HIS MAJESTY'S GOVERNMENT OF NEPAL

FEASIBILITY STUDY ON SAPT GANDAKI HYDROELECTRIC POWER DEVELOPMENT PROJECT

INTERIM REPORT I

JULY 1981

JAPAN INTERNATIONAL COOPERATION AGENCY

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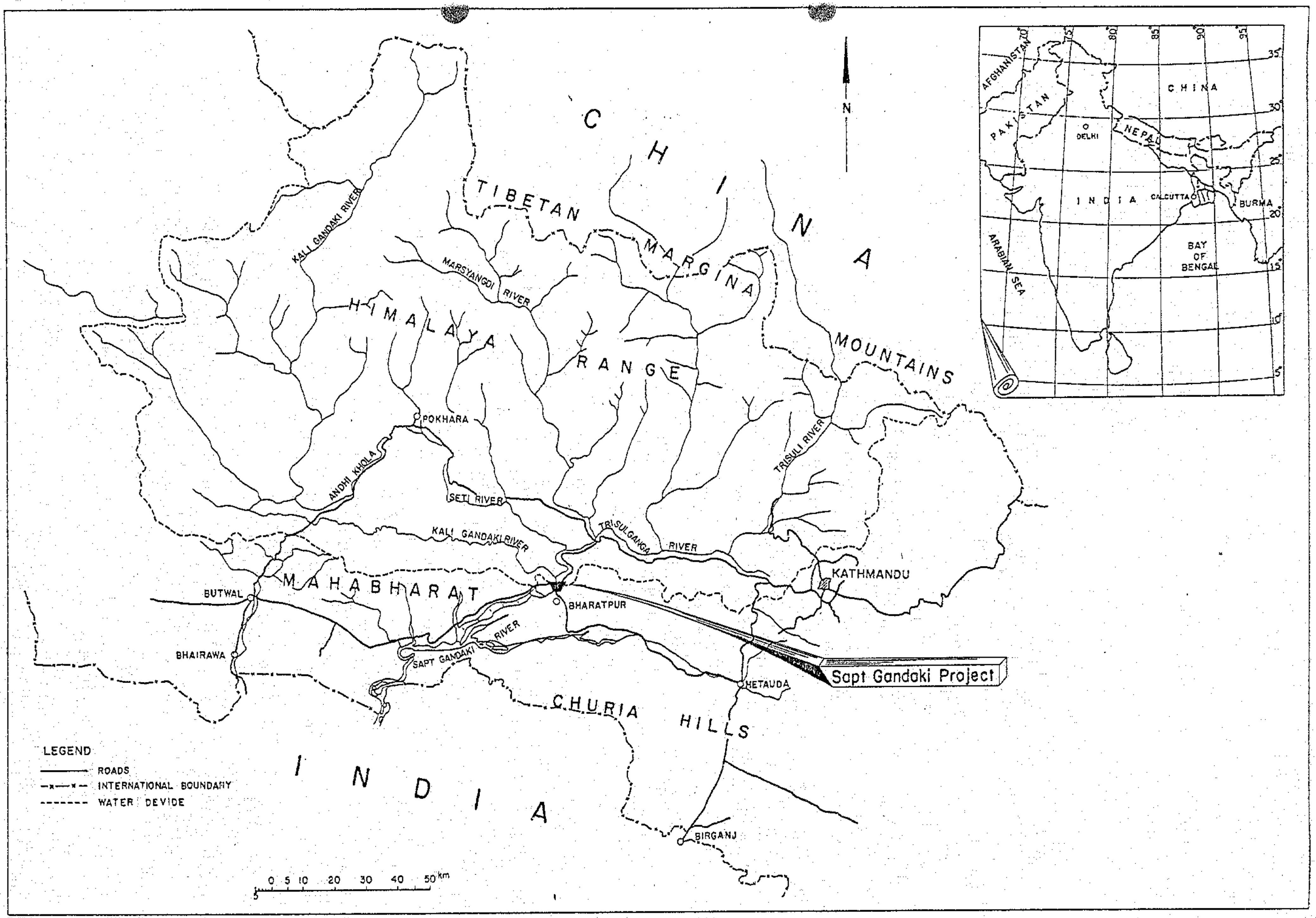

CHINA
TIBETAN MARGINA
HIMALAYA RANGE
MOUNTAINS
KALI GANDAKI RIVER
MARSYANGDI RIVER
POKHARA
ANDHI KHOLA
SETI RIVER
KALI GANDAKI RIVER
TRISULGANGA RIVER
TRISULI RIVER
KATHMANDU
MAHABHARAT
BUTWAL
BHAIRAWA
BHARATPUR
SAPT GANDAKI RIVER
HETAUDA
CHURIA HILLS
BIRGANJ
INDIA
Sapt Gandaki Project
N
LEGEND
ROADS
INTERNATIONAL BOUNDARY
WATER DEVIDE
0 5 10 20 30 40 50 km
5
AFGHANISTAN
PAKISTAN
CHINA
NEPAL
DELHI
INDIA
CALCUTTA
BURMA
ARABIAN SEA
BAY OF BENGAL
70 75 80 85 90 95
35 30 25 20 15 10 5

SUMMARY AND CONCLUSION

PROJECT AREA

1. The Sapt Gandaki River drains a basin of about 31,000 km^2 in the southern part of the Central Nepal before entering into the Inner Terai Plain. The river is abundant in stream flow and its annual average runoff amounts to about 1,600 m^3/sec.

   The area widely spreading in the south of Narayangarh in the Inner Terai Plain which is a lenticular basin elongated in the east-west direction and called the Chitwan Valley is blessed with new developments. Now in progress are an east-west paved highway reached from Hetauda, a new 132 kV transmission line running east-west, a new north-south highway connecting with the Kathmandu - Pokhara road at Mugling and the Chitwan Valley irrigation scheme of 8,600 ha with a pump station. Such a situation makes the development of the Sapt Gandaki River more attractive in view of its accessibility and regional development.

2. The electric power demand in Nepal, now about 65,000 kW, has almost reached to the supply capacity, so that a power deficit occurs from time to time and a load shedding program is being imposed in the load center, Kathmandu area.

   In view of such a chronic power shortage, the Electricity Department which is responsible for the planning and construction of power generation and transmission facilities in Nepal is planning to develope the Sapt Gandaki Project in an appropriate time.

3. The Sapt Gandaki Hydroelectric Project is located just downstream of the confluence of the Kali Gandaki and Trisulganga, both the tributaries of the Sapt Gandaki. The site is about 4 Km north of Narayangarh.

OBJECTIVES OF THE STUDY

4. The Feasibility Study of the Sapt Gandaki Hydroelectric Power Development Project consists of three stages, namely Stage I, II and III. The objectives of Stage I Study are to roughly clarify the geological condition of the dam foundation at the proposed damsite and collection of the relevant information for the project. Another objective is to make the preliminary technical and economic evaluation using those data available to see if it is justifiable to go into the succeeding Stage II and III Studies.

5. After the geological, technical and economic feasibility are verified, the Stage II Study which includes the field survey of topography, construction materials and hydrology in more details will be commenced at the beginning of August, 1981. In the Stage III Study, the detailed study consisting of the design, construction planning and cost estimate of the project components will be carried out to fully prove the feasibility of the Project.

FIELD SURVEY OF STAGE I

6. JICA dispatched a field survey team which consisted of 10 members to the site for 2 months from February 1 to March 31, 1981. The field survey included the power demand survey, hydrological observation, construction material survey and geological investigation inclusive of core boring, water pressure test and seismic exploration, among which the stress was placed on the geological survey, particularly on the depth of gravel deposit in the river channel, which is a key factor to construct a dam at the site.

PRESENT STATUS AND PROJECTION OF POWER DEMAND

7. The total installed capacity of power in Nepal is 77.1 MW as of 1980 out of which available output is 63.6 MW. However, the power supply condition is getting worse as seen in the fact that the annual increase rate of power supply was drastically down from 10.1 % of 1977/78 to 4.2 % of 1978/79 in the whole Nepal.

8. The increase of power and energy demands was estimated as a function of the expansion of power supply capacity and distribution facilities. The annual growth rate of peak demand was projected at 17.9 % during 5 years from 1980/81 to 1985/86 and 10.5 % during 5 years from 1985/86 to 1990/91. The maximum power demand in 1990/91 would reach 283 MW, while energy demand would be 1,203 GWh by assuming the load factor ranging from 45 % to 50 %.

9. The power and energy requirements will be met until 1990/91 by the construction in series of the power plants such as the Kulekhani No.1 Seti, Devighat, Marsyandi, Kulekhani No.2 and Mulghat plants. To fulfill the power and energy requirements after 1990/91, the Sapt Gandaki plant is urged to be put in service.

DAMSITE GEOLOGY

10. The dam foundation is composed of Neogene sandstones, mudstones, conglomerates and intraformational breccias. Among them, gray and massive sandstones are predominant. As the result of the above investigation, it was confirmed that the river gravel deposit in the proposed site was within an acceptable thickness, more or less than 20 m, and the geological condition might allow to construct high dam by appropriate design of structures and foundation treatment.

11. Another problem is mechanical strength of the foundation rock. In view of flood diversion during the dam construction works, it is preferable to design the dam in concrete gravity type, at least partly, whereas it appears that the shear strength of the rocks of Siwalik formation may be marginal for concrete gravity dam of ordinary form. In-situ shear test of the foundation rock in the Stage II is essential for design and cost evaluation of the dam.

HYDROLOGY

12. The annual average runoff at the damsite was estimated to be 1,600 m^3/sec based on the runoff data observed for a time period between 1963 and 1980. The average discharge of each month ranges from 5,389 m^3/sec on August to 275 m^3/sec on March. The maximum discharge of 16,050 m^3/sec was recorded on August 5, 1974. The flood frequency analysis indicated that the magnitude of the 200-and 1000-year floods are 18,000 and 21,000 m^3/sec respectively. On the other hand, the sediment yield into the reservoir was estimated to be 4,000 m^3/year/km^2.

PLAN FORMULATION

13. Though the reservoir has the storage capacity of 346 x $10^6 m^3$ by setting full supply level to EL.220 m, the reservoir is expected to be filled up by three years, since the sediment trapped by the reservoir will become 118 x $10^6 m^3$/Year considering the catchment of about 31,000 km^2. The hydropower plant installed is considered as a run-of-river plant with the effective storage volume of 12 x $10^6 m^3$ required for the daily operation by setting the minimum operation level to EL.216 m and by assuming that a channel will be formed with the spillway width.

OPTIMIZATION OF THE INSTALLED CAPACITY

14. The optimal installed capacity of the Sapt Gandaki is, for the time being, determined to be 200 MW at which the benefit-cost ratio is maximum. The energy produced with the installation of 200 MW is 1,416 GWh per year, of which firm and secondary energy are 753 and 663 GWh, respectively. The capacity factor through the year is estimated at 81 %.

PRELIMINARY DESIGN

15. A preliminary design of the Sapt Gandaki dam is prepared based on the results of geological investigation of Stage I. As for the main part of the dam, a concrete gravity type is selected in consideration of the large magnitude of floods. In determining a typical section of the gravity dam, the shearing strength of the base rock is tentatively assumed to be approximately 7 kg/cm^2 for cohesion and 40° for internal friction angle. The concrete dam so designed is about 70 m high from the bedrock and 900,000 m^3 in volume. The spillway is capable to release the flood up to 25,000 m^3/sec (10,000-year flood) with the freeboard of 2 m.

16. Since much gravels of 10 to 20 cm in diameter scatter in the river bed to such extent that the coffering works of using the sheet piles are very difficult, a diversion method consisting of the construction of wide diversion channel on the left bank and the up- and downstream cofferdams is adopted. Taking into account the large seasonal variation of the river runoff, the construction of the dam is planned to be made in the dry season from November to May. The river flow of more than 2,000 m^3/sec is allowed to flow over the construction area in the first wet season.

