HIS MAJESTY'S GOVERNMENT OF NEPAL

MINISTRY OF WATER RESOURCES

# MASTER PLAN STUDY ON THE KOSI RIVER WATER RESOURCES DEVELOPMENT

# FINAL REPORT

## Volume 3

## APPENDIX Ⅳ

MARCH 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

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## APPENDIX IV



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# MULTIPURPOSE DAM AND HYDROPOWER

## 1. INTRODUCTION

Nepal is entering a phase of economic development essentially based on the exploitation of its abundant water resources. The total hydroelectric potential of the country has been estimated at 80,000MW of which approximately 25,000MW are considered technically and economically feasible. Master plan studies to identify the hydro potentials of the Gandaki River basin and the Karnali River basin have already been carried out. This Master Plan Study covers the remaining Kosi River basin which is one of the three largest rivers in Nepal, the other two being the above-mentioned Gandaki and Karnali rivers.

In order to obtain a sound basis for the selection of the best project to be developed during the next decade, a program of studies at progressive levels is required. For this purpose, the Electricity Department (ED), His Majesty's Government of Nepal (HMG/N) has entrusted the Japan International Cooperation Agency (JICA) with the execution of the Master Plan Study on the Water Resources Development of the Kosi River Basin in 1983.

This Appendix of the Master Plan Study concerns hydroelectric development by identification of potential sites, selection of priority sites and implementation schedule at the earliest possible time.

### 1.1 Objective of the Study

The objective of the Study which concerns this appendix is to identify all potential hydropower sites and to list the sites in terms of priority for formulation of the Kosi River Water Resources Development Master Plan. This Appendix comprises study findings based on analyses of existing data, hydrology, geology, topography, etc. and site reconnaissance, field investigation, surveying and drilling investigation of provisional priority sites.

The Study is conceived so as to:

a) analyse the hydrology and meteorology in the Basin and review future electricity demand;

b) investigate the dam sites to confirm topography, geology, etc;

c) identify all potential dam sites based on analyses and site investigation;

d) prepare topographical maps with a scale of 1/20,000 for the Sun Kosi River to cover the proposed reservoir area and 1/10,000 for the priority sites;

e) estimate the capital cost of the projects;

f) select priority and high priority projects;

g) make an implementation schedule of development for high priority projects taking into account future demand; and,

h) evaluate the socioeconomic impacts of the projects.

## 1.2 General

### (1) Multipurpose Dam

The large reservoir of the high dam will effectively utilize water resources not only for hydroelectric power generation but also for irrigation, flood mitigation, etc. River flow in Nepal fluctuates greatly as approximately 80% of annual rainfall is concentrated in the rainy season. To utilize water resources fully or effectively, a large reservoir is required.

The potential for reservoir development was studied for all rivers in the Kosi Basin, including the Sun Kosi, Arun, Tamur and Sapt Kosi rivers. Studies were based on existing and newly prepared topographical maps to confirm the reservoir capacities required to counteract the high sedimentation volume of the rivers.

### (2) Hydropower

Present and future electricity demand and supply was studied based on present status and review of the demand forecast. Potential sites were identified for hydroelectric power development and planning conditions and methods are described hereunder.

Priority and high priority sites were selected with the objective of early development and with due consideration of economic viability, ease of development, suitable capacity and social impact. Detailed descriptions of the selected high priority sites are also presented herein.

## 2. MULTIPURPOSE DAM

### 2.1 General

The Kosi Rivers Basin is composed of 7 rivers, the main affluents of which are from west to east, the Sun Kosi, the Arun and the Tamur. Major tributaries are the Indrawati, Tama Kosi and Dudh Kosi rivers. The three main affluents converge at Tribeni village to become the Sapt Kosi River. The characteristics of the rivers in the Kosi Basin are the large sediment volume and the steep gradient of the river profile in the upstream courses.

The longitudinal profiles of all the rivers were established to determine the potential for reservoir development, and the following four rivers were studied in detail, confirming the effective reservoir volumes, topography and geological conditions.

- Sun Kosi River
- Arun River
- Tamur River
- Sapt Kosi River

### 2.2 The Sun Kosi River

#### 2.2.1 Layout of the Study

The total length of the Sun Kosi River is approximately 330km, 280km of which is in Nepalese territory. The river gradient is approximately 1/210 throughout the entire length of its course in Nepal and 1/450 between Tribeni and Dolaghat. Tribeni is the confluence point of the Sun Kosi, Tamur and Arun rivers while Dolaghat is the site at which the Indrawati River joins the Sun Kosi River.

Reservoir development can be effected along the river course between Tribeni and Dolaghat. For optimum development of the said area, the following was considered:

a) The existing Sapt Kosi High Dam Project was planned downstream of the confluence of the three main affluents;

b) In the upstream courses of the Sapt Kosi High Dam Site, construction of three dams, Sun Kosi No.1, No.2 and No.3 was considered;

c) The Sun Kosi No.1 Site was selected at Kurule in consideration of the High Water Level of the Sapt Kosi High Dam and the future inter-basin diversion project from the Sun Kosi River to the Terai Zone;

d) The altenative dam heights studied for the Sun Kosi No.1 were 147 - 195m;

e) The Sun Kosi No.2 dam sites were selected with river elevation coinciding with the highest water level of the Sun Kosi No.1 dam and the alternative dam heights studied for the same were 60 - 180m at each site;

g) The Sun Kosi No.3 dam sites were selected and studied in the same way as Sun Kosi No.2;

h) Three cases of dam height were studied for the Sapt Kosi High Dam.

The above layouts are shown in FIG. 2.1.1 and FIG. 2.1.2 below.

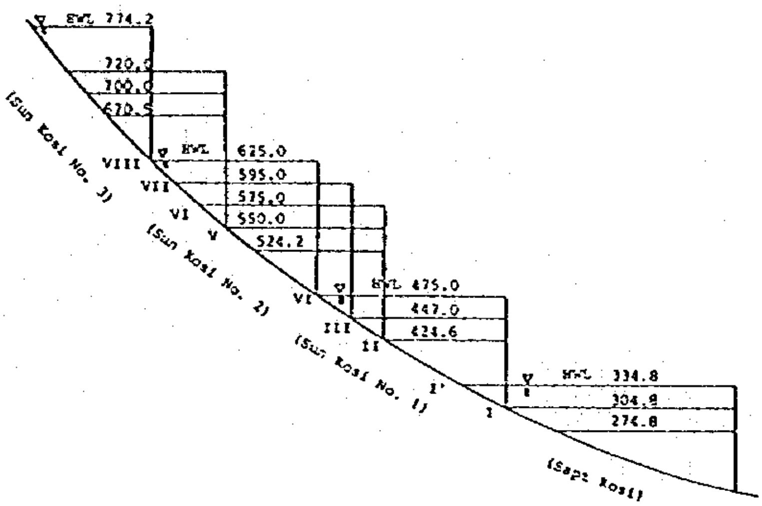



**FIG. 2.1.1 LAYOUT PROFILE OF THE SAPT KOSI AND SUN KOSI NO. 1 - 3**

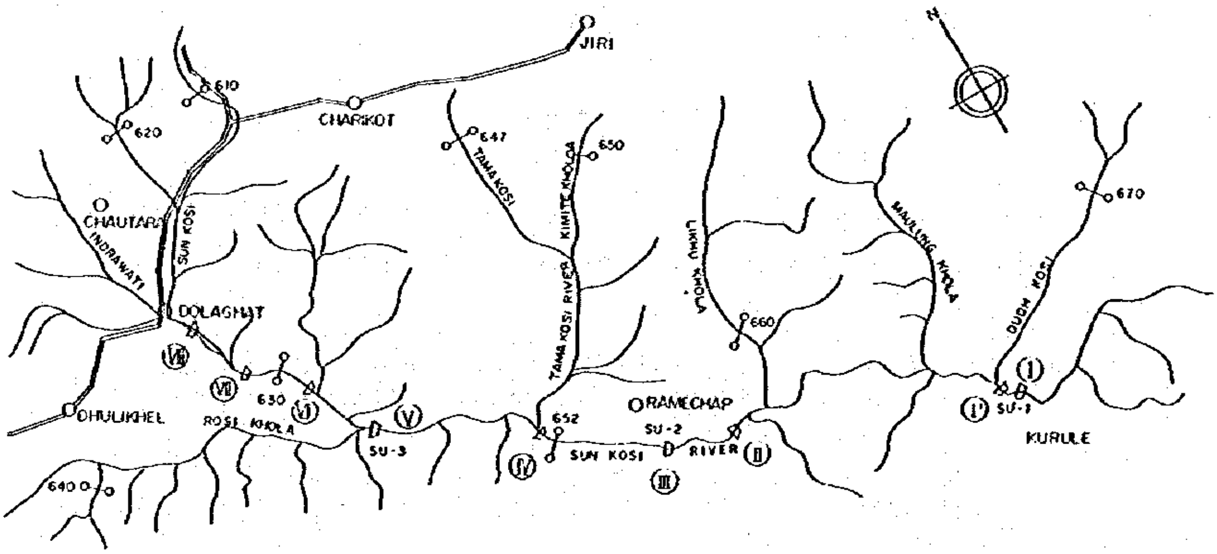



**FIG. 2.1.2 LAYOUT PLAN OF SUN KOSI NO. 1 - 3**

### 2.2.2 Optimum Dam Planning

The optimum dam plan on the Sun Kosi River was determined through comparative study of the alternative combinations of the Sapt Kosi High Dam and Sun Kosi No.1 - No.3. Comparative study was carried out by quantifying cost and benefit in terms of electricity as shown in the Chapter on Hydropower. Selected combinations are listed in TABLE 2.2.1.

The planning conditions were:

a) Reservoir storage capacities were estimated on the basis of newly prepared maps (scale: 1/20,000) for Sun Kosi No.1 - No.3 dams and of the "Feasibility Study Report", Kosi High Dam for the Sapt Kosi High Dam; and,

b) The effective storage volumes were estimated applying the Brune's trap efficiency to the sediment load of 2,840$m^3/km^2$/year. In this case, four reservoirs were independently estimated.

The selected development combinations are as follows:

Alternative: 1

This is the most economical in view of the hydropower component. Irrigation water supply to the Terai Area through the diversion tunnel with intake at Kurule, will be ensured after completion of the Sun Kosi No.2 dam and the downstream effects will be relieved by annual regulation to compensate river water in the dry season.

Alternative: 2

This is less economical than Alternative 1. However, irrigation water will be ensured after completion of the Sun Kosi No.3 dam development of which is easier than the Sun Kosi No.2 dam due to lower construction cost and easier access. However, SU-3 can not provide complete downstream compensation due to the smaller reservoir capacity compared to SU-2.

Alternative: 3

This is less economical than Alternatives 1, 2 and represents maximum development of the Sun Kosi River. In particular a large area of inundation is required around Dologhat by raising the HWL of Sun Kosi No.3. This coupled with the rapid river gradient results in less economic viability.

TABLE 2.2.1 SELECTED DEVELOPMENT COMBINATION

| Alternative | Item \ Dam | Sapt Kosi High Dam | Sun Kosi No.1 | Sun Kosi No.2 | Sun Kosi No.3 |
|---|---|---|---|---|---|
| (1) | Dam Site | 2km up-stream of Barakshetra | I | II | III |
| | H.W.L. (EL m) | 304.8 | 424.6 | 575.0 | 670.5 |
| | Dam Height (m) | 239 | 147 | 166 | 110 |
| | Gross Storage Capacity (Mill. $m^3$) | 8,500 | 1,500 | 4,370 | 620 |
| | Available Storage Capacity (Mill. $m^3$) | 4,420 | 40 | 3,040 | 70 |
| (2) | Dam Site | 2km up-stream of Barakshetra | I | II | III |
| | H.W.L. (EL m) | 304.8 | 424.6 | 575.0 | 700.0 |
| | Dam Height (m) | 239 | 147 | 166 | 140 |
| | Gross Storage Capacity (Mill. $m^3$) | 8,580 | 1,500 | 4,370 | 1,220 |
| | Available Storage Capacity (Mill. $m^3$) | 4,420 | 40 | 3,040 | 550 |
| (3) | Dam Site | 2km up-stream of Barakshetra | I' | IV | VIII |
| | H.W.L. (EL m) | 334.8 | 475.0 | 625.0 | 774.2 |
| | Dam Height (m) | 269 | 160 | 180 | 170 |
| | Gross Storage Capacity (Mill. $m^3$) | 13,450 | 2,720 | 4,800 | 2,690 |
| | Available Storage Capacity (Mill. $m^3$) | 9,370 | 860 | 3,480 | 2,080 |

## 2.3 Arun River

The total length of the Arun River is approximately 510km, of which only 150km lies in Nepalese territory. Back-water from the Sapt Kosi High Dam at H.W.L., EL.304.8m reaches 70km upstream of the Arun River. In this course, the river gradient is 1/360. A river gradient of 1/100 occurs 100km upstream where the two sites were selected, while from this point to the border upstream, river gradient is steep at 1/50.

The reservoir capacity of the dams which are over 200m in height in these course, above the H.W.L. of the Sapt Kosi High Dam, would be 400 - $500 10^6 m^3$.
However, annual sediment load is estimated at approximately $30 10^6 m^3$/annum. Applying this value and a trap efficiency of 0.6, estimated reservoir life is within 30 years. Reservoir type development on the Arun River was therefore abandoned and PRR type and SRR type were studied.

## 2.4 Tamur River

The total length of the Tamur River is approximately 190km. The middle cours of the river is relatively gentle with a river gradient of 1/350. Reservoir type development with a high dam approximately 3km upstream of Lukpa was planned based on comparative study with the PRR type development.

The said study evaluated cost and benefit in terms of electricity, which is described in detail in the Chapter on Hydropower. Features of the dam and reservoir are as follows:

TABLE 2.4.1 FEATURES OF TAMUR NO.1 SITE

| Item | Tamur No.1 Dam |
|---|---|
| Dam Site | 3 km upstream of Lukpa |
| H.W.L. (EL m) | 487.6 |
| Dam Height (m) | 153.0 |
| Gross Storage Capacity ($10^6 m^3$) | 2,750.0 |
| Available Storage Capacity ($10^6 m^3$) | 838 |

## 2.5 Sapt Kosi River

Three main affluents in the Kosi Basin join at Tribeni to become the Sapt Kosi River which flows into the Terai plain at Chatra. The river course between Tribeni and Chatra, has carved a deep gorge. The Sapt Kosi High Dam is planned 2km upstream of Barakshetra in the same course. Both banks of the river at the dam site are narrow and steep with rock outcrops. The Government of India has studied the site since 1946 conducting various investigations, topographical surveys, drilling, seismic prospecting, adit excavation and hydrological measurement. The "Feasibility Study Report on Kosi High Dam" was prepared by the same and submitted to HMG in 1981. According to this Report, the project consists of hydroelectricity, irrigation and flood mitigation in Nepal and India.

The Team has reviewed the project. However, it was difficult to assess the benefits of irrigation and flood mitigation, as almost all benefits occurred in India data for which was unavailable. The Team therefore reviewed the project in terms of hydroelectricity and accuracy of evaluation was adopted as in other projects in the Study.

## 3. HYDROPOWER

### 3.1 General

Hydropower development is planned based on various studies including consideration of existing power supply system, demand forecast, site conditions (topographical, geological, discharge data, flood data, sediment load, etc.), environmental considerations, installed capacity, generated energy and cost-benefit estimations.

This section deals with methodology of studies, data analysis, assumptions, results and recommendations for hydropower development in the Kosi River Basin.

