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 Middle & Far Western Regions (3.7%). 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.

5.4.2 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, which is 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 on power consumption customer categories and economic performance. The latest Disaggregate Forecast by ED is considered to be the most reliable disaggregate forecast 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 which assumes that limitation on implementing transmission lines and distribution lines would continue to suppress demand growth.

(1) 1983 Trend Forecast

The methods and assumptions used in ED's 1983 Trend Forecast and results of the same are described below.

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 times.

The mathematical equation of Scheer Model for average annual load growth is

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

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

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

The forecasted annual growth rates for the various regions with this model are prepared because the historical growth rates for each region differ greatly. The forecasted annual growth rates with this model and regional information are summarized in TABLE 5-7.

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 5-8 and 5-9.

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 5-10.

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 5-11.

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 2001/02. The total required power supply and peak load with potential export of 1991/92 and 2001/02 will be 1,167.8GWh and 264.5MW and 3,345.5GWh and 723.3MW, respectively.

The results of trend forecast are summarized in TABLE 5-12.

(2) 1983 Disaggregate Forecast

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

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 5-13 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. Unspecified annual growth rate of industrial loads is estimated to be 5% annually in the Central Region, and 10% annually in the other regions.

2) Domestic Load

The electrification project and distribution system reinforcement is already being carried out in the Central Region and Eastern Region. 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) Irrigation and Water Supply Load

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 ground water 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 5-14.

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

5) Transport Load

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) Street Lighting and Other Loads

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

7) Power Export

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) Losses

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 for 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 5-15 while comparison of the 1983 Trend Forecasts to the 1983 Disaggregate Forecast and previous forecasts are shown in FIG. 5-4 and 5-5.

(3) Long-Term Demand Forecast

In addition to the above 1983 ED power demand forecasts, a long-term power demand forecast beyond 2000/02 was undertaken in this Master Plan Study based on the 1983 Trend Forecast (Basic Forecast). The assumptions used in this long-term forecast and results are given 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

Potential export was considered in this load forecast as shown in TABLE 5-16 and is 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 5-16, while the long-term generation expansion program up to 2030/31 is shown in FIG. 5-6.

5.4.3 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. The 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 (Nepalgunj, 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 (1st.) unit (75MW) of Sapt Gandaki Project in July 1990.

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

1) Devighat project

Installed capacity is 14.1MW (3 x 4.7MW), design discharge is $45.3m^3$/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 Cooperation Program of the Government of India.

2) Kulekhani No.2 project

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. 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

Installed capacity is 66MW (22MW x 3), while average annual generation is estimated to be 450GWh. The project will be SRR type with daily peak capacity during dry season. Total cost of the project is about $327.4 10^6$US$ (Foreign currency = $246.5 10^6$US$ and local currency = $80.9 10^6$US$) including price escalation during the construction period.

Project completion is envisioned by July 1988.

1/ Source: ED, Hydropower Development in Nepal, May 1983

4) Sapt Gandaki Project

This is an SRR 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.

5.4.4 Planning Conditions

(1) Topography

1) General

Nepal embraces a unique variety of geographical features ranging from the southern lowlands to the high mountains. Between these marginal regions, there are three zones, 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.

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 rivers, and 27,500km^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.

(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 Cnetral Trust
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 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 season resulting in sediment runoff; 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 increase 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, 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) Discharge Data

There are 14 gauging stations on the rivers in the Kosi Basin. All recorded data until 1978 were processed. 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.

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.

(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, these 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 the following Table.

FLOOD RECORD

Gauging Station			Available Recorded Period
Code No.	Name	River	
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	1949 - 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, respectively in the rainy season of 1984.

(5) Sedimentation Load

1) General

Landslides and heavy sediment runoff occur frequently in the mountainous area primarily due to severe natural conditions and environmental degradation. Erosion occurs mainly during the rainy season and soil, sand and debris are swept downstream in the rivers. Suspended sediment, 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.

SEDIMENT LOAD OF EACH RIVER

River	Catchment Area at Tribeni (km^2)	Total Annual Sediment Load (Mill. 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.

(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 including gate, screen, penstock, mechanical equipment and electrical equipment were based on the international 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.

In addition to the contingency for each work described above, 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 13 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 without preparation of 1:1,000 scale maps.

Cost estimate for 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, and is for the base capital cost of the project. This does not include any costs for escalation beyond 1983 or 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.

Description of contingency

The unit price of each work and cost estimation method are shown in TABLE 5-17.

3) Annual Cost

The annual costs of the selected schemes were calculated for the optimization study to decide 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% per annum.

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, from the 1st -5th year, as follows:

$$C_1 = 0.120417 \times (0.1x1.573519 + 0.2x1.404928 + 0.3x1.254400 + 0.3x1.120000 + 0.1x1.0) = 0.150600$$

Operation and maintenance cost (O&M Cost)

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

$$C_2 = 0.015$$

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 the discount factor of 0.052521, becomes,

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

Annual cost

The annual cost factor (C) becomes,

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

(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 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 are derived based on 1) the international coal price of US$63/t; and, 2) a service life of 25 years.

<u>kW-Value</u>

- 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

<u>kWH-Value</u>

- 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

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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

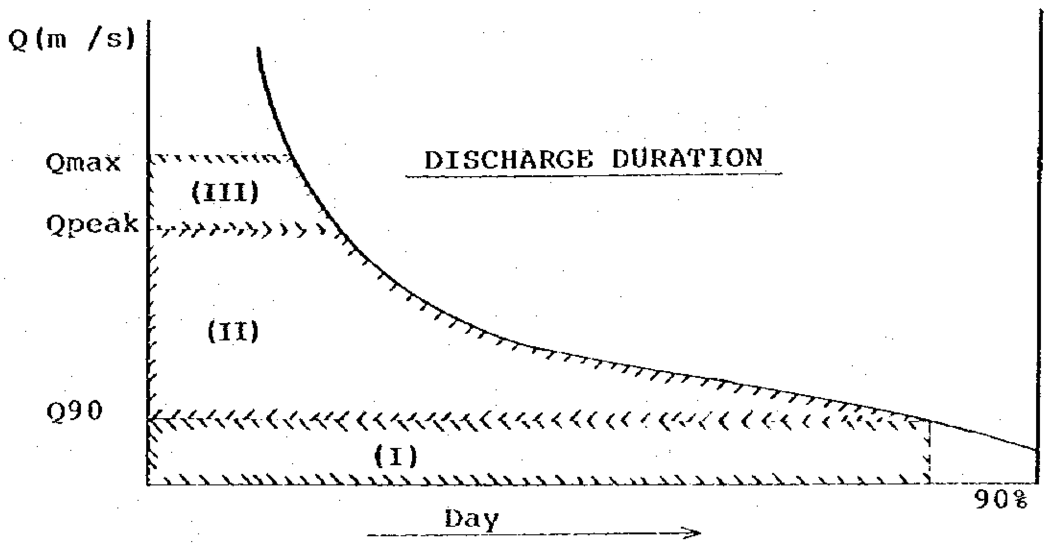
2) Annual Power Benefit

The annual power benefit was calculated multiplying the unit kW-Value, 191.8US$/kW, by the stalled capacity and unit kWH-Value, 0.043US$/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 exported and the value of energy will therefore primarily be 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



i) In the case of the SRR type,

- Firm capacity (Pf): Capacity by the discharge corresponding to 90% dependable

  $Pf = F_1\ (Q90)$

- 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)

ii) In the case of the PRR and Reservoir types,

- Firm capacity (Pf): Assuming a peak of 6 hours,

  $Pf = F_1(Q_{90} \times \frac{24}{6})$

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

  $Eseason = F_2$ (Area II)

  $Esecond = F_2$ (Area III)

(8) Environmental Considerations

1) General

Dam construction will result in river water storage which is closely related to the livelihood of residents in the vicinity, and the transformation of natural rivers into artificial lakes greatly influencing the natural environment and ecosystem. 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 degradation, eutrophication and fishery losses, are a few of these effects.

On the other hand, positve effects may also be expected as project development functions "to give water environment and the improvement of infrastructures to people". Project development facilitates regional development by increasing accessibility and creates enjoyable landscape by the combination of dam structures, new lakes and nearby natural surroundings. In addition, 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.

5.4.5 Planning Methodology

(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. Planning criteria and results were confirmed at the meeting held between the Study Team and the HMG personnel concerned.

(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 schemes sites with installed capacity of over 10MW, envisaged for development in the future, were selected in the Nepalese portion of the Kosi Basin.

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

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 of 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 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.

- Sedimentation load

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

Site Selection

In site selection, Reservoir type schemes were studied first based on the longitudinal profile of all rivers, and in consideration of the existing Sapt Kosi High Dam Scheme on the Sapt Kosi River and the Sun Kosi High Dam Scheme at Kurule on the Sun Kosi River. Topographical conditions at the 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 with headrace tunnel and surge tank.

In the upper courses, the 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 or weir sites was estimated for project identification.

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 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 effective storage capacities.

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

(3) Field Reconnaissance

The dam sites were selected based on 1/50,000 scale topographical maps except for the previously planned Sapt Kosi High Dam and Sun Kosi High Dam (Sun Kosi No.1 site) scheme. The field survey was undertaken to confirm the topographical and geological conditions of the dam and penstock - powerhouse sites and accessibility for construction works. Almost all sites are scattered in the vast Kosi Basin, and therefore, helicopters were used for survey. 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 given below.

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, such as slope, outcrops and talus deposits, 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.

PRR type

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

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 dams in terms of flood diversion works and materials such 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.

(4) Project Optimization

Project optimization was studied for selected and identified schemes, according to the results of field investigations. This study was based on the 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

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 was planned and investigated until 1947. The Team collected previously investigated data and carried out site reconnaissance to confirm a site suitable for a high concrete gravity dam.

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 fault and landslides on banks and river deposits.

The layout of structures, dam, headrace tunnel and penstock - powerhouse were reviewed.

2) Criteria Formulation

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

SRR type

The dam was planned as an intake weir with a height of approximately 20m and waterway was located taking into consideration the river loop and suitable powerhouse location.

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.

PRR type

Dam location and height were decided first on the basis of site reconnaissance 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.

Reservoir type

First, dam height was studied to obtain the total maximum effective 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.

(5) Selection of Priority Schemes

1) General

The Team has selected and identified 52 hydropower project schemes, through site selection on maps, site reconnaissance and optimization study. These 52 schemes were undertaken 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 not only on power benefit but also on social impacts on the point Evaluation System.

In the said Evaluation System, the following items were evaluated quantitatively.

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

The Project evaluation system is shown in TABLE 5-18.