17. In view of a risk that the concrete dam may be found uneconomical or impracticable due to less shear strength of the bedrock by the further investigations, an alternative plan of embankment dam was worked out. This plan involves a far larger diversion scheme and an embankment dam of more than 2 million cubic meters in the river channel. The project cost and construction time roughly estimated on this plan are almost same as on the plan of the concrete dam. Further study will be needed on this plan in the successive stage of the study.

CONSTRUCTION SCHEDULE

18. A construction plan is prepared based on the preliminary design of the project components. It takes nearly 6 years (67 months) for the construction of dam and appurtenant structures from the commencement of the works. In addition to the construction period, 2 years are necessary for the finance arrangement, supplemental investigation, tender and contract awarding.

19. Assuming that the additional investigation and design for tender are commenced in the middle of 1983, the power commissioning of the project could be made by the end of 1990. As the electric power demand in Nepal is estimated to grow to some 283 MW and 375 MW in 1990/91 and 1994/95 respectively, it is recommended to put the initial 100 MW in service in 1990/91 and the additional 100 MW in 1994/95.

PROJECT COST

20. The project construction cost for 200 MW installation is estimated to be US$283 million at a price level of early 1981 excluding the cost of the price escalation. The cost up to the initial installation of 100 MW is estimated to be US$258 million. The estimate is based on the latest international tender price of the large scale dam project in Nepal.

CONCLUSION

21. The feasibility of the Project is tentatively examined by the economic internal rate of return (EIRR). The value of EIRR of the project is estimated to be 16.0 %. It is preliminarily confirmed that the Project is technically and economically feasible and that the proceeding to the successive studies, Stage II and III of the Project is warranted justifiable.

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CHAPTER 1 INTRODUCTION

The installed power capacity in the whole Nepal is, at present, 77 MW out of which 64 MW is available. The major power consumed in the Kathmandu area is being supplied by the hydro-power plants which share 64 % of the available installed capacity. As the hydro-power plants installed are almost a run-of-river type and the first reservoir type power plant will be the Kulekhani No.1 which will be commissioned on 1981/82, the power supply capacity is decreased in winter of the low flow season, while power demand is high in winter.

As Nepal is a mountainous country with the ranges such as the Great Himalayan Range and the Tibetan Marginal Mountains, there are isolated towns and villages. The electric power supply for these towns and villages is made by diesel generators, of which the installed capacity including the supply to the central demand area is 24.2 MW and shares 31.4 % of the available installed capacity.

On the other hand, the electric power demand is 64.8 MW as of 1979/80. As the electric power demand has almost reached to the supply capacity, the increase rate of power demand is drastically down from 10.1 % of 1977/78 to 4.2 % of 1978/79. A load shedding program is, at present, being imposed on the big demand center and the applications of new consumers are suspended.

The idea to harness the Sapt Gandaki River for hydroelectric development was firstly presented in the "MASTER PLAN OF HYDROELECTRIC POWER DEVELOPMENT IN NEPAL" which was prepared by JICA and submitted to HMG in September, 1974. The project which was named Dev-Ghat in the report is located just downstream of the confluence of the Kali Gandaki and Trisuli Ganga Rivers, both the tributaries of the Sapt Gandaki.

In the above report, the project is classified into the group of medium scale hydro power development and it was recommended that an installed capacity of the power plant be 150 MW and operation of the power plant be commenced in 1984/85, following the installation of power plants of both Kulekhani No.1 and 2 projects, to meet the increasing power demand of the system in Nepal. In making the study of the said master plan, no detail site survey was carried out besides the site reconnaissance in the project area.

In 1979, Snowy Mountain Engineering Corporation (SMEC) prepared the prefeasibility report for the Sapt Gandaki Hydroelectric Project based on the field investigations and studies carried out under the contract with United Nations Development Programme (UNDP).

It is stressed in this report that further investigation, especially for geological condition of the dam foundation, is needed to fully assess the economic and technical soundness of the project.

In view of the pressing need of hydropower development to follow the projects presently in progress, HMG officially requested the Government of Japan to provide technical assistance for the feasibility study of the Sapt Gandaki Project in December 1980.

The Government of Japan agreed to the request and sent a JICA's preliminary survey mission in December, 1980, to discuss the scope of works of the Project with HMG. The mission made an agreement of the Scope of Work (S/W) on the Sapt Gandaki Hydroelectric Power Development Project with HMG.

The study consists of Stage I, II and III. The objectives of the Stage I Study are to carry out the geological investigation of the dam site and to collect the relevant data and information for the project. Its objective is also to make preliminary technical and economic assessment of the project using the data obtained to see if it is justifiable to enter to the Stage II Study.

According to an agreement on the Scope of Works, the field survey team in Stage I has been dispatched by JICA and the team arrived at Kathmandu on February 2, 1981 and left there March 30, 1981 after finishing the field investigation. This Interim Report I is prepared and submitted to HMG as a fruit of the Stage I Study.

The Stage II Study will be commenced after the preliminary technical and economic feasibility is verified by the Stage I Study. The field survey of topography, geology, construction materials and hydrology will be made in details. The Interim Report II will be prepared and submitted to HMG as the results of Stage II Study.

The Stage III Study which follows the field survey of the Stage II Study performs the design, construction planning and cost estimates of the structures. Based on the above information, the economic and financial evaluations of the project will be made. The Draft Final Report will be prepared and submitted to HMG as the results of the Stage III Study. The Final Report of the Feasibility Study on the Sapt Gandaki Hydroelectric Power Development will be prepared and submitted to HMG after the comments of HMG are discussed and made clear.

CHAPTER 2 BACKGROUND

2.1 General Geography and Topography

Geography: The Kingdom of Nepal lies along the southern slopes of the Himalayan Ranges. The country extends between India and the Tibetan Plateau of China from North-West to South-East. Its rectangular-shaped land covers an area of 141,059 km^2 with about 800 km length from East to West and about 130 km to 240 km width from North to South. The land is situated between the latitudes of 26°30' N to 30°15' N and the longitudes of 80°00' E to 88°15' E.

Topography: The land of Nepal of which 83 % is mountainous and 17 % is in the Terai plains, comprises six topographic zones; they include, from the south to the north, the Terai Belt, Siwalik Hills, Mahabharat Mountain Range, Mid-land zone, Himalayan Range and the Tibetan Plateau.

The Terai belt extends from the left bank of the Ganges River and lies between the Indian border and the foot of the Siwalik Hills. It has an altitude ranging from about 60 m to 300 m and a width from about 15 km to 40 km.

The Siwalik Hills rises sharply from the Terai belt up to an altitude of 1,500 m. Main features of the Siwalik Hills are characterized by its rugged relief, dense forest, poor soil consisting of soft sandstone rich in mica and quartz and large-grained conglomerates.

The Mahabharat Range rises to an altitude of some 3,000 m. Geologically, it is a front of the big overthrusted nappes, the breakers against the Siwaliks. In general, the Mahabharat Range forms a large syncline which covers nearly the whole length of the country.

The Midlands of Nepal covers a zone of about 65 km to 100 km in width between the Mahabharat Range and the Himalayas. The Midland zone has a terrain of very gentle slopes lying at altitudes ranging from about 600 m to 2,000 m. The midland is very fertile. All kinds of fruits, vegetables and grains of subtropical and moderate climate are grown.

The main range of the Himalayas is divided by the big traversal rivers into different groups. The main range of the Himalayas forms the border line between Nepal and Tibet in its eastern part.

In the western part, Nepalese territory extends far beyond the main range of the Himalayas into the Tibetan Plateau. The Tibetan Plateau in Nepal consists of a mountain desert between 3,000 m and 5,000 m in altitude. With irrigation, barley and other grains are raised besides potatoes.

Climate: The climate of Nepal is affected by the physical features of the land. Terai Belt and Siwalik Hills are dominated by sub-tropical climate with maximum temperature rising over 40°C in summer (April and May) and minimum temperatures falling to 4°C in winter (January).

The air temperature in the Mahabharat Range and the Midlands is usually 6°C to 7°C lower than that of the Terai Belt and the Siwalik Hills. The annual precipitation in the Terai Belt is about 2,200 mm to 2,500 mm, and over the Mahabharat Range varies from about 2,500 mm in the east to 1,000 mm to 1,500 mm in the west. The Himalayan Ranges and the Tibetan Plateau have a climate peculiar to the high mountains, with maximum temperatures up to only 21°C and the minimum temperatures falling below freezing point. The annual precipitation in the Himalayan Ranges and the Tibetan Plateau is below 1,000 mm. The average annual rainfall of Nepal is about 1,500 mm.

2.2 General Economy

Administration: Nepal is administratively divided into 14 zones and subdivided into 75 districts. At the same time, in the execution of economic development policy, Nepal is divided into the Central (with central town of Kathmandu), Eastern (Dankuta), Western (Pokhara) and Far Western (Surkhet) Development Regions as shown in Figure 2-1.

Population: The population of Nepal is estimated at 14.0 million in 1980. The annual growth rate of population is estimated at around 2.2 % these several years as depicted in Table 2-1. The population density in 1980 was 99 persons per square km. The two thirds of Nepal's population are crowded on the mountains and hilly areas, where the fertility of the soil is depleted and where deforestation is common. The resultant mas migration to the southern plain of the Terai leads to the cultivation of marginal lands, soil exhaustion and also deforestation.

Employment: Lack of employment is a serious problem. Official statistic register unemployment at 6 %. Underemployment is wide-spread and greater in magnitude than the employment. According to the National Planning Commission of HMG, unemployment in rural and urban areas was 63 % and 45 % in 1976/77. In the Sixth Plan, it is the policy of the government to place high priority in its development program and planning to the expansion of employment and the reduction of underemployment.

GDP: The Gross Domestic Product of Nepal amounted to Rs.17,344 million (=US$1,445 million) in 1976/77 at current market price as tabulated in Table 2-2. The GDP per capita was estimated at US$110 in the same year. The growth rate of GDP in 1976/77 was estimated at 3.2 % per year. The agriculture sector was the major contributor to GDP occupying 62 % followed by service sector (20 %). The manufacturing sector contributed to GDP by only 4 %. The historical data on GDP is shown in Table 2-2.

Foreign Trade: The share of exports and imports in national income was 5 % and 15 % respectively in 1979/80. During the fiscal year 1979/80, exports earned Rs.1,305.7 million and imports costed Rs.3,053.2 million; as a result, the balance of international trade brought a deficit of Rs.1,747.5 million (US$145.6 million). The main export items are rice, maize, oil seeds, hides and skins, butter, tea, jute, timber, carpet and handicrafts. The main items of import are machineries, semi-processed raw materials, construction materials, vehicles, etc.

The foreign exchange holdings in 1979/80 amounted to Rs.2,133.2 million (US$177.8 million), which can pay the import four months.

Agriculture: Agriculture is the mainstay of the Nepalese economy. About 90 % of the population is engaged in agriculture and agro-based industries. Agriculture supplied 80 % of exports and 60 % of the GDP in 1976/77. In addition, it provides much of the raw materials for industries.

Industry: Industry is in an infant stage of development, with fewer than 60,000 persons employed in about 3,500 firms. Despite various problems faced by the country, industrial output has increased by 6.7 % per year, during the Fifth Plan, and its contribution to GDP was 4 %. The policy of the Government in the Sixth Plan is to give priority to the development of import-substituting industries, e.g., cement, textile, paper, iron and steel etc., and to the development of cottage and small-scale industries with a view to expanding employment opportunities.

Tourism: Tourism continued to play a significant role in Nepalese economy. Tourism industry has become one of Nepal's major sources of foreign exchange earnings. Convertible foreign exchange earnings from tourism increased from Rs.120.7 million in 1974/75 to Rs.518.7 million in 1979/80. The number of tourist having visited Nepal amounted more than 162,000 in 1979 as shown in Table 2-3.

