Chapter 1

CHAPTER 1 INTRODUCTION

1.1 Conclusion and Recommendation

Nepal aims to establish a long-tem self-supply of electricity by utilizing its hydropower potential. Hydropower generation in Nepal amounted to 528MW (90%) of the total electricity supply facilities of 585MW in FY2001/02. Run-of-river type hydropower stations produce 436MW (74%) of the power generation. Their power output is affected by river flow, resulting in a drastic decrease of power generation in the dry season. In the past, 10MW to 60MW of load shedding occurred from 17:00 to 22:00 in the evening of the dry season. After commissioning Kaligandaki A Hydropower Project in March 2002, the load shedding decreases at present. However, new power sources are needed to cope with the increasing peak power demand in the near future. Nepal is not intending to introduce thermal plants, taking into account the unstable supply of fuel. Under such circumstances, Nepal imports electricity from India and scatters the application of load shedding of 50 to 100MW in the dry season, but to cope with the shortage of peak electricity power under these conditions, the development of peak power stations is needed.

The Kulekhani cascade project consisting of the Kulekhani I power station of reservoir type (60MW) and the Kulekhani II run-of-river type (32MW) alone can supply reliable peak power in the integrated power system in the dry season by utilizing the seasonally regulated water in the Kulekhani reservoir. The Kulekhani III Hydropower Project (The Project) is also envisaged as a peak power station by using the seasonally regulated water released of the Kulekhani reservoir as the final stage of the Kulekhani cascade project.

The Upgrading Feasibility Study on the Kulekhani III Project concludes that the Project is developed as the peak power station of regulating pond type with an installed capacity of 45MW, bearing in mind the above circumstance in the system and the reliable supply of peak power in the dry season as follows:

Items	Results of Study
1) Optimum development scheme	Underground power station of regulating pond type with 475,000m^3
2) Installed capacity and annual energy production	45MW and 47.3GWh/year
3) Project cost and construction period	US$ 78Million and 3.5 years
4) Economic and financial values	EIRR of 15.3% and FIRR of 5.0%

The study of the input timing of the Project into the integrated power system reveals that the Project's power generation needs to be commissioned in 2007 to meet the peak power and energy demands, even though the power of 100MW is imported from India. Further, it is necessary to input the Project in the system in 2008, even if the power is imported from India up to the maximum limit of power exchange of 150MW, being not reliable power. A study on the effect of the Project feeding into the system revealed that the Project could supply peak power for four hours in the evening to prevent the power deficit in the dry season of FY2007.

In the Tenth Development Plan, the Government of Nepal has a position that the reliable electricity supply is apprehended as important to achieve both national economic development and nation-wise equitable development. In this line, the development of the Kulekhani project is given to the first priority as the project that can supply the reliable peak power to the demand center. In addition, the Nepal Electricity Authority (NEA) nominates the Kulekhani project as the first priority project in the Cooperate Development Plan in 2002, and aims at commencing its power generation in 2007. Accordingly, the implementation of the Project is recommended as early as possible by proceeding to the detailed design in 2003 following acceptance of this Upgrading F/S.

1.2 Background of the Project

Nepal is an inland developing country situated between the great plain of India and the desert-like plateau of Tibet. Its area is 147,181 km^2. The population is 22.7 million with an annual growth rate of 2.1% from 1991 to 2000. Over 85% of people live in rural areas and mostly depend on subsistence farming. The GDP per capita for the year 2000/01 is US$ 243. The average annual per capita growth rate of GDP from the year 1990/01 to 2000/01 was 2.91%.

The annual energy production in Nepal reached 2,088GWh in the fiscal year of 2001/02（an increase of 11.8% from 1,868GWh in FY2000/01）.This consists of 1,117GWh by hydropower, 18GWh by diesel, 953GWh by purchase from independent power producers. The imported energy from India totals to 238GWh. The total installed capacity in FY2001/02 was 584.6MW, consisting of 395.2 MW by major hydropower, 19.0MW by small hydropower, 56.7MW by diesel, 0.1 MW by solar energy, and 113.6MW by independent power producers.

	Power Source	Installed Capacity（MW）	Available Energy（GWh）
1.	Major Hydropower	395.2	1,117
2.	Small Hydro	19.0	
3.	Independent Power	113.6	953
	Subtotal	527.8（Run-of-river 435.5）	2,070
4.	Diesel	56.7	18
5.	Solar Power	0.1	
6.	Import from India		238
	Total	584.6	2,326

Data source: NEA"FY2001/02 A Year in Review" in August 2002

The energy production and peak load of the Nepal Electricity Authority (NEA) have grown at an annual rate of 7.71% and 7.99% over the last ten years. The annual growth rate will continue to be about 8%. The breakdown of energy consumption into household customers, industrial customers and others for FY2001/02 was 37%, 38% and 25% respectively. The electrification ratio of Nepal still remains at 15%. According to the demand forecast of the NEA annual report for the fiscal year of 2001/02, the energy demand is expected to reach 2,598GWh and 3,855GWh in FY2005 and FY2010, and the peak power, 570 MW and 846 MW in 2005 and 2010.

Fiscal Year	Energy (GWh)	Peak Power (MW)
2002	2,088	426
2005	2,598	570
2007	3,094	679
2010	3,855	846
2015	5,456	1,198
2020	7,668	1,683

Data source: NEA"FY2001/02 A Year in Review" in August 2002

The theoretical potential of hydropower development in Nepal amounts to 83,600 MW. Out of the theoretical potential, 43,000 MW can technically be developed. His Majesty's Government of Nepal has a plan of developing the hydropower potential, aiming at long-term self-supply of electricity and exporting the surplus power to India. The NEA intends to develop hydropower stations totaling 383 MW by the year 2007. The Kaligandaki-A Hydroelectric Project of 144 MW commenced its power generation at the end of March 2002, and the Middle Marsyandi Hydroelectric Project of 70 MW is planned for completion in 2005.