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.

Among priority schemes 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 abundant and economical power generation potential. Although long access roads are required for development of hydropower stations, development of the same will be a major stimulus for regional development. With completion of the first stage development on the Arun River in the form of the Arun No. 3 scheme, subsequent potential will be facilitated by the improved transportation facilities.

The Sapt Kosi High Dam also has abundant and economic power generation potential as well as navigation and irrigation potentials downstream in Nepal and India.

5.4.6 Hydropower Potential in the Basin

(1) General

The Team has studied and identified hydropower potential in the Basin on the basis of 5.4.4 Planning Conditions and 5.4.5 Planning Methodology. As a result, 52 hydropower schemes were identified 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. Hydropower schemes identified are shown in TABLE 5-19.

(3) Study of layout and development

The Sun Kosi River has a long gentle course which flows from Tribeni to Dolaghat. This river is planned for reservoir type development so as 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 middle stream 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 in the lower and middle reaches and one SRR type directly downstream from the existing Sun Kosi power station scheme have been planned for the Sun Kosi River. The 3 reservoir type schemes are described in section 5.3 Multipurpose Dam.

Many combinations of alternatives for Sun Kosi No.1, 2 and 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 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 (APPENDIX IV). The combinations and the results, are presented in TABLE 5-18, and show that the optimum combination is H.

Costs of access roads and transmission/substation were excluded in evaluation due to common costs. A substantial construction cost and an extensive 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 as shown in TABLE 5-21.

2) Tamur River

The lower and middle reaches 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, schemes 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, and 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 the following table. The costs of access road and transmission/substation which are common, are excluded in the comparison.

COMPARISON OF TAMUR NO. 1 SCHEME ALTERNATIVES

Case	I	II
Item	Reservoir	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 (10^6US$)	838	202
Benefit/Cost (B/C)	1.78	1.73
Benefit - Cost (10^6US$: 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 (APPENDIX IV).

3) Arun River

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 lowest reaches. The comparison of both types is presented in the following table but excludes costs of road and transmission/substation.

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 (10^6US$)	254	331
Benefit/Cost (B/C)	1.82	1.21
Benefit - Cost (10^6US$: 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.

4) <u>Sapt Kosi River</u>

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, 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 5-22. 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.

(4) 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. However, monthly river flow was used in calculations for the Sapt Kosi High Dam.

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 schemes No.3 -No.10 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) Schemes 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 schemes No.3, No.4 and No.5 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) Schemes on the Balephi Khola

The results of the Bhote Kosi No.1 scheme were applied to the 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 by site reconnaissance.

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 (Tamur No. 1 scheme; PRR type) and the result was applied to Tamur No.3 scheme of case I (Tamur No. 1 scheme; Reservoir type). 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.

(5) Economic Evaluation

Economic evaluation for all 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.

(6) 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$/m was applied for road length in cost estimation except for those schemes on the Arun River in which the top priority scheme was selected. Arun River schemes were further studied, taking into account the cost of bridges. Access roads for Sun Kosi Diversion project were estimated with detailed routes on the 1:50,000 map and a unit cost of 400US$/m in the mountain cross section and 310US$/m in other sections. Access roads for each river and scheme were planned as described below.

1) Schemes on the Sun Kosi River

An access road is planned along the Sun Kosi River from Dolalgat, the upstream confluence point of the Indrawati and Sun Kosi rivers except Sun Kosi No. 1 scheme for the Sun Kosi Diversion project. Dolalghat, is easily accessible from Kathmandu by truck road.

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) Schemes on the Maulung Khola

The Sun Kosi access road will again be utilized and roads to the 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 are planned to downstream areas for the Tama Kosi No. 2 scheme, the powerhouse of the Tama Kosi No. 3 scheme and 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 unnecessary.

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 in the upper stream of the river. 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 on 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.

EVALUATION OF HYDROPOWER SCHEMES

No.	Schemes	Evaluated Points	Installed Capacity (MW)	Construction Cost. including access road (10^6US$)	Remarks
1	Sapt Kosi	371	3,489	2,721	For Export
2	Arun No.3	336	240	268	
3	Arun No.2	331	239	292	
4	Sun Kosi No.1	315	1,357	1,051	For Export
5	Sun Kosi No.3	313	536	582	
6	Sun Kosi No.2	312	1,110	1,027	For Export
7	Arun No.1	307	146	277	
8	Bhote No.1	307	64	89	
9	Tama Kosi No.3	301	123	206	
10	Tamur No.1	301	696	846	
11	Tama Kosi No.2	299	196	245	
12	Khimte No.1	299	49	66	
13	Dudh Kosi No.1	295	228	449	

Among the top 13 schemes, the Team selected 3 export and 10 domestic priority schemes. However, other schemes should be given due attention for further study and implementation. Total capacities of priority schemes are 5,956MW for export, 2,517MW for domestic use and 8,473MW in total. These occupy 25% and 78% of the whole respectively in terms of number of schemes and capacity.

Economic evaluation was conducted for the 13 selected priority schemes taking into account term capacity, primary energy and secondary energy. The results are shown in TABLE 5-21.

5.4.7 Priority Schemes

(1) General

The project evaluation system was applied for all 52 hydropower schemes to select the 13 priority schemes which would be developed in future. The top 13 priority schemes are ranked as shown in the table on the following page.

TABLE 3-6-30 TOP 13 HYDROPOWER SCHEMES

No.	Schemes	Evaluated Points	Installed Capacity (MW)	Construction Cost including Access Road and Transmission/ Substation (10^6US$)	Remarks
1	Sapt Kosi	371	3,489		For Export
2	Arun No.3	336	240		
3	Arun No.2	331	239		
4	Sun Kosi No.1	315	1,357		For Export
5	Sun Kosi No.3	313	536		
6	Sun Kosi No.2	312	1,110		For Export
7	Arun No.1	307	146		
8	Bhote No.1	307	64		
9	Tama Kosi No.3	301	123		
10	Tamur No.1	301	696		
11	Tama Kosi No.2	299	196		
12	Khimte No.1	299	49		
13	Dudh Kosi No.1	295	228		

Among the top 13 schemes, the Team identified 3 other export and 10 domestic priority schemes. However, other schemes deserve due attention for future study and implementation. Total capacities of priority schemes are 5,956MW for export, 2,517MW for domestic use and 8,473MW in total. These occupy 25% of the whole respectively in terms of number of schemes and capacity.

Economic evaluation was conducted for the 13 selected priority schemes based on the capital cost including the costs of hydropower station, transmission/substation and access roads, taking into account 1) Potential Capacity and Energy and 2) Firm Capacity, Energy and Secondary Energy. The costs of structures of each scheme are shown in TABLE 5-24. While the discharge data at each dam site of the 13 priority schemes are shown in TABLE 5-25.

(2) Priority Scheme Descriptions

1) Sapt Kosi High Dam

This scheme is planned as a Reservoir type hydropower station with a 239m high dam and hydropower station located immediately downstream of the dam. The installed capacity is

3,489MW with a maximum discharge of 2,500m^3/s, and a firm capacity of 3,489MW. Annual generated energy is estimated to be 16,810GWh which will be exported to India. This scheme was identified in 1946 by the Government of India, and a "Feasibility Report On Kosi High Dam Project" was prepared and submitted to HMW in 1981.

The project prepared by India consists of construction of a 269m high and 710.5m wide concrete gravity dam about 2km upstream of the sacred temple of Barakshetra. Installed capacity would be 3,000MW. The project also includes construction of a barrage 969.9m long near Chatra, 8km downstream of the dam and canal system with three powerhouses of 300MW capacity along the irrigation canal as well as watershed management for the Basin.

In the Master Plan Study, the optimization study to determine dam height and installed capacity was carried out by the same method and with the same accuracy as the other schemes due to unavailability of data for the downstream area, particulary in the Indian region. The optimization study reveals that a maximum discharge of 2,500m^3/s is optimum.

Incremental benefit cost analysis was undertaken for varying dam heights ranging from 23.9m to 299m. Results show that a larger dam height decreases the economic viability in terms of incremental benefit/cost ratio and energy cost. It should be noted that the optimization study in the Master Plan Study was carried out in consideration of hydropower planning only. Consequently, it should be reviewed in consideration of flood control and irrigation benefit anticipated in the Indian territory for the future implementation stage.

2) Arun No.3 Scheme

This scheme is planned as an SRR type hydropower station with an intake weir, a 7.1km long headrace tunnel and a powerhouse directly upstream of the intake weir for the

Arun No.2 scheme. The installed capacity is 240MW by the maximum discharge of $156m^3/s$, with a firm capacity of 176MW. Annual generated energy is estimated at 1,965GWh which is planned for domestic consumption.

The site for the intake weir with silting basin was selected directly upstream of Khokda Khola, a tributary joining from the left and the headrace tunnel is planned along the left bank to effectively utilize the river loop and easier access from Dhankuta. The powerhouse is planned directly upstream of the intake weir for the Arun No.2 scheme.

Both banks of the dam site consist of cliffs with hard rock outcrops. River width is about 70m at the riverbed. For the silting basin, there is sufficient area on the left bank directly downstream of the intake weir. Planned intake weir height is 23m and the headrace tunnel is planned as a non-pressure type. The powerhouse site, located immediately upstream of the Menkhuwa khola is the best site in this area in which vertical cliffs extend both upstream and downstream.

However, a PRR type hydropower station should be studied in the next stage of investigation as the power station has a planned plant factor of 93% which would generate very inexpensive energy. In the case of PRR type development, energy cost increases but loss of water resources decreases. Such a study must be carefully executed taking into consideration future demand, daily peak, annual peak, the electricity network in Nepal and the possibility of exporting surplus energy to India, etc.

The main difficulty envisioned is the need for a long access road (99km) from Dhankuta. Access road construction should therefore proceed prior to the construction work for the intake weir, headrace tunnel, powerhouse, etc. Headrace tunnel works must be completed as soon as possible due to the critical path of the project.

3) Arun No.2 Scheme

This scheme is planned as an SRR type hydropower station with an intake weir and 10.4km long headrace tunnel and powerhouse directly upstream of the intake weir for the Arun No.1 scheme. The installed capacity is 239MW with a maximum discharge of 160mx3/s, and a firm capacity of 185MW. Annual generated energy is estimated at 1,967GWh which is planned for Nepalese consumption.

The site for the intake weir with silting basin was selected directly downstream of the confluence of the Suki Khola which joins from the left and the headrace tunnel is planned along the left bank to effectively utilize the river loop and easier access from Dhankuta. The powerhouse is planned near Cauribate Village, directly upstream of the intake weir for the Arun No.1 scheme. Planned height of the intake weir is 18m and the headrace is non-pressure type.