Development Plan of Nepal: The Fifth Plan (1975 - 80) ended in June 1980 and the Sixth Plan (1980 - 85) came into operation in July 1980. The first and foremost aim of the Sixth Plan is to get agriculture moving, building on the base of past investments in infrastructure, agriculture, transportation and communications and looking to more directly productive investments, better utilization of manpower and increasing productivity.

The total outlay during the Sixth Plan (1980 - 85) is projected as Rs.33.94 billion, of which Rs.20.49 billion is to be invested in public sector, Rs.11.65 billion in private sector, and Rs.1.8 billion in the Panchayat sector (Local bodies). Allocation of the total development expenditure for the Sixth Plan is given in Table 2-4.

Water Resources: Nepal is rich in water resources. The total hydropower potential is estimated at 83,000 MW of which less than 0.1 % is at present exploited. Water resources development would contribute to the economic development of the country as well as to the development of agriculture, by irrigation including pumping, potential for electrified transportation system, needs for industry, and by exporting the hydroenergy produced.

Consumer Price: The consumer price has been increasing by the rate of 4.6 % per year in the period of 1975 - 1979 as shown below (1975 = 100).

Year	1975	1976	1977	1978	1979	1975/79
Price Index	100	98.9	105.8	112.6	119.6	-
Annual Increase (%)	-	-1.1	7.0	6.4	6.2	4.6

Table 2-1 HISTORICAL POPULATION OF NEPAL

Year		Millions	Growth Rate
1971	(Population Census)	11.56	
1972		11.81	2.2
1973		12.06	2.1
1974		12.32	2.2
1975		12.59	2.2
1976		12.86	2.1
1977		13.14	2.2
1978		13.42	2.1
1979		13.71	2.2
1980		14.01	2.2

Source: Monthly Bulletin of Statistics, April 1981, Vol. XXXV, United Nations

Table 2-2 HISTORICAL GDP AND ITS SECTORAL COMPOSITION

		1974/75	1975/76	1976/77
Gross Domestic Product (GDP)				
GDP at current market prices	(Rs.mn.)	16,571	17,394	17,344
GDP at 1974/75 constant prices	(Rs.mn.)	16,571	17,300	17,853
Growth rate (%)		n.a.	4.4	3.2
Per capita GDP (US$)		90	100	110
GDP (at current market prices by industry) (%)				
Agriculture, forestry and fishery		69.7	66.8	62.3
Mining and manufacturing		2.8	3.1	4.1
Construction		1.0	1.1	1.7
Electricity and water supply		0.3	0.2	0.3
Transport and communications		2.7	4.6	6.9
Commerce		4.4	4.8	4.9
Other services		19.1	19.4	19.8
Total GDP		100.0	100.0	100.0

Source: "Economic Memorandum of Nepal", ADB, January 1979

Table 2-3 TOURIST ARRIVAL AND HOTEL BED

	1975	1976	1977	1978	1979
1. Number of Tourist	92,440	105,108	129,329	156,123	162,276
2. Number of Hotel Beds	1,663	2,099	4,600	4,888	5,018

Note: Calendar year

Source: Department of Tourism thru "Economic Survey" 1979/80, Ministry of Finance, 1980

Table 2-4 ALLOCATION OF THE TOTAL DEVELOPMENT EXPENDITURE, 1980-85

(At 1979/80 Prices)

Rs. in million

	Public Sector 1/	Panchayat Sector	Private Sector	Total	%
Agriculture, Irrigation and Forest	6,260	490	3,820	10,570	31.1
Industry, Mining and Power	5,280	30	3,500	8,810	26.0
Transport and Communications	4,230	540	1,106	5,870	17.3
Social Services 2/	4,720	740	3,230	8,690	25.6
Total	20,490	1,800	11,650	33,940	100.0

Source: The Sixth Plan (1980-85), A Summary, Part 1, National Planning Commission, January 1981.

1/ Of the total development expenditures of Rs.21.75 billion to be incurred in the public sector, the sum of Rs.1.26 billion which is to go to other sectors as financial assistance, has been included in the sectors concerned instead of lumping it up with the public sector expenses. Of the net development outlay of Rs.20.49 billion, 60 percent or Rs.12.30 billion, is estimated to be spent in the form of investment.

2/ The amount shown under the head social services also includes expenses relating to residential housing construction and other miscellaneous development expenditures also.

CHAPTER 3 PRESENT STATUS AND PROJECTION OF POWER DEMAND

3.1 Organization and Power Supply System

Power development and supply are administratively controlled under the Ministry of Water Resources. The Electricity Department (ED), a department of the Ministry of Water Resources, is a sole agent respondsible for the planning and construction of the power generation facilities and transmission lines in Nepal. Besides, there are three semiautomonous management organizations, Nepal Electricity Corporation (NEC), Eastern Electricity Corporation (EEC) and Butwal Power Company (BPC). The organization charts of the Ministry of Water Resources and ED are shown in Figure 3-1 and 3-2, respectively.

The total installed capacity of power in Nepal as of 1980 is 77.1 MW. The electric power supply system in Nepal is divided into four regions, Eastern, Central, Western and Far West as shown in Figure 3-3. NEC is in charge of the power supply in the Central and Western Regions except the Butwal area with installation of 66.7 MW in 1979, BPC for Butwal area with installation of 4.3 MW, and EEC for the Eastern Region with installation of 5.2 MW. The power supply for the Far Western Region is directly made by ED with installation of 0.8 MW. The installed capacity and available output of the four regions are summarized as depicted in Table 3-1 and 3-2.

3.2 Power Supply Condition

The power supply conditions of the whole Nepal and the four regions are shown in Table 3-3 and 3-4, respectively. According to the records, the annual increase rate of power supply was drastically down from 10.1 % of 1977/1978 to 4.2 % of 1978/1979 in the whole Nepal. In the Central Region which has the demand center of Kathmandu, the annual increase rate of power supply was down from 8.3 % in 1977/78 to 2.3 % in 1978/79. On the other hand, the power supply in the other three regions was stably increased, even though the power demand is beyond the power supply capacity.

The reason why the power supply is getting worse especially in the Central Region is that the power required in the Central Region is mainly supplied with the domestic plants. On the other hand, the power supply in the other three regions is supported with local diesel generators and import from India based on the mutual-dependent contract on power supply between Nepal and India.

The energy consumed in the Central Region was 171.7 GWh in 1978/79 as shown in Table 3-4, while the energy of 175.2 GWh was generated with the domestic plants in the Central Region. The balance was made with the minor swapping of 2.7 GWh import and 6.2 GWh export. Thus, the power and energy in the Central Region are supplied with the domestic plants.

On the other hand, the energy of 54.3 GWh was consumed in the Eastern, Western and Far West Regions in 1978/79 as shown in Table 3-4. Out of that figure, energy of 38.0 GWh was imported from India. To get the power supply from India, the towns near the bordor between Nepal and India are connected with the Indian power grid as shown in Table 3-5.

The daily load curves of the Central Nepal Power System (CNPS) for summer and winter are shown in Figure 3-4 and 3-5, respectively. The load factors of summer and winter are 56.3 % and 75.0 %, respectively. Considering that electric heaters are used in winter, the power and energy demands in winter are expected to be higher than those in summer. However, the peak power supply in winter is actually less than that in summer as showin in Figure 3-4 and 3-5. Thus, it is considered that the power supply capacity of the system in winter is far short for the peak demand due to the insufficient capacities of the hydropower plants.

The serious power shortage on the system in winter is endorsed by the facts that a load shedding program is being imposed on a continuous rotation basis to the region covered by each substation and that applications of new consumers are suspended. In February, 1981, the targeted amount of the load shedding was about 15 MW on an average and, even with this load shedding, the system supply condition was very poor. The system voltage at the substation was about 8.5 KV, 46 cycles instead of the rated voltage of 11 KV, 50 cycles. At that time the available output was only 37,250 KW (Installed capacity 51,700 KW except the Gandak P/S, because outputs of almost all the existing power stations were less than their rated capacity due to flow shortage and various troubles).

From the above condition, it can be assumed that, if the normal proper voltage of 11 KV is kept in the system, the total power demand including the load shedding would be about 74 MW in rough estimate without consideration of diversity ratio. This means that if the supply condition is kept normal, the maximum demand would be more than 63 MW in actual condition and that under such condition the total installed capacity would not be sufficient for the present power demand. Thus, the Kathmandu area is keenly demanding the early completion of the Kulekhani hydropower project.

Figure 3-6 and 3-7 show the monthly peak power demand and generated energy in CNPS. There are two peaks in winter of November to January and in summer of May to June, because electric heaters and air conditioners are used in winter and in summer, respectively.

3.3 Power Demand Projection

The population in Nepal is estimated to be 14 million in 1980 as depicted in Table 2-1. Assuming that a household consists of 6 persons, the number of households becomes 2.3 million. On the other hand, the domestic consumers of electricity are estimated to be 99,600 in 1978 as shown in Table 3-6. The electrification rate in Nepal is as low as 4.3 %.

The gross domestic product (GDP) in Nepal was estimated in the preceding chapter. The GDP per capita of Nepal was only 1,330 Rs (about 111.3 US$). The average increase rate of GDP per capita per annum was 0.2 % during the five years period from 1974/75 to 1979/80, while the annual growth rate of power demand in the same period was 10.5 % on an average. The electricity consumption per capita is only 13.7 KWH per annum in 1979/80.

The above conditions show that the estimation of future power demand by correlation with GDP in Nepal would be very difficult, and it would be reasonable to assume that the power demand increase will be the function of the expansion of power supply capacity and distribution facilities. After the completion of the Kulekhani No.1 and reinforcement of the Kathmandu distribution system, the present load shedding and low voltage supply will be improved. From this view point, power demand will increase remarkably within several years in the Central Region. In the other three regions, the lift irrigation systems of about 5 MW capacity in each area are planned by the Irrigation Department. If power for the water pumps is available, these plan would be realized immediately. These increments of load in these areas are also considered.

Under these circumstances, the power and energy demand projection is made as shown in Table 3-7 and Figure 3-8 and 3-9. The annual growth rate of peak demand is estimated to be 17.9 % during 5 years period from 1980/81 to 1985/86 and 10.5 % during 4 years period from 1985/86 to 1990/91. The drastic increase of growth rate is expected for 5 years after completion of the Kulekhani No.1 power station and improvement of the distribution system. The maximum demand in 1990/91 fiscal year would be 283 MW. The projection of energy demand is made by assuming the load factor ranging from 45 % to 50 %.

3.4 Expansion Program

To improve the chronical power shortage, the Kulekhani No.1 and Devighat hydropower stations in CNPS and the Seti hydropower station in the Pokhara area are under construction.

The Marsyangdi and the Kulekhani No.2 power stations are proposed to be constructed after the completion of the Kulekhani No.1 Power Project. There are several hydropower projects under investigation such as the Sapt Gandaki (tentatively proposed output of 200 MW) in the Central Region and the Mulaghat hydropower station (proposed output of 36 MW) in Eastern Region.

The implementation program of these hydropower plants is assumed as shown in Table 3-8 and Figure 3-8 and 3-9. The available capacity of the existing plants is derived from Table 3-1. The energy which can be generated by the existing plants is estimated by assuming the capacity factor of 0.65.

To transmit the generated power from these plants, the plan of transmission line of 132 KV is scheduled to be implemented as given in Table 3-9 and Figure 3-3. According to this construction schedule, the supply systems of all the four regions are to be interconnected to single grid system. Taking into account this situation, the load forecast of the Sapt Gandaki Project will be discussed as a unit grid system in the whole Nepal.

The power and energy requirements will be met until 1990/91 by the construction of the power plants such as the Kulekhani No.1, Seti, Devighat, Marsyangdi, Kulekhani No.2 plants, and Mulghat even though a minor deficit occurs in 1984/85 and 1985/86. To fulfill the power and energy requirements after 1990/91, the Sapt Gandaki Project should be put in service. As explained in the succeeding chapter, the Sapt Gandaki Project is preliminarily planned to have an installed capacity of 200 MW. The first two units with 100 MW will be able to satisfy the power requirement until 1994/95, namely 4 years after commissioning the first units. The second two units with 100 MW should be commissioned in 1994/95 to especially meet the power requirement. As the second two units will be able to satisfy the power and energy requirements until 1998/99, the Sapt Gandaki Project will be able to satisfy the power and energy requirement for 8 years after the commission of the first units.