### 3.2 Present Status

#### 3.2.1 Present Power Supply Situation

(1) Power Supply System

There are three (3) main power supply systems in Nepal; namely, the Central Nepal Power System (CNPS), Eastern Nepal Power System (ENPS) and Western Nepal Power System (WNPS), load centers for which are Kathmandu, Biratnagar and Bhairawa, respectively. CNPS and WNPS are interconnected as the Integrated Central Nepal Power System. ENPS is not yet interconnected with CNPS, but interconnection is scheduled for completion in the near future.
In addition to the above three (3) systems, a number of small systems exist throughout the nation, especially around the towns of Nepalganj, Dhangadhi, Mahendranagar and Janakpur.

Existing power supply systems are shown in FIG. 3.2.1.

(2) Power Generating Facilities

The total installed generating capacity owned by the public power sector (NEC and ED) is 153.3MW as of June 1984 of which 127.6MW (83%) consists of hydro plants and 25.7MW (17%) consists of diesel plants. In addition to the above generating facilities owned by public power sectors, generating plants (10.9MW) are owned and operated by private sectors for their own use. Location of such facilities are scattered all over the country.

The generating capacity of public and private sectors installed in each development region are shown in TABLE 3.2.1 and TABLE 3.2.2. Detailed generating facilities are shown in TABLE 3.2.3 while locations of existing power plants are shown in FIG. 3.2.1.

Major hydropower plants are Kulekhani No.1 Power Station (Reservoir Type) with a capacity of 60MW and Trisuli Power Station (SRR Type) with a capacity of 21MW. Kulekhani No.2 Power Station (SRR Type) with a capacity of 32MW is being constructed and is expected to be commissioned in September 1986. Hetauda Power Station is the largest diesel power station with a capacity of 14.5MW.

(3) Transmission and Distribution Facilities

Three (3) voltage levels, namely 132kV, 66kV and 33kV are used for transmission lines. The total route lengths of the existing transmission lines for each voltage level are 239km, 227km and 26km for 132kV, 66kV and 33kV, respectively. ED has a plan to complete interconnection of the national trunk transmission lines (132kV) by 1987 extending over 800km from east to west. The above-mentioned 239km of 132kV line, part of the 800km, was completed as of March 1983. FIG. 3.2.2 and FIG. 3.2.3 show the transmission line route and system diagram. TABLE 3.2.4 shows the list of existing main transmission lines.

The existing distribution system consists of 11kV, 3.3kV and 0.4kV lines with respective lengths of 436.5km and 2,286km. The low voltage circuit is operated using an AC 50Hz, 400V/230V, 3-phase 4 wire system.

(4) Substations

Sixteen (16) substations of over 66kV levels exist in the Central Region and Western Region. Total capacity of substations is 295.2MVA as of June 1984. TABLE 3.2.5 lists the existing substations.

### 3.2.2 Present and Historical Power Demand

Total supplied energy for all of Nepal including imported power from India in the fiscal year of 1982/83 is about 341GWh. The peak power demand and annual load factor in the fiscal year of 1982/83 is 83.7MW and 46.5%, respectively. Historical power supply and consumption by tariff categories from 1973/74 to 1982/83 are shown in TABLE 3.2.6 and FIG. 3.2.4. Historical power supply and consumption in various regions are shown in TABLE 3.2.7.

In terms of power consumption, the Central Region shares about 75.0% of total power supply followed by the Eastern Region (14.9%), Western Region (6.4%) and Mid & Far Western Regions (3.7%). The power consumption pattern in various regions in 1981/82 is shown in FIG. 3.2.5.

About 76.3% of total power consumption in Nepal is supplied by power generation within the Integrated Central Nepal Power System in the Central Region and part of the Western Region. It is clear that CNPS supplies electricity to the dominant power consumption region in Nepal. Power supply to the other power systems, namely ENPS, WNPS and a number of isolated small systems along the Indian border is heavily dependent on imports from India. Total imported energy from India in 1982/83 was 63.3GWh which represents about 18.6% of the total power supply of Nepal. On the other hand, only about 6.0GWh in 1982/83 was exported from Nepal to the Raxaul Region in India.

The annual average compound growth rate of power supply and peak power demand from 1973/74 to 1982/83 is 13.73% and 12.15% respectively. TABLE 3.2.8 shows the recent power generation pattern of CNPS from March 1982 to July 1983. TABLE 3.2.9 and FIG. 3.2.6 show the monthly generation records and daily load curve at the recorded maximum peak load for CNPS.

## 3.3 Power Demand Forecast

ED proposed in 1983 to use their recently completed trend forecast without price elasticity and with potential exports to India as the 1983 Basic Forecast to be used for all generation planning studies. This forecast being lower than the 1981 ED forecast, is prepared for the period from 1982/83 to 2001/02 and indicates an average annual growth rate of 14.4% from 1982/83 until 1991/92, based on a historical Nepal power load of 341GWh and power export of 6.0GWh in 1982/83.

ED also prepared the 1983 Disaggregate Forecast based on the 1982 World Bank forecast with some reviews and analyses. The latter forecast utilized the 1981 Disaggregate Forecast prepared by MWR for a period of 10 years which suffered from data deficiencies in power consumption customer categories and economic performance. The latest Disaggregate Forecast by ED is considered to be the most reliable considering that it reflects the results of past review and subsequent updating. ED also recommended use of the 1983 Disaggregate Forecast as an official low forecast.

In addition to the above three (3) previous forecasts there is the 1981 forecast prepared by ADB's study team, which is substantially lower (approx. 48%) than the 1981 ED forecast. The main reason for such a low forecast results from ADB's approach that limitations on implementing transmission lines and distribution lines would continue to suppress demand growth.

Previous power demand forecasts for the Integrated Nepal Power System are summarized in TABLE 3.3.1 and FIG. 3.3.1 and FIG. 3.3.2.

### 3.3.1 1983 Trend Forecast

The methods and assumptions used in ED's 1983 Trend Forecast and results of the same are as follows:

(1) Growth Rate

The 1983 Trend Forecast by ED was based on the development of "Scheer Model" 1/ considering the historic trend in power load growth since 1970/71. "Scheer Model" developed from studying historic load growth patterns in 97 countries over long periods of time, and is defined as the average annual growth rate of electricity demand which declines by about one-tenth when per capita consumption doubles, and by about one-half when per capita consumption increases one hundred time. The mathematical equation of Scheer Model for average annual load growth is presented on the following page.

---

1/ G.B. Scheer, "Prediction of Long-range Power Generation Requirements in Foreign Countries", AIEE CP62-164 and Electrical Engineering, June 1962.

$$\log g = C - 0.15 \log U$$

where,

- $g$ = average annual growth rate
- $C$ = a constant over time which is characteristic of the power demands in the country ($C = 1.348$ is estimated in Nepal)
- $U$ = per capita consumption of electricity (kWh/capita)
- $0.15$ = rate of decline in the annual growth rate as the level of per capita consumption of electricity

The forecasted annual growth rates for the various regions with this model are prepared because the historical growth rates for each region greatly differ. The forecasted annual gorwth rates with this model and regional information for the various regions are summarized in TABLE 3.3.2.

(2) Power Export

In 1983, Nepal exported power only to the Raxaul Region in India, while importing power (63GWh/year) from India at 15 points along the border to supply isolated load centers in Nepal. Power exports to Raxaul amounted to about 6.0GWh/year in 1982/83. The Northern Indian States which border Nepal expect to increase power imports from Nepal, to relieve widespread power shortages in India.

At present, definitely committed export is 5MW (22GWh/year) at Raxaul, while forecasted "Committed Exports" and "Potential Exports" are shown in TABLE 3.3.3 and 3.3.4.

(3) Interconnection Dates

The expected schedules for interconnection of other isolated load centers to the Integrated Power System in Nepal was considered in making the said load forecast. The expected interconnection dates for isolated load centers are shown in TABLE 3.3.5.

(4) Annual Load Factor

In this forecast, the load factor is assumed to increase gradually to 50% in 1990/91 and thereafter to approach a long-term target of 60%. The forecasted annual load factors are shown in TABLE 3.3.6.

(5) Sensitivity of Load Forecast to Tariff Increases

Sensitivity analysis for price elasticities of power demand due to electricity tariff increases was undertaken for load forecast. A short-term elasticity of -0.1 and a long-term elasticity of -0.2 which would take full effect after a period of ten (10) years were selected.

The recent 48% real tariff increase would reduce the load forecast by 4.8% in the short-term and 9.6% in the long-term.

(6) Results of 1983 Trend Forecast

The average annual growth rate for total Nepal power supply excluding power export from 1982/83 until 1991/92 and from 1991/92 until 2001/02, is 13.2% and 11.8%, respectively. The total required power supply and peak load with committed export of 1991/92 will be 1,079.8GWh and 244.6MW, and 3,257.5GWh and 704.3MW in the year of 2001/02. The total required power supply and peak load with potential export of 1991/92 and 2001/02 will be 1,167.8GWh, 264.5MW and 3,345.5GWh and 723.3MW, respectively.

The results of trend forecast are summarized in TABLE 3.3.7. and 3.3.8, FIG. 3.3.3 and 3.3.4 show the power demand forecasts for various regions based on the trend forecast (Basic Forecast).

### 3.3.2 1983 Disaggregate Forecast

The ED's 1983 disaggregate load forecast for the period from 1982/83 to 1991/92 was based on the work of the World Bank's 1982 Disaggregate Forecast, with some revisions. The assumptions used in this disaggregate load forecast and results of the same are as follows:

(1) Industrial Load

The present industrial power load derives from small scale agro-industries such as the processing of rice, wheat, jute, tobacco, textiles, leather and wood, etc. However, Nepal is planning to establish large scale industries for production of cement, steel, paper, etc. by 1991. The power load of all proposed industries is estimated and summarized in TABLE 3.3.9 as specified loads.

Future industrial power demands are estimated based on the regional annual growth rate from 5% to 10% of the total industrial load to accommodate unspecified new industrial load growth plus the annual increase in load due to the specific industries shown in TABLE 3.3.9.

Unspecified annual growth rate of industrial loads is estimated to be 5% in the Central Region, and 10% in the other regions.

(2) Domestic Load

The electrification project and distribution system reinforcement is already being carried out in the Central and Eastern Regions. It is expected that about 5,000, 1,200, 1,000, and 500 new consumers will be connected each year from 1982/83 in the Central, Eastern, Western and Far & Mid Western Regions respectively. In addition to the above new consumers, the annual growth rates of the number of consumers (6% in Central and 7% in the other regions) are considered in this forecast.

The average annual consumption per consumer is initially 939kWh in the Central Region, 715kWh in the Eastern Region, 580kWh in the Western Region and 676kWh in the Far & Mid Western Regions. An annual increase of 20kWh/year in consumption per consumer is assumed for the Central Region and 10kWh/year for other regions.

(3) Commercial Load

Non-industrial loads in excess of 50kW are classified as commercial load in the Central Region. At present, about 150 commercial consumers are connected, while commercial load consists mainly of large hotels. In the Central Region, two large new hotels (Kathmandu and Sherpa) are under construction with an expected power consumption of 5.3GWh/year and 6.0GWh/year. In addition to the above, a growth rate of 10% for the existing commercial load is assumed for the next ten (10) years in the Central and Western Regions.

Other regions are also concerned; however, no separate commercial loads are estimated as these are presumed to be included in domestic load.

(4) <u>Irrigation and Water Supply Load</u>

At present, three (3) irrigation projects, i.e. Battar (lift irrigation), Birganj and Lumbini (tube wells) are in operation in the Central Region and Western Region. HMG has embarked on a number of lift irrigation and groundwater pump irrigation schemes. The assumed power loads for eight (8) of these projects are considered in this load forecast as specified irrigation load, shown in TABLE 3.3.10.

For other prospective unspecified irrigation and water supply loads, a 5% annual growth rate is considered.

(5) <u>Transport Load</u>

The present power loads for transportation derive from the Kathmandu-Hetauda ropeway and the Kathmandu city trolley bus.

There is a ropeway improvement plan and a trolley bus extension plan up to the airport. Load requirement for these plans is estimated in this load forecast at an annual growth rate of 5%.

(6) <u>Street Lighting and Other Loads</u>

For street lighting and ceremonial lighting loads, a 5% annual growth rate is assumed in all regions.

(7) <u>Power Export</u>

In this load forecast, it is assumed that the committed export load (22GWh/year) is continued supply to the Raxaul Region in India from 1983/84.

(8) <u>Losses</u>

Losses due to power system losses and unmetered consumption are recorded at about 32% of the total supply in Nepal in 1982/83. Effective programs to reduce and control these losses are being implemented including improvement of the distribution system, and appropriate legislation and enforcement to control unmetered consumption. Therefore, it is estimated that total losses in the Central Region will be reduced to 20% of the total supply by 1990/91, and losses in other regions will be reduced to 15% of total supply.

(9) Annual Load Factor

The annual load factor of 1982/83 is recorded at about 46.5%. In this load forecast, the annual load factor is assumed to increase gradually to 50% in 1990/91, similar to that in the trend forecast.

(10) Results of the 1983 Disaggregate Forecast

The average annual growth rate for total Nepal power supply excluding power export is 10.9% from 1982/83 until 1991/92, compared to the 1983 trend forecast growth rate of 13.2%. The total required power supply and peak load of 1991/92 with committed export will be 872.1GWh and 197.5MW, compared to the 1983 trend forecast of 1,079.8GWh and 244.6MW.

These differences suggest that either the growth rate in the trend forecast is too high or that the growth rates in the disaggregate forecast are too low. Therefore, the 1983 Disaggregate Forecast is recommended as the 1983 Low Forecast. The results of the 1983 Disaggregate Forecast are shown in TABLE 3.3.11 while comparison of the 1983 Trend Forecasts to the 1983 Disaggregate Forecast is shown in FIG. 3.3.5 and FIG. 3.3.6. FIG. 3.3.7 and FIG. 3.3.8 compare 1983 load forecasts to previous load forecasts.

### 3.3.3 Long-Term Demand Forecast

In addition to the above 1983 ED power demand forecasts, a long-term power demand forecast beyond 2001/02 was undertaken in this Master Plan Study based on the 1983 Trend Forecast (Basic Forecast). The assumptions used in this long-term forecast and the results are presented hereunder.

(1) Growth Rate

The forecasted annual growth rate of all Nepal beyond 2000 is assumed to decrease gradually to 7% in 2020/21 and thereafter to approach a balance target of 6% based on the estimated annual growth rate of 10.84% in 2000/01 of the 1983 Basic Forecast.

(2) Power Export

This load forecast considered potential export as shown in TABLE 3.3.4 similar to that in the Trend Forecast.

(3) Annual Load Factor

The annual load factor is assumed to increase gradually to 60% in 2020/21 as a long-term balance target.

(4) Results of the Long-Term Demand Forecast

The total required power supply and peak load with potential export of 2010/11 will be 7,718.1GWh and 1,567.7MW, and 16,526.8GWh and 3,144.4MW in 2020/21, respectively. According to this forecast, power generation capacity amounting to about 2,250MW must be developed from 1995/96 until 2015/16.

The results of this long-term demand forecast are summarized in TABLE 3.3.12, while the long-term generation expansion program up to 2030/31 is shown in FIG. 3.3.9.

### 3.3.4 Existing Power Development Plans

(1) Previous Power Development Studies

Power development plans in Nepal for the period up to 1992 were described in the report on "Update to the Generation Expansion Plan, Period 1985/86 to 1992/93" Report No. 3/2/100981/1/3 published by the Water and Energy Commission of the Ministry of Water Resources in September 1981 based on the 1981 Load Forecast.

This report proposed a sequence of hydropower developments including the Devighat Project (14.1MW) to be in-service in 1984, Kulekhani No.2 Project (32MW) in 1985, Marsyangdi Project (66MW) in 1986 and Sapt Gandaki Project (225MW) in 1989.