The main difficulty envisioned with this site is the need for a long access road (85km) from Dhankuta. Development of this scheme is therefore planned after completion of the most economical scheme on the Arun River, ie. the Arun No.3 scheme planned directly upstream of this scheme.

4) Sun Kosi No.1 Scheme

This scheme is planned as a reservoir type hydropower station with a 147m high dam and hydropower station located immediately downstream of the dam. Installed capacity is 1,357MW by the maximum discharge of 1,400m^3/s, with a firm capacity of 555MW. Annual generated energy is estimated to be 4,640GWh which would be exported.

The dam site was investigated first by the Government of India and reviewed in the "Feasibility Report on Kosi High Dam Project". Subsequently the site was investigated through the "Feasibility Study of Irrigation Development Project in Terai Plains" in 1972.

The site was selected about 10km downstream from the confluence of the Sun Kosi and Dudh Kosi rivers where the riverbed is about 130m wide, with thick deposits of sand and gravel. Maximum depth of these deposits is about 28m according to the above mentioned study. The foot of the left bank consists of exposed rock 10m high while the upper most slope is covered with thick table-like debris. According to the above study, the top layer of about 10-20m of formation rocks is considerably weathered or rich in cracks and fissures indicating a low seismic propagation velocity of 1.5 to 1.8km/s.

The right bank also has an exposed rock cliff several meters in height and the steep upper slope has a thin overburden. The thickness of weathered rocks seem to be 5 to 8m, under which lies a 10m layer with many cracks.

The dam was planned as a concrete gravity type taking into consideration the difficulties of flood diversion. For a concrete gravity dam, the overburden on debris should be completely removed, the weathered or cracked layer of rocks should be excavated and suitable foundation treatment should be applied such as grouting for consolidation and prevention of seepage.

Heavy sedimentation from the Sun Kosi River will flow into the reservoir at an annual rate of 45 $10^6 m^3$ which will decrease storage capacity annually from the capacity of 1,500 $10^6 m^3$ at the initial stage.

This scheme is planned as a hydropower development plan without consideration of the Sun Kosi Multipurpose scheme. Consequently acquirement of the same will be required in the next stage. As mentioned in APPENDIX V the intake dam with H.W.L EL. 338m at Kurule for the Sun Kosi diversion is planned 480m downstream from the Sun Kosi No.1 Dam site.

If this hydropower scheme is considered for energy export it should be implemented before Sun Kosi

Multipurpose scheme, thus the Sun Kosi No.1 Dam can be used as an intake dam for diversion. In this case, this hydropower plan will be re-planned for comprehensive development. On the other hand, if the Sun Kosi Multipurpose Scheme is implemented prior to the Sun Kosi No.1 Dam, this hydropower plan will also be re-planned considering the intake dam for diversion, tailrace water level and diversion water of the Sun Kosi Multipurpose Scheme.

One of the problems of this scheme as well as most other schemes is access. The access road is planned across the Maharabat Mountain Range from the Terai with a total length of 70km in which 40km crosses the mountain area.

5) Sun Kosi No.3 Scheme

This scheme is planned as a reservoir type hydropower station with a 140m high dam and hydropower station located directly downstream of the dam. Installed capacity is 536MW, with a firm capacity of 376MW and annual generated energy, 2,070GWH will be utilized in Nepal.

The dam site was selected 5km downstream of Panchuwar Village, and the riverbed is about 130m wide, with thick deposits of sand and gravel. Maximum depth of deposits is about 44m according to the results of investigation, drilling and seismic prospecting.

The foot of the left bank consists of exposed rock 70m high while the upper most slope is almost gentle and covered with thick talus deposits. According to the investigation, the talus deposit on the top layer is about 15-20m under which there is a weathered layer of 13-16m. This weathered layer has a seismic propagation velocity of 2.7-2.9km/s. The right bank also has an exposed rock cliff and a steep upper slope with a thin talus deposit and upper and lower weathered layers of 9-13m and 13-18m thick, respectively.

The dam is planned as a concrete gravity type taking into consideration the difficulties of flood diversion. However a combined dam and fill dam on the left flat bank is also considered. For a concrete gravity dam the overburden of deposit should be completely removed and the weathered layer should be excavated to some extent according to dam height. Suitable foundation treatment should also be applied such as grouting for consolidation and prevention of seepage.

This site is only about 20km from the existing truck roads, near Dolaghat. The main difficulty in project implementation at this site is the deep river and talus deposit along the left bank. This scheme is considered as Phase II of the Sun Kosi Multipurpose Scheme.

6) Sun Kosi No.2 Scheme

This scheme is planned as a reservoir type hydropower station with a 166m high dam and hydropower station located directly downstream of the dam. Installed capacity is 1,110MW, with an estimated annual generated energy of 4,760GWh which would be exported to India.

The dam site was selected in the area where the dam site of Plan "c" (lower dam site) was proposed in the aforementioned "Feasibility Study of Irrigation Development Project in Terai". Chyakutar village is situated on the right bank downstream of the gorge where the dam site was proposed. The riverbed is about 120m wide, with thick deposits of sand and gravel. Maximum depth of deposits is about 30m according to the results of investigation, drilling and seismic prospecting.

Both banks consist of thin talus scattered along the slopes and upper, middle and lower weathered layers, and a hard foundation of schist. On the left bank, the middle and lower weathered layers are relatively thick ranging from 7-30m and 20-45m, respectively. Middle and lower weathered layers on the right bank are also thick ranging from 6-10m and 19-22m, respectively. According to the results of investigation, the above layers exhibit a seismic propagation velocity of 1.6-1.8 and 2.7-2.9km/s, respectively.

The dam is planned as a concrete gravity type taking into consideration the difficulties of flood diversion. For the concrete gravity dam, the talus deposit and weathered layer should be completely removed; however, removal of the lower layer should be carefully studied.

The lower weathered layer has a seismic propagation velocity of 2.7-2.9km/s and is classified as CM-CH rock which is considered a suitable foundation for a high concrete gravity dam. Appropriate foundation treatment should be applied such as grouting for consolidation and prevention of seepage.

The main difficulty in implementation of this scheme is the distance (107km) from Dolaghat along the Sun Kosi River. An access road must be constructed prior to construction of such works as diversion, dam and power station.

7) Arun No.1 Scheme

This scheme is planned as an SRR type hydropower station with intake weir, a 9.6km long headrace tunnel and a power-house upstream of the Sapt Kosi High Dam reservoir. The installed capacity is 146MW by the maximum discharge of $180m^3/s$, with a firm capacity of 100MW. Annual generated energy is expected to reach 1,166GWh which is planned for Nepalese consumption.

The site for the intake weir with a silting basin was selected 5km upstream of Sankhuwa Khola, a tributary joining from the right bank, and the headrace tunnel is planned along the left bank to effectively utilize the river loop and allow easier access from Dhankuta. The powerhouse is planned about 9km downstream from Chyawalik Village, in the remaining undeveloped river course between the reservoir of Sapt Kosi High Dam where a large tributary converges on the left bank downstream.

The left bank consists of outcropped rock cliff, while the right bank consists of a gentle slope and a terrace formed by river deposits at the foot of the slope at a height of about 10-20m above the riverbed.

The height of the intake weir is planned at 20m and the headrace tunnel will be a non-pressure type. The main difficulty foreseen at this site is the necessity for construction of a long access road (72km) from Dhankuta. Development of this scheme is therefore planned after completion of the more economical Arun No.3 and No.2 schemes.

8) Bhote Kosi No.1 Scheme

This scheme is planned as an SRR type hydropower station with an intake weir, a 10.9km long headrace tunnel, and a powerhouse near Bahrabise, at which the Sun Kosi River joints the Bhote Kosi River from the left. The installed capacity is 64MW by the maximum discharge of 34mx3/s, with a firm capacity of 29MW and annual generated energy is estimated to be 444GWh which is planned for domestic consumption to the demand center, (Kathmandu) and districts near the scheme.

The site for the intake weir with silting basin was selected directly downstream of Kahule Khola in Tyathali and the headrace tunnel is planned on the left bank taking into consideration the river loop. The powerhouse site is planned in the remaining undeveloped river course downstream between the existing Sun Kosi Power Station to utilize the Sun Kosi River which joins the site from the left.

Planned intake weir height is 24m and the headrace tunnel is planned as a non-pressure type. The most advantageous point of this scheme is that the truck road runs along the river from Kathmandu to Tibet and consequently no access road is needed. Moreover, access tunnels can be easily excavated to shorten the construction period of the long headrace tunnel.

This scheme is relatively small scale similar to the Khimte Khola No.1 scheme; and the construction and energy costs are inexpensive. As the distance from demand center, Kathmandu, is minimal, this scheme is expected to be developed to supply cheap energy to Kathmandu and districts near the scheme.

Tama Kosi No.3 Scheme

This scheme is planned as a PRR type hydropower station with a 60m high dam, a 7km long headrace tunnel and a powerhouse located 5km downstream of the existing iron bridge on the Tama Kosi River on the way to Jiri from Kathmandu through Charikot. The dam is planned 2.4km upstream of the abovementioned bridge and 400m upstream of the existing Busti Gauging Station (No.647). The installed capacity is 123MW with the maximum discharge of 150m^3/s, and a firm capacity of 82MW. Annual generated energy is estimated to be 603GWH which is planned for supply within Nepal.

The dam site is 60m wide at the riverbed and river deposits of sand and gravel 23m thick were confirmed by investigations, drilling and seismic prospecting. The right bank consists of a relatively gentle slope with a gradient of about 30^o and is covered with 5m thick talus deposits. The upper, middle and lower weathered layers have thickness and seismic propagation velocities of 10m and 0.9-1.1km/s, 13m and 1.6-1.8km/s, 13m and 2.6-2.8km/s, respectively.

The left bank has the same degree of slope and thin talus deposits and outcrops are found at the foot. The upper, middle and lower weathered layers have thickness and seismic propagation velocities of 6-15m and 0.9-1.1km/s, 9-15m and 1.6-1.8km/s, 10-19m and 2.6-2.8km/s, respectively.

The dam is planned as a concrete gravity type taking into consideration dam height and function. The available storage can be maintained to flush sedimented sand and soil through the flush gate, and 10m high flush and spillway gates are planned on the concrete gravity dam. A diversion tunnel for large floods is also needed for the construction work of the dam. Dam height is moderate and excavation of lower weathered layers will not be necessary. However, foundation treatment should be applied such as grouting for consolidation and prevention of seepage. The headrace tunnel is planned as a pressure type. An access tunnel is therefore planned at Khani Khola to shorten the construction period. The longest tunnel for construction work will be about 2.5km.