A route of transmission line for the Project is proposed between the damsite and Kathmandu as shown in Figure 3-10. The transmission system of 132 KV is proposed with the substations at Bharatpur and Kathmandu as shown in Figure 3-11 (the costs of transmission line and substation are not included in the Project cost).

Table 3-1 INSTALLED CAPACITY AND AVAILABLE OUTPUTS OF EXISTING POWER PLANTS (1981)

Unit: KW

Region	Hydel P/S	Diesel P/S	Steam P/S	Total P/S	Available output in dry season
Eastern Reg.	240	3,592	1,400	5,232	4,800
Central Reg.	46,590	18,488	1,600	66,678	54,240
Western Reg.	2,000	1,650	700	4,350	3,800
Far Western Reg.	345	500		845	745
Total:	49,175	24,230	3,700	77,105	63,585

Table 3-2 DETAILS OF INSTALLED CAPACITY

Unit: kW

Eastern Region	
Dhankuta Hydel P/S	240
Biratnagar Diesel P/S	2,934
Dharan Diesel P/S	212
Bhadrapur Diesel P/S	446
Biratnagar Jute Mill Steam P/S	1,400
Sub Total	5,232
Central Region	
Trisuli Hydel P/S	18,000 (Spare set)
Sunkosi " "	10,050
Pananti " "	2,400
Sundarijal "	640
Pharping "	500
Gandak "	15,000
Mahendra Diesel P/S	1,696
Patan " "	1,490
Hetauda "	4,470
" "	10,000
Janakpur "	832
Birganji Sugar Mill Steam P/S	1,600
Sub Total	66,678
Western Region	
Pokhara Hydel P/S	1,000
Butwal " "	1,000
Pokhara Diesel P/S	1,038
Bahairahawa "	500
Krishnanagar " "	112
Mahendra Sugar Mill Steam P/S	700
Sub Total	4,350
Far Western Region	
Nepalganj Diesel P/S	500
Surkhet Hydel P/S	345
Sub Total	845

Table 3-3 POWER AND ENERGY SUPPLY IN NEPAL

Year	Energy Supplied to: Domest.	Indus.	Comm.	Street light & Others	Total Sold	Station Use	Total Utilized	Loss		Total Supplied Energy	Yearly Rate of Increase	Energy: Produced in Nepal	Imported from India	Exported to India	Aggregated Max Demand	Yearly Rate of Increase
	MWH	MWH	MWH	MWH	MWH	MWH	MWH	MWH	%	MWH	%	MWH	MWH	MWH	KW	%
1970/71	24866	20443	4611	1188	51108	1692	52800	19901	27.4	72701		72084	617		19020	
1971/72	32918	21605	5164	1049	60736	1767	62503	24203	27.9	86706	19.3	84691	2015		24490	28.8
1972/73	38775	26470	5975	1241	72461	1783	74244	29346	28.3	103590	19.5	100713	5201	2324	29690	21.1
1973/74	47710	28646	6526	1378	84260	1840	86100	34894	28.8	120994	16.8	115884	8812	3702	34430	16.0
1974/75	54070	32868	7912	1505	96375	2311	98686	37896	27.7	136582	12.9	126569	14634	4621	40670	18.1
1975/76	61820	40336	9191	1711	113058	2462	115520	43890	27.5	159410	16.7	139978	25372	5940	43860	7.8
1976/77	65770	50469	10427	1927	128593	2455	131048	46815	26.3	177863	11.6	154838	29141	6116	49230	12.2
1977/78	71351	56497	13068	2250	143166	2238	145404	55763	27.7	201167	13.1	174411	32726	5970	54235	10.1
1978/79	77224	60656	18020	2292	158192	3603	161795	64154	28.4	225949	12.3	191483	40626	6160	56495	4.2
1979/80																

Table 3-4 POWER AND ENERGY SUPPLY IN FOUR REGIONS (1)

1. Eastern Region

Year	Energy Supplied to: Domest.	Indus.	Comm.	Street light & Others	Total Sold	Station Use	Total Utilized Energy	Loss	Loss	Total Supplied Energy	Yearly Rate of Increase	Available Energy: Generated	Imported	Export	Max Demand	Rate of Increase	Yearly Load Factor
	MWH	MWH	MWH	MWH	MWH	MWH	MWH	MWH	%	MWH	%	MWH	MWH		kW	%	%
1970/71	1630	10428	31	367	12456	143	12.599	1085	7.9	13684		13067	617		3240		48.2
1971/72	1849	10838	38	182	12907	133	13.040	1286	9.0	14326	4.7	12311	2015		3490	7.7	46.9
1972/73	2155	11956	34	259	14404	101	14.505	1592	9.9	16097	12.4	11282	4815		3800	8.8	48.4
1973/74	2626	11982	33	287	14928	100	15.028	1783	10.6	16811	4.4	10226	6585		4130	8.7	46.5
1974/75	3322	11929	15	325	15591	105	15.696	2180	12.2	17876	6.3	7492	10384		4915	19.0	41.5
1975/76	4086	14785	18	395	19278	109	19.387	3459	15.1	22846	27.8	4747	18099		5285	7.5	49.3
1976/77	5958	17755	22	334	24069	130	24.199	983	3.9	25182	10.2	6524	18658		6565	24.2	43.8
1977/78	6846	17192	–	555	24593	139	24.732	3211	11.5	27943	11.0	7249	20694		7715	17.5	41.3
1978/79	7812	19854	–	668	28334	137	28.471	3233	10.2	31704	13.5	5794	25910		8690	12.6	41.6

2. Central Region

Year	Energy Supplied to: Domest.	Indus.	Comm.	Street light & Others	Total Sold	Station Use	Total Utilized Energy	Loss	Loss	Total Supplied	Yearly Rate of Increase	Available Energy: Generated	Imported	Export	Max Demand	Rate of Increase	Yearly Load Factor
	MWH	MWH	MWH	MWH	MWH	MWH	MWH	MWH	%	MWH	%	MWH	MWH		kW	%	%
1970/71	22826	9574	4576	794	37761	1516	392777	18443	31.9	57720		57720			15340		42.9
1971/72	30131	9392	5090	800	45413	1523	46936	22295	32.2	69231	20.0	69231			19540	27.4	40.4
1972/73	35205	12952	5910	879	54946	1596	56542	26713	32.1	83255	20.0	85540	39	2324	24010	22.9	39.6
1973/74	42495	14627	6394	919	64435	1585	66020	31938	32.6	97958	17.7	101319	341	3702	27760	15.6	40.3
1974/75	47734	17628	7778	936	74076	1872	75948	34170	31.0	110118	12.4	114025	714	4621	32610	17.5	38.5
1975/76	52921	21330	8951	961	84163	1450	85613	37946	30.7	123559	12.2	127798	1701	5940	34460	5.6	40.9
1976/77	53825	27410	10133	1024	92392	1186	93578	42882	31.4	136460	10.4	140033	2543	6116	37705	9.4	41.3
1977/78	56200	33195	12792	1101	103288	805	104093	49727	32.3	153.820	12.7	157527	2263	5970	40870	8.3	42.9
1978/79	60468	33393	17987	927	112775	2173	114948	56749	33.0	171697	11.6	175193	2664	6160	41840	2.3	46.8

Table 3-4 POWER AND ENERGY SUPPLY IN FOUR REGIONS (2)

Western Region

Year	Energy Supplied to: Domest.	Indus.	Comm.	Street light & Others	Total Sold	Station Use	Total Utilized Energy	Loss		Total Supplied Energy	Yearly Rate of Increase	Available Energy: Generated	Imported	Export	Max Demand	Rate of Increase	Yearly Load Factor
	MWH	MWH	MWH	MWH	MWH	MWH	MWH	MWH	%	MWH	%	MWH	MWH		kW	%	%
1970/71	410	348	13	27	798	33	831	361	30.2	1192		1192			400		34.0
1971/72	938	1174	36	67	2215	111	2326	595	20.4	2921	45.1	2921			1370		24.3
1972/73	1256	1302	31	88	2677	66	2743	966	26.0	3709	26.9	3521	188		1650	20.4	25.7
1973/74	1976	1701	99	104	3880	73	3953	924	18.9	4877	31.4	3887	990		2020	22.4	27.6
1974/75	2093	2452	119	136	4800	278	5078	1103	17.8	6181	26.7	4659	1522		2400	18.8	29.4
1975/76	3465	2848	222	173	6708	878	7586	1931	20.3	9517	54.0	7098	2419		3005	25.2	36.2
1976/77	4311	3543	272	378	8504	1077	9581	2218	18.9	11799	24.0	7921	3878		3550	18.1	37.9
1977/78	5017	4279	276	385	9957	1207	11164	1746	13.5	12910	9.4	9143	3767		3800	7.0	38.8
1978/79	5515	5224	33	449	11221	1167	12388	3136	20.2	15524	20.2	9660	5864		4200	10.5	42.2

For Western Resion

Year	Energy Supplied to: Domest.	Indus.	Comm.	Street light & Others	Total Sold	Station Use	Total Utilized Energy	Loss		Total Supplied Energy	Yearly Rate of Increase	Available Energy: Generated	Imported	Export	Max Demand	Rate of Increase	Yearly Load Factor
	MWH	MWH	MWH	MWH	MWH	MWH	MWH	MWH	%	MWH	%	MWH	MWH		kW	%	%
1970/71		93			93		93	12	11.4	105		105			40		30.0
1971/72		201			201		201	27	11.8	228		228			90		28.9
1972/73	159	260		15	434	20	454	75	14.2	529		370	159		230		26.3
1973/74	613	336		68	1017	82	1099	249	18.5	1348	155.	452	896		520		29.6
1974/75	941	859		108	1908	56	1964	443	18.4	2407	78.6	393	2014		745	43.3	36.9
1975/76	1354	1373		182	2909	25	2934	554	15.9	3488	44.9	335	3153		1110	49.0	35.9
1976/77	1676	1761		191	3628	62	3690	732	16.6	4422	26.8	360	4062		1410	27.0	35.8
1977/78	3288	1831		209	5328	87	5415	1079	16.6	6494	46.9	492	6002		1850	31.2	40.0
1978/79	3429	2185		248	5862	126	5988	1036	14.7	7024	8.2	836	6188		2070	11.9	38.7

Table 3-5 POWER EXCHANGE AT BORDER TOWNS

As of Dec. 1977

	Name of Town	Initial Supply	Committed Power	Supplied Date from	Present Max. Demand
1.	Mahendranagar	100 kW at 11 kV	500 kW at 33 kV	From July 1973	350 kW
2.	Dhangadhi	50 kW at 11 kV	500 kW at 33 kV	From 1974	310 kW
3.	Nepalgunj	150 kW at 11 kV	1,200 kW at 33 kV From March 1974	From Feb. 1973	1,150 kW
4.	Koilabas		800 kW at 33 kV (March 1973)	From Feb. 1974	120 kW
5.	Bhairahawa	200 kW at 11 kV	1,200 kW (Dec. 1973)	From March 1973	1,110 kW
6.	Krishnanagar	500 kW at 400 Volts	1,000 kW (Dec. 1973)	From Nov. 1973	420 kW
7.	Bhadrapur	200 kW at 11 kV	1,000 kW	From March 1975	600 kW
8.	Sirha	100 kW at 11 kV	200 kW		170 kW
9.	Gaur		300 kW		230 kW
10.	Janakpur & Jaleshwar	100 kW at 11 kV	1,000 kW	From April 1974	1,000 kW
11.	Malangawa	100 kW at 11 kV	200 kW Export	From April 1974	180 kW
12.	Birganj	100 kW at 11 kV	5,000 kW Export	From March 1973	1,500 kW
13.	E.E.C. Biratnagar	By 33 kV	6,800 kW		3,250 kW
	Total: Import		14,700 kW		8,990 kW
	Export		5,000 kW		1,500 kW

Note: All these towns are receiving power from Indian Grid except Birganj town.