This report also proposed the transmission line expansion program that would connect the Western Region (Butwal, Bhairawa, etc.) into the Integrated Power System in 1984, the Eastern Region (Janakpur, Biratnagar, etc.) in 1985, the Far Western Region (Nepalganj, etc.) in 1986 and the Bhadrapur, Dhangadhi and Mahendranagar areas in 1989.

Since this power development study was based on the 1981 Load Forecast, the power development plans were revised according to 1983 Load Forecasts.

(2) Revised Power Development Plans

In 1983, ED reviewed the power development schedules in which the Devighat Project would be completed in January 1984, the Kulekhani No.2 Project in September 1986, the Marsyangdi Project in July 1988 and the first unit (75MW) of the Sapt Gandaki Project in July 1990.

The revised expected completion dates of hydropower projects, the transmission line expansion program and the substation expansion program are shown in TABLE 3.3.13, 3.3.14 and 3.3.15.

(3) Features of Hydropower Development Projects[1/]

1) Devighat Project

The project site is located about 70km northwest of Kathmandu on the Trisuli River. It envisages utilization of tailrace water from the existing Trisuli Power Station, which is conveyed a distance of about 4.5km through a cut and section open channel and tunnels on the right bank of the Trisuli so as to reach the forebay located about 40m above the river.

Installed capacity is 14.1MW (3 x 4.7MW), design discharge is 45.3$m^3$/sec and head is 37.3m. Annual energy generation is estimated at approximately 92GWh. Total cost of the project, including escalation, is about 55.7 million US$. The project was completed in January 1984 under the Technical and Economic Co-operation Program of the Government of India.

1/ ED, Hydropower Development in Nepal, May 1983

2) Kulekhani No.2 Project

The project site is located in the upper basin of the Rapti River in the Central Region, about 35km southwest of Kathmandu. The project consists of downstream development of the Kulekhani No.1 Power Station.

The Kulekhani No.2 Power Station will primarily utilize the regulated flow from Kulekhani No.1 and the Mandu River, a tributary of the Rapti River. Intake from the same is through a 6km long headrace tunnel, a 42m high and 8m diameter restricted orifice type surge tank and a 870m long inclined underground steel penstock which terminates at the Kulekhani No.2 Power Station. Installed capacity is 32MW (16MW x 2), while the cost of the project, with escalation, is 63.91 million US$, at 1981 price levels.

The project is being constructed with funds from the Overseas Economic Cooperation Fund (Japan) and HMG/N, and is expected to be completed by September 1986.

3) Marsyangdi Project

The project site is located at Marsyangdi River, in the Gandaki zone, about 110km west of Kathmandu on the Kathmandu-Pokhara highway, near the village Anboo Khaireni. The objective of the project is utilization of the hydropower potential of the Marsyangdi River along a river section approximately 13km long by constructing a diversion weir, a tunnel and a powerhouse.

Installed capacity is 66MW (22MW x 3), while average annual generation is estimated to be 450GWh. The project will be run of river type with daily peak capacity during dry season. Total cost of the project is about 327.4 million US$ (Foreign currency = 246.5 million US$ and local currency = 80.9 million US$) including price escalation during the construction period. Project completion is envisioned by July 1988.

4) Sapt Gandaki Project

The project site is located downstream of the confluence of the Kali Gandaki and Trisuli Ganga rivers about 4km north of Naryangadh. This is a run of river type project with a dam height of 71m and a powerhouse located downstream of the dam with an installed capacity of 225MW (75MW x 3). Rated discharge per unit will be 205.3m$^3$/sec and net head will be 39m. Annual primary and secondary energy production will be 735GWh and 663GWh, respectively.

Estimated total cost of the project is 355 million US$ at July 1982 price levels without price escalation. Feasibility study was carried out under the assistance of the Japanese Government and the Japan International Cooperation Agency, and the final feasibility report was completed in January 1983. The first unit (75MW) of the project is expected to be completed by July 1990.

## 3.4 Planning Conditítions

### 3.4.1 Topography

(1) General

Nepal embraces a unique variety of geographical features ranging from the southern lowlands to the high mountains. Between these marginal zones, there are three zone belts, the Terai, the Hill and the Mountain zones. The projects are mainly located in the Hill Zone, which constitutes a broad complex of hills and valleys.

The Sun Kosi River originates in Tibet and crosses the Mountain Zone from north to south, then flows east in the Hill Zone gathering the waters of many tributaries, such as the Indrawati, Tama Kosi, Rosi Khola, Likhu Khola and Dudh Kosi. The Arun River originates in Tibet and crosses the Mountain Zone to flow through the Hill Zone from north to south. The Tamur River originates in the Mountain Zone in Nepal and flows northeast to southwest.

(2) Topographical Maps

The catchment area of the Kosi River is 61,000km$^2$ at Tribeni, the confluence point of the Sun Kosi, Arun and Tamur, and 27,500 km$^2$ (45%) of the said area is located within Nepalese territory.

Existing topographical maps (scale: 1/50,000) cover the entire Nepalese portion of the Kosi Basin. These maps were used at a preliminary stage to clarify the characteristics of all rivers in the Basin and to identify all potential sites.

New 1/20,000 scale maps were prepared along the Sun Kosi River between Kurule and Panchuwar Ghat from which the Sun Kosi No.1 - No.3 sites were selected. These photogrammetric maps were prepared with the standard ground point survey and used to ascertain the reservoir volumes of the Sun Kosi No.1 - No.3 dams.

In addition, 1/10,000 scale photogrammetric maps were prepared for the priority sites which were selected after project identification, studies and site reconnaissance. Finally 1/1,000 scale maps were prepared by ground survey for high priority sites after project identification and optimization studies and site reconnaissance. The existing maps previously prepared at the Sun Kosi No.1 and Sapt Kosi sites were also used.

### 3.4.2 Geology

(1) General

The general stratigraphy of the Basin can be divided into six major geo'stratigraphic groups as presented in the table below.

GEO'STRATIGRAPHIC GROUPS OF EASTERN NEPAL

| Possible Period | Group | Lithology |
|---|---|---|
| 1. Cenozoic | Recent | Unconsolidated sediments, gravels alluvium |
| | Siwalik | Shale, Sandstone, Conglomerate |
| | | Main Boundary Fault |
| 2. Mesozoic - Paleozoic | Tethys | Shale and limestone |
| 3. Paleozoic - Precambrian | Kathmandu | Mainly clastic rock and carbonate |
| | Midland | Mainly clastic rock and carbonate |
| | | Main Central Fault |
| 4. Precambrian | Himal | Gneiss and schist (highly metamorphic rock) |
| | Igneous Rock | Granite and paragranite |

The geotectonic lines which determine the geological structure of the Basin consist of two major thrusting faults; the Main Central Thrust (MCT) and the Main Boundary Fault (MBF). These faults extend in an east-west trend across Nepal, acting as the major division between formation groups.

The mountainous region is in the process of large-scale erosion, and sediment produced from the same is carried to the lower reaches. Sediment volume in each river is great due to i) steep terrain; ii) young orogenic movement; iii) location in the sub-tropical monsoon belt with over 2,000mm rainfall during rainy reason resulting in sediment run-off; iv) weathering of bedrock due to high humidity, heavy rainfall and location in the tectonic belt; v) steep river gradient; vi) deforestation and poor vegetation on steep mountain slopes; vii) soil composition of easily eroded unconsolidated sediments; and viii) lack of river treatment and soil erosion control schemes in the mountains and hillsides and along river banks.

The combination of the above factors results in widespread landslides, slope failure, etc., which increases the amount of sediment in the rivers.

(2) Geological Maps

Large scale geological maps (scale: 1/1,000,000) covering the whole Basin are available. Some 1/50,000 scale maps also exist but do not cover the entire Basin. The Arun River and the tributaries of the Sun Kosi River, including the Indrawati, Bhote Kosi, Khimte Khola, Likhu Khola, Rosi Khola and Dudh Kosi rivers, are not covered.

At the particular sites, the following sources of previously investigated geological information were used.

- Sun Kosi No.1 Site: "Feasibility Study of Irrigation Development in the Terai Plain" prepared by UNDP in 1972
- Sapt Kosi High Dam: "Feasibility Study of the Kosi High Dam" prepared by the Government of India

### 3.4.3 Discharge Data

(1) General

The catchment area of the Kosi Basin is 61,000km$^2$ at Tribeni, 45% of which lies within Nepalese territory. Approximately 10% of the catchment area is covered year-round by glacier, ice and snow.

The relative proportions of each catchment area of the three main rivers that eventually join to form the Sapt Kosi River are presented below:

| River | Catchment Area (km$^2$) | Proportion (%) |
|---|---|---|
| Sun Kosi | 19,000 | 31 |
| Arun | 36,000 | 59 |
| Tamur | 6,000 | 10 |
| Total | 61,000 | 100 |

(2) Gauging Station and Discharge Record

There are 14 gauging stations on the rivers in the Kosi Basin, as shown in the TABLE 3.4.1. All recorded data until 1978 were processed except for No.670. The data at G.S. No.604 and G.S. No.604.5 on the Arun River were processed by the Team during the study as no processed data was available for the Arun River.

The Barakshetra gauging station located on the Sapt Kosi River has been in operation since 1947. This gauging station is operated by the Government of India and only monthly data is published.

### 3.4.4 Flood Data

(1) General

Gauging stations equipped with automatic recorders are as follows:

- No.647, Busti G.S., Tama Kosi River
- No.670, Rabuwa Bazar G.S., Dudh Kosi River
- No.680, Kampu Ghat G.S., Sun Kosi River
- No.690, Mulghat G.S., Tamur River
- No.604.5, Turik Ghat G.S., Arun River

At other gauging stations, measurements are recorded manually according to eye-observation.

Hydrographs of the floods on the Sun Kosi, Arun, Tamur and Sapt Kosi rivers at Tribeni were available as described in the "Feasibility Study Report on Kosi High Dam". However, those data were collected in 1948 and 1954 with no recently recorded data.

(2) Recorded Data

The Team collected flood data provided by ED. The recorded gauging station and period are shown in TABLE 3.4.2.

TABLE 3.4.2 **FLOOD RECORD**

| Code No. | Gauging Station Name | River | Available Recorded Period |
|---|---|---|---|
| 630 | Panchuwar Ghat | Sun Kosi | 1964 - 1974 |
| 652 | Khurkot | Sun Kosi | 1967 - 1974 |
| 670 | Rabuwa Bazar | Dudh Kosi | 1964 - 1974 |
| 680 | Kampu Ghat | Sun Kosi | 1965 - 1977 |
| 690 | Mulghat | Tamur | 1970 - 1978 |
| 695 | Barakshetra | Sapt Kosi | 1948 - 1978 |

The Team carried out continuous measurement for one week to obtain flood hydrographs at gauging stations No.604.5 and No.680 on the Arun and Sun Kosi rivers, respeotively in the rainy season of 1984.

### 3.4.5 Sedimentation Load

#### (1) General

Landslides and heavy sediment run-off occur frequently in the mountainous area due mainly to severe natural conditions and environmental degradation. Erosion occurs mainly during rainy season and soil, sand and debris are swept downstream in the rivers. Suspended soil and sand are deposited in the middle and lower reaches of the rivers.

#### (2) Measured Data

The sedimentation load including suspended load of the Kosi Basin studied by Dr. C.K. Sharma is presented below.

**TABLE 3.4.3 SUSPENDED LOAD OF KOSI BASIN BY DR. C.K. SHARMA**

| River | Catchment Area at Tribeni ($km^2$) | Total Annual Sediment Load ($10^6 m^3$/year) | Annual Sediment Load ($m^3/km^2$/year) |
|---|---|---|---|
| Sun Kosi | 19,000 | 54 | 2,840 |
| Arun | 36,000 | 35 | 970 |
| Tamur | 6,000 | 30 | 5,000 |
| Total | 61,000 | 119 | 1,950 |

The Team carried out various calculations of sedimentation estimates in consideration of the characteristics of the Basin, coefficient of reliefs, elevations, steepness and the geology of the area defined for the estimation. These parameters were analysed by several methods of sediment estimation developed and adapted in Japan and throughout the world.

The Team also measured the suspended load in the rivers of the Basin.

### 3.4.6 Cost Estimation

(1) Unit Price

The unit price for cost estimates utilized in the Study is based on data from completed projects and planned projects in Nepal and cost of past projects outside Nepal adapted to Nepalese conditions. All unit costs are updated to allow for inflation and price levels were set according to 1983 price levels.

Unit costs of civil works were estimated for the main works of each structure; such as open excavation and tunnel excavation works, concrete works, reinforcement works and grouting works. Other works were estimated based on a percentage of 20 - 30% of the costs of the main works of each structure including physical contingency allowance. Unit costs of metal works; gate, screen, penstock, mechanical equipment and electrical equipment were based on the internaional market price, including manufacturing, transport, installation, erection and insurance.

The costs for compensation, land acquisition and temporary facilities were calculated on the basis of percentage, while allowances for indirect items such as owner's temporary facilities and engineering consultant were based on historical percentage.

Besides contingency in each work described above an additional physical contingency allowance of 10% was used for all costs.

(2) Cost Estimate Method

The quantities used in estimation were taken from 1/50,000 scale maps. These were up-graded with 1/10,000 scale maps for the priority sites and further up-graded with 1/1,000 scale maps for the high priority sites except for the Arun No.3 Site which was planned as an SSR type and no 1/1,000 scale maps were prepared.

The estimate of the selected schemes was prepared at the master plan level and as such has an accuracy of plus or minus 20%. The estimate is presented in United States dollars. The estimate is for the base capital cost of the project and does not include any costs for escalation beyond 1983 and interest during construction.

The base estimates provide the amounts required for construction of the project and do not include any allowance for the owner's head office costs other than those directly associated with the project. Regarding access road cost for construction, each project is assumed to be developed independently. The cost estimate method is presented in TABLE 3.4.4.

(3) Annual Cost

The annual costs of the selected schemes were calculated for the optimization study to decide the optimum scale of each project and to estimate the Benefit Cost Ratio and Net Present Value. Annual costs consist of i) capital recovery cost, ii) operating and maintenance cost and iii) replacement cost. The discount rate is set at 12% annum.

1) Capital recovery cost

The project life and construction period were assumed as 50 years and 5 years, respectively, while the annual disbursement ratio was assumed as follows:

- 1st-year: 10% of capital cost
- 2nd-year: 20% "
- 3rd-year: 30% "
- 4th-year: 30% "
- 5th-year: 10% "

The capital recovery factor ($C_1$) was calculated applying the capital recovery factor of 0.120417 for 50 years and the compound factors to each year as follows:

$$C_1 = 0.120417 \times (0.1 \times 1.573519 + 0.2 \times 1.404928 + 0.3 \times 1.254400 + 0.3 \times 1.120000 + 0.1 \times 1.0) = 0.150600$$

2) Operating and maintenance cost (O&M Cost)

Operating and maintenance cost is assumed as 1.5% of the capital cost, and the O&M factor ($C_2$) is,

$$C_2 = 0.015$$

3) Replacement cost

The replacement of mechanical and electrical equipment is assumed to occur once in the project life of 50 years. The replacement portion is assumed at 40% for metal works and mechanical and electrical equipment and 10% for the civil works involved in the same. Total replacement cost is thus 50% of capital cost. This cost is assumed to occur in the twenty-fourth year, at which time the replacement cost factor ($C_3$) applying the capital recovery factor of 0.120417 and discount factor of 0.052521, becomes,

$$C_3 = 0.120417 \times (0.5 \times 0.052521) = 0.003162$$

4) Annual cost

The annual cost factor (C) becomes,

$$C = C_1 + C_2 + C_3 = 0.168763 = 0.169$$

### 3.4.7 Benefit Estimation

(1) Unit Power Benefit

For evaluation of power production, it is necessary to estimate the unit value. The value of power generation should be based on the long-term marginal cost of supply in the Nepal power system.