The most advantageous condition of this scheme is the location, which is easily accessible from Kathmandu by car on the truck road. Only a 6km access road will be needed to the dam site and powerhouse site. After completion of this scheme, the downstream Tama Kosi No.2 scheme can be developed as a peak power station without any high dam, and both power stations, combined with other cheap base-operated power stations as Arun No.3, No.2 schemes will greatly contribute to meeting fluctuating demand.

10) Tamur No.1 Scheme

This scheme is planned as a reservoir type hydropower station with a 153m high dam and hydropower station located directly downstream of the dam. Installed capacity is 696MW by the maximum discharge of $650m^3/s$, with a firm capacity of 493MW and expected annual generated energy is 2,750GWh which will be utilized in Nepal.

The dam site was selected about 45km upstream of the confluence of the Tamur and Sapt Kosi rivers. Both banks are high enough for a high dam, and rock outcrops occur. A dam height of 153m was selected to obtain available storage capacity against heavy sedimentaiton load, $5,000m^3/km^2$/year.

Accessibility of this site is relatively good, although an access road of 25km is needed from Dhankuta. The main constraint of this site is the geological conditions which must be carefully investigated to determine possible dam height. The dam is planned as a concrete gravity type taking into consideration the difficulties of flood diversion. However, a fill type dam should also be studied because of the foundtion conditions.

11) Tama Kosi No.2 Scheme

This scheme is planned as an SRR type hydropower station with an intake weir, a 9.9km long headrace tunnel and a powerhouse 1km upstream from the confluence of the Tama

Kosi and Khimte rivers. The installed capacity is 196MW with a maximum discharge of 150m^3/s, and a firm capacity of 130MW. Annual generated energy is estimated at 1,013GWh which is planned for domestic consumption.

This scheme is planned in combination with the upstream Tama Kosi No.3 scheme, a PRR type scheme with a storage dam. Accordingly, Tama Kosi No.2 should be constructed after Tama Kosi No.3 and can be operated as a peak power station without high dam for storage.

The intake weir site with silting basin was selected about 1km directly downstream of the powerhouse for the Tama Kosi No.3 scheme. The headrace tunnel is planned along the left bank to effectively utilize the river loop and in consideration of the continuous hard rock on the left bank contrary to the right.

Planned intake weir height is 20m, and length is 150m and the headrace tunnel is planned as a non-pressure type. The powerhouse site has terrace-like river deposits about 10m deep with sufficient width. The penstock slope consists of outcropped foundation rock.

Accessibility to this site is good from Kathmandu through Charikot. The truck road runs to Jiri from Kathmandu and an iron bridge has been constructed on the Tama Kosi River. After the completion of the Tama Kosi No.3 scheme, access to the intake site will be easier and only a 15km road will be required for access to the power site.

12) Khimte Khola No.1 Scheme

This scheme is planned as an SRR type hydropower station with intake weir, a 7.4km long headrace tunnel and a powerhouse 800m upstream of the confluence of the Tama Kosi and Khimte rivers. The installed capacity is 49MW by the maximum discharge of 10m^3/s, with a firm capacity of 26MW. Annual generated energy is estimated to be 344GWh which is planned to supply the demand center (Kathtmandu) and districts near the scheme.

The site for the intake weir with silting basin was selected 11km upstream of the confluence of the Tama Kosi and Khimte rivers and the headrace tunnel is planned on the right bank in consideration of the river loop. The powerhouse site was selected by the Tama Kosi River in consideration of the cliffs extending along the Khimte Khola. Penstock length is thus shortened and topographical and geological conditions at the site are favourable. Planned intake weir height is 20m high and the headrace tunnel is planned as a non-pressure type. An access road of 25km is needed to reach the powerhouse and intake dam sites from the aforementioned iron bridge on the Tama Kosi River.

This scheme is a relatively small scale power station; however, construction and energy costs are minimal. Furthermore construction will be smoother after completion of Tama Kosi No.3 and No.2 schemes due to construction of the access road to the powerhouse site and transmission line to the demand center, Kathmandu.

13) Dudh Kosi No.1 Scheme

This scheme is planned as a PRR type hydropower station with a 104m high dam, a 2.6km long headrace tunnel and a powerhouse. The dam site is located 28km upstream of the confluence of the Sun Kosi and Dudh Kosi rivers, to which the back water of the Sun Kosi No.1 dam reaches. The Rabuwa Bazar Gauging Station (No.670) is installed 2km upstream from dam site. The installed capacity is 228MW with a maximum discharge of $300m^3/s$ and a firm capacity of 118MW. Annual generated energy is estimated at 978GWh which is planned for domestic supply.

The dam site is about 70m wide at the riverbed and river deposits of gravels occur. The right bank consists of a steep outcropped slope, while the left bank is relatively gentle with apparent talus deposits. Gross storage capacity is $162 10^6 m^3$ which will enable annual regulation of natural river flow at the initial stage. However, the effective period of the reservoir depends on the specific sedimentation load of the Dudh Kosi River for which no data were available. This scheme is therefore planned as a PRR type.

The dam is planned as a concrete gravity type taking into consideration the difficulties of flood diversion and dam function. Available storage capacity must be maintained to flush sedimented sand and soil, and accordingly 10m high flush and spillway gates are planned on the dam. Diversion tunnel and foundation treatment are needed for construction. The headrace tunnel is planned as a pressure type with a surge tank on the right bank.

The main difficulty envisioned at this site is the long access road (177km) required from Dolaghat along the river. Accordingly, this scheme should be developed after the Sun Kosi No.1, No.2 and No.3 Schemes.

5.5 Irrigation

5.5.1 Present Status

(1) General

Development plans for irrigation were studied in the Terai Area between the Bagmati and Kankai rivers located in the eastern portion of the Terai Zone. The same has a gross land area of about 749,000ha which includes approximately 620,000ha of cultivated land. Administratively, the area is composed of the 8 districts of Jhapa, Morang, Sunsari, Saptari, Siraha, Dhanusha, Mahottari and Sarlahi. Population of the area is estimated at about $2.8 10^6$ as of 1982, of which about 82% is considered to be engaged in the agricultural sector.

The area is bordered on the north by the Siwalik hills in the western part of the Sapt Kosi River and by the Mahabharat range in the eastern part of the same, and slopes gradually southwards to the Indian border with a gentle incline of 1/400 on the average. There are numerous rivers and rivulets traversing the area from north to south. The Sapt Kosi River, the largest river in Nepal, originates in Tibet, runs through the Terai Area and flows south to join the Ganges river. Medium size rivers, which have their sources in the Mahabharat range, are the Kankai, Kamla and Bagmati rivers. There are a number of small streams and creeks originating from Siwalik hills, which are not taken into account in irrigation planning as there is no water available from the same during dry season.

The climate in the area is typical sub-tropical monsoon type, with occasional rains starting in May and the southwest monsoon covering the area during June to October. A relatively dry period occurs from November to April under the influence of the northeast monsoon. Mean annual precipitation in the area east of the Sapt Kosi is 1,631mm and in the west 1,265mm, more than 90% of which occurs between May and October. Temperatures rise steadily from a minimum of 8.4°C in January to a maximum of 34.5°C in April. A summary of the climate of the Study area is presented below.

SUMMARY OF CLIMATE DATA FOR TERAI AREA

	Mean Monthly Temperature (°C)		Mean Monthly Rainfall (mm)		Mean Monthly Evaporation (mm)	
	West	East	West	East	West	East
Jan	16.3	15.8	10.3	12.1	58.9	62.0
Feb	18.3	17.8	9.3	10.5	67.2	81.2
Mar	22.9	22.0	12.3	11.5	145.7	142.6
Apr	27.5	26.6	43.6	57.3	201.0	177.0
May	28.4	27.7	81.6	123.8	204.6	182.9
Jun	29.3	28.5	218.3	318.5	171.0	174.0
Jul	28.8	28.5	363.1	465.0	145.7	133.3
Aug	28.6	28.5	280.8	274.7	139.5	127.1
Sep	28.1	27.8	166.3	231.8	120.0	108.0
Oct	26.1	25.5	70.3	96.6	99.2	105.4
Nov	22.1	21.6	5.2	15.0	78.0	84.0
Dec	17.5	17.3	4.2	14.8	65.1	65.1
Total	-	-	1,265.3	1.631.3	1,495.9	1,442.6

Note: West signifies Sapt Kosi West Zone
East signifies Sapt Kosi East Zone

Source: Hardinath and Tarahara Meteorological Stations

(2) Existing Agriculture

1) Cropping pattern

Major crops grown in the Terai Area include both traditional and improved varieties of paddy. With the recent introduction of Mexican varieties of wheat and successful plant breeding, cultivation of wheat has increased rapidly. Several kinds of oilseeds and pulses are also grown. Jute is grown in the eastern portion of the Terai Area while tobacco is mainly cultivated in the west. Mono cropping is prevalent, involving about 34.9% of farmland. The ratio of fallow land resulting from lack of irrigation water is calculated at about 15.6%.

Double cropping of paddy and oilseeds is prominent including relayed cropping. Paddy/paddy, jute/paddy, and maize/paddy cropping patterns are practiced in areas where irrigation water is available while maize/tobacco and paddy/wheat cropping patterns are practiced in both irrigated and rainfed areas. The total area of double cropping is larger than that of mono cropping, calculated at more than 41.2%.

The area where triple cropping occurs is small, involving only 8.3% of total farmland. This pattern includes paddy/paddy/mixed crops, paddy/paddy/winter cereals, jute/paddy/wheat and maize/paddy/wheat.

2) Cropping Intensity

Cropping intensity has been calculated based on data from the Land Resources Mapping Project (LRMP) and information obtained at the site. Cropping intensity in the case of single cropping has been calculated at 100% while that for double cropping has been converted to 200%. Cropping intensity for miscellaneous crops was assumed at 125% while, in consideration of crop rotation, the intensity for triple cropping has been assumed at 250%. Total cropping intensity in all 8 districts concerned was calculated at 137.8% under the Land Resources Mapping Project.

3) Crop yield and crop production

Paddy production in the area is estimated at about 1 million tons involving 62% of the total cropped area. Paddy productivity in the Study area is low at about 1.7t/ha which is lower than that in other areas of Nepal.

Although wheat cultivation has been increasing, cultivated area is still limited due to low availability of irrigation water and lack of a proper sowing schedule to coordinate combined cultivation of long duration paddy varieties which are harvested during the months of November and December. Wheat productivity is low at 1.1t/ha while production in the Study area reached about 0.1^{10^6}t.