Table 3-6 NUMBER OF CONSUMERS BY CATEGORY
FISCAL YEAR 2035/36 (1978/79)

DEVELOPMENT REGION	Domestic	Indus-trial	Commer-cial	Others	TOTAL
EASTERN (DHANKUTA)					
Ilam	125			2	127
Bhadrapur	1,412	48		12	1,472
Dhankuta	610	6		6	622
Dharan	2,312	76		18	2,406
Birathagar	4,054	203		61	4,318
Rajbiraj	1,146	43		18	1,207
Siraha	452	35		8	495
Sub-Total	10,111	411	-	125	10,647
CENTRAL (KATHMANDU)					
Janakpur	1,517	77		2	1,596
Jaleswar	486	22			508
Malangawa	328	17			345
Gaur	397	14		2	413
C.N.P.S.	71,028	1,249	71	18	72,366
Sub-Total	73,756	1,379	71	22	75,228
WESTERN (POKHARA)					
Pokhara	2,875	55	5	1	2,936
Tribeni	152	3		4	159
Parasi	247	12		3	262
Tansen	897	13		1	911
Bhairahawa	1,825	93		6	1,924
Lumbini	132	6		3	141
Taulihawa	504	15		7	526
Bahadurgunj	265	21		9	295
Krishnanagar	436	12		4	452
Butwal Power Company	1,213	72		1	1,286
Sub-Total	8,546	302	5	39	8,892
FAR WESTERN (SURKHET)					
Goorahi-Tulsipur*	150			10	160
Koilabas*	275	4		9	288
Surkhet	230	5		1	236
Nepalgunj	2,205	697		8	2,910
Dhangadhi	697	16		9	722
Mahendranagar	519	28		4	551
Sub-Total	4,076	750	-	41	4,867
GRAND TOTAL	96,489	2,842	76	227	99,634

Remarks: * The exact data are not available and the estimated figures are presented.

Table 3-7 POWER AND ENERGY DEMAND PROJECTION

Year	Eastern Region Max. Demand kW/2	Eastern Region Required Energy MWH	Eastern Region Load Factor %	Central Region Max. Demand kW/2	Central Region Required Energy MWH	Central Region Load Factor %	Western Region Max. Demand kW/2	Western Region Required Energy MWH	Western Region Load Factor %	Far Western Region Max. Demand kW/2	Far Western Region Required Energy MWH	Far Western Region Load Factor %	Whole Nepal Max. Demand kW/2	Whole Nepal Required Energy MWH
1977/78	7,715	27,943	41.3	40,870	153,820	43.0	3,800	12,910	38.8	1,850	6.494	40.0	54,235	201,167
1978/79	8,690	31,704	41.6	41,840	171,697	46.8	4,200	15,520	42.2	2,070	7,024	38.7	56,800	225,945
1979/80	10,260	43,050	45	46,900	184,900	45.0	5,100	17,880	40.0	2,540	8,900	40.0	64,800	254,730
1977/78 - 1979/80 /1	15.2	24.1		7.1	9.6		15.8	17.7		17.2	17.0		9.3	12.5
1980/81	12,110	49,280	47	53,740	225,970	48	5,850	20,500	40	3,130	10,970	40.0	74,830	306,720
1981/82	14,300	56,370	"	61,580	242,740	45	6,560	22,980	"	3,750	13,140	"	86,170	335,230
1982/83	16,400	67,520	"	77,900	307,100	"	8,520	29,870	"	4,510	15,800	"	107,330	420,290
1983/84	18,500	76,170	"	92,000	378,800	47	10,910	38,230	"	5,180	18,150	"	126,590	511,350
1984/85	21,160	87,120	50	107,600	442,900	"	13,750	48,170	"	6,480	22,710	"	148,990	600,900
1985/86	24,000	98,810	"	122,150	502,900	"	14,490	57,110	45	10,170	31,180	35	170,810	690,000
1980/81 - 1985/86 /1	14.7	14.9		17.8	20.3		19.9	22.7		26.5	23.2		17.9	17.6
1986/87	27,200	119,140	50	132,300	556,200	48	17,380	68,530	45	13,160	40,350	35	190,040	784,220
1987/88	30,800	134,900	"	144,500	607,800	"	19,990	78,800	"	16,130	49,450	"	211,420	870,950
1988/89	34,800	152,420	"	156,700	672,500	49	22,990	90,640	"	18,660	57,210	"	233,150	972,770
1989/90	39,600	164,690	"	173,400	744,300	"	26,120	102,980	"	20,930	64,170	"	260,050	1,076,140
1990/91	44,800	196,220	"	186,400	816,400	50	28,200	118,400	"	23,500	72,050	"	282,940	1,203,070
1986/87 - 1990/91 /1	13.3	13.3		8.9	10.0		10.2	14.6		15.6	15.5		10.5	11.3
1977/78 - 1990/91 /1	14.5	16.2		12.4	13.7		16.7	18.5		21.5	20.3		13.5	14.7

Note /1 Average annual compound growth by %.
/2 Agrigated max. demand.

Table 3-8 CONSTRUCTION SCHEDULE OF POWER PLANTS

Name of P/S	Capacity, MW	Available annual energy, GWH	Condition	Date of commission
1. Kulekhani No.1	60.0	171.50	under construction	1981/82
2. Seti	1.0	5.26	"	1982/83
3. Devighat	14.4	91.98	"	1984/85
4. Marsyangdi	70.0	260.0	under D/D	1985/86
5. Kulekhani No.2	33.3	95.1	F/S done	1986/87
6. Mulghat	36.0	158.00	under F/S	1987/88
7. Sapt Gandaki	200.0	1,100.00	under F/S	1990/91

Table 3-9 CONSTRUCTION SCHEDULE OF 132 kV TRANSMISSION LINE

From - To	Length km	Expected Completion Date
1. Bharatpur - Pokhara	86	1982
2. Hetauda - Janakpur - Biratnagar	260	1984/85
3. Butwas - Dumkibas	50	1983
4. Butwas - Nepalganj	225	1985/86
Total Length	621 km	

CHAPTER 4 SITE CONDITION

4.1 Topography

The Sapt Gandaki River is located in the southern part of Central Nepal. The site considered for hydropower development is situated in the foothill of the Mahabharat Range, around 0.5 km downstream of the confluence of the Kali Gandaki and Trisuliganga Rivers. After the confluence, the Sapt Gandaki River flows through a gorge confined with low cliffs at both banks which is about 200 m wide at EL.180 m and 2.5 km long in a reach, and then finally enters into the Inner Terai Plain. At the entrance of the Inner Terai Plain, about 4 km from the damsite, there is a town, Narayangwarh which will be the communication center of the Project.

The watershed of the Sapt Gandaki River faces to the Karnali and West Rapti River basins in west and to the Sun Koshi and Bagmati River basins in east. The catchment of the Sapt Gandaki River is measured to be 31,100 km^2 at the damsite. The elevation of the basin ranges from EL.8,000 m at the peak of the Great Himarayan Range to EL.180 m at the damsite. The mean slope of the river channel is around 0.0015.

4.2 Geology

4.2.1 Regional Geology

General: The Trisulganga River and the Kali Gandaki River as shown in the location map head in the Tibetan Marginal Mountains, then pass through an area of granitic rocks and ancient metamorphic rocks gathering many tributaries and finally meet at 1 km upstream of the Sapt Gandaki Damsite, after which it is called the Sapt Gandaki River. The damsite area is underlain by the Tertiary sedimentary rocks of the Siwalik Group which bounds on the above mentioned metamorphic rocks along the east-west trend Main Boundary Thrust running about 5 km north of the damsite.

Stratigraphy: As shown in the Figure 4-1, the oldest stratigraphic unit within the reservoir area consists of a variety of Paleozoic metamorphic rocks which are exposed in the northern part of the Main Boundary Thrust. On the otherhand in the sourthern side of the Main Boundary Thrust, the Tertiary sedimentary rocks of the Siwalik Group widely spread upto the flat alluvial plain of the Chitwan Valley.

The Siwalike Group of this area consists of (1) banded sandstones and slates, (2) banded sandstones and mudstones, (3) massive and pebbly sandstones and (4) conglomerates from lower to upper. The banded sandstone and slate formation occupy the strip bounded by the Main Boundary Thrust and a inner Siwalik fault. The upper part of the banded sandstones and slates formation, and the lower part of the banded sandstones and mudstones formation are petrographically similar and may be the same horizon.

The Sapt Gandaki damsite is located on the gradual transition of the banded sandstones and mudstones formation, and the massive and pebbly sandstones formation. The other unit of geological facies is alluvial terrace deposits which develop on various elevations and are classified into four terraces as shown in the Figure 4-1. It is remarkable that the terrace IV is thickly developed in front of the Main Boundary Thrust and a inner Siwalik fault and includes thick cemented conglomerates and breccias. The layers of cemented conglomerates and/or breccias are observed not only in the terrace IV deposits, but also in other terrace deposits except the terrace III which widely extends on the left bank of the damsite.

Folding and Faulting: The most striking structural feature is the Main Boundary Thrust which is located in the nothern part of the reservoir area and bounded the Paleozoic Midland Group and the Tertiary Siwalik Group. There are two other prominent faults of a inner Siwalik fault and a foothill fault with east-west trend as the Main Boundary Fault has the same trend. An anticline extends in the northern side of a foothill fault and plunges to the east. Strikes of bedding, an axis of folding and directions of faulting are harmonic in their directions.

4.2.2 Damsite Geology

General: The Damsite is located in the straight channel of the Sapt Gandaki River which cuts the Siwalik Hills and flows into the Chitwan Valley. At the damsite the base rock is exposed on both the banks and the river is 200 m wide at the river level.

The right abutment rises at about 20° on an average from river level to about EL.230 m, and then more steeply rises to ridges. The left abutment rises steeply from the river level to about 210 m, then flattened to a gentle slope about 400 m wide underlain by the terrace deposits of unconsolidated soils and gravels.

The foundation of the damsite consists of Neogene sandstones, mudstones, conglomerates and intraformational breccias out of which gray and massive sandstones are predominant. The strike and dip of the strata are N 55° to 65° W and 43° to 53° NE.

Overburden: To survey the thickness of overburden, particularly the depth of the riverbed deposits, was the main object of the site survey in the Stage I. And the results of this survey made it clear as followings (see Fig. 4-2 also).

Site	Depth of the bedrock from the surface	Evidence
Right bank	less than 10 m; including weathered rock zone	Seismic survey SL-1, 2 and 4
Riverbed	more or less than 20 m; in the center of the riverbed	Test drilling B80-1 and 2 and Seismic survey SL-1 and 2
Left bank	20 to 40 meter	Test drilling B80-3 and Seismic survey SL-1, 2, 3 and 6

On the right bank, there are exposed weathered rocks in both the rivulets located just up-and downstream of the damsite. This is suggesting that the overburden on the right bank is generally thin. The result of seismic survey also indicates that the upper layer of low seismic wave velocity of 0.3 km/sec to 0.7 km/sec is only a few to several meters in thickness. The underlying weathered rock zone is indicated by the middle velocity of 1.0 km/sec to 1.5 km/sec.

In the riverbed area, two test borings, namely hole Nos. B80-1 and B80-2, 40 m deep each, were drilled. The core drilling reached the bed rock at the depth of 17.8 m in the B80-1 and 16.2 m in the B80-2 through the riverbed sand and gravel. Together with the result of seismic traverses SL-1 and SL-2, the depth of riverbed sand and gravel is assumed to be more or less than 20 m in the deepest portion.