The unit benefit attributable to the hydropower project is assumed to be derived from the cost of the dominant, competitive power supply system.

The coal-fired power system with unit capacity of 100MW was adopted as the alternative power supply system in consideration of the fact that this system is widely operated and dominant in India and that unit capacity is expected to prevail to meet power demands in Nepal in the future. The construction cost of a coal-fired thermal power station with a 100MW unit is estimated to be US$1,000/kW. Annual fixed operation and maintenance cost is considered to be proportional to the installed capacity and is estimated at US$30/kW.

Benefit consists of kW-value and kWH-value which are derived based on 1) the international coal price of US$63/ton; and, 2) a service life of 25 years.

1) kW-Value

| | |
|---|---|
| - Unit Construction Cost (US$/kW) | 1,000 |
| - Service Life (Years) | 25 |
| - Capital Recovery Factor (CRF) | 0.127500+0.127500x (0.9x0.052521) = 0.133527 |
| - Operation and Maintenance Cost | 0.03 |
| - Adjustment Factor | 1.173 |

kW-Value : 1,000 x (0.133527 + 0.03) x 1.173
= US$191.8/kW

2) kWH-Value

- Fixed Cost (US$/kWH) $\frac{1,000 \times 0.03}{8,760 \times (1 - 0.23)} = 0.004$

| | |
|---|---|
| - Fuel Cost | 0.038 |
| - Price of coal | 63 |
| - Heat value | 4,600 |
| - Thermal efficiency | 31 |
| - Heat rate | 2,774 |

- Adjustment Factor $\frac{(1 - 0.003) \times (1 - 0.05)}{(1 - 0.06) \times (1 - 0.02)} = 1.028$

kW-Value : (0.004 + 0.038) x 1.028 = US$0.043/kWH

Adjustment factors are calculated based on the following values.

| | Hydropower Station | Thermal Power Station |
|---|---|---|
| - Auxiliary power use (%) | 0.3 | 6.0 |
| - Transmission loss (%) | 5.0 | 2.0 |
| - Forced outage (%) | 0.5 | 5.0 |
| - Overhaul (%) | 2.0 | 10.0 |

(2) Annual Power Benefit

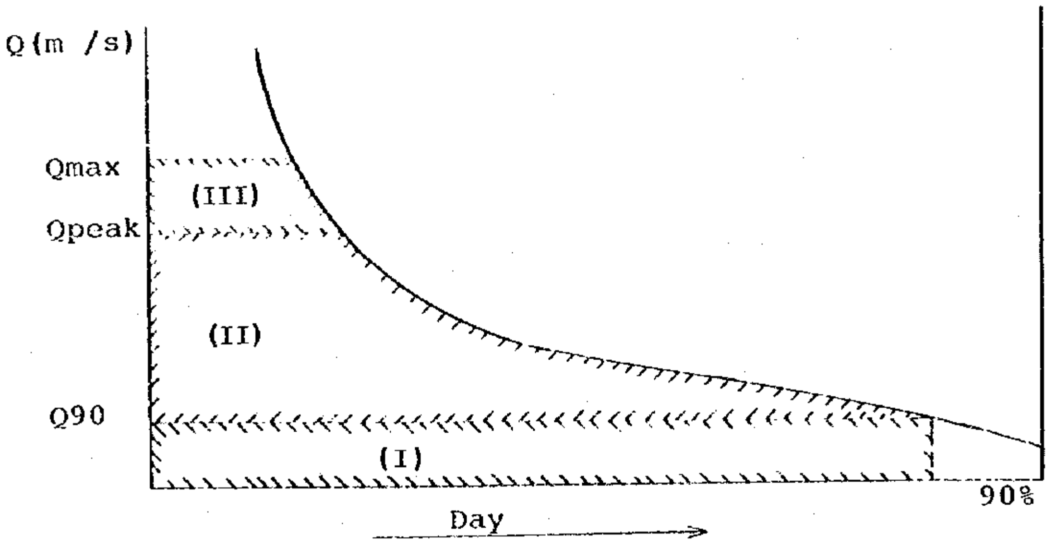
The annual power benefit was calculated multiplying the unit kW-value, 191.8US$/kW, by the installed capacity and unit kWH-value, 0.043US$/kWH, by the annual generated energy for the potential study of all schemes.

Further study was carried out for 13 priority schemes in consideration of the present low potential for power use in Nepal. Under these conditions, surplus energy generated in rainy season must be exparted and then the value of energy will therefore primarily by determined by energy export potential. In this study, the firm capacity and the firm and secondary energies were identified and valued.

The annual power benefit was determined by multiplying the kW-Value, 191.8US$/kW, by the firm capacity and the kWH-Values, 0.043US$/kW and 0.028US$/kWH, by firm and secondary energies, respectively. A kWH-Value of 0.028US$/kWH was obtained deducting the transmission cost in consideration of assumed export.

The classification of firm capacity and firm, secondary energies is as follows:

DISCHARGE DURATION



1) SRR type

- Firm Capacity (Pf):

  Capacity by the discharge corresponding to 90% dependable, $Pf = F_1 (Q_{90})$

- Firm energy (Ef):

  Energy by Firm capacity, $Ef = F_2$ (Area (I))

- Secondary energy (Esecond):

  Surplus energy in rainy season,

  Esecond = $F_2$ (Area (II) + Area (III))

2) PRR and Reservoir types

- Firm capacity (Pf):

  Asuming a peak of 6 hours, $Pf = F_1 (Q_{90} \times \frac{24}{6})$

- Secondary energy is divided into seasonal energy (Eseason) and secondary energy (Esecond),

  Eseason = $F_2$ (Area (II))

  Esecond = $F_2$ (Area (III))

### 3.4.8 Environmental Considerations

#### (1) General

Dam construction will result in river water storage which is closely related to the livelihood of the people around them, and transform the natural rivers into artificial lakes greatly influencing the natural environment and ecosystems. It will also effect great social changes by submergence of existing villages and separation of communities.

In assessment of the environmental impact, both short-term and long-term effects must be considered. Short-term effects occur in almost any type of development, while long-term effects mainly occur in reservoir type developments. Landslides around the reservoir, environmental degration, eutrophication and fishery losses, are a few of these effects.

On the other hand, positive effects may also be expected as project development functions "to give water environment and the improvement of infrastructures to people". Development facilitates regional development by easier accessibility and creates enjoyable landscape by the combination of dam structures, new lakes and nearby natural surroundings. In addition, the reservoirs may be used for fishing, sports and general recreation.

In the Kosi Basin, 52 schemes have been selected, of which 5 are reservoir type, 5 are PRR type and 42 are SRR type.

(2) Consideration of Countermeasures for Environmental Impact

To cope with the environmental problems associated with dams, reconstruction measures should be taken for residents whose houses will be submerged as well as provision of land, work opportunities, etc. As for landslides and eutrophication, it is essential to assess the possibility of the same and adopt countermeasures before or during construction.

Some fishery losses are likely to occur due to reservoir trapping without regeneration of nutrients in the reservoir and interference with the migratory process. Therefore, in the case of SRR and PRR types, fish ladders might be considered as a countermeasure.

## 3.5 Planning Methodology

### 3.5.1 General

Hydropower planning was carried out from data collection and analyses through project identification, project optimization and priority schemes selection, combined with appropriate site investigations, site reconnaissance, surveying and geological investigation. Detailed work and planning are shown in FIG. 3.5.1. Planning criteria and results were confirmed at the meeting held between the Study Team and the HMG personnel concerned.

### 3.5.2 Preliminary Selection

Preliminary selection was carried out for maximum development of the hydropower resources of Nepal. Selection included the following procedures.

- Data collection and analyses
- Site selection and project identification

(1) Data Collection and Analyses

All existing data necessary for hydropower planning were collected and analysed. Topographical maps, hydrological and geological data, present status and future plan of power supply, road planning and other necessary data were collected. Hydrological data, daily discharge data at 13 gauging stations and monthly data at one gauging station were analysed.

At this stage, field surveys were carried out for measurement of suspended load in the river and preliminary site reconnaissance on the Bhote Kosi, Tama Kosi, and Indrawati rivers which are accessible by car.

(2) Site Selection and Project Identification

The principal of hydropower planning is to achieve maximum utilization of Kosi River water resources for power generation while satisfying the prerequisites of economic viability and technical suitability. In the Master Plan Study, hydropower scheme sites with installed capacity of over 10MW, envisaged for development in the future, were selected in the Nepalese portion of the Kosi Basin.

1) Identification of river characteristics in the Kosi Basin

The longitudinal profiles not only for the 7 main rivers (Sapt Kosi rivers) but for other rivers which have power potential, were identified based on the 1/50,000 scale maps. As a result the following rivers were selected for hydropower development.

- Sun Kosi river system: Sun Kosi, Dudh Kosi, Maulung Khola, Likhu Khola, Tama Kosi, Khimte Khola, Rosi Khola, Indrawati, Balephi and Bhote Kosi
- Arun river system: Arun River
- Tamur river system: Tamur and Kabeli Nadi
- Sapt Kosi river system: Sapt Kosi River

The topographical and geological conditions of each river were studied, particularly the potential for large reservoirs, taking into account reservoir volume, sedimentation load and location of the Main Boundary Fault (MBF) and Main Central Trust (MCT).

Existing and planned roads were studied to investigate access conditions and decide the access roads for project development. Cities, towns and villages along or near the rivers were studied to determine the area to which the electric power would be supplied from nearby power stations after completion of transmission networks.

2) Formulation of planning criteria

The following criteria were made for site selection and project identification.

a) Type of development

Reservoir type

Reservoir type hydropower stations are planned in downstream areas where the river gradient is gentle, permitting construction of large reservoirs which overcome the problem of sedimentation.

This type of station effectively utilizes water resources by annual regulation the natural flow which fluctuates greatly from dry to rainy season. The same also contributes to flood mitigation and water uses other than power generation including irrigation and river navigation.

However, topographical and geological conditions should be carefully checked in selection of dam sites.

Pondage Run of River type (PRR type)

PRR type hydropower stations are planned in the middle courses of a river or in those with a relatively gentle river gradient, ensuring available pondage capacity for peak generation. In this case, the topographical and geological conditions for dams with a height of 60 - 80m should be studied.

This type of hydropower station contributes to fulfillment of daily peak demand in Nepal, power for which is predominantly supplied by hydropower.

Simple Run of River type (SRR type)

SRR type hydropower stations are planned in the upper courses of rivers with a steep gradient.

This type fulfills base demand. In the upper most courses of the rivers in Nepal, SSR development can effectively contribute to regional development, protection against deforestation by new road construction, and cheaper energy supply.

b) Hydrological data

Discharge data

Daily discharge data at 13 gauging stations were analysed to show the durations of river flow. The discharge data from each gauging station were applied to sites located on the same rivers by the Catchment Area Conversion Method.

For those rivers without gauging stations, discharge data of neighbouring rivers were applied.

On the Arun River, which has special hydrological characteristics, a correlation study was carried out by using the recorded discharges of the Sapt Kosi, Tamur and Arun rivers.

Flood data

Flood discharge is needed for cost estimation.

To determine the same, a statistical analysis of the recorded flood peak discharge must be used to derive values corresponding to various probabilities of occurrence. However, the recorded peak discharges were not available.

An attempt was therefore made to collect and analyse the adopted design flood for existing and planned dams in Nepal.

c) Sedimentation load

For reservoir type dam planning, specific sediment road data is indispensable. The specific sedimentation loads on the Sun Kosi, Arun and Tamur rivers, studied by Dr. C.K. Sharma was used.

3) Site Selection

In site selection, the Reservoir type schemes were studied first based on the longitudinal profile of all rivers, and in consideration of the existing schemes; the Sapt Kosi High Dam on the Sapt Kosi River and the Sun Kosi

High Dam at Kurule on the Sun Kosi River. Topographical conditions at dam site and the reservoir volume were confirmed from existing topographical 1/50,000 scale maps.

In the middle and upstream courses, both PRR and reservoir type schemes were studied. In this case, two types of powerhouse location were studied. In gentle river courses downstream of the dam, powerhouse location was planned at the toe of the dam. In relatively steep river gradients, on the other hand, powerhouse location was selected headrace tunnel and surge tank.

In the upper most courses, SRR type schemes were studied in consideration of the headrace tunnel length of approximately 5-10km.

After selection of all sites, the catchment area at the dam site was measured and river flow at dam and weir sites was estimated for project identification.

4) Project identification

Project identification of selected schemes was carried out, classifying the same into SRR, PRR and Reservoir types as follows:

a) SRR type

The intake weir is planned as an overflow dam with a height of approximately 20m. Flush gate and intake structures are non-pressure type with a silting basin. The headrace tunnel is planned as a non-pressure type with a headtank while the powerhouse is planned as an open building type. The maximum discharge is assumed to be twice the firm discharge of 90% dependable river flow.

b) PRR type

The dam is planned as a concrete gravity type with spillway gates to discharge flood water and to maintain available storage volume.

Dam height was determined by the storage-capacity curve. Intake structures and headrace tunnel are planned as pressure type with surge tank and the powerhouse is an open building type. The maximum discharge was estimated in consideration of a 6 hours of peak generation time.

c) Reservoir type

The dam is a concrete gravity type with spillway gates to manage the large flood discharge. Dam layout was determined in consideration of the existing Sapt Kosi High Dam and Sun Kosi High Dam at Kurule and the diversion scheme which will divert Sun Kosi River water to the Terai Area for irrigation.

Dam heights and locations on the Sun Kosi River were studied for optimum development of the Sun Kosi River, in consideration of available storage capacities.

The powerhouse is planned at the toe of the dam. Maximum discharge was determined same way as PRR type after analysis of river flow by mass curve analysis using the available storage-capacity of the reservoir.

### 3.5.3 Field Reconnaissance

The dam sites were selected based on 1/50,000 scale topographical maps except for the previously planned schemes; Sapt Kosi High Dam, and Sun Kosi High Dam (Sun Kosi No.1 site). The field survey was undertaken to confirm the topographical and geological conditions of the dam and penstock - powerhouse sites and accessibilities for construction works. Almost all sites are scattered in the vast Kosi Basin, and therefore, helicopters were used for surveys. For the high dam sites with Reservoir type development, a base camp was set-up from which field reconnaissance was undertaken. The remaining sites were visited by helicopter to confirm and determine suitable dam and penstock-powerhouse sites.

(1) Topography and Geology

Topographical and geological conditions were investigated for dam and penstock - powerhouse sites as follows:

1) Reservoir type

Field reconnaissance of river courses in 3 - 5km gorges confirmed by helicopter-borne survey was carried out on foot to determine suitable dam sites, confirming river width, topographical and geological conditions on both banks, including slope, outcrops, talus deposits, etc. and the existence of any faults and landslides near the site.

Detailed field reconnaissance was subsequently undertaken. The area for the next investigation, and topographical survey were identified, and finally sites of temporary facilities for construction and materials were investigated.

2) PRR type

The same investigations were carried out for PRR scheme dam sites as sites as in the reservoir type. For the penstock -powerhouse sites, topographical and geological conditions, slope gradient, talus deposits etc. were investigated. Moreover, the tunnel route was surveyed by helicopter checking large faults and landslides.

3) SRR type

The same investigations were carried out as for the PRR type above.

(2) River Condition

River width was measured as much as possible as dam length is an important factor in cost estimation. River deposit and flow were also observed for planning, design and construction of dam in terms of flood diversion works and materials as concrete aggregate.

(3) Environmental Conditions

Houses and lands were investigated considering future submergence by the reservoir and regional development by improvement of transportation facilities and tourism, and creation of employment opportunities.