Oilseed crops, particularly mustard, have local importance, but poor management results in yields as low as 646kg/ha. Maize, millet and barley are supplementary food crops while jute, tobacco, potato and sugar cane are important cash crops in the area. Productivity of these crops is quite low however, in comparison with the potential of the same. Pulse yield is estimated at only about 350kg/ha, although pulses are extremely important in the local diet, supplying about 75% of the total protein requirement.

5.5.2. Food Balance and Irrigation Needs

(1) Present Food Balance in Nepal

According to analysis of the food balance in Nepal in a recent normal crop production year (1981/82), current production for the entire country exceeds about 20.8% of the total demand. This is due to high production in the Terai Zone which produces about 76.5% of the nation's harvest. However, rice supply in the Hill and Mountain Zones has a deficit of about 18.4% and 15.3%, respectively.

The supply balance of wheat, which is also an important food grain, is similar to that of paddy rice. About 63% of the national wheat product is produced in the Terai Zone and 33.8% in the Hill

Zone. Both areas have a surplus in wheat production. Production of other food grains, however, such as maize and millet, including buckwheat and barley, are deficit in all the agro-climatic zones. From the viewpoint of total food grain supply and demand, there is a surplus of about 11.6% at the national level. In the Terai Zone itself supply of food grains exceeds about 36.2% of the total demand. Due to inadequacies of transportation networks and natural constraints, however, production and distribution of food grains in the Hill and Mountain Zones is inefficient.

(2) Future Food Balance

Future food balance forecasting was analysed with the year 1981/82 as the base year. Actual food balance for the year 1981/82 obtained from the Department of Food and Agriculture Marketing Services, differs from the trend indicated by analysis results. The analysis was based on several assumptions stated below.

a) Annual population growth rate and projected population were based on information obtained by the Agricultural Project Services Centre (APROSC) which assumes average population growth including migration.

b) Increased annual growth of per capita cereal consumption per year was assumed at 1.6kg where per capita consumption is 150kg in the year 1981.

c) The base production level of cereals in edible form was estimated at 2,205,000t per year. This base was computed on the basis of cultivated area in 1981/82 and the average yield during the period from 1976/77 to 1981/82.

d) Gross production was converted to production processed and available for consumption by assuming an overall 15% loss and wastage including animal feed. A conversion rate of 60% was used for paddy, and 90% for other cereals. Seed requirement per hectare was assumed at 55kg for paddy, 45kg for maize, 100kg for wheat and 30kg for millet and barley.

According to the results of analysis, the trend of food balance indicates that the earlier food surplus became deficit in 1982. Future food supply appears to be decreasing with an estimated food grain deficit of 41.7% of the total demand by the end of this century. This trend continues, exceeding 50% in 2005 (TABLE 5-26). The above analysis results indicate a similar trend to those of ADB's analysis conducted in 1982 and of the Nepal Agriculture Sector Strategy Study report. These reports estimate that to supply minimum food and nutritional needs, cereal production should at least double from present levels by the year 2000.

(3) Proposed Cropping Pattern

1) Selection of crops

Selection of crops for the proposed cropping pattern was based on consideration of the local economic and social importance of the same. Accordingly, paddy, wheat and maize were selected as basic crops. Potato and sugar cane are presently important cash crops with future potential while jute is an important industrial crop in the eastern part of the Sapt Kosi River and tobacco in the western part. Oilseeds are one of the important crops for local consumption as well as for commercial use.

2) Proposed cropping pattern

From the viewpoint of distribution of different crops, two cropping patterns are proposed, one for the western study area and one for the eastern both of which are bordered by the Sapt Kosi River. The basic pattern is the same for both areas; however, the crops selected are different. Jute will be cultivated in the eastern area and tobacco in the western area.

Single cropping will be limited to sugar cane which is usually cultivated as a perennial crop for three consecutive years. Double cropping patterns will predominate, accounting for 82% of total farmland area while triple cropping patterns are proposed for 17% of the land area in both eastern and western areas.

In addition to the above mentioned crops, pulses are a promising leguminous crop, high in protein, the use of which will increase soil fertility by providing synthetic nitrogen and organic materials to the soil. Cultivation of 25 to 27%

summer and winter pulses for a 4 year cropping rotation is therefore proposed to recover soil fertility.

3) <u>Cropping intensity</u>

A substantial increase in cropping intensity from the existing 137.8-216% is projected under the Project. The major change in cropping intensity with Project implementation will be in cereal grains including paddy, wheat and maize which will increase from the existing 105% to 169% in the eastern area and to 172% in the western area.

4) <u>Anticipated yield</u>

Present crop yields in the Study area are low. This is caused by various factors, including lack of technology, lack of adequate irrigation water supply, poor soil fertility management, segregation of proper varietal characteristics, insufficient application of fertilizer due to economic limitations, and inadequate distribution system.

It is envisaged that Project implementation will result in stable irrigation water supply and improvement of the agricultural input distribution system. In addition, development of support institutions is also expected in such areas as research and breeding activities, agricultural extension, agricultural credit, organization of cooperatives and rural development, agricultural input supply, and marketing. These activities should be pursued prior to, or in conjunction with, construction of the Project's material structures. It is forecasted that demands for food grains will be doubled in the country by the year 2000, the Project's target year for agricultural development.

The anticipated yield of each crop has been projected as given on the following page. In consideration of yield potential and the envisaged success of the subjects discussed above, these target yields are believed to be reasonable and attainable.

TARGET YIELD OF CROP WITHOUT/WITH PROJECT

Crop	Present Status kg/ha	Without Project kg/ha	With Project kg/ha
Wet Local Paddy	1,479	1,479	-
Improved Wet Paddy	2,200	2,876	4,000
Improved Summer Paddy	2,200	2,876	3,500
Wheat	1,140	1,443	3,000
Maize	1,411	1,411	2,000
Millet	898	898	-
Barley	769	769	-
Tobacco	754	754	1,000
Jute	1,673	1,673	2,500
Oilseeds	646	646	1,000
Pulses	350	350	800
Sugar Cane	22,046	22,046	30,000
Potato	6,257	6,257	1,500

(4) Measurement for Incremental Production

Of the various alternative irrigation plans under the proposed Sun Kosi Diversion Plan, the net command area of 175,100ha between the Bagmati and Kanro rivers has been selected as the optimum plan from an economic viewpoint. Other potential irrigable areas have also been determined such as the Sun Kosi-Trijuga diversion plan which has a net command area of 17,100ha, and the Tamur-East Terai diversion plan which will serve the eastern area from the Sapt Kosi River with a net command area of 49,350ha.

Estimated cereal production in the target year of 2005 will be about 0.47 10^{6}t under without project conditions and 1.47 10^{6}t under with project conditions for the area within the above irrigation plans (about 241,550ha). With implementation of these three irrigation plans, about 1,023,000t of cereal products is expected to be made available incrementally by 2005. Food balance forecasting analysis results indicate that by 2005 a deficit equivalent to over 50% of food requirements will occur if food is not imported.

The envisaged incremental product under the proposed plans may cover about 21.5% of the food deficit.

(5) Need for Irrigation

As most cultivation in Nepal is rainfed, crop production is unstable. Due to restriction of land reclamation, erosion of existing farmland, and unstable climate, nation-wide crop production has tended to decline while food demand is rapidly expanding. It is forecasted that food grain production will supply less than 50% of the nation's demand by 2005 even in consideration of natural growth increase in crop productivity. Increased crop production is therefore the most urgent need at this time. To achieve the same, the traditional crop production system should be diversified and modernized. Cropping intensities under rainfed conditions range from 100-120% with the success of both first and second crops dependent upon the pattern of monsoon rainfall. With assured supply of irrigation water and provision of drainage as necessary, double or even triple cropping may be possible, increasing cropping intensities to over 200%. At the same time, productivity of each crop will increase due to reduced risk of crop loss from drought. Farmers can thus safely enhance the level and quality of inputs and package practices.

Of the several irrigation development plans in the Study area, the Sun Kosi Diversion Plan has the greatest economic reliability with the largest irrigation benefit area. Moreover, if this project is implemented, the project itself will produce about 746,000t of grain products by 2005, thus supplementing 15.6% of the national food grain deficit. Analysis results show that implementation of this project as soon as possible is an urgent priority.

(6) Existing and On-going Irrigation Projects

The soil of the Terai is well-drained and fertile, and the area is developing into Nepal's agricultural belt. Annual rainfall for the same however is only 1,000-1,500mm. Accordingly, several on-going and existing projects have been developed to ensure adequate irrigation and water supply systems.

Irrigation projects are divided into gravity (G.T.), lifting (L.T.), and tubewell types (T.T.) and also into year-round and supplementary according to their water supply systems. Those projects which occur within the Study area are listed below.

ON-GOING & EXISTING PROJECTS IN THE STUDY AREA

Water Source	Name of Project & Gross Command Area	Status	Water Source & Intake Quantity	Irrigation Type	Water Supply System
Sapt Kosi River	1. Sunsari Morang 107,700ha	On-going	Sapt Kosi Q max=$45m^3/s$	G.T.	year-round
	2. Rajbiraj Pump-up 16,450ha	On-going	Sapt Kosi - West cannal Q max=$8.7m^3/s$	L.T.	year-round
	3. Kosi West Canal 15,000ha	On-going	Sapt Kosi Q max=$17m^3/s$	G.T.	year-round
Other Rivers	4. Trijuga-Chandra 16,250ha	Existing	Trijuga Q max=$11.3m^3/s$	G.T.	year-round
	5. Bagmati Left Bank 109,500ha	On-going	Bagmati River Q max=$64.4m^3/s$	G.T.	supplementary (future; year-round)
	6. Kamla 65,450ha	Existing	Kamla River Q max=$28m^3/s$	G.T.	supplementary
	7. Kankai Right Bank 17,450ha	On-going	Kankai River Q max=$25m^3/s$	G.T.	supplementary (future; year-round)

In addition to the projects in the table, there are 2 existing projects, the Kosi Eastern Canal (Q max $500m^3/s$) and the Kosi Western Canal ($300m^3/s$), both originating from the Bhimnagar Barrage on the Sapt Kosi and crossing the Nepal-India border, and several tubewell irrigation projects in various localities in the Terai Area.

5.5.3 Planning Conditions

(1) Irrigation Study Area

The Study area for irrigation planning extends from east to west for about 250km between the Bagmati and Kankai rivers in the Terai Zone. The said area ranges in width from 15-45km from north to south sloping southwards to the Indian border with an incline of 1/200-1/400. Of the 749,000ha of land included within the said area, 620,000ha of existing farmland is considered as a potential irrigation area for the Study.