On the left bank where the terraces are widely developed, a bore-hole No. B80-3, 45 m deep, was drilled this time, while the boring core of hole Nos. DG-1 and DG-2 which have been drilled in 1980 by the Electricity Department's team were available. In these holes the base rock was encountered at 15.2 m, 16.1 m and 29.45 m in the depth in the B80-1, DG-1 and DG-2 respectively from the ground surface through the terrace deposit which consists of silty soil, pebbles, cobbles and boulders.

According to the result of the seismic survey the surface of the base rock overlain by the terrace deposit appeares to be forming flat planes in three steps; i.e. the lower plane is at EL.190 m to 200 m in the width of about 300 m from the riverside to the mountain side. This plane is followed with the middle plane at EL.220 m to 230 m, extending in the width of about 150 m to the further mountain side. On the most mountain side the higher thin terrace widely spreads at EL.260 m to 270 m (see Figure 4-3).

The middle and higher bedrock planes are covered by the terrace deposit in the depths of about 5 m and 10 m respectively, and the upper part of the bedrock in the depth of 5 m to 15 m may be weathered because the seismic wave velocities are 1.3 km/sec to 1.6 km/sec.

On the other hand, the lower bedrock plane is overlain by the thick deposit, 15 m to 40 m deep, which is recognized by both the results of core drillings and seismic traverses. In addition, this bedrock plane appeares rather deeper in the mountain side than in the riverside. This is suggesting that the old river channel, about 130 m wide, existed in the mountain side.

In the terrace deposit of this deeper portion, it seems that an intermediate layer of 0.5 km/sec wave velocity is sandwitched by an upper layer of 0.6 km/sec to 0.7 km/sec and the lower layer of 0.9 km/sec to 1.0 km/sec velocity but its thickness and extension could not be defined, because the seismic refraction method is unable to define a lower velocity layer overlain by a higher velocity layer where refracted seismic wave passes faster.

The composition of this terrace deposit and the extension of the deepest channel will be checked by core drillings and additional seismic traverses in the next survey stage.

Permeability: Field permeability test was performed at thirteen (13) stages in the three bore holes. The results of permeability test are listed in the following table.

Depth	Permeability (cm/sec) Bore hole No. B80-1	B80-2	B80-3
15 to 20 m	-	-	4.35×10^{-5} /1
20 to 25 m	-	1.16×10^{-4}	3.05×10^{-5} /2
25 to 30 m	1.41×10^{-4}	1.61×10^{-4}	1.70×10^{-5}
30 to 35 m	2.3×10^{-4}	1.09×10^{-4}	5.18×10^{-4}
35 to 40 m	2.14×10^{-4}	1.47×10^{-4}	9.01×10^{-4}
40 to 45 m	-	-	5.58×10^{-4}

/1: This test section was in the depth of 16 to 21 m

/2: This test section was in the depth of 21 to 25 m

The permeability of the bedrock varies between 1.7×10^{-5} and 9.01×10^{-4} cm/sec. They may be classified in three groups; i.e. (1) massive but some weak sandstones in the riverbed portion, ranging 1.09×10^{-4} to 2.3×10^{-4} cm/sec, (2) massive sandstones in the bore hole No. B80-3 on the left bank, ranging 1.7×10^{-5} to 4.35×10^{-5} cm/sec and (3) cracky part in the bore hole No. B80-3 on the left bank, ranging 5.18×10^{-4} to 9.01×10^{-4} cm/sec.

Distribution of seismic wave velocities in bedrock

The field seismic wave velocities of the bedrock were measured by the refraction method. On the right bank and the riverside of the left bank, the velocities were 3.0 km/sec to 3.5 km/sec, and in the riverbed and the mountain side of left bank some lower velocities of 2.8 km/sec and 2.9 km/sec were measured. Besides, two low velocity zones, which often imply the existence of faults and/or weak zones, were observed on the left bank along both the seismic traverses SL-1 and SL-6. The location of these low velocity zones are about 300 m and 470 m apart from the river bank respectively.

The lower seismic wave velocity in the riverbed portion than in both abutment was observed on the seismic traverse SL-1 and SL-2 even though the contrast is not so distinct. It may indicate the existence of some minor faults or weakened bedrock, but significant displacement of rocks is not recognized so far as the observation of outcrops on both banks is concerned.

Engineering properties of the bedrock

Three pieces of drilling core have been sampled from the drill hole No. B80-3 and laboratory-tested in Japan. Summary of the test is as follows:

	Test item	Range	Average
1.	Apparent specific gravity	2.15 to 2.50 g/cm^3	2.33 g/cm^3
2.	Porosity	9.1 to 17.4 %	12.1 %
3.	Super-sonic velocity;		
	P-wave	555 to 1260 m/sec	975 m/sec
	S-wave	342 to 739 m/sec	577 m/sec
4.	Uniaxial compression strength	22.0 to 201.3 kg/cm^2	105.5 kg/cm^2
5.	Tensile strength	1.7 to 15.4 kg/cm^2	8.2 kg/cm^2

The velocities of P-wave measured in the laboratory are considerably low compared with the seismic wave velocitieies of 2800 m/sec to 3500 m/sec measured in the field. The difference may be due to the saturated condition of the bedrock in the field and a tendency of the sampled bedrock to disintegrate rapidly when it is exposed in the air.

Provided that the specific gravity and the Poisons ratio of the bedrock are 2.3 g/cm^2 and 0.22 respectively. the dynamic modulus of elasticity is calculated at 1.6×10^5 to 2.5×10^5 kg/cm^2 from the field seismic wave velocity of 2800 m/sec to 3500 m/sec. In case of the seismic velocity being 555 to 1260 m/sec such as measured in the laboratory, the dynamic modulus of elasticity becomes 0.63×10^4 to 3.26×10^4 kg/cm^2.

Considering the uniaxial compression strength of 105.5 kg/cm^2 on an average, it seems that the shearing strength of the bedrock is marginal for the construction of a concrete gravity dam with a height of 60 m to 80 m.

In the next survey stage (Stage II), in-situ loading tests and in-situ block shearing tests are planned to determine a static modulus of elasticity and a shearing strength of the foundation rock for design purpose.*

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* Note: For the time being, the cohesion and the internal friction angle of the bedrock are assumed empirically at 7 kg/cm^2 and 40° respectively for this preliminary study.

4.2.3 Geological Investigation

Geologic data reported here were developed through the Stage I site survey which was carried out in February and March 1981. This site survey contained (1) preliminary geological mapping in the reservoir area, (2) diamond core drilling with permeability test and (3) seismic survey to reveal the site geology, particularly the depth of riverbed deposits.

The geologic data of the drilling log, record of the permeability, time-distance plot of the seismic survey and others are submitted in the Appendix A attached in this report.

4.3 Construction Materials

4.3.1 Previous Study

In the Prefeasibility Report in 1979, SMEC proposed the construction material sources as below.

- Concrete Aggregates

  Coarse Aggregates: River gravel deposits in the Kali Gandaki, Trisulganga and Sapt Gandaki in the vicinity of the damsite.

  Fine Aggregates: Sand deposits in the Jaishri Khola and Khageri Khola.

- Fill Material

  Rockfill: Gravel deposit in the Sapt Gandaki near Narayangarh, or quarry rock from north side of the Siwalik-zone.

  Filter: To be manufactured by crushing or screening river gravels, or transported from the sand sources provided they are coarse enough.

  Earthfill: Red tropical soil covering the right bank of Devi Ghat and the hills on the left bank of the damsite.

Those locations are shown in Figure 4-4.

Field reconnaissance and collection of local informations in the present study confirmed that the above view is generally appropriate. Descriptions of the conceivable materials sources are presented hereunder.

4.3.2 Concrete Aggregates

- Coarse Aggregates

Large quantity of river gravels for coarse aggregate is available in the river channels of the Kali Gandaki, Trisulganga and Sapt Gandaki, within 4 km of distance upstream and downstream of the damsite.

The deposits in the river beds comprise gravels of biotite hornblends quartz gneisses, quartzites, dolomites and other calcareous rocks, schistose sandstones and slates, which are round and hard, ranging predominantly from 2 cm to 10 cm in diameter with mixed cobbles up to 30 cm.

The gravel deposit nearest to the damsite is located at Devi Ghat, the confluence of the Trisulganga and Kali Gandaki. On the left bank of the confluence, 400 m to 1 km upstream of the damsite, formed are a sand and gravel bar with approximately 80 thousand square meters of area. The gravel bed is deemed to be sufficiently thick. If the surfacial 3 m zone is to be scraped, the available quantity in this gravel bar would be 240 thousand cubic meters. Another 550 thousand cubic meters are estimated to be available in sand-gravel bars in Kali Gandaki and on the right bank of the Trisulganga within 2 km upstream of the confluence. The latter will, however, require temporary bridges across the above two rivers for hauling in dry season. If extraction of deeper gravel bed under water is enabled by such method as the use of pump barge, the quantity would be more than doubled.

The other large sand-gravel bars are located 2 km to 4 km downstream of the damsite, where the Sapt Gandaki debouches from the Siwalik Hills into Inner Terai Plain. Area of gravel bars is 270 thousand square meters and the estimated quantity from the top 3 m zone is 800 thousand cubic meters.

- Fine Aggregates

River sands in the Kali Gandaki, Trisulganga and Sapt Gandaki are too fine for concrete aggregate, so far as the deposits in sandgravel bars are concerned.

In this area, sand for concrete has been usually taken from minor rivers which originate in the southern rim of Mahabharat Range and flow southward through Siwalik Hills to Terai Plain. Within 15 km east and west from Narayangarh located are three rivers of this sort, that is, the Khageri, Jaishri and Beldeha Khola. Each of these rivers has medium grained quartz sand deposits apparently around and below the eater level in dry season, whereas the sands in the higher levels of sand bars are often finer or very fine. Particles are largely siliceous, mixed with fine fragments of slates and other sedimentary rocks. Homogeneity of the deposits in the lower levels has not been proved. Local variations of grain size distribution, especially to the finer side, seem possible. Generally speaking, the sands in these minor rivers never appear to be very good sources for fine aggregates. Nevertheless, they can be the sand deposits which are relatively preferable in this vicinity. Pitting, sampling and testing of the materials are essential in the Stage II Study.

The river channels of the Jaishri and Beldeha Khola in the west of Narayangarh are only 20 to 30 m wide in the most part of their course. The deposits are rather meager for required quantity.

The Khageri Khola has a large deposit area, some 100 m wide and 1 km long, in the reach more than 1 km upstream of the bridge on the East-West Highway which is located about 10 km southest from Narayangarh. The sand borrow area may be extended further upstream, if necessary. Accordingly, the Khageri Khola can be one of the sand borrows which deserve the future investigation.

Grading of the Khageri Khola sand, given in the Prefeasibility Report by SMEC (1979) based on the data from Gammon India Ltd., is as follows:

ASTM Sieve	% Passing
3/8 in.	100.0
No.4	97.3
No.8	89.2
No.16	65.9
No.30	45.9
No.50	11.6
No.100	4.6
No.200	0

The other data, kindly provided by N.D.Lea & Associates Ltd., are as follows:

BS Sieve	% Passing		
	Sample 1	Sample 2	Sample 3
3/16 in.	98.3	95.7	92.0
No.7	90.2	89.1	81.2
No.14	76.0	75.8	67.3
No.25	52.5	68.3	61.8
No.52	16.0	9.9	3.0
No.100	0.9	1.9	0.7
FM	2.66	2.59	2.94

Sand in the Khageri Khola is now utilized for concrete in construction of Narayangarh pumping station, Narayan bridge, Mugling road, etc.

Another conceivable source of sand is in the Rapti River which runs from east to west through the Inner Terai Plain south of the East-West Highway. Evading the area of the Mahendra National Park, the haul distance will be 21 km or more. Sand in the Rapti River channel is not always coarse enough but appears well competitive in quality to that of the Khageri Khola. It is reliability in quantity that makes the Rapti sand highly attractive, in spite of relatively longer haul distance. This shall be the alternative sand borrow area for the investigation in Stage II Study.

