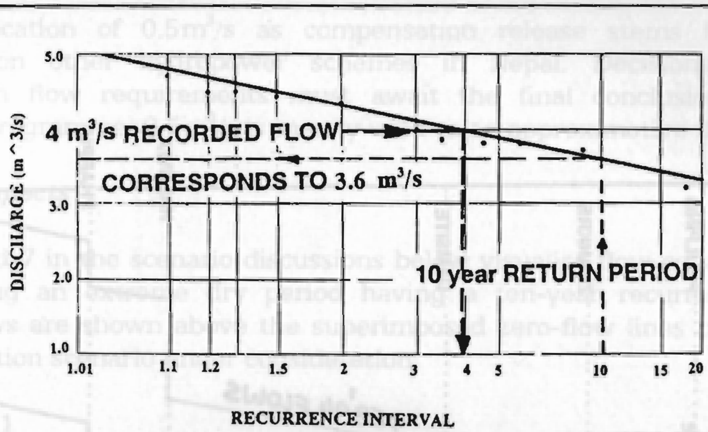

Figure 3: Low Flow Frequency Curve

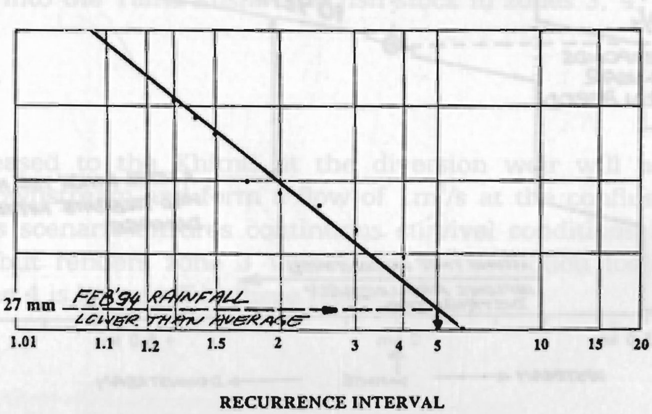

Figure 4: Rainfall Frequency Curve

gives us a clear picture of the accumulated flows in the Khimti *Khola* resulting from the inflows of the various tributaries. Though February 1994 was a drier month than average, a design return period had to be selected which would represent a relatively dry year, yet not an extreme. Therefore, a ten-year return period low flow was selected, a level which the natural system will normally accommodate without too much damage. The ten-year return period corresponds to about 3.7m^3/s on the frequency curve in Figure 3. The February 1994 accumulated flows then had to be adjusted by the ratio of the one in ten-year low flow (i.e. 3.7m^3/s) to the February 1994 measurement (4.0m^3/s). This ratio amounted to 3.7/4.0=0.93, and all the flows in Figure 5 were adjusted accordingly to yield a ten-year design curve. This design curve gives a fair indication of low flow values and helps to arrive at a better understanding of how much water would be available to the various water users below the proposed intake site in a typical dry year. This then forms a basis for looking at different project operation scenarios.