(2) Water Resources

Required irrigation water for the Study area will be supplied mainly from two sources, the Sun Kosi and Sapt Kosi rivers. Intake from local rivers in the Terai Area except the Kamla and Trijuga rivers was not considered, as flow of the same tends to dry up during the dry season.

(3) Irrigation System and Target

Based on the results of technical and economic analyses, gravity irrigation was selected as the most suitable method for irrigation planning. The upland areas within the command area where gravity irrigation is not possible will be considered for future lift irrigation schemes. Alignment, cross-section and slope of canals will likewise be determined according to technical and economic considerations.

The target for the proposed irrigation plan is facilitation of year-round irrigation, which will result in subsequent increase in agricultural production and alleviation of expected increases in food demand.

(4) Irrigation Project Area

Canal alignment has been planned to include as much command area as possible considering technical and economic conditions of the irrigation Study area.

In the Study area, there are several on-going and proposed year-round irrigation projects with gravity irrigation systems (namely, the Kosi West Canal, Sunsari-Morang and Kankai Irrigation Projects) which have been excluded from the proposed project area. However, the left bank of the Bagmati Irrigation Project which has been planned as a year-round irrigation Project in Phase-II of the initial stage will be included in the Master Plan, as the same has been designated by HMG for provision of supplementary irrigation to compensate shortage in the comprehensive Bagmati River water resources development plan.

Lift irrigation (Rajbiraj Pump Canal Project) and groundwater irrigation projects will be considered for possible future integration into the irrigation system of the Study upon termination of their respective project lives.

Inclusion of the same within the gravity irrigation system is expected to be less costly than rehabilitation and cost for operation and maintenance.

(5) Water Demand

Irrigation water requirement has been determined on the basis of the proposed cropping pattern and the total anticipated water operation loss including that from canal seepage, etc. The basic factors determining irrigation water demand are consumptive use of water for crops and percolation. The Pan Evaporation Method was used to determine the water requirement.

The command area has been divided into 2 sections, west and east, due to differences in climate and crop type, with the Sapt Kosi as the dividing line. Data from Hardinath and Tarahara Stations have been adopted for the west and east section, respectively.

Calculation of water requirement has been based on the proposed cropping patterns which are aimed to provide year-round irrigation for maximization of crop production. As agreed in the minutes of the meeting with HMG on 7 August, 1984, water requirement for the sandy area along the Sapt Kosi River (9400ha) was calculated based on a maximum of 2.5 l/sec/ha for paddy in rainy season and 1.0 l/sec/ha for upland crops in dry season.

Based on the above, water requirement for each crop are as shown in TABLE 5-27.

(6) Cost Estimates

Preliminary cost estimates have been prepared for all irrigation schemes based on the following conditions:

a) The exchange rate used in the estimation is US$ 1.00 = NRs. 15.60 (end 1983 level);

b) Civil works are to be carried out by international competitive bidding with the contractor supplying heavy construction machinery and equipment;

c) Project costs consist mainly of temporary work, civil work, O/M facilities, administration and engineering costs and physical contingency;

d) Taxes on construction materials, machinery and equipment to be imported from abroad are exempted from the cost estimate;

e) Unit cost rates of civil works have been derived from cost parameters obtained from recently executed or planned irrigation projects in Nepal;

f) Cost estimates are based on price levels at the end of 1983;

g) Administrative and engineering service cost is assumed to be 10% of direct cost including O/M facilities;

h) Annual operation and maintenance cost is estimated to be 3% of direct cost; and,

i) Physical contingency of 8% of total cost is included in the Project cost in view of the preliminary nature of the estimate.

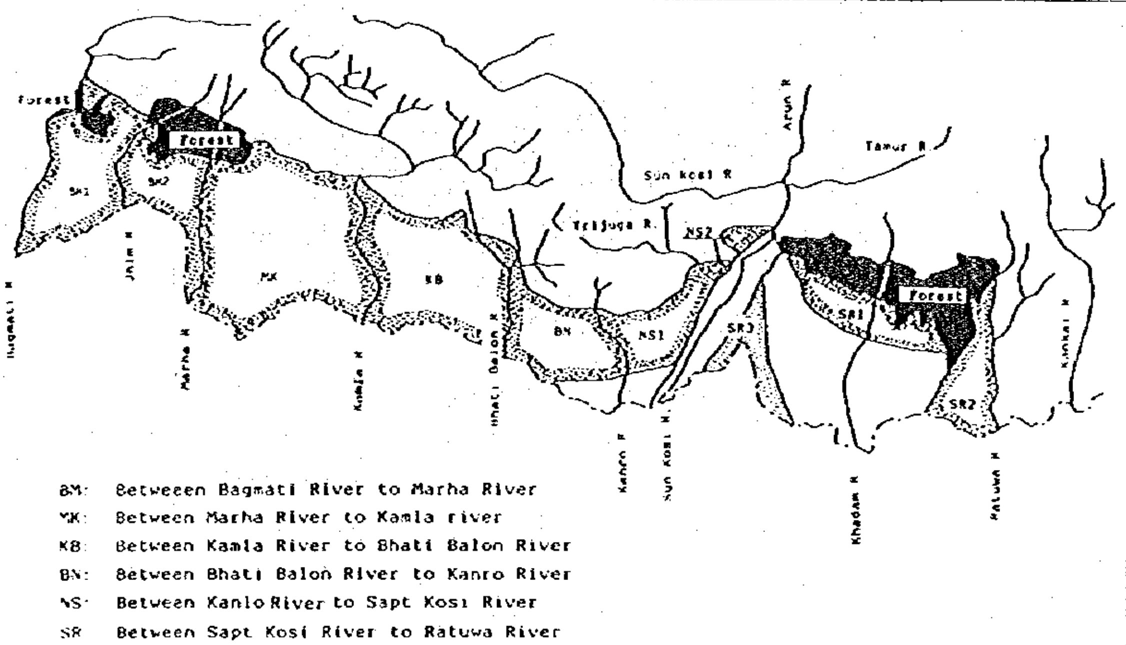
j) Cost estimate for irrigation facilities include all necessary facilities up to tertiary canal.

5.5.4 Irrigation Area Development

(1) Potential Irrigation Area

The irrigation area for the Study was selected in due consideration of both physical and socioeconomic conditions. The rainfed area in the Terai is estimated at about 62% of the total farmland, and the remaining area is either presently irrigated or planned for irrigation. The area of year-round gravity irrigation within the latter area accounts for only 15% of total farmland while supplemental irrigation area accounts for 23%.

The proposed irrigation area has been delineated in order to irrigate the majority of farmland (76.6%) except for the year-round gravity irrigation area and Ratuwa River - Kankai River. The same can be sub-divided into 6 component areas according to geographical location and accessiblity to water supply sources. The figure below gives the locations and designations of each component area, and detailed technical figures.



MAIN INDICATORS FOR EACH AREA

MAIN INDICATORS FOR EACH AREA

Designation of[1/] Component Area	Gross Area (ha)	Potential Irrigation Area (ha)
BM	88,700	66,500
MK	138,200	103,700
KB	99,000	74,300
BN	44,200	33,200
NS	33,200	24,900
SR[1/]	71,500	53,600
Total	474,800	356,200

1/ This area includes 9,400ha along the left bank of the Sapt Kosi which is part of the command area of the Sunsari Morang Irrigation Project, but not fully irrigated.

(2) <u>Irrigation Development Schemes and Alternative Plans</u>

On the basis of topography and geology, diversion from the Sun Kosi and Trijuga rivers, as well as direct intake from the Sapt Kosi River, are both feasible for irrigation water supply on the Sapt Kosi right bank. As for the Sapt Kosi left bank, supply from the Sapt Kosi and Tamur rivers is possible.

The irrigation Study area is divided into 3 seperate schemes in consideration of possible alternative sources from the Sun Kosi and other rivers traversing the area from north to south. Those schemes are named from west to east as follows:

- Sun Kosi Diversion Scheme
- Sapt Kosi West Irrigation Scheme
- Sapt Kosi East Irrigation Scheme

The command area of each scheme was formulated to maximize irrigation area.

Alternative plans have been formulated for each of the above mentioned schemes consisting of different intake levels of the Kamla River in the case of the Sun Kosi Diversion Scheme, and different diversion plans for the Sapt Kosi West and Sapt Kosi East irrigation schemes. Alternative plans for these irrigation schemes and irrigation component areas are listed below (FIG. 59).

Sun Kosi Multipurpose Scheme

Chisapani Barrage Intake Plan

- area covered
  Bagmati River - Kanro River (Case, SK-400-BK): 175,100ha
- area covered
  Jhim River - Kanro River (Case, SK-400-JK): 159,100ha
- area covered
  Marha River - Kanro River (Case, SK-400-MK): 136,700ha

Kamla Dam Intake Plan

- area covered
  Bagmati River - Kanro River (Case, SK-450-BK): 215,200ha
- area covered
  Jhim River - Kanro River (Case, SK-450-JK): 189,800ha
- area covered
  Marha River - Kanro River (Case, SK-450-MK): 160,600ha

Sapt Kosi West Irrigation Scheme

Sun Kosi-Trijuga Diversion Plan

- area covered
  Kanro River - Sapt Kosi River (Case, SW-ST, Diversion):
  17,100ha (excluding north of the Trijuga River)

Sapt Kosi Intake Plan

- area covered
  Kanro River - Sapt Kosi River (Case, SW-Dam Intake):
  20,900ha (including north of the Trijuga River)

Sapt Kosi East Irrigation Scheme

Sapt Kosi Intake Plan

- Area covered
  Sun Kosi River - Ratuwa River (Case, SE-Dam Intake): 47,950ha

Tamur River - East Terai Diversion Plan

- Area covered
  Sapt Kosi River - Ratuwa River (Case, SE-TT Diversion) 49,350ha

5.5.5 Required Irrigation Water and Additional Water

(1) General

The majority of the 620,000ha of farmland in the Study area is rainfed irrigation area. Moreover, the main irrigation water supply sources for those areas which have irrigation facilities are the major rivers traversing the region, and except for the Kosi River, river discharge is almost non-existant during the dry season from Feb - May. Consequently, even after completion of on-going projects, water shortage will occur in the dry season and a cropping intensity of only 135% may be expected.

The Master Plan aims to maximize agricultural production. Therefore additional water for irrigation will be required to increase agricultural production. In the irrigation Study area it is possible to supply irrigation water via the Sapt Kosi, Sun Kosi or Tamur rivers. Water resources in the Kosi Basin are sufficient to supply irrigation water to the Terai Area even during the dry season.