4.3.3 Fill Materials

- Rockfill Material

In case that the dam is designed in fill type, the conceivable sources of major fill material are river gravels in the Kali Gandaki, Trisluganga and Sapt Gandaki or quarrying from Paleozoic meta-sedimentary rocks in the north of the Main Boundary Fault or Lower Siwalik sedimentary rocks.

The river gravels are hard and sufficiently strong but their majority is less than 20 cm in size and big boulders are rarely contained. To supply 3 million cubic meters from sand-gravel bars, the area of exploitation will cover from 6 km upstream to about 10 km downstream of the damsite or will extend to terrace deposits if suitable.

The Siwalik formation around the damsite is not suitable for quarry because of insufficient strength of the rocks. The possible nearest source of quarry rock is the Lower Siwalik sandstones and slates. Sandstones are massive. Slates are often likely to break into small fragments of 5 to 10 cm in size but can be expected also to produce big blocks. One of the promissing area is located around the Trisulganga 4 km to 7 km north-northeast as the crow flies from Devi Ghat. At least 7 km long haul road should be newly constructed. Otherwise the haul distance would be 14 km in the minimum by utilizing the Mugling road now under construction. The Paleozoic meta-sedimentary rocks are farther northern side of these Siwalik rocks.

- Filter Material

Good filter material is not found in the reasonable distance. It has to be prepared by mixing manufactured coarse sand with the natural sand of the Khageri Khola or Rapti River. Coarse sand should be manufactured by crushing river gravels or quarry rocks.

- Earthfill Material

Red soil, derived from decomposition of Siwalik sandstone and mudstone, covers the terrace which develops around EL.250 m on the left bank of the damsite. Quality of the red soil varies from clayey sand to silty clay, reflecting the original mother rock, and appears predominantly to fall under SC and ML-CL of Unified Classification. According to SMEC (1979), CH and MH also exist, and the soil has near optimum moisture content in the surfacial 1 m zone but drier and denser in the deeper zone. The soil seems good for impervious earth core of fill dam.

The terrace on the left bank is extensively developed between the Sapt Gandaki and Ramnagar village on the Mugling road. Though it is dissected by numerous minor gullies, the red soil crowned area is estimated to be more than 1 million square meters within 2 km from the damsite. Thickness of the red soil varies locally, but sufficient supply is expectable from the left bank area.

Another deposit of the similar red soil is located on the terrace of similar ground height around Keradi village on the right bank of the Kali - Sapt Gandaki at Devi Ghat. The area is estimatedly 300 thousand square meters.

Though this area is closer to the damsite, haul road will be rather difficult to approach because of steep slopes surrounding it. The borrow pit on the left bank is deemed preferable in view of access and preserved quantity of material.

4.4 Meteorology and Hydrology

4.4.1 Meteorology

The Department of Irrigation, Hydrology and Meteorology (DIHM), Ministry of Food, Agriculture and Irrigation is a sole responsible agency to collect and analyze hydrologic and meteorological data in Nepal.

Meteorological data such as rainfall, humidity and temperature summarized in the Climatological Records of Nepal were collected between 1966 and 1975. Though there are 66 rain gages in and around the Sapt Gandaki River basin, rainfall data are available at 21 stations as shown in Table 4-1. The annual average precipitation of these stations for 9 years is 1,826 mm with the extremel values of 263 mm at Jonson (0601) and 3,483 mm at Pokhara (0803). The rainfall concentrates in the wet season between June and September (80 % of total annual rainfall), in which the south-wast monsoon is dominant. May and October are the transition periods from the wet season to the dry season.

The annual average temperature in the basin is 24.1°C through the year. The warmest month in a year is May and temperature is sometimes beyond 30°C. January is the most chilly month in a year, but temperature is not below the freezing point except the higher region.

The annual average relative humidity is around 75 %. April is the driest month in a year and the average relative humidity is around 50 %, while the most humid period is in the wet season between June and September and the average relative humidity reaches 85 %.

4.4.2 Hydrologic Measurements and Data

Runoff data were collected at the stream gaging stations called 450 and 420 located on the Sapt Gandaki and Kali Gandaki Rivers, respectively. The stage readings at those stations are once a day. The records of stage were collected between 1963 and 1979 at the station 450 and between 1964 and 1977 at the station 420 as shown in Table 4-1.

The stream gaging station 450 is located 0.9 km downstream of the Sapt Gandaki Project site. Runoff data estimated by HMG Department of Hydrology and Meteorology, and SMEC were scrutinized using the stage records and the rating curves developed by DIHM and SMEC. Moreover, estimates of runoff after December 15, 1976 were made using the stage records as shown in Appendix B.

The rating curves used for the estimate of runoff are ones developed by DIHM and by SMEC as shown in Figure 4-5. The former rating curve were used for the period May 1963 to July 1970, while the latter one were used for the period Aug. 1970 to Apr. 1980 considering the time when discharge measurements were made by DIHM and SMEC. To confirm the rating curves developed, discharge measurements were performed by the JICA team. The observed discharges as depicted in Table 4-2 are shown as black dots in Figure 4-5. Though the measurements were made on the low flow season due to the limited time period of survey, the observed discharges were well fitted to the rating curve developed by SMEC in the range between 185 m^3/sec and 286 m^3/sec. However, the verification which rating curve is usable at the station 450 depends on the discharge measurements of the Stage II Study.

The discharge rating curve at the Sapt Gandaki damsite as depicted in Figure 4-6 were obtained by adjusting the datum difference of the rating curve developed by SMEC at the station 450. The improvement of the rating curve at the damsite will be made using the river cross sections which will be surveyed in the Stage II Study.

4.4.3 Hydrologic Analysis

The annual average runoff was estimated to be 1,600 m^3/sec based on the runoff data shown in Appendix B. The average discharge of each month at the Project site ranges from 5,389 m^3/sec on August to 275 m^3/sec on March as shown below. The maximum discharge of 16,050 m^3/sec was recorded on August 5, 1974. However, as it is considered that the staff gage was washed away with the flood, it is expected that the historical maximum discharge was bigger than 16,050 m^3/sec. On the other hand, the historical minimum discharge of 131 m^3/sec was recorded on December 27, 1976 and February 3, 1977.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct	Nov.	Dec.
Average discharge, m^3/sec	387	294	275	363	621	1,683	3,979	5,389	3,289	1,733	833	496

The annual average runoff, 1,600 m^3/sec is equivalent to 1,622 mm rainfall on the whole basin. As the annual average precipitation of the basin is estimated to be 1,826 mm, the runoff coefficient becomes 0.89 (1,622/1,826) which would be a high value. It can be considered that average rainfall on the basin is bigger than 1,826 mm.

A flow-duration curve as depicted in Figure 4-7 was prepared using the runoff data shown in Appendix B for the estimate of power and energy generated by the run-of-river plant. The daily discharges for selected exceedance probability are given as shown in the first table of the next page. For the derivation of the flow duration curve, all the available data were used, that is, a time period between May 1963 and April 1980.

	Percentage of time when daily discharge is exceeded									
	10	20	40	50	60	70	80	90	95	100
Discharge, m^3/sec	4,325	2,975	2,211	665	505	405	320	264	220	131

The flood frequency analysis for each month was made for ensuring the time period available for the construction works. The discharges for each recurrence interval as given below and in Figure 4-8 were estimated assuming the hydrologic events are log-normally distributed. It can be seen that discharges of the wet season between June and October are tremendously large compared with discharges of the dry season between December and April.

Return Period in Years	Estimated discharges, m^3/sec											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	450	354	345	560	920	3,648	6,855	7,261	5,070	2,924	1,172	646
5	591	431	418	703	1,184	5,518	8,415	8,760	6,236	4,742	1,433	734
10	684	479	403	795	1,354	6,887	9,392	9,686	6,967	6,145	1,596	785
20	767	521	502	875	1,506	8,204	10,242	10,485	7,604	7,538	1,738	829
25	794	534	514	901	1,554	8,640	10,508	10,734	7,803	8,008	1,782	842

It is unrealistic to estimate the design floods of the spillway from the relationship between rainfall and runoff, because it can not be considered that it rains simultaneously in the extremely large watershed of 31,1000 km^2. Thus, the flood frequency analysis for the design of the spillway was made using the runoff data. The annual instantaneous maximum discharge was observed by 1968. After that, the annual maximum discharge was obtained from the daily mean discharge shown in Appendix B by assuming the hydrograph exponentially recesses.

The flood frequency analysis was made using the log-normal and Gumbel's methods as shown in the table of the next page. As the peak discharge estimated by the Gumbel's method is greater than that estimated by the log-normal method, the Gumbel's method is applied for the estimate of the design floods for the spillway.

Recurrence interval, year	Peak discharge, m^3/sec	
	Log-normal	Gumble's
2	9,100	9,100
5	11,000	11,200
10	12,000	12,500
20	12,900	13,800
25	13,200	14,200
50	14,100	15,500
100	15,100	16,800
200	15,900	18,100
1,000	17,800	21,100
10,000	20,200	25,200

4.4.4 Sedimentation and Water Quality

Sampling of water was made for the estimate of sediment load and water quality. Water samples collected on February and March, 1981 were analyzed by the laboratory of DIHM. The results are summarized as Table 4-3 and Table 4-4.

As for water quality, water is adequate as mixing water of concrete and as potable water during the construction. Moreover, water has no adverse effects on turbines and metals.

The results of suspended load analysis show that suspend load scatters from 24 mg/ℓ to 1206 mg/ℓ, though streamflow ranges from 200 m^3/sec to 220 m^3/sec. Figure 4-9 shows the results of suspended load analysis including the studies performed by SMEC. The relationship between discharge and concentration in Figure 4-9 was developed by SMEC.

The estimate of sediment load into the reservoir is made using the runoff data shown in Appendix B and the relationship between suspended load and discharge. The sediment into the reservoir is estimated to be 4,000 m^3/year/km^2 which is bigger than that estimated by SMEC. It is necessary for the accurate estimate of sediment load to continue the sampling of water.

4.5 Other Information Related to the Project

4.5.1 General

In addition to the data collection mentioned in the preceding chapters and clauses on geology, construction materials, hydrology and power, JICA team visited concerning offices for collection of data and informations on the following items:

Items	Offices Visited
Irrigation	° Department of Irrigation, Hydrology and Meteorology
	° Chitwan Irrigation Project Office
Road	° Road Department Bharatpur Office
	° Gorkha-Narayangarh Highway Project Mugling Office
Fishery	(Local information by enquiry)
Population	° Bureau of Statistic
Commodity Price	° Nepal Rastra Bank
Economic Survey	° Ministry of Finance
	° Agriculture Marketing Service Department
Construction Cost	° Kulekhani Project
	KHDB Office (Employer)
	Nippon Koei (Consultant)
	Sambu Construction Co. (Contractor)

4.5.2 Irrigation schemes in the Chitwan Valley Development Project

The Chitwan Valley consists of alluvial plains and terraces widely spreaded between the Mahabharat Mountains to the North and the Churia Hills to the South as shown in Figure 4-10. In the southern side of the Valley, the Rapti River runs from east to west and the Sapt Gandaki River flows into the Valley from northern side and changes the direction towards south-west, where the Sapt Gandaki River is called as the Narayani River. Both rivers meet each other at the south-east end of the Valley.

As shown in Figure 4-11, a pumping station which is under construction at about 3.5 km downstream of the Sapt Gandaki damsite is situated at the point like pivot of the fan-shaped Valley.

In the Chitwan Valley the area of about 24,000 ha is irrigable, out of which 13,400 ha will be irrigated by the end of 1983, according to the revised implementation schedule of the Chitwan Valley Development Project as shown below and in Figure 4-12.