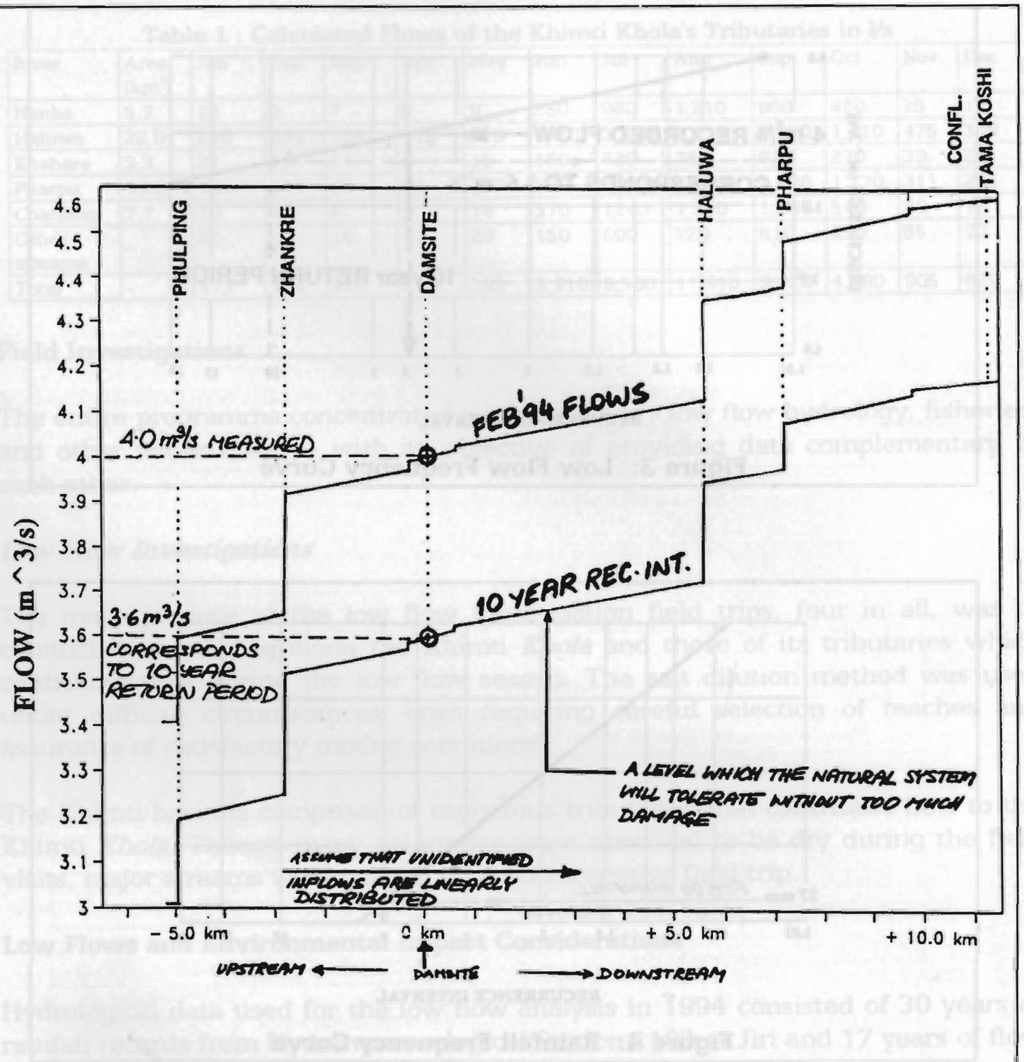

Figure 5: Accumulated Flows

Flow Diversion and Release Scenarios

The maximum diversion capacity of the project is 10.6m^3/s. From Figure 2 it can be seen that, for the period from November/December through to May, the flows at intakes are less than the diversion capacity. Hence, if all the flow is diverted into the tunnel, dry riverbeds will result at certain locations, posing a threat to aquatic life and people's utilisation of the river. There is thus a strong need to properly assess the effects that the regulated winter flows in the Khimti *Khola,* combined with unregulated tributary inflows, will have on in-stream fish production and water utilisation. The two different hydrological low flow scenarios to be assessed are: zero residual flow below the diversion weir and a residual flow of 0.5m^3/s below the diversion weir.

The quantification of 0.5m^3/s as compensation release stems from general experience on other hydropower schemes in Nepal. Decisions on setting compensation flow requirements must await the final conclusions from the monitoring programme; 0.5m^3/s is merely used as an approximative illustration.

Low Flow Impacts

Figures 6 and 7 in the scenario discussions below visualise flow conditions in the Khimti during an extreme dry period having a ten-year recurrence interval. Residual flows are shown above the superimposed zero-flow lines corresponding to the regulation scenario under consideration.

Scenario No. 1

Lack of compensation water below the diversion weir will result in a virtually dry riverbed for 5.5km, whereafter tributary inflows will bring the flow back to 0.3m^3/s seven kilometres downstream from the diversion and 0.5m^3/s by the time the Khimti flows into the Tama Koshi. The fish stock in zones 3, 4, and 5 will be affected.