### 3.5.4 Project Optimization

Project optimization was studied for selected and identified schemes, according to the results of field investigations. This study was based on 1/50,000 topographical maps, hydrological data and the results of site reconnaissance. New photogrammetric maps (scale: 1/20,000) were used for the projects on the Sun Kosi River. The study was carried out as described hereunder.

(1) Review of Site Layout

1) Reservoir type

Three sites were selected on the Sun Kosi River aiming at full and effective development of water resources upstream of the Sapt Kosi High Dam. For most effective development, many alternatives of the 3 dams were made and compared in terms of economic viability indicated by hydroelectric benefits based on the newly prepared 1/20,000 maps. Finally, the most effective and economical combination of three dam sites and heights was decided and confirmed by the site reconnaissance survey.

On the Tamur River, 1 site for Reservoir type development was selected with an alternative PRR type. Economical comparison was undertaken for adoption of the Reservoir type and the same was confirmed by the site reconnaissance survey. On the Sapt Kosi, the Sapt Kosi High Dam has been planned and investigated until 1947. The Team collected previously investigated data and carried out site reconnaissance to confirm the dam site suitable for high concrete gravity dam.

2) PRR and SRR types

The dam site and penstock - powerhouse sites were mainly reviewed based on the results of site reconnaissance, in view of river width, slope gradient of both banks, existence of talus deposit and any faults and landslides on banks and river deposit. The layout of structures, dam, headrace tunnel, penstock - powerhouse and head were reviewed.

(2) Criteria Formulation

The criteria for project optimization were first established for each type as described below.

1) SRR type

Dam was planned as intake weir with height of approximately 20m and water way was located taking into consideration of river loop and suitable location of power house.

Unit cost of generated energy was calculated and used to determine optimum scale of power station. At least 3 cases with varying maximum discharges were compared to determine the minimum unit cost, i.e., optimum installed capacity.

2) PRR type

Dam location and height were decided, first on the basis of site reconnaisoance survey and storage-capacity curve to ensure the effective storage capacity for peak generation.

Benefit Cost Ratio (B/C Ratio) was used to determine installed capacity in consideration of unit energy cost. At least 3 cases were compared to obtain the maximum B/C ratio and the minimum unit cost, i.e., optimum installed capacity.

3) Reservoir type

First, dam height was studied to obtain the total maximum available storage capacity of schemes on each river in consideration of the heavy sediment load. The effective storage capacity was calculated assuming the total sediment load in 50 years, applying the trap efficiency by Brune's Formula. The range of dam heights were assumed within 200m taking into account the safety side plan except for the Sapt Kosi High Dam due to lack of information in this study stage.

To determine the installed capacity, the Mass Curve Analysis was carried out to obtain the available river flow for power generation. Then, B/C Ratio was used to decide the optimum installed capacity.

### 3.5.5 Selection of Priority Schemes

(1) General

The Team has selected and identified 52 hydropower project schemes, through site selection on maps, site reconnaissance optimization study. These 52 schemes were understood to be technically and economically feasible, with the exception of some schemes with relatively small capacity and poor access to existing roads. However, these small scale schemes are expected to become feasible and necessary in future after improvement of infrastructures and access roads. The 52 schemes were listed and evaluated based on the Point Evaluation System, not to evaluate power benefit but also social impacts.

In the Evaluation System, shown in TABLE 3.5.1, consists of evaluation for the following effects.

- Economic viability
- Infrastructure for construction
- Resettlement
- Effects on downstream reaches
- Inundation
- Development impact

(2) Priority Schemes

All schemes were evaluated according to the Evaluation System and ranked. Then the top 13 schemes were selected as priority projects which would be developed in future for the purposes of domestic use and energy export. The 13 priority schemes are scattered widely in the Kosi Basin. The development potential of the Sun Kosi River is enormous due to abundant river water and long river courses and the development schemes for the same are highly evaluated.

The Arun River has a abundant and cheap power genration potential. Although long access roads are required for development of hydropower stations, development of the same will be a major stimulus for regional development.

After completion of first development on the Arun River, Arun No.3, it becomes possible to easily develop the economical energy potentials due to improvement of transportation facilities.

The Sapt Kosi High Dam has also abundant and economical power generation potentials. Besides the above potential, it could also be effective for flood mitigation, navigation, irrigation in downstream in Nepal and India. However, substanical finanical resources would be required to develop this scheme.

## 3.6 Results of Study

### 3.6.1 Hydrology

(1) General

This chapter summarizes the principal findings of the hydrological study which is presented in more detail in APPENDIX - II.

The main objectives of the hydrological study can be described as follows:

a) Calculation and summarization of river discharges, including processing of water levels recorded at gauging stations;

b) Estimation of river discharge at selected dams and intake weirs;

c) Analysis and consideration of the accuracy of data; and,

d) Estimation of flood discharges for dams by frequency analysis and review of past data adopted for existing and planned dams in Nepal.

(2) River Discharge at the Gauging Station

In the Kosi Basin, 14 gauging stations have been installed and measurements recorded as shown in FIG. 3.6.1. However, 1 gauging station on the Sapt Kosi River is controlled by the Government of India and only monthly data are published for the same. Moreover, another gauging station at Legwa Ghat on the Arun River was terminated in 1982. Therefore, 12 gauging stations have been maintaind by HMG and 1 gauging station by the Government of India in the Kosi Basin.

Recorded data on the Arun river were not processed. The Team therefore carried out measurements at the gauging station sites in rainy and dry season, for preparation of a rating curve. The recorded water levels were thereby processed to obtain river discharges and the monthly average discharge data at the above gauging stations are shown in TABLE 3.6.1. Durations of the above discharge data are shown in TABLE 3.6.2 except for data on the Sapt Kosi River, daily discharge data for which was unavailable.

### (3) River Discharge at the Dam Site

For hydropower planning, river discharge data for each dam site is indispensable. As the location of gauging stations and dam sites differed, and some rivers had no gauging stations, the following estimations were carried out.

a) In the case of rivers with gauging stations, river discharge at the dam sites was estimated by applying the "Catchment Area Conversion Factor" to the recorded river discharges at the gauging station. The Catchment Area Conversion Factor is an estimation method based on the assumption that river discharge at the dam site is proportional to the catchment area of the same or neighbouring rivers.

b) In the case of rivers without gauging stations, the above method was applied by using the river discharge recorded on a neightbouring river.

c) In the case of the Arun River, the same is considered to have special hydrological characteristics as the greater part of the river basin is located in Tibet, where rainfall is extremely small in comparision with that of Nepal. Therefore, river discharges in the remaining areas, the river basin between the sites of the gauging station and dam sites, were estimated by applying the specific river discharge of the neighbouring Tamur River.

The catchment area of each dam site and the applied gauging station are shown in TABLE 3.6.3. The river discharges at each dam site are shown in TABLE 3.6.4 and the duration of the same are shown in TABLE 3.6.5.

### (4) Consideration of Discharge Data

Discharge data have been recorded at 14 gauging stations in the Kosi Basin. The Team investigated all gauging stations and methods of measurement in the field. At most gauging stations, discharge is measured by staff gauge except for that at No.640.5, Turik Ghat on the Arun River. Recently, HMG has been installing automatic recorders and at present, these have been installed in stations No.647 (Tama Kosi), No.670 (Dudh Kosi), No.680 (Sun Kosi), No.690 (Tamur) and No.640.5.

HMG conducts river flow measurement 1-3 times a year; however, revisions of the rating curve have not been executed. For the latter, river flow should be measured at least twice a month particulary after flooding. Results should be adopted to revise the rating curve according to changes in the riverbed in order to maintain accuracy.

The Team evaluated discharge data based on rainfall data recorded at meteorological stations scattered in the vast area of the Basin. Meteorological stations in the Basin are installed in the following zones and as shown in FIG. 3.6.2.

- Bagmati Zone: 27 stations
- Janakupur Zone: 14 "
- Kosi Zone: 23 "
- Mechi Zone: 19 "

Based upon rainfall data, the Team prepared an isohyeto map as shown in FIG. 3.6.3. Runoff coefficients estimation derived from rainfall and river discharge at the gauging stations were then tried for the evaluation of discharge data as shown in TABLE 3.6.6.

1) Evaluation of runoff coefficient

Run-off coefficients of about 1.0 or more were calculated at gauging stations No.647 (Tama Kosi), No.650 (Khimte), No.660 (Likhu), No.670 (Dudh Kosi) and No.690 (Tamur).

The above inconsistent runoff coefficients were considered for the following reasons:

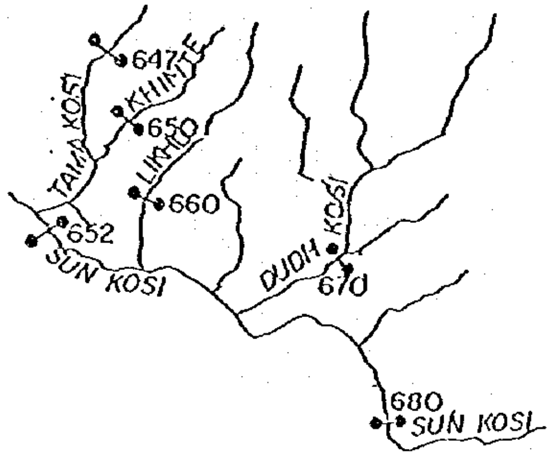
a) Accuracy of river discharge at the gauging station;

b) Inconsistency of recording year (time);

c) Accuracy of rainfall data due to scarcity of stations in the vast Basin; and,

d) The special characteristics of the Basin and existence of a glacier area in the same.

Gauging stations which have run-off coefficients of more than 1.0 are on relatively small rivers or in the mountainous area such as the Tama Kosi, Khimte, Likhu and Dudh Kosi rivers. The above river system with gauging stations is shown below.




GAUGING STATION OF TAMA KOSI RIVER, ETC.

a. Inconsistency of river discharge

The annual average discharges and run-off coefficients at the gauging stations are as follows:

- No.652: $526.08m^3/s$ f = 0.82
- No.660: $55.03m^3/s$ f = 1.28
- No.670: $227.43m^3/s$ f = 1.25
- No.680: $714.14m^3/s$ f = 0.73

Combined discharge of No.652, No.660 and No.670, ($808.54m^3/s$) is greater than that of No.680, ($714.14m^3/s$). Usually the run-off coefficient downstream is smaller than that upstream.

Therefore, these inconsistencies must be carefully investigated taking into account the above in the following stage.

2) Evaluation of river discharge on the Arun

The catchment area at the Turik Ghat gauging station on the Arun River in Nepal ($5,115km^2$) and Tibet territory ($28,650km^2$) is $33,766km^2$. The annual average discharge at the Turik Ghat gauging station is $458.47m^3/s$

Assuming that the same specific runoff of the neighbouring Tamur River applies to the river courses in Nepal by the discharge at Mulghat gauging station ($5,640km^2$), the river discharge in Nepal becomes,

$$341.43 \times \frac{5,116}{5,640} = 309.71 m^3/s$$

and thus discharge from Tibet thus becomes,
$458.47 - 309.71 = 148.76 m^3/s$

It is said that annual rainfall in Tibet is around 300m/m. The run-off coefficient (f) of the Arun River in Tibet therefore can be calculated as,

$$f = \frac{148.76 \times 1,000 \times 365 \times 24 \times 3,600}{28,650 \times 1,000 \times 1,000} \times \frac{1}{300} = 0.55$$

The run-off coefficients of large rivers were studied as below.

a. Mekong River

This river orginates in Tibet and flows through China, Laos, Thai and Kampuchea with a total catchment area of $795,000 km^2$. The run-off coefficients on the main river and its tributaries are said to be 0.3-0.4 and 0.1-0.6; respectively.

b. Solo and Brantus rivers

These rivers, located in west Java, Indonesia, have catchment areas of $16,100 km^2$ and $12,000 km^2$, respectively and run-off coefficients of 0.4 and 0.5.

A run-off coefficient of 0.55 therefore seems reasonable for the Arun River which means that river discharges at the gauging station and dam sites on the Arun River are also reasonable.

(5) Flood Discharge

The Team collected previously recorded flood discharge data and analysed the same by the Hazen Plot Method to determine probable flood. The Team also reviewed previously adopted design flood discharge for constructed and planned dams in Nepal. Recorded data are shown in TABLE 3.6.7 while the Flood Probability Curve by the Hazen Plot Method is shown in FIG. 3.6.4. The probable flood discharges are plotted in FIG. 3.6.5 with those adopted for other dams in Nepal.

The Team obtained flood hydrographs on the Sun Kosi River at Kampu Ghat G.S. and the Arun River at Turik Ghat G.S., in rainy season in 1984, which are shown in FIG. 3.6.6. Thus the design discharges were estimated from the correlation of the flood and catchment area according to the envelope line plotted in FIG. 3.6.5.

### 3.6.2 Sedimentation

#### (1) General

The Team estimated the sediment loads of the Sun Kosi, Arun, Tamur and Sapt Kosi rivers. The Sun Kosi, Tamur and Sapt Kosi rivers for which reservoir-type schemes are planned, were studied in more detail.

#### (2) Sediment Load

The sediment loads of existing and planned dams in Nepal are tabulated on the following page.

TABLE 3.6.7 **SEDIMENT LOADS OF DAMS IN NEPAL**

| Dam | Catchment Area ($km^2$) | River | Sediment Load ($m^3 km^2/yr$) | Remarks |
|---|---|---|---|---|
| Sapt Gandaki | 31,000 | Sapt Gandaki | 2,800 | Feasibility Report (1982) |
| Sapt Kosi High Dam | 61,000 | Sapt Kosi | 1,430 | Feasibility Report (1981) |
| Sun Kosi Power Station | 2,340 | Sun Kosi | 1,795 | Design Report (1972) |
| Kulekhani | 156 | Rapti | 700 | Design Report (1983) |
| Mulghat | 5,640 | Tamur | 5,053 | Feasibility Report (1982) |
| Kamla | 1,550 | Kamla | 1,820 | Feasibility Report (1972) |
| Chisapani | 43,890 | Karnali | 2,098 | Feasibility Report (1977) |

The sediment loads of rivers in Nepal were studied and summarized in the "Gandaki River Basin Power Study" report undertaken by UNDP in 1979. These are tabulated below.

TABLE 3.6.8 **SEDIMENT LOADS OF RIVERS IN NEPAL**

| River | Location | Catchment Area ($km^2$) | Sediment Load ($m^3/km^2/yr$) | Remarks |
|---|---|---|---|---|
| Seti | Phoolbari | 582 | 3,290 | |
| Trisuli | Betrabati | 4,110 | 660 | |
| Karnari | Chisapani | 42,840 | 2,220 | |
| Gandaki | Bhaisolatan | 36,000 | 3,275 | |
| Kosi | Barahkshetra | 59,000 | 2,083 | |
| Sun Kosi | Tribeni | 19,230 | 2,818 | C.K. Sharma's data |
| Arun | Tribeni | 36,533 | 947 | " " |
| Tamur | Tribeni | 5,900 | 5,016 | " " |
| Kosi | Chatra | 61,600 | 1,880 | |
| Rivers of the Himalayan Region* | - | - | 2,638 | |

* This is the mean total sediment load (adjusted for bedload and deficiencies of suspended sediment sampling) of 21 rivers.

The Team carried out the following studies.

- Sediment load derived from measured suspended sediment in the river
- Theoretical analyses in consideration of the topographical and geological characteristics of the Basin.

Details of the above studies are described in APPENDIX - II. Based on the results, the Team adopted the following design sedimentation loads for the Reservoir type plans.