(2) <u>Sun Kosi Multipurpose Scheme</u>

The location of the Sun Kosi Multipurpose Scheme is between the Bagmati and Kanro rivers in the Study area. The said scheme proposes to supply irrigation water to both sides of the Kamla River using natural flow from the Kamla River and by diversion of the Sun Kosi at the Kurule site (Refer to General Map).

Total Annual discharge of the Kamla River for the standard year, 1969, is 1,555.24 $10^6 m^3$. This discharge could be regulated by a dam, and irrigable area would be about 46,000ha if downstream maintenance flow is considered.

IRRIGATION AREA BY KAMLA NATURAL FLOW
(without diversion from the Sun Kosi River)

Description	Amount
Kamla Natural Flow ($10^6m^3/yr$)	1,555.24
Evaporation from the Reservoir ($10^6m^3/yr$)	47.85
Downstream Maintenance Flow ($10^6m^3/yr$)	706.83
Available Irrigation Water ($10^6m^3/yr$)	800.56
Water Requirement ($m^3/ha/yr$)	17,454
Irrigation Area (ha)	45,835

Irrigable area in the case of diversion from the Sun Kosi Kurule site to an upstream tributary of the Kamla River without regulation by the Kamla dam amounts to 113,000ha (Kurule site natural flow) and 153,000ha (Kurule site discharge after regulation by SU-3) in April, the month of minimum discharge in the Sun Kosi River. If a dam is constructed on the Kamla River however, irrigable area with a diversion of $100m^3/s$ amounts to 226,550ha as shown in the table on the following page.

IRRIGABLE AREA BY DIVERSION WATER FROM KURULE
(with Kamla Dam)

	Diversion Water			
	$40m^3/s$	$60m^3/s$	$80m^3/s$	$100m^3/s$
Diversion Water	1,161.44	1,892.16	2,522.88	3,153.60
Kamla Natural Flow		1,555.24		
Inflow	2,816.68	3,447.40	4,078.12	4,708.84
Evaporation from Reservoir		47.85		
Downstream Maintenance Flow		706.83		
Outflow		754.68		
Available Irrigation Water	2,062.00	2,692.72	3,323.44	3,954.16
Water Requirement ($m^3/ha/year$)		17,454		
Irrigable Area (ha)	118,140	154,380	190,410	226,550

This would cover the 215,200ha command area of the alternative plan which lies between the Bagmati and Kanro rivers, has 450ft intake and comprises the largest command area proposed for the Sun Kosi multipurpose scheme.

(3) Sapt Kosi West Irrigation Scheme

The irrigation area for the Sapt Kosi West Irrigation Scheme is located between the Kanro and Sapt Kosi rivers. Potential water sources for the same consist of natural flow from the Trijuga River and diversion from the Sun Kosi River. Total annual discharge in the Trijuga River was estimated at $613,190 10^6 m^3/s$, and, as annual water requirement in the Sapt Kosi West area is $17,454 m^3/ha/year$, natural flow from the Trijuga River can provide irrigation water to a 35,100ha area. However, there is no suitable dam site in the upper Trijuga and therefore, as water regulation to cover water shortage in the dry season will not be possible, diversion from the Sun Kosi River will be necessary.

The Sapt Kosi West Irrigation Scheme involves two alternative plans; namely, the Sun Kosi-Trijuga Diversion Plan and the Sapt Kosi Intake Plan. The net command area of the former is greater than that of the latter, amounting to 17,000ha, with a total water requirement of $298.5 10^6 m^3$ for the standard year, 1969. Available discharge from the Trijuga River for irrigation purposes is about $203.9 10^6 m^3$, indicating an annual shortage of $94.6 10^6 m^3$. Accordingly, intake from the Kosi Basin will be required to supplement Trijuga flow.

(4) Sapt Kosi East Irrigation Scheme

The irrigation area for the Sapt Kosi East Irrigation Scheme is located between the Sapt Kosi and Ratuwa rivers and the sole source of irrigation water for the same is diversion from the Tamur Rivers.

As mentioned under Planning Criteria, natural flow utilized for irrigation in this Master Plan will be derived from the Kamla and Trijuga rivers. Accordingly, supply from another basin system will be required as the irrigation water of the plan cannot be fulfilled by the natural flow from the said rivers alone. Required irrigation water and required diversion water for each plan was calculated on the basis of the areas formulated in section 5.5.4 and the results of the same are presented in TABLE 5-28 and TABLE 5-29, respectively.

5.5.6 Result of Alternative Study

The costs and benefits of all the alternatives were quantified and compared on the basis of benefit-cost analysis using a discount rate of 12% per annum (TABLE 5-30). As a result of the study, the following plans were selected and formulated as the optimum irrigation development plans in the Master Plan.

a) Sun Kosi Diversion Plan

- Chisapani barrage intake
- Command area: 175,100ha
- Required diversion water: $72m^3/s$
- B/C ratio : 1.33 (Irrigation sector only)

b) Sapt Kosi West Irrigation Plan

- Sun Kosi River diversion to the Trijuga catchment area
- Command area: 17,100ha
- B/C ratio: 1.10

c) Sapt Kosi East Irrigation Plan

- Tamur River diversion to the Khadam catchment area
- Command area: 49,350ha
- B/C ratio: 0.76

From the viewpoint of engineering as well as economic viability, the Sun Kosi Diversion Plan is considered to be the most promising plan among the three development plans in the irrigaition sector. To make this plan more attractive, further efforts were made to combine irrigation benefit with power generation benefits. There are two suitable sites for hydropower generation in relation to the Sun Kosi Diversion Plan. One is at the outlet of the diversion tunnel and the other is at the toe of the Kamla Dam. The diversion power station with an installed capacity of 61MW was planned at the former site and the Kamla Dam power station with an installed Capacity of 32MW at the latter site. Thus medium scale hydropower plants will greatly contribute to rural development in the project area by providing economical and high quality energy.

A transmission line with substation is planned to connect the two plants with the Hetauda - Biratnagar line. Proposed capacity of the said line is 132KV and total length for both plants is 32KM. The construction costs for the hydropower component are 31.96 10^6US$ for the diversion power station, 23.36 10^6US$ for the Kamla Dam power station and 7.32 10^6US$ for the transmission line, totaling 62.64 10^6US$. By combining the irrigation component with the hydropower components, ratio is increased from 1.33 to 1.54 (TABLE 5-30). The Sun Kosi Diversion Scheme thus formulated is summarized as follows.

Sun Kosi Diversion Scheme

1) Diversion Project

a) Kurule diversion dam

Dam type	concrete gravity
Dam height	48.9m

b) Diversion tunnel

Length	16,600m
Design discharge	$72m^3/s$

c) Diversion power station

Qmax	$72m^3/s$
He	102.5m
Pmax	61,400kW
Generated energy	511GWh

2) Kamla Dam Project

a) Dam and reservoir

C.A	$1,450km^2$
HWL	EL 178m
LWL	EL 163m
Vg	713 10^6m^3
Ve	493 10^6m^3
Dam type	gravel fill
Dam height	51.0m

b) Kamla dam power station

Qmax	$120m^3/s$
He	32m
Pmax	32,000kW
Generated Energy	121GWh

3) Irrigation Development in the Terai Area

a) Command area (net) 175,100ha

b) Chisapani Barrage

-Height	3m
-Length	300m

c) Main canal

Length:	Right bank	78.4km
	Left bank	74.1km
Design discharge:		
	Right bank	$135m^3/s$
	Left bank	$84m^3/s$

d) Other irrigation facilities

- Total construction cost: 550.7 x 10^6US$
- Comprehensive B/C ratio: 1.54

4) Development Effects of Sun Kosi Diversion Scheme

The irrigation development scheme proposed in the Master Plan would change the present farming system into the improved irrigation system, providing farmers with a more reliable supply of water through the existing and new irrigation facilities. Crop production would be considerably increased through the higher input application and adoption of advanced farming practices. Cropping intensity and crop yields would gradually increase after commencement of water supply and reach full development stage in about five years after completion of construction works. Cropping intensity and crop yields under present, future "without" project and future "with" project conditions are shown in TABLE 5-31. With the implementation of the proposed scheme, additional employment opportunities would be created for family workers on the farm and for landless families. Food grain production would be increased to provide a surplus for export as well as for internal distribution to food-deficit areas in Nepal. Increase in cash crop production would provide raw materials not only for the doemestic market but also for the export market. Incremental farm production of major crops under the proposed scheme is 784,300t as presented in TABLE 5-32. With the implementation of the irrigation scheme, farm labor requirements are estimated to rise due to higher cropping intensities requiring more labor. It is expected that employment in the rural and urban non-farm sector would increase correspondingly as additional demands for marketing, transport and processing facilities arise. During the construction period of irrigation facilities, construction works would temporarily open employment opportunities for the people in the Project area.

A diversion power station (61MW) and a Kamla Dam power station (32MW) will significantly contribute to regional economic growth in providing relatively inexpensive electricity not only for domestic but also for industrial, agricultural and commercial uses in the region.

5.5.7 Sun Kosi Multipurpose Scheme

The Sun Kosi Multipurpose Scheme (Case SK-400-BK) has the highest priority among various schemes in the Kosi River Water Resources Development Master Plan. It is a multipurpose project aimed at irrigation and hydropower development. The scheme will contribute greatly to the integrated socioeconomic development of Nepal by creating a substantial increase in agricultural production through modernized irrigation of approximately 175,000ha and an attractive hydropower development scheme. Irrigation water for the scheme is supplied from the Sun Kosi River basin which is diverted through a 16.6km long diversion tunnel with $72m^3/s$ discharge.

The governments of Nepal and India concluded an agreement on utilization of Sun Kosi River Water in 1966. Moreover when planning a project in the upper stream compensation flow to downstream areas is generally considered. Accordingly, in order to allow compensation to downstream areas from the future diversion site, it is recommended that a regulation dam on the Sun Kosi River be combined with the Sun Kosi Multipurpose scheme. SU-3 should be combined to the Sun Kosi Multipurpose Scheme as a regulation Dam for the following reasons.

1) Of the above 3 sites, Sun Kosi No. 1 has the largest catchment area and consequently a large sedimentation volume in the reservoir. This will decrease effective capacity of the same thus preventing increase of regulated water. This reservoir has therefore been excluded from the diversion plan.