Chitwan Valley Development Project

No.	Scheme	Area (ha)	Location in the Figure 4-11
1.	Lohathar Scheme	1,900	A, B
2.	Khageri Scheme	600	C
3.	Narayani Scheme (Pumping Scheme)	8,600	I, II
4.	Narayani Extention (Pumping Scheme)	2,300	I (Ext.)
	T o t a l	13,400	

The pumping station above-mentioned will supply water to the Narayani Scheme and Narayani Extention of the Chitwan Project. The installation capacity of this pumping station will be 24.2 m^3/sec, which will require power of 17.3 x 10^6kWh per year. The monthly requirement for pumping is shown in the Table 4-5.

In addition to the above irrigation project, Gandaki barrage was constructed at border area of the Nepal and the India, far downstream from the Sapt Gandaki damsite.

4.5.3 Road

The Gorkha-Narayangarh Highway is under construction and runs along the left bank of the Trisulganga. 4 to 6 km of this road may be submarged in the future reservoir of the Sapt Gandaki Dam, according to the location map of the road which is too small in scale of 1:100,000 in horizontal and 1:10,000 in vertical to study in detail.

The Narayani Bridge which is under construction at about 5 km downstream of the damsite will be completed after two to three years according to the verbal information from the Road Department Bharatpur Office and be utilizable for the construction work of the Sapt Gandaki Project.

4.5.4 Fishery

The present situation of reverine fisheries in the river basin was investigated by reconnaissance, monitoring and collection of information and data.

Reconnaissance was performed around the damsite. Monitoring was carried out on the left bank around 1 km downstream from the damsite, Shimnasu which is located on the right bank around 1 km downstream, Narayangarh about 4 km from the damsite and Shiva Ghat which is located on the left bank around 6 km downstream from Narayangarh.

Data Collection was tried, but any useful data were not available in the offices concerned.

Collected informations as "common knowledge" are as follows:

1. The species, which are locally named as Sahar, Galari, Gard and Phaita, are inhaviting in downstream of the damsite.

2. Fish are caught and consumed locally.

3. Number of fisheries as special occupation is limited around this project area.

4.5.5 Agriculture and industry

The latest population census of Chitwan District conducted in 1971 by the Central Bureau of Statistics gave over 68,590 for the economically active persons, namely for older than 10 years./1 Among those about 60,000 persons are engaged in farming, forestry and fishing.

According to the feasibility report prepared AGRAR UND by HYDRO-TECHNIK GMBH in 1972, the crops of major importance of Chitwan Valley are corn, mustard seed, rice and wheat. The area planted and production of these crops are as follows:

Area Planted, Production of the Main Crops of Chitwan Valley, 1971

1. Crops	2. Area Planted (ha)	3. Production (tons)
Corn	27,000	40,392
Mustard	25,079	12,635
Rice	23,565	33,933
Wheat	3,290	3,429

1/ Population Census-1971, Economic Characteristics Tables Vol. III Part I.

About 60 percent of cereal grains in Chitwan District was consumed in the adjoining hill areas (Dhading, Gorkha, Tanahun, Pokhara, Lamgung and Manag district), Kathmandu Valley and Indian Markets.

The above said report mentioned that there are agriculturally-related industries in Chitwan Valley for the processing of paddy and mustard, but a large percentage of the total market production of these two products are exported in unprocessed condition due to the limited capacities of the local processing plants, etc.

It seems that other kinds of industries are extremely limited in Chitwan Valley.

4.5.6 Data on construction cost

The data on construction cost were obtained from Kulekhani No.1 Hydroelectric Project which is now under construction and deemed to be appropriate project to refer to the current data. The construction cost estimate in Chapter 6 of this Report is based on these data.

Table 4-1 METEOROLOGICAL AND HYDROLOGIC STATIONS

Hydrological Data	Period
1. Climatological Records of Nepal	1964 - 1975
2. Daily Rainfall Records (INDEX NO.)	
- Shera Gaun (0502)	1957 - 1975
- Libang Gaun (0504)	1957 - 1975
- Bijuwar Tar (0505)	1957 - 1975
- Jomsom (0601)	1957 - 1975
- Ridi Bazar (0701)	1958 - 1975
- Tansen Agric (0702)	1956 - 1975
- Butwal (0703)	1956 - 1975
- Beluwa (Girwari) (0704)	1957 - 1975
- Musikot (0722)	1956 - 1975
- Jagat (0801)	1957 - 1975
- Khudi Bazar (0802)	1957 - 1975
- Pokhara (0803)	1965 - 1975
- Kuncha (0807)	1956 - 1975
- Bandiput (0808)	1956 - 1975
- Gorkha (0809)	1956 - 1975
- Chapkot (0810)	1957 - 1975
- Jhawani (0903)	1957 - 1975
- Chisapani Gandhi (0904)	1956 - 1975
- Aru Ghat Dhodeni Bazar (1002)	1957 - 1975
- Nuwakot (1004)	1956 - 1975
- Sundarijar (1013)	1940 - 1975
3. Surface Water Records of Nepal	1965 - 1974
4. Daily Runoff Records	
- Gauging Station 450	1963 - 1979
- Gauging Station 420	1964 - 1977

Table 4-2 DISCHARGE MEASUREMENTS

Date	Gage Height (m)	Discharge (m^3/sec)	Area (m^2)	Mean Velocity (m/sec)
Mar. 22	0.88	286	553	0.52
Mar. 1	0.60	257	519	0.50
Feb. 28	0.55	230	511	0.45
Mar. 19	0.52	205	505	0.41
Mar. 16	0.47	185	497	0.37

Table 4-3 RESULTS OF WATER QUALITY ANALYSIS

Date of Sampling		2-25-'81	3-9-'81
1.	Cation		
	Ca	32 (mg/ℓ)	31 (mg/ℓ)
	Mg	10 (mg/ℓ)	11 (mg/ℓ)
	Na+K	3 (mg/ℓ)	3 (mg/ℓ)
2.	Anion		
	CO_3	112 (mg/ℓ)	104 (mg/ℓ)
	SO_4	20 (mg/ℓ)	34 (mg/ℓ)
	Cl	10 (mg/ℓ)	10 (mg/ℓ)
3.	pH	7.9	7.9

Table 4-4 SUSPENDED LOAD ANALYSIS

Sample No.	Date	Gage Height (m)	Weight of Sediment (mg/ℓ)
1.	Mar. 5	0.51	25
2.	Mar. 5	0.51	32
3.	Mar. 6	0.52	30
4.	Mar. 6	0.52	24
5.	Mar. 7	0.53	34
6.	Mar. 7	0.53	27
7.	Mar. 8	0.58	31
8.	Mar. 8	0.58	39
9.	Mar. 9	0.59	1,206
10.	Mar. 9	0.59	156
11.	Mar. 10	0.51	45
12.	Mar. 10	0.51	369

Table 4-5 NARAYANI PROJECT, POWER REQUIREMENT OF PUMPING FOR FULL SUPPLY

Area	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total per year
I	10^3 kWh	435	572	831	842	872	384	158	278	575	435	490	398	6300
	Mean kW	875	1275	1675	1751	1755	800	318	561	1200	878	1040	803	
	Max. kW													
I Ext.	10^3 kWh	119	428	595	613	360	154	40	16	231	198	154	159	3100
	Mean kW	240	955	1200	1278	727	321	81	32	481	400	321	321	
	Max. kW													
II	10^3 kWh	438	603	730	790	835	605	271	314	725	397	505	354	6600
	Mean kW	884	1345	1472	1645	1684	1260	547	634	1510	801	1050	714	
	Max. kW													
III	10^3 kWh	95	111	150	158	163	92	54	54	131	82	118	82	1300
	Mean kW	192	248	303	330	329	192	109	109	273	165	246	165	
	Max. kW													
Total kW														
- excluding I-Ext.		1954	2868	3450	3726	3768	2252	974	1304	2983	1844	2336	1682	
- including I-Ext.		2194	3823	4650	5004	4495	2573	1055	1336	3464	2244	2657	2003	

(1) No supplementary supply from Khageri Khola

CHAPTER 5 PLAN FORMULATION

5.1 Development Plan of Hydropower

The Sapt Gandaki Project is a scheme of the Gandaki River basin development. To fully use the available head of the Sapt Gandaki River, the full supply level (FSL) of the reservoir is set at EL.220 m which will be the tailrace water level of the Kali Gandaki No.2 Project envisaged in the basin master plan of the Gandaki River.

The sediment load carried into the reservoir is expected to be 4,000 m^3/year/km^2 as mentioned in the previous chapter. Considering the catchment of 31,100 km^2, sediment to be trapped by the reservoir is 118 x 10^6/m^3/year assuming the trap ratio of 0.95. Thus, it is expected that the reservoir with a capacity of 346 x $10^6 m^3$ will be filled up by three years.

As the reservoir has no effective storage to control the seasonal flow change, the hydropower plant installed is considered as a run-of-river plant. However, the effective storage volume, 12 x $10^6 m^3$, daily required for the peak operation is ensured by setting the minimum operation level to EL.216 m and by assuming that a channel will be formed with the spillway width (200 m wide) and that the slope of sediment will be equal to that of the present river bed, 0.0015.

5.2 Installed Capacity and Energy Outputs

The rated head and discharge for the installed capacities were summarized as shown in Table 5-1. The rated head was determined to be 39 m to fully utilize the available head on the dry season, because the rated head for the rated discharge arbitrarily selected was varied from 37 m of the wet season to 39 m of the dry season considering the fluctuation of the reservoir and tailrace water levels. Figure 4-6 was used for the estimate of variation on the tailrace water level, so that the refirement of the Figure 4-6 is a key factor to estimate the available head exactly.

The reason why the available head on the wet season decreases is that the reservoir water level is maintained at the full supply level even though river runoff tremendously increases, but that the tailrace water level rises as the river runoff increases. The rated discharge for each output was obtained from the rated head and the combined efficiency assumed to be 0.85.

The annual generated energy was calculated using the hydrologic data shown in Appendix B. The energy produced is divided into primary and secondary energy; the primary energy is defined as the energy warranted more than 90% of time and the secondary energy is the energy residually available. The annual firm and secondary energy, and the capacity factor of the plant are also depicted in Table 5-1.

The economic evaluation was made by the annual-cost method to obtain the optimal development scale of the Sapt Gandaki Project. The development scale which maximized the net benefit is defined as the optimal development scale of the Project. The economic benefits are capital, operation and maintenance, and replacement costs of the most competitive alternative, namely a coal-fired thermal plant in Nepal. The capital, operation and maintenance, and replacement costs of the coal-fired thermal plant as well as the criteria and assumptions applied for economic evaluation will be described in the succeeding Chapter 7.

The economic cost is the capital, operation and maintenance, and replacement costs of the Project. The estimate of the Project costs will be made in the succeeding Chapter 6.

The results of the optimization study as given in Table 5-2 and Figure 5-1 were derived based on Table 5-1 applying the discount rate of 12 %. Power and energy benefits represent the costs of capital and O & M on the coal-fired plant, respectively. The results show that the larger the installed capacity is, the more the net benefit is. However, the optimal installed capacity is, for the time being, determined to be 200 MW considering the financial problem and the economic efficiency of the project, namely the benefit-cost ratio is maximum at 200 MW.

5.3 Operation Plan of the Plant

The first two units of 100 MW are planned to be installed on 1990/91 as shown in Figure 3-8. The capacity factor of the plant through the year is 98 % as shown in Table 5-1. On the other hand, the capacity factor of each month as shown below is warranted by 100 % except 95 % of February and 89 % of March. Thus, the plant with 100 MW can be operated to supply the base load, even though there is a minor deficit.

After installing the second two units of 100 MW on 1994/95, the capacity factor of the plant decreases to 81 % through a year. As the variation of the capacity factor for each month is shown below, the capacity factor decreases to around 50 % in winter, while a 24-hour operation of 200 MW generation can be warranted by 100 % in summer. Thus, the plant will be operated to supply peak load in winter, while the plant can share the base load in summer.

Capacity Factor, %

Installed Capacity, MW	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
100	100	95	89	100	100	100	100	100	100	100	100	100
200	62	47	45	58	100	100	100	100	100	100	100	80