- Sun Kosi: 2,800$m^3/km^2/yr$
- Tamur River: 5,000 "
- Sapt Kosi River: Same as that of "Feasibility Study Report"

### 3.6.3 Field Reconnaissance

(1) General

Field reconnaissance was carried out for the selected sites on foot and by helicopter, excluding several sites located in the extreme upper reaches of the rivers and small sites determined to be less economical by advance studies. In the helicopter borne survey the Team followed the river courses flying slowly or hovering over site areas, to investigate river characteristics and confirm the initially selected sites by means of 1/50,000 maps. After confirmation, the helicopter was landed and field reconnaissance was carried out. This chapter presents the results of hydropower planning aspects. Geological study results are presented in APPENDIX - III.

(2) Schemes on the Sun Kosi River

The Sun Kosi River is one of the largest rivers, along with the Arun and Tamur rivers, in the Kosi Basin. The river has many tributaries; the Tama Kosi, Khimte, Bhote Kosi, Indrawati, Balephi, Rosi, Likhu, Dudh Kosi and Maulung. The Sun Kosi has the longest river course of the rivers in Nepal territory in the Basin. On the trunk river course, four schemes were selected -- 3 Reservoir type and 1 SRR type.

The helicopter-borne survey for this scheme was carried out from the upstream Dolaghat, a town located at the confluence of the Indrawati River, to the downstream Tribeni which is a village located at the confluence of the Arun River. Field reconnaissance survey was carried out at the Sun Kosi No.1, No.2, No.3 and No.4 sites.

1) Sun Kosi No.1 scheme

This scheme is planned as a Reservoir type project with high dam and power station located directly downstream of the dam. The dam site was previously selected and investigated through the "Feasibility Study of Irrigation Development in the Terai Plain" by the UNDP in 1972. The scheme is considered appropriate as a diversion project from the Sun Kosi River to the Terai Area.

The left bank at the dam site is adequate for a high dam, but the right bank flattens out at approximately 120-130m above the riverbed. Hard outcrops with some cracks were observed on both banks at riverbed level at the dam site, while weathered rocks were found on the right bank at the middle and top level.

The river width from the upper reaches to the confluence of the Dudh Kosi River, is wide with fine sand deposits and heavy landslides were observed 2-3km downstream from the dam site. The top flat lands are presently cultivated.

Location of the powerhouse is planned directly downstream of the dam. On the left bank, downstream of the proposed dam site, the flat area is expanding and was tentatively selected as the powerhouse site.

2) Sun Kosi No.2 scheme

This is planned as a Reservoir type project with high dam and power station located directly downstream of the dam. The dam site area has been selected on the basis of optimum development studies of the Sun Kosi River. The river course follows a gorge for approximately 5km. The dam site has been selected in the downstream reaches of the gorge where river width begins to widen and Chyakutar village is located on the right flat bank.

Both banks at the dam site are adequate for a dam of 160-170m and hard outcrops on both banks are found at river water level. The left bank is steep while the right bank is gentle below the middle level. On the right bank, some deposits of talus are observed; however, outcrops continue from the riverbed to the higher level on the left bank.

The powerhouse tentatively planned on the left bank where there is a relatively flat area. The Chyakter village located downstream is relatively large and, this area could therefore, be used as a site for temporary facilities during construction. There are also large stones, gravel and fine sand deposits in this river course. These materials can be used as aggregate materials together with materials from the quarry site on the left bank downstream of the dam site.

3) Sun Kosi No.3 scheme

This is planned as a Reservoir type project with high dam and power station located directly downstream of the dam. The dam site area has been selected by the same method as the Sun Kosi No.2 scheme. The area selected is downstream of the Jakhadi Purana Gaon, approximately 3km downstream of Panchuwar village. This site is approximately 16km downstream of Dolaghat, the town at the confluence of the Sun Kosi and Indrawati rivers.

The right bank at the dam site is very adequate for a high dam with outcrops extending from the riverbed to the top of the bank. The left bank is a vertical cliff extending 70-80m above the riverbed consisting of hard rock. However, the upper slope gradually becomes gentle and is covered with relatively thick talus deposits eventually forming a terrace along on the left bank. A footpath exists; however it is a hazardous route as it cuts along the cliff.

The powerhouse is tentatively planned on the left bank. The river width upstream of the dam site is expanding and some landslides were observed. The dam type was tentatively planned as a concrete gravity type. The fill type or combined type dam, however, might be considered later in view of the substantial fill deposits on the left bank.

4) Sun Kosi No.4 scheme

This scheme is planned as an SRR type project in the river course between the Sun Kosi No.3 scheme and the existing Sun Kosi Hydroelectric Power Station. Two intake weirs were planned on the Sun Kosi River and the Balephi Khola. River flow is to be drawn from both rivers by two tunnels which converge into one and conveyed through a penstock. Location of the intake weir on the Sun Kosi River is planned to be located downstream of the Sun Kosi Hydroelectric Power Station, and the intake weir on the Balephi Khola is planned to coincide with the intake water level of the Sun Kosi River. The powerhouse is located at the confluence point of both the above rivers.

The sites for intake weirs and powerhouse are easily accessible, particularly, the intake weir on the Sun Kosi River and powerhouse site.

(3) Schemes on the Tama Kosi River

The Tama Kosi River is the second largest tributary of the Sun Kosi River. The downstream courses will be submerged by the planned Sun Kosi No.2 reservoir. Therefore, the river courses upstream of the Khimte Khola confluence were studied for hydroelectric power development. This river is easily accessible. A national paved road extends from Kathmandu to Jiri through Charikot, and crosses the Tama Kosi River by a recently constructed iron bridge. Seven schemes were initially planned on the river; however, one sheeme which was planned farthest downstream was disregarded after further study since the same will be submerged by the Sun Kosi No.2 reservoir.

Field reconnaissance has been carried out on Tama Kosi No.1 (disregarded), No.2, No.3, No.4, No.5 and No.6.

1) Tama Kosi No.1 scheme

This scheme was planned as a PRR type project with pondage dam and a powerhouse located directly downstream of the dam. The dam site was located 5km downstream from the confluence of the Khimte Khola where river width was large and rice land extended on the left bank. The right bank was steep and outcropped. This scheme was later eliminated from the possible development project after the optimum development study on the Sun Kosi River.

2) Tama Kosi No.2 scheme

This scheme was planned as a SRR type project. This type of project mainly consists of intake weir, intake structures, long headrace tunnel, penstock and powerhouse. To fully develop the water resources of the river, this scheme is planned to be combined with the Tama Kosi No.3 scheme, a PRR project planned directly upstream.

Planned location of the intake weir is just downstream of the powerhouse of the Tama Kosi No.3 scheme which is sited 6km downstream of the aforementioned iron bridge on the Tama Kosi River. River width at the dam site is relatively large, widening further downstream. The left bank is outcropped but the right bank is gentle and covered with trees. River deposits appear to be thick.

The headrace tunnel is planned along the left bank. Planned location of the power station is 1km upstream of the confluence with the Khimte Khola, where there is a large flat river terrace area. The slope of left bank at this site is outcropped and appears suitable for penstock layout. The river deposits in this area appear relatively thick.

3) Tama Kosi No.3 scheme

This scheme is planned as a PRR type project with a pondage dam, pressure headrace tunnel, surge tank, penstock and powerhouse. The dam site is located 2km upstream of the iron bridge, described in 2) above and just upstream of the existing gauging station No.647. The site is 10 minutes on foot from a truck road. The powerhouse site is located 5km downstream of the iron bridge where a new road is now under construction on the left bank. The headrace tunnel route is to be situated on the left bank. Topographical and geological conditions at the dam site are as follows:

a) On both banks, outcrops occur and talus deposits appear thin;
b) The right bank is steep, while the left bank is gentle towards the bottom gradually becoming steeper at the upper level; and,
c) Large quantities of round gravels are deposited on the riverbed.

Topographical and geological conditions of the tunnel route and powerhouse site are as follows:

a) The left bank of river course contains hard rocks and steep slopes, while the right bank is gentle and covered with talus deposits; and,

b) High cliffs formed of hard rocks appear at the powerhouse site while at the lower level, some talus deposits are found.

4) Tama Kosi No.4 scheme

This scheme is planned as a PRR type project. All structures are planned in the same way as the Tama Kosi No.3 scheme located downstream.

Topographical and geological conditions at the dam site are as follows:

a) The slope of the left bank is relatively steep and hard rocks occur from the riverbed to the upper level; and,

b) The slope of the right bank is gentle and covered with some talus deposits which are not assumed to be thick.

5) Tama Kosi No.5 and No.6 schemes

These schemes are planned as SRR type projects. A gorge is located upstream of the Tama Kosi No.4 site and both banks of the river at the same are about 60°. Hard outcrops occur continuously along both banks and the river width gradually narrows upstream.

(4) Schemes on the Khimte Khola

The Khimte Khola is a tributary of the Tama Kosi River. This river is not very large; however, the river gradient is very steep resulting in a site with hydropower potential. Two schemes were planned as SRR type projects.

1) Khimte Khola No.1 scheme

Location of the intake weir was selected 11km upstream from the confluence of the Tama Kosi River. The river gradient is extremely steep resulting in heavy, rapid river flow and large stones (over 3m) are deposited in the river.

River width is narrow. The right bank is composed of cliffs while the left bank is relatively gentle and some areas on the top of the bank are cultivated. The powerhouse site was selected by the Tama Kosi River due to shorter length of penstock and a wide area available for powerhouse construction.

2) Khimte Khola No.2 scheme

Location of the intake weir is selected approximately 4km upstream of the Khimte Khola No.1 intake weir. The river course has carved a deep gorge with high cliffs on the right bank and a relatively gentle left bank. The powerhouse site was selected on the right bank directly upstream of the Khimte Khola No.1 intake weir.

(5) Schemes on the Bhote Kosi River

The upstream reaches above the existing Sun Kosi Hydroelectric Power Station is called the Bhote Kosi River. The river gradient is steep and a truck road extends along the river from Kathmandu to Tibet. The area along the river is accordingly well developed. Two SRR type schemes were planned upstream of the existing Sun Kosi Hydroelectric Power Station.

1) Bhote Kosi No.1 scheme

The intake weir site was selected approximately 10km upstream of Bharabise which is the largest village along the river in the area. A large tributary joins the Bhote Kosi River from the right bank at the intake site. Both banks are outcropped and the road runs along the left bank. The headrace tunnel route was topographically selected on the left bank and the powerhouse site is planned on the left bank near Bharabise. At the powerhouse site, a large tributary joins the river from the left bank. The road runs along the left bank from the powerhouse to the intake site and an access tunnel may be easily constructed to shorten the construction period of the long headrace tunnel.

2) Bhote Kosi No.2 scheme

Location of the intake weir was selected approximately 1.5km downstream from the border of Tibet. High cliff outcrops occur continuously on both banks in this area. The headrace tunnel was topographically selected on the left bank while the powerhouse site was selected directly upstream of the Bhote Kosi No.1 intake weir site. Topographical conditions along the river are worse than that of the Bhote Kosi No.1 site and the condition of the existing road is poorer in the upstream area which washed out during the monsoon.

(6) Schemes on the Indrawati River

The Indrawati river is located relatively near to Kathmandu and the Indrawati No.1 site is easily accessible from the same by the existing road. The special characteristic of this river is the large river width in comparison to the size of the river basin. It is assumed that continued heavy sedimentation over a long period of time resulted in deep valley deposits making the river wider.

Three schemes, 1 PRR type and 2 SRR type are planned on the river.

1) Indrawati No.1 scheme

This scheme was planned as a PRR type with pondage dam, pressure headrace tunnel, surge tank, penstock and powerhouse. The dam site was selected approximately 2.5km upstream of the confluence with the Dhanr Khola. The right bank is gentle with numerous villages, while the left bank is steep with sandstone outcrop. River width is as great as 300-400m. The headrace tunnel was selected on the left bank, while the penstock and powerhouse site are planned on the flat area where villages and cultivated land were distributed.

2) Indrawati No.2 scheme

This scheme is planned as a SRR type similar to the Indrawati No.3 scheme. Two intake weirs are planned in order to utilize a large tributary, the Melama River.

One intake weir site on the Indrawati river was selected approximately 7km upstream from the confluence of the two rivers while the intake weir on the Melama River was selected where water level coincides with that of the Indrawati River. The right bank is covered with trees while the left bank is deforested at the dam site. The powerhouse site was selected at the confluence of both rivers, and a village exists at the site.

3) Indrawati No.3 scheme

The intake site was selected 7km upstream of the Indrawati No.2 intake site. River width at this site is relatively narrow; however, river deposits appear extremely thick. The powerhouse site was selected directly upstream of the Indrawati No.2 intake weir.

(7) Scheme on the Balephi Khola

The Balephi Khola is a gentle river, with gentle slopes on both banks on which rice is cultivated, particularily on the right bank. The downstream course is planned to be developed as the intake weir site for the Sun Kosi No.4 scheme. In the upstream, the Balephi Khola scheme is planned as a SRR type.

The intake weir site is planned 12km upstream from the intake weir site for the Sun Kosi No.4 scheme. The river courses are well developed and deforested. Relatively heavy sand deposits are presumed at the dam site. Gentle slope continues to the dam site. Roads are virtually non-existent except for the footpath. The headrace tunnel is planned on the left bank to intake river flow from the large tributary and the powerhouse site is planned directly upstream of the intake weir for the Sun Kosi No.4 scheme, at which a gauging station has been installed.

(8) Schemes on the Rosi Khola

The Rosi Khola originates in the Kathmandu valley. This river is small but the upstream area where the Panauti Hydroelectric Power Station was constructed in 1964 and easily accessible by car from Kathmandu.

Four SRR type schemes are planned in the downstream courses of the the Panauti; namely, the Rosi Khola No.4, 3, 2, 1 (from upstream to downstream).

1) Rosi Khola No.4 scheme

Location of the intake weir is planned directly downstream from Panauti. The headrace tunnel was selected on the right bank. The intake weir site is located at a narrow point on the river where both banks are steep with rock outcrops. Helicopter-borne survey was carried out for the powerhouse site. Both banks are very steep with many valleys joining the Rosi Khola, and the river meanders.

2) Rosi Khola No.3 Scheme

The intake weir site was selected directly downstream of the Rosi Khola No.4 scheme, where landing is difficult. The river is gorge-like with comparatively low vertical cliffs cultivated along the top. The headrace tunnel is planned along the left bank and the powerhouse approximately 11km downstream from the intake site.

3) Rosi Khola No.2 scheme

The intake weir site was selected just downstream of the Rosi Khola No.3 scheme. The river in this area is also gorge-like making landing difficult. The headrace tunnel is planned along the right bank. At the powerhouse site, the slope is gentle with a village and rice fields located on the lower left bank.

4) Rosi Khola No.1 scheme

The intake weir site is planned just downstream of the Rosi Khola No.2 scheme. The right bank at the dam site is high and hard rock outcrops were observed. On the left bank, on the other hand; outcrops are seen only at the riverbed and the bank is covered with thick deposits.

The headrace tunnel route was planned on the left bank while the powerhouse was selected 3km upstream of the confluence with Sun Kosi River. Heavy sand deposits were observed near the confluence.

(9) Schemes on the Likhu Khola

The Likhu Khola is a tributary of the Sun Kosi River, and joins the Sun Kosi River 5km downstream of the Sun Kosi No.2 scheme. Four SRR type schemes are planned on the river.

1) Likhu Khola No.1 scheme

The intake weir site is planned near Sangtar, the largest village in this basin. The headrace tunnel was selected on the right bank to effectively utilize the bend of the river while the powerhouse is planned at the back-water level site of the Sun Kosi No.1 scheme.

At the dam site, the right bank is a relatively thin ridge; the structure of the same consisting of hard rocks. The left bank slope is relatively gentle and thin talus deposits and outcrops are found. This river has abundant fish stock and some traps are installed near the dam site. The powerhouse is planned 2km upstream from the confluence.