2) As Sun Kosi No. 2 has a large effective capacity of $3{,}040\,10^6 m^3$, potential for large increase in regulated water may be expected. The largest monthly average discharge for diversion was $117.9 m^3/s$ (April 1969) with an effective capacity of $3{,}040\,10^6 m^3$. Estimated average increase in regulated water during the 6 month dry season is $195 m^3/s$. With combined use of the reservoir and a diversion tunnel with discharge of $72 m^3/s$ therefore, diversion should be possible without harmful effects on downstream water users. As the dam is planned for energy export however, implementation of the same is not envisioned in the near future.

3) Maximum reservoir capacity of Sun Kosi No. 3 permitted by topographical and geographical conditions is $560\,10^6 m^3$. Increase in downstream regulated water in April with this capacity is $46.7 m^3/s$. As discharge a the Kurule intake site is at the minimum in April ($72 m^3/s$), downstream discharge decreases to $105.1 m^3/s$. The latter, however, represents 80% of the Kurule site natural flow of $130.4 m^3/s$ and therefore the same is considered reasonable.

5.6 River Management

5.6.1 General

River management has two functions; one is river control to protect land and communities along the river from damage mainly due to floods, and the other is utilization of water resources for various activities.

Water resources development in the Kosi Basin, particularly the proposed large reservoir projects, will promote river management in the same. The above mentioned river management development components could not be clarified in the present study. However, the following general descriptions and recommendations were made.

5.6.2 Flood Control

(1) Kosi Basin

As mentioned above, the Kosi Basin is a vast catchment area. Forest area in the same is rapidly disappearing and as a consequence the water holding capacity of the soil has greatly decreased while peak flood discharge has increased.

In general flood control consists of construction of a large scale reservoir within a catchment area to reduce peak flood discharge and mitigate flood damage in the lower reaches. Several reservoir plans, as mentioned in 5.3, were formulated under the present Study, including 3 projects on the Sun Kosi (Sun Kosi No. 1-3), one on the Sapt Kosi (Sapt Kosi High Dam Project) and one on the Tamur River (Tamur No.1). Of these, Sun Kosi No. 2 with an effective reservoir volume of $2,700 10^6 m^3$ and the Sapt Kosi High Dam with $4,420 10^6 m^3$ were considered to have large scale reservoirs sufficient for flood control. Large reservoir capacity for flood control could not be obtained at other sites due to topographical limitations and heavy sedimentation.

As the Sapt Kosi is endowed with an expansive catchment area and long water course, flood discharge continues for a period of several days. According to the probable maximum flood hydrograph for the Kosi High Dam Project proposed by India, the peak flood discharge of $43,000 m^3/s$ continues for 7 days while flood baseflow with a peak discharge of over $10,000 m^3/s$ continues for 100hrs. In this case, if the discharge curve is assumed to form a triangle, total volume of peak discharge over 10,000m^3/s is estimated as; (43,000m^3/s - 10,000m^3/s) x 100hrs x 1/2 = 5,940$10^6 m^3$. As the peak discharge curve is not in fact trinngular the required volume for flood control will be about 7,000$10^6 m^3$. Moreover the flood baseflow of 10,000m^3/s mentioned above is a safe discharge for the Sapt Kosi in the Terai Area (Chatra -Barakshetra).

Maximum peak flood discharge and total annual runoff discharge at the Barakhshetra site[1/] for the present Study are tabulated below.

MAXIMUM PEAK FLOOD DISCHARGE AND TOTAL ANNUAL RUNOFF DISCHARGE TO BARAKHSHETRA

Year	Max. Peak Discharge (m^3/s)	Annual Total Runoff ($10^9 m^3$/year)
1965	6,650	42.8
1966	10,810	52.2
1967	8,830	47.8
1968	25,840	61.9
1969	8,130	53.3
1970	13,840	62.6
1971	12,170	63.4
1972	10,700	47.6
1973	7,820	56.6
1974	11,410	58.2
1975	9,200	57.2
Average	11,580	54.9

1/ Feasibility Report prepared by India.

Study of flood control for the Sapt Kosi was conducted in the Kosi High Dam Project Study. Study of flood control for the 3 main tributaries of the same, the Sun Kosi, Arun and Tamur rivers, has yet to be undertaken.

The Team calculated the probability curve of peak flood discharge at the conjunction of the 3 tributaries by the Hazen Plot Method, utilizing maximum daily discharge records from 1966-78 for each river. Results of the same adjusted to the flood curve at the dam site for the Kosi High Dam Project Study are presented below. Peak flood discharge and flood wave measurement must be made to determine flood volume of the Sun Kosi, Arun and Tamur rivers and evaluation should take place based on the results of the same.

PEAK FLOOD DISCHAGE (HAZEN METHOD)

(Unit: m^3/s)

Return Period	Sapt Kosi ($CA=61,000km^2$)	Sun Kosi ($CA=19,000km^2$)	Arun Kosi ($CA=36,000km^2$)	Tamur Kosi ($CA=6,000km^2$)
5	20,300	8,200	8,200	4,300
10	22,700	9,200	9,200	4,700
20	25,100	10,300	10,100	5,100
100	30,100	12,300	12,200	5,900
200	32,100	13,100	12,900	6,300
1,000	36,700	15,100	15,000	7,100
10,000	43,000	17,800	17,600	8,200

The Sun Kosi No. 2 dam site has a catchment area of $10,400km^2$, 1/6 of that for the Sapt Kosi High Dam site, and probable peak flood discharge in 10,000 years is estimated at a maximum of $17,100m^3/s$, based on the study of design flood for existing and on-going dam projects in Nepal. The maximum average monthly flow of $4,000m^3/s$ for the Sun Kosi No. 2 dam site between 1968-75 was selected as the base flow during flood period. The flood control objective was accordingly set at $13,000m^3/s$ and, as the peak period was estimated at about 30 hours, 1/3 of that for the Sapt Kosi, peak cut for the required flood control volume is as follows: $13,000m^3/s \times 30hrs \times 1/2 = 702^{10^6}m^3$.

Although peak out for the above is 13,000m^3/s, that for the Terai Area where flood devastation is likely to occur is estimated at about 10,000m^3/s as the plain is about 200km from the Sun Kosi No. 2 site.

Finally, the following items should be noted and considered for further study.

1) As flood data was scarce, study was based on extremely rough estimations.

2) The predicted flood area on the Kosi River includes the 40km distance from Chatra to Bhimnagar Barrage. Embankments were constructed along both banks of the river in the said area in 1963 and flood damage has not occured since that time.

3) However, an annual 5cm rise in the riverbed has been reported from Chatra to Bhimnagar Barrage, resulting from sedimentation. Accordingly, increased embankment height or flood mitigation by means of an upstream reservoir will be required in the near future.

4) Although conditions on the Indian side are not clearly known, flood control on the Kosi River will greatly benefit India as well.

5) The Sapt Kosi High Dam Project reservoir is the most promising method of Kosi River flood control. Use of Sun Kosi flood control is less promising as it is far from the flood devastation area and its catchment basin is small.

6) The following are required for flood control planning on the Kosi River in the future:

a) long-term flood gauging on the Sapt Kosi, Sun Kosi, Arun and Tamur rivers;

b) socioeconomic survey of predicted flood areas;

c) establishment of predictable inundation areas;

d) study of embankment stability from Chatra to Bhimnagar Barrage; and,

e) flood control requirements on the Indian side.

(2) Terai

The numerous medium and small rivers flowing into the Terai Area are natural flows without dikes or bank protection. The banks of the same are consequently subject to erosion with each flood, changing the river channel and resulting in loss of valuable farmland. As the Terai Zone is the most arable area in Nepal, efforts are required to protect the same from flood.

The river channel should be stabilized by bank protection works or by construction of dikes and farmland should be protected by afforestation on the river banks. At the same time, flood control capacity should be included and a plan for soil and water conservation through afforestation and earth dams etc., should be developed. These steps are essential to agricultural development of the Terai Area.

A large scale reservoir is presently planned in the middle reaches of the Kamla River (the Kamla Dam Project) under the Study. The said reservoir will supply irrigation water to about 175,000ha of farmland on both sides of the river. Reservoir volume is large (Ve: $492 10^6 m3$) with a comparatively low dam height. As the catchment area is only 1,450km^2, flood control for the Kamla River will be uncomplicated. However, discharge data and flood gauging for the Kamla and other small rivers in the Terai Area are unobtainable. Accordingly, formulation of a flood control plan for the Kamla River is presently impossible and data for the same must therefore be collected in subsequent studies.

5.6.3 River Training

Under the present Study, a river training plan in the vicinity of the confluence of the Trijuga and Sapt Kosi rivers was studied. The Trijuga River joins the Sapt Kosi on the right bank of the latter in its lower reaches about 21km upstream from the Bhimnagar Barrage on the Indian border. The catchment area of the Trijuga River is about 800km^2 and the Chandra Canal Barrage is located about 7km upstream from the confluence of the said rivers.

The Chandra Canal runs southwest in approximately parallel alignment with the Sapt Kosi. The area between the 2 rivers consists of farm fields and numerous farm villages, of which Fatehpur, located near the Chandra Canal Barrage, is a particularly lively center with a daily bazaar.

The barrage is equipped with 5 intake gates for the canal and 5 sediment trap spillway gates. Riverbed slope upstream of the barrage is a gentle 1/1,000-1/1,500. Except for the intake area, the front face of the dam is almost entirely covered by sediment accumulation. Results of an interview survey indicate that water level during annual floods is as high as 1.5m above the dam crest.

Due to irrigation canal intake, almost no water flows downstream of the barrage during the dry season. Both banks of the Trijuga River downstream from the barrage however, are eroded by high water levels during floods. Although annual erosion of fields due to flood is minimal, the effects of the same are evident on the Trijuga's right bank.

As farm fields near the confluence of the Trijuga and Sapt Kosi rivers are 1m or more above Sapt Kosi flood levels, flood damage to personal property was previously unknown in nearby rural communities. Similarly, as 9km of the 21km distance from Bhimnagar Barrage to the confluence point on the right bank is 1-2m above Sapt Kosi flood levels, embankments have not been constructed although spur dikes have been installed. Embankments have been constructed by India along the remaining 12km as well as 1-2km of spur dikes. Survey results are as follows:

a) Minimal flood damage occurs on the right bank of the Sapt Kosi at the Bhimnagar Barrage due to approximately 12km of embankment and spur dikes. Renewal of embankments in the said area is not considered necessary.

b) Embankments about 7km from the Bhimnagar Barrage have suffered about 10m of damage from field drainage and consequently bank protection and drainage works are required.

c) Although there are no embankments for about 9km from the end of the embankment 12km upstream of the Bhimnagar Barrage, construction of the same is not considered necessary as land elevation is 1-2m higher than flood level. Bank protection works are required however, to arrest erosion of the banks during flood periods.