Scenario No. 2

The 0.5m^3/s released to the Khimti at the diversion weir will accumulate to 0.6m^3/s 5.5km downstream and form a flow of 1m^3/s at the confluence with the Tama Koshi. This scenario ensures continuous survival conditions for fry in the regulated reach but renders zone 3 vulnerable to production losses and over-fishing, while zone 4 is better off in these respects.

Other Uses

The physiographic constitution of the Khimti Valley downstream from the diversion weir precludes irrigation close to the main river channel, since most of the agricultural land is situated well above the river. An exception to this is the stretch between Khimti Besi and the confluence of the Pharpu and Khimti *Khola*(s).

Whilst it is true that the agricultural lands irrigated exclusively from the tributaries of the Khimti *Khola* are unaffected by diversion of water from the Khimti *Khola* at the proposed intake site, these lands reduce the contribution to flow available downstream to other irrigation schemes drawing water from the Khimti *Khola* itself. Therefore, the future extension of agricultural lands is seen to pose a more serious threat than the proposed diversion of the Khimti *Khola*.

Changes that take place on the Khimti *Khola* will affect the potential for expanding the present water-driven mill at Khimti Besi. The main canal at Khimti Besi supplies the water mill in addition to irrigation and drinking water needs. The mill requires approximately 1,80l/s of water to run at full capacity, and in its present state it will not be affected by the proposed flow regulations.