2) Likhu Khola No.2 scheme

The intake weir site is planned 8km upstream of the Likhu Khola No.1 scheme, the headrace tunnel was selected along the left bank and the powerhouse was selected just upstream of the Likhu Khola No.1 intake site.

At the dam site, river width is relatively large, ranging from 150-200m. A river terrace extends along the left bank and is used for rice cultivation. The right bank is formed by a ridge of outcropped foundation rocks. The left bank appears to be a cliff. The powerhouse site has a gentle slope with apparently thick river terrace deoposits.

3) Likhu Khola No.3, 4 scheme

The river course in the upstream of the Likhu Khola No.2 scheme, grows steeper and vertical cliffs extend along both banks, which made helicopter landing difficult.

(10) Schemes on the Dudh Kosi River

The Dudh Kosi River is the largest tributary of the Sun Kosi River, joining the same 10km upstream of the planned Sun Kosi No.1 dam site. The downstream reaches have a relatively gentle river slope and the back-water of the Sun Kosi No.1 dam reaches 25km upstream of the Dudh Kosi River. The Dudh Kosi River originates in the Himalayan area and flows directly from north to south resulting in a rapid river gradient in the middle and upper reaches. Ten schemes, including 1 PRR type and 9 SRR types, are planned. In the upper reaches, the river forms a gorge with a narrow river width and high, vertical cliffs on both banks. This made helicopter landing difficult and helicopter-borne survey was carried out by flying slowly over the river course to confirm the topography, and geology at the intake dam and powerhouse sites.

1) Dudh Kosi No.1 scheme

This scheme is planned as a PRR type with a pondage dam, pressure headrace tunnel; penstock and powerhouse. The pondage dam site was selected approximately 3km upstream from the back-water of the Sun Kosi No.1 scheme, at which a large tributary joins the river from the right bank. At the dam site, the right bank is steep and outcropped, but the left bank is relatively gentle and covered with some talus. River width is approximately 80-100m, and round gravels are deposited on the riverbed. Upstream of the dam site, river width is sufficient to create a large pondage. The headrace tunnel and powerhouse area planned on the right bank which is high and outcropped.

2) Dudh Kosi No.2 - 10 schemes

The survey along the river courses was carried out by helicopter. The river course from the No.2 scheme site to the No.5 scheme site is relatively gentle; however, the upper courses have a steep river gradient and narrow river width with high cliffs on both banks. All schemes are planned as SRR types and powerhouse sites will require further study in the next stage.

(11) Schemes on the Arun River

The Arun River has the largest catchment area among the rivers in the Kosi Basin, 85% of which is located in Tibet with only 15% in Nepal. The Arun River, after entering Nepalese territory, flows directly from north to south, joining the Sun Kosi River at Tribeni.

In the downstream area of the Basin, relatively flat banks extend along the left bank and many villages exist. The truck road has been constructed from the East-West Highway in the Terai Area, to Dhankuta and is now planned to be extended to Tumlingtar. In the lower and middle courses, the mountains are almost deforested due to cutting for firewood, etc.

The special characteristics of the Arun River are quite different from other rivers in Nepal in terms of hydrology, and river flow annual fluctuation. The fluctuation of river flow in rainy and dry seasons is extremely small compared to that of other rivers and is presumed the results from the fact that the majority of the river basin is located in Tibed. Precipitiation in Tibet is very small, approximately 1/5 of that of Nepal; however, the large river basin compensates for the same, supplying sufficient and advantageous river water to the Arun River. From this fact it appears that the Arun River has optimum conditions for development of hydropower potential. The six schemes are planned as SRR type based on comparative study for the PRR type.

1) Arun No.1 scheme

The intake weir site is planned 25km upstream from Tumlingtar where there is an airport for small plane, in consideration of the back-water level of the Sapt Kosi High Dam. The headrace tunnel was selected along the left bank due to the curved river course between the intake weir and powerhouse.

The left bank at the dam site consists of a cliff formed of hard rocks, while the right bank has a gentle slope with rice-cultivated river terrace. Large stones over 10m are found in the riverbed and river width is approximately 150m.

2) Arun No.2 scheme

The intake weir is planned aproximately 13km upstream from the Arun No.1 intake weir site. The headrace tunnel route was selected along the left bank and the powerhouse site was selected directly upstream of the Arun No.2 intake weir.

At the dam site, the right bank has a gentle slope and the left bank is relatively steep and covered with trees. In the downstream area, river gradient is so steep that river flow is turbulent and the left bank is lined by continuous cliffs, while on the right bank a river terrace presumed to be 20-30m in thickness is found. River width at the dam site is approximately 100m.

3) Arun No.3 scheme

The intake weir is planned approximately 12km upstream from the Arun No.2 dam site. The river course rapidly changes direction from north-east to north and south, making a loop. The intake weir, headrace tunnel and powerhouse site were located to utilize the excellent natural hydropower development conditions.

Regarding the dam site, two alternatives were considered. On the left bank there is a wide flat area. One alternative is upstream of this open space where steep banks with hard rocks are found on both banks and the river is narrow. In this case, the flat left bank downstream could be used for the silting basin site.

The other alternative is 700m downstream where the left bank is formed by cliffs with hard outcrops and the right bank is relatively gentle covered presumably with thin talus deposits and trees. As it may be difficult to find a suitable site for the silting basin, for this alternative, a PRR type could be considered.

In this Master Plan Study, the SRR type was adopted to utilize the rapid river gradient and abundant, firm river flow. The powerhouse site is planned on the gentle slope of the left bank found between the vertical cliffs in the upstream and downstream areas.

(12) Schemes on the Tamur River

The Tamur River is one of the three largest rivers in the Kosi Basin. It originates in Nepal, near Mt. Kanchenjunga and flows down from north-east to south-west to join the Sapt Kosi River at Tribeni. In the downstream and middle reaches, the river gradient is so gentle that backwater of the Sapt Kosi High dam reaches 30km upstream.

The river course is shorter than that of the Arun River, and river flow in rainy and dry seasons varies greatly. In the downstream courses up to approximatey 45km from Tribeni, the river gradient is gentle and many villages are seen in the area. Further upstream, the river course has a relatively gentle gradient and the river is narrow and both banks are high.

Schemes, consisting of 1 Reservoir type, 1 PRR type, and 4 SRR types are planned on the river.

1) Tamur No.1 scheme

This scheme was planned as a Reservoir type project based on the comparative study of Reservoir and PRR types. The scheme consists of a high dam with a powerhouse located just downstream of the same. The dam site selected is approximately 45km upstream from the confluence with the Sapt Kosi River. A 15km section of the river course with approximately 40m head downstream of dam was left for future development as effective high dam sites could not be found and river gradient is too gentle for economic development at this time.

The river at dam site is relatively narrow and both banks are high. In the downstream area, the river widens.

A footpath runs along the middle of the left bank. Both banks have tree coverage but some outcrops were observed.

2) Tamur No.3 scheme

This scheme is planned as a PRR type with a pondage dam, pressure headrace tunnel, penstock and powerhouse. The dam was selected at the confluence with the tributary, Kabeli Nadi. The headrace, penstock and powerhouse are located on the left bank to utilize river condition and the river loop.

At the upper reaches of the confluence, continuous hard rock cliffs are found on the left bank of the Tamur River and the right bank of the Kabeli Nadi. The right bank of the Tamur River has a gentle slope and is covered with trees; however, rock outcrops were observed. At the lower level, there is a river terrace composed of stone and sand.

Downstream of the confluence, river deposits form a high bank on the left which extends to the upper stream of the Kabeli Nadi. The dam site was selected just downstream of the confluence. Accordingly, it is important to investigate foundation rocks on the left bank.

(13) Schemes on the Sapt Kosi River

The Sapt Kosi River is one of the three largest rivers in Nepal with the Karnali, Gandaki rivers from the west. The Sapt Kosi is formed by the confluence of 3 rivers; namely, the Sun Kosi River which has many tributaries originating in Tibet, the Arun River which also originates in Tibet and the Tamur River. The Sun Kosi and Arun rivers join at Tribeni and are joined by the Tamur River 1km downstream. The Sapt Kosi flows through a gorge for 4km passing Barakshetra. From this point, it travels 5km to Chatra where it flows into the vast Terai Zone. The dam site was selected in the 4km between Barakshetra and the confluence. The river course in this area has steep banks on both banks, particularly on the left bank which forms a vertical cliff, and the river is narrow. A footpath runs along the left bank by excavation of hardrock approximately 50m above river level. The dam site was previously selected through studies and investigations carried out by the Government of India. The dam site was selected approximately 2km upstream of Barakshetra. River width is 150m at the footpath level and foundation rocks are hard sandstone.

The gorge continues downstream to Barakshetra. Downstream from Barakshetra however, heavy landslides were observed which are presumed to be caused by large faults. Many investigations by the Government of India have been carried out at the dam site including 24 test adits on both banks. In particular, a test adit on the left bank at the dam axis is maintained.

### 3.6.4 Hydroelectric Power Potential in the Basin

#### (1) General

The Team has studied and identified hydropower potential in the Basin on the basis of 3.4 Planning Conditions and 3.5 Planning Methodology. As a result, 52 hydropower schemes were indentified on 14 rivers in the Basin.

Total installed capacity and annual generated energy were estimated at 10,909MW and 56,546GWH, respectively, 82% and 78% of which is provided by 4 major rivers, the Sapt Kosi, Sun Kosi, Arun and Tamur.

| | |
|---|---|
| - Sapt Kosi River | 3,489MW, 16,810GWh |
| - Sun Kosi River | 3,029MW, 11,651GWh |
| - Arun River | 1,185MW, 9,644GWh |
| - Tamur River | 1,180MW, 5,647GWh |

In addition to the above, two hydropower schemes with installed capacity of 93MW are planned in the Sun Kosi Multipurpose Scheme.

#### (2) Hydropower Potential of Each River

The hydropower potential of each river was identified and its economic viability analysed. For estimation of construction costs, access roads were counted assuming independent development of each scheme; however, transmission/substation costs were not included.

The identified potential of each river is shown in TABLE 3-6-10 and FIG. 3-6-7.

(3) Hydropower Schemes

Fifty-two hydropower schemes were planned through site selection on maps, site reconnaissance and optimization study. All schemes were evaluated as independent development schemes for determination of priority and high priority schemes. Therefore, access roads were estimated at the minimum length from the existing truck road. The layout of structures, dam, waterway, penstock and powerhouse was confirmed by site reconnaissance study. Some river courses were set aside for future development and some water head loss occured.

Hydropower schemes identified are shown in TABLE 3-6-11 and FIG. 3-6-8 and the features of structures are shown in TABLE 3-6-12.

(4) Study of Layout and Development

The Sun Kosi River has a long gentle course which flows from Tribeni to Dolaghat. This river is planned to be developed as a reservoir type scheme to fully utilize the water resources. Layout and height of the dams proposed for development on the river have been studied to determine the optimum plan. The Tamur River also has a gentle course in the downstream and middlestream area. Accordingly, reservoir type development was studied in comparison with PRR type development approach.

The Arun River has a relatively steep gradient in the downstream section and a steep river gradient in the upstream area. The SRR type development approach was therefore compared to PRR type development in consideration of maximum water use and peak load demand.

1) Sun Kosi River

Three reservoir type schemes and one SRR type scheme have been planned for the Sun Kosi River. The 3 reservoir type schemes are described in section "2. Mulipurpose Dam". As shown in FIG. 2-1-1 and 2-1-2, the following dam sites have been selected:

- Sun Kosi No. 1 Dam Site I & I'
- Sun Kosi No. 2 Dam Site II, III & IV
- Sun Kosi No. 3 Dam Site V, VI, VII & VIII

And many combinations of alternatives for Sun Kosi No.1, 2, 3 were processed and evaluated in terms of Vg/Vc for the preliminary selection of 3 optimum combinations. Here, Vg and Vc represent gross storage volume of reservoir and dam volume, respectively. The features of the alternatives and the values of Vg/Vc for all combinations are shown in TABLE 3-6-13 and 3-6-14. While total values of Vg/Vc are plotted in FIG. 3-6-9, with total dam height. FIG. 3-6-9 shows that increasing the height of the Sun Kosi No.3 dam decreases the effective reservoir capacity.

The top 3 combinations, H, J and E were selected for economic evaluation to decide the final optimum combination. Combination K, which is considered to represent maximum development, was also evaluated. The features of combinations H, J, E and K are shown in TABLE 3-6-15 and economic evaluation in terms of electricity was carried out for the same. The results, as presented in TABLE 3-6-16, show that the optimum combination is H.

Costs of access roads and transmission/substation were excluded in evaluation due to common costs. Economic evaluation of each combination is shown in TABLE 3-6-17. A substantial construction cost and an extentive construction period are required for all three schemes, Sun Kosi No.1, No.2 and No.3. The Sun Kosi No.3 scheme, however, is located at a relatively accessible site and requires less cost in comparison with the other two schemes. Planned installed capacity is also appropriate for future energy supply in Nepal.

Based upon the above, the Sun Kosi No.3 was further studied in combination with the Sun Kosi Multipurpose Scheme. Moreover, as the Sun Kosi No.3 dam will be regulated to supply water downstream during the dry season, an alternative increased dam height was studied and adopted (TABLE 3-6-18).

2) Tamur River

The lower and middle streams of the Tamur River have a relatively gentle river gradient suitable for either reservoir or PRR type development.

At the site, 3km upstream from the village, Lukpa, the river is narrow and both banks are high. Construction of a high dam and large reservoir which would counteract heavy sedimentation, was studied in comparison with PRR type development.

In Reservoir type development of Tamur No.1 scheme, Tamur River schemes No.3, 4, 5, 6, 7 were planned for development in the upstream courses. On the other hand, in the case of PRR type development No.2, 3, 4, 5, 6, 7 were planned for development of the Tamur River.

The comparison was carried out in terms of economic viability, induced benefit from electricity for Tamur No. 1 scheme alternatives and all schemes on the Tamur River.

Comparison of Tamur No. 1 scheme alternatives is shown in TABLE 3-6-19 and the economic evaluations of all schemes are shown in TABLE 3-6-20. The costs of access road and transmission/substation which are common, are excluded in the comparison. The features of all Tamur River schemes are shown in TABLE 3-6-21.

TABLE 3-6-19

COMPARISON OF TAMUR NO. 1 SCHEME ALTERNATIVES

| Case / Item | I Reservoir | II PRR |
|---|---|---|
| Dam Height (m) | 153 | 65 |
| Gross Storage Capacity ($10^6/m^3$) | 1,890 | 160 |
| Available Storage Capacity ($10^6/m^3$) | 760 | 80 |
| High Water Level (m) | 487.6 | 396.2 |
| Low Water Level (m) | 460.0 | 386.2 |
| Maximum Discharge ($m^3/s$) | 650 | 390 |
| Installed Capacity (MW) | 696 | 155 |
| Generated Energy (GWh) | 2,750 | 683 |
| Construction Cost ($10^6$US$) | 838 | 202 |
| Benefit/Cost (B/C) | 1.78 | 1.73 |
| Benefit - Cost ($10^6$US$ : B - C) | 110 | 25 |
| Energy Cost (¢/kWh) | 5.15 | 5.00 |

As shown in the above table, the economic viability in terms of B/C and energy cost of both types, Reservoir and PRR, is almost the same. However, the development scale, installed capacity and generated energy, of the Reservoir type is over 4 times that of the PRR type.

Reservoir type development not only effectively maximizes development of water resources but also enables energy supply during dry season. Furthermore, reservoir type development is advantageous in view of future development of the Tamur River.

3) <u>Arun River</u>

The Arun River has special characteristics which differ from those of other rivers in Nepal. Variation of river flow in dry season and rainy season is extremely small and river gradient is as steep as 1/30 - 1/50 in the upstream area. These conditions are very effective for utilizition of water resources for hydropower.

SRR type development in the rapid river courses is considered reasonable for abundant and economical energy supply, on the basis of planning conditions and criteria. However, PRR type development was also studied in comparison with the SRR type for the Arun No. 1 scheme which is located in the upmost downstream. And the comparison of both types is tabulated below, excluding costs of road and transmission/substation.

TABLE 3-6-22

**COMPARISON OF SRR AND PRR TYPES FOR ARUN NO.1**

| Case | I | II |
|---|---|---|
| Item | SRR | PRR |
| Dam Height (m) | 20 | 68 |
| Gross Storage Capacity ($10^6/m^3$) | - | 52 |
| Available Storage Capacity ($10^6/m^3$) | - | 16 |
| Maximum Discharge ($m^3/s$) | 180 | 180 |
| Installed Capacity (MW) | 146 | 127 |
| Generated Energy (GWh) | 1,166 | 1,009 |
| Construction Cost ($10^6$US$) | 254 | 331 |
| Benefit/Cost (B/C) | 1.82 | 1.21 |
| Benefit - Cost ($10^6$US$ : B - C) | 35 | 12 |
| Energy Cost (¢/kWh) | 3.68 | 5.54 |

As shown in the above table, the SRR type scheme is advantageous in terms of B/C, B-C and energy cost. Regarding schemes in the upper stream, the river gradient becomes more rapid and decrease in river water is minimal. Upstream schemes were accordingly planned as SRR types. The feature of all Arun River schemes are shown in TABLE 3-6-23.

4) Sapt Kosi River

The development of the Sapt Kosi River has been planned and investigated by the Government of India and the "Feasibility Study Report on the Kosi High Dam" was submitted in 1981. The project envisions construction of a large dam at the gorge 2km upstream from Barakshetra aiming at power generation, flood mitigation, irrigation and protection of sand and soil downstream.

The Team collected previously investigated data; however, except for the aforementioned report, monthly hydrological data are not available. Data regarding geotechnical conditions of dam site and the large benefit area in India is particularly lacking. The study was therefore carried out on the basis of site reconnaissance and with the same methods as other schemes.

Regarding dam height selected hydropower generation benefit confirmed that irrigation projects in Nepal planned downstream would not be affected. Three cases of dam height were studied as shown in TABLE 3-6-24 and the features of each case are shown in TABLE 3-6-25. Optimum dam height was 239m; however, this comparison took into account the benefit from power generation alone, without considering benefit to India. Therefore, further studies must be carefully carried out before final selection of dam height.

(5) Optimization Study

The optimization study was carried out on the basis of 3.4 Planning Conditions and 3.5 Planning Methodology. At least 3 cases of varying maximum discharge and installed capacity were compared to obtain the optimum capacity for each scheme.

For the SRR type, data for neighbouring schemes on the same river were used to determine the maximum discharge by applying the Catchment Area Conversion Factor. In the case of PRR types, the relation between schemes in the upstream and downstream reaches were considered for future development. To optimize each scheme, the common costs of access road and transmission/substation were excluded. Generated energy was estimated by simulation study of natural daily river flow for the SRR and PRR types and daily river flow calculated by the Mass Curve Analysis Method for the Reservoir type. However, monthly river flow was used in calculations for the Sapt Kosi High Dam. The results are shown in TABLE 3-6-26 and FIG. 3-6-10.

1) Schemes on the Sun Kosi River

The optimization study of the Sun Kosi No.1, No.2, No.3 schemes was carried out to obtain optimum combinations for H, J, E, and K which were previously selected through study of layout and development type.

Preliminary optimization study was carried out for Sun Kosi No.4 scheme on the basis that the H.W.L of the Sun Kosi No.3 scheme was 670.5. Economic evaluation of Sun Kosi No.4 was subsequently re-studied for a Sun Kosi No.3 H.W.L of 700.00.

2) Schemes on the Dudh Kosi River

Dudh Kosi No.1 and No.2 schemes were studied and the results of No.2 were applied to Dudh Kosi No.3 -No.10 schemes by the Catchment Area Conversion Method as all are SRR types. Economic evaluation of the Dudh Kosi No.1 scheme was reviewed using newly prepared 1/10,000 scale maps.

3) Schemes on the Likhu Khola

Optimization study was conducted for Likhu Khola No.1 scheme and the Catchment Area Conversion Method was applied to Likhu Khola No.2 to No.4 schemes.

4) Scheme on the Maulung Khola

The results of Likhu Khola No.1 were applied to the Maulung Khola scheme.

5) Schemes on the Tama Kosi River

Tama Kosi No.3, No.4, and No.5 schemes were studied. Tama Kosi No.2 scheme was planned in combination with Tama Kosi No.3 and the same maximum discharge was used. The results of Tama Kosi No.5 scheme were applied to Tama Kosi No.6 using the Catchment Area Conversion Method.

6) Schemes on the Khimte Khola

Optimization study was conducted for Khimte Khola No.1 scheme and results were applied to Khimte Khola No.2 scheme by the above method.

7) Schemes on the Bhote Kosi River

Optimization study was conducted for Bhote Kosi No.1 scheme and results were applied to Bhote Kosi No.2 scheme as above.

8) Scheme on the Balephi Khola

The results of the Bhote Kosi No.1 scheme were applied to Balephi Khola scheme as above.

9) Schemes on the Rosi Khola

Optimization study was carried out for Rosi Khola No.1 scheme and the economic evaluation was reviewed due to a change in layout and H.W.L of the Sun Kosi No.2 scheme. The result was applied to the Sun Kosi schemes No.2 through No.4.

10) Schemes on the Indrawati River

Indrawati No.1 and No.2 schemes were optimized and results of the Indrawati No.2 scheme were applied to the Indrawati No.3 and No.4 schemes. The economic evaluation of Indrawati No.1 was reviewed due to a layout change.

11) Schemes on the Tamur River

Tamur No.1 scheme was optimized for both reservoir and PRR types. Tamur No.2 and No.3 schemes were optimized in case II and the result was applied to Tamur No.3 scheme of case I. Tamur No.4 scheme was optimized and results of the same applied to Tamur schemes No.5, No.6 and No.7 by the above mentioned method.

12) Schemes on the Kabeli Nadi

The results of Tamur No.4 scheme optimization study were applied to Kabeli Nadi schemes Nos.1, 2 and 3 as above.

13) Schemes on the Arun River

Optimization study was conducted for Arun No.1 scheme for both SRR and PRR types. Results of the same were applied to Arun schemes No.2 through No.6.

14) Schemes on the Sapt Kosi River

Optimization study was carried out for dam heights 239m, 269m, and 299m with varying maximum discharges.

(6) Economic Evaluation

Economic evaluation for the hydropower schemes has been carried out subsequent to the optimization study, including access road construction cost, but excluding transmission/substation facilities cost.

The access road cost has been estimated for each scheme assuming independent development. The access roads have been planned to lead to each site from the nearest existing truck road. Therefore, economic evaluation of each river includes the development of the longest road concerned. Road planning is discussed below. The results of the economic evaluation are presented in TABLE 3-6-27.

(7) Road Planning

Access roads were planned at minimal distance from existing truck roads on the basis of 1/50,000 scale maps, and cost was estimated for each scheme. A unit cost of 310US$/m was applied for road length in cost estimation except for those schemes on the Arun River in which the top priority scheme was selected. Arun River schemes were further studied, taking into account the cost of bridges. Access roads for each river and scheme were planned as described below and presented in TABLE 3.6.28.

1) Schemes on the Sun Kosi River

An access road is planned along the Sun Kosi River from Dolaghat except for SU-1, the upstream confluence point of the Indrawati and Sun Kosi rivers. Dologhat is easily accessible from Kathmandu by truck road. An access road for SU-1 is planned from Sindhuri through the Mahabharat mountiains.

2) Schemes on the Dudh Kosi River

The Sun Kosi River access road above is also planned as an access road to the Dudh Kosi River and a road was planned from the confluence of the Sun Kosi and Dudh Kosi rivers to each site along the latter.

3) Schemes on the Likhu Khola

As above, the Sun Kosi River access road will be used for access to the confluence with the Likhu Khola, and roads are planned from this point to each site in the upstream area along the Likha Khola.

4) Scheme on the Maulung Khola

The Sun Kosi access road will again be utilized and roads to each site are planned along the Maulung Khola.

5) Schemes on the Tama Kosi River

The Jiri road, which connects Kathmandu and Jiri through Charikot, provides access to the Tama Kosi River. From this point, access roads area planned to downstream areas for the Tama Kosi No. 2 scheme, the powerhouse of the Tama Kosi No. 3 scheme to the upstream area for the Tama Kosi No. 4, No. 5 and No. 6 schemes.

6) Schemes on the Khimte Khola

The access road for the Tama Kosi No. 2 scheme provides access to the powerhouse site of the Khimte Khola No. 1 scheme while an access road to the intake site of the Khimte Khola No. 1 scheme and Khimte Khola No. 2 scheme is planned along the Khimte Khola.

7) Schemes on the Bhote Kosi River

As an existing road which connects Kathmandu to Tibet through Kodari runs along the Bhote Kosi River, construction of an access road is needed.

8) Schemes on the Balephi Khola

The existing road described above for the Bhote Kosi River, also provides access to the confluence of the Sun Kosi and Balephi Khola rivers. An access road is therefore planned from the confluence point to sites along the Balephi Khola.

9) Schemes on the Rosi Khola

A truck road runs from Kathmandu to the existing Panauti Hydroelectric Power Station located upstream. Access roads to each site were planned from upstream.

10) Schemes on the Indrawati River

The existing road described for the Bhote Kosi River also extends to Dologhat, the confluence point of the Sun Kosi and Indrawati rivers. The road is now under construction from the confluence to the nearer Indrawati No. 1 scheme site. Access roads to each site were planned along the Indrawati River.

11) Schemes on the Tamur River

The east-west highway and the existing truck road to Dhankuta through Dharan can be used. Access roads are planned from the bridge site an the Tamur River on the way to Dhankuta to each site along the Tamur River.

12) Schemes on the Kabeli Nadi

The access road for the Tamur River will provide access to the confluence of the Tamur River and Kabeli Nadi. Further access roads are planned from the confluence to each site along the Kabeli Nadi.

13) Schemes on the Arun River

The existing road described for the Tamur River provides access to Dhankuta. Access roads are planned from Dhankuta to each site through Khandbari. The road from Dhankuta and Khandbari was previously planned by HMG.

14) Schemes on the Sapt Kosi River

An existing truck road extends from the east-west highway to Chatra and the road to Barakshetra must be rehabilitated, including some relocations, due to damage caused by landslides, etc.

(8) Mass Curve Analysis

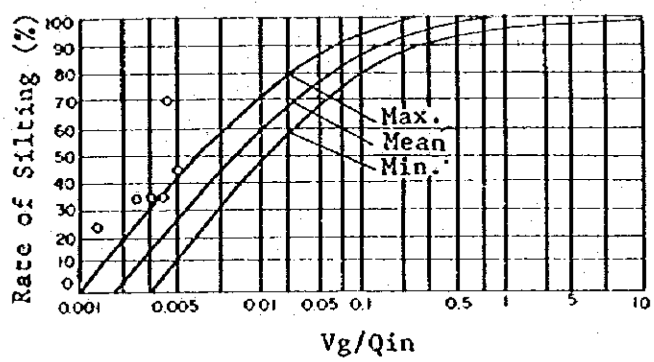
Mass curve analysis was carried out to calculate the river flows in daily discharge for power generation after creation of a large reservoir in the case of Reservoir type schemes. On the Sun Kosi River, stage development is planned for Sun Kosi No. 1, No. 2 and No. 3 schemes and accordingly the same period of measurement was adopted. (8 years from 1968-1975).

For the Sapt Kosi High Dam, the monthly discharge data were analysed for 1947-1978 while for the Tamur No. 1 scheme the daily discharge from 1970-1978 was analysed. The results are shown in FIG. 3.6.11.

(9) Storage Capacity Curve

Storage capacity curves for reservoir and PRR types schemes were prepared from maps with a scale of 1/20,000 for the Sun Kosi No. 1, No. 2 and No. 3 schemes and from maps with a scale of 1/50,000 for the Tamur No. 1, Dudh Kosi No. 1, Tama Kosi No. 3, No. 4, Indrawati No. 1 and Tamur No. 2, No. 3 schemes. The storage capacity curve for the Sapt Kosi High Dam scheme was derived from the "Feasibility Report and the Kosi High Dam" prepared and submitted in 1981 by the Government of India. All curves are shown in FIG. 3.6.12.

To estimate the available storage capacity of reservoir type schemes, the specific sediment loads of $2,800m^3/km^3$/year and $5,000m^3/km^2$/year were applied on the Sun Kosi and Tamur rivers, respectively. The total amount of sedimentation for Sun Kosi No. 1, No. 2 and No. 3 and Tamur No. 1 was calculated by estimation of trap efficiencies according to "Brune's Method" assuming a life of 50 years. Sedimentation for the Sapt Kosi High Dam scheme was derived from the aforementioned report.




Vg = Reservoir Capacity (m³)

Qin = Discharge Inflow (m³)

FIG. 3.6.15 BRUNE'S CURVE

### 3.6.5 Previous Studies

#### (1) General

In the Study area, the following studies for water resources development have been carried out.

- Feasibility Study of Irrigation Development Project in Terai Plain by UNIDO, 1972
- Feasibility Study of Sapt Kosi High Dam Project by the Government of India, 1981.
- National Hydroelectric Project Reconnaissance Profiles by the Water and Energy Commission of HMG, 1981.
- Feasibility Study of Mulghat Hydropower Project by ADB, 1982.

In the above studies, the following plan and schemes were identified and studied.

- Sun Kosi Diversion Plan
- Sapt Kosi High Dam Scheme
- Mulghat Hydroelectric Power Schemes
- 13 Hydroelectric Power Schemes in the Kosi Basin

Under the Master Plan Study, the Team reviewed the above schemes as described below.

#### (2) Sun Kosi Diversion Plan

This scheme was re-studied on the basis of newly collected data and in combination with the hydroelectric power schemes in the upper and lower courses of the Sun Kosi River as described in APPENDIX V.

(3) Sapt Kosi High Dam Scheme

The Team re-studied the scheme by collecting topographical, geological, and hydrological data, as well as data on land use at the dam site and in the downstream courses and site reconnaissance survey in the gorge.

Except for topographical and hydrological data, data were unavailable, particularly data from India. Therefore, review study was carried out by the same method as that used for other schemes and described in 3.6.4 4) Sapt Kosi River.

(4) Mulghat Hydroelectric Power Scheme

Reconnaissance survey was carried out for the dam site, confirming a high bank with hard outcrops on the right bank and thick talus deposits on the left bank. This scheme was identified as one which would be submerged by the Sapt Kosi High Dam. Therefore, this scheme was disregarded in the Master Plan Study.

(5) 13 Hydroelectric Power Schemes

Thirteen hydroelectric power schemes were identified by HMG in the Kosi Basin. The Team re-studied and identified the schemes in the view of total development of water resources in the entire area. The relationships between the 13 schemes and the schemes identified through the Master Plan Study are presented below.

Arun River

- Tumlingtar Micro Project
  This project is planned as a micro hydropower project with an installed capacity of 2MW and is thereby disregarded in the Master Plan Study.
- Upper Arun Diversion Project
  This corresponds to the Arun No. 3 project in this Master Plan Study.

Tamur River

- Pithun Project
  This corresponds to the Tamur No. 7 project.
- Taplejung Project (Alternative B)
  This corresponds to the Tamur No. 4 project.
- Bhaniyang Project
  This corresponds to the Tamur No. 3 project.