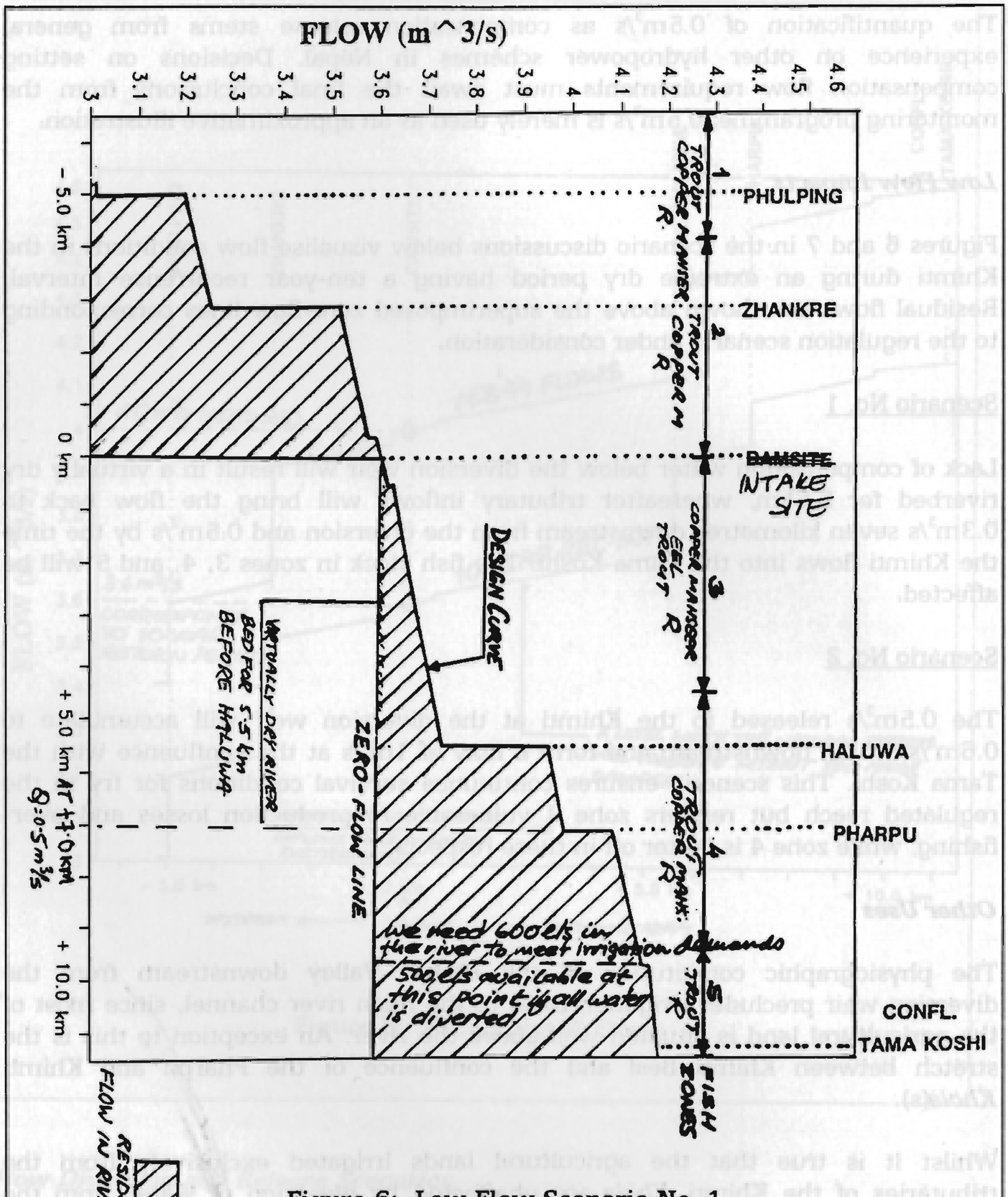

Figure 6: Low Flow Scenario No. 1
No Compensation Release

Proposed Mitigation Measures

1. Compensation release: Water diversion at the proposed intake site will significantly reduce the amount of water available to the Khimti downstream in the low flow season. Releasing a minimum flow of $0.5 m^3/s$ downstream is seen as a suitable mitigation measure to ensure the survival of the spawning and nursery beds of fish.

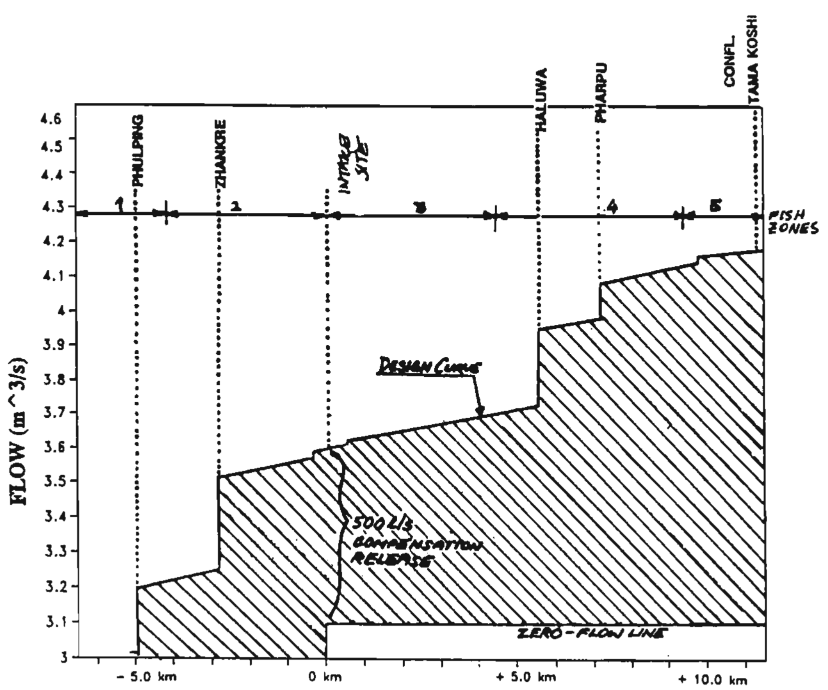

Figure 7: Low Flow Scenario No. 2
Compensation Release

2. Control of water pollution

3. Other measures: Constructing suitable fish passage facilities, discouraging illegal and hazardous methods of fishing, and reducing fishing pressures in the river by providing alternative sources of fish to the local population. Involvement of the local people and concerned authorities is very important.

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