As explained in Section 1.1, Nepal has a shortage of peak power supply in the dry season because of decrease of power generation by run-of-river type hydropower stations. Both Kulekhani I and II hydropower stations, total installed capacity of 92 MW, are played a role in peak power generation owing to the Kulekhani dam having a seasonal reservoir regulating capacity, together with small scaled diesel power plants. However, the peak power demand could not be satisfied. The NEA is obliged to execute load shedding of 50-100 MW during the dry season when the river runoff decreases.

To cope with the deficit of peak electricity power in the dry season, the NEA plans the implementation of the Kulekhani III Hydropower Project as a peak power station. The Project supplies peak power for four hours from 5 pm to 9 pm in the evening by utilizing the runoff seasonally regulated by the Kulekhani reservoir. The Project was proposed as a run-of-river type power station having a daily regulating pond according to "Kulekhani III Hydroelectric Project, Updated Feasibility Study for 42 MW in September 1999" by the NEA.

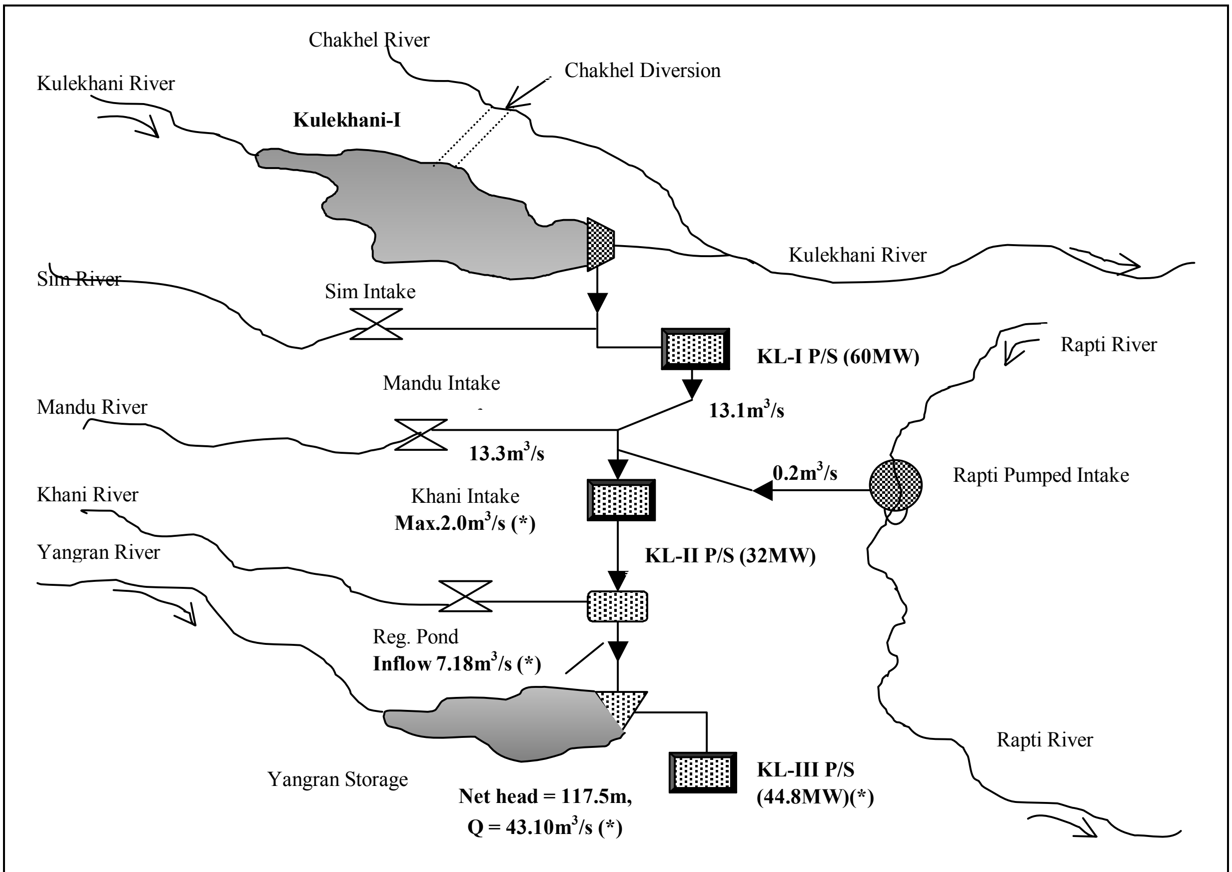
His Majesty's Government of Nepal requested the Government of Japan to carry out the feasibility study (F/S) and the detailed design (D/D) in October 2000. The NEA intends the early input of the Kulekhani III project into the integrated power system in order to reduce the shortage of peak power in the dry season. The Upgrading Feasibility Study of the Project was commenced in September 2001.

1.3 The Project

The joint survey team of Switzerland and Nepal proposed the first study of hydropower development in the Kulekhani River in 1956. The Kulekhani Overall Development Study was adopted by OTCA (re-organized to JICA at present) to implement hydropower projects for the purpose of satisfying the requirements for domestic power demand in Nepal. As a team of studies commissioned by OTCA, Nippon Koei Co., Ltd. submitted the preliminary design report on the overall development study in 1963 in line with the purpose of the overall development study. It was followed as a sector survey by OTCA experts in the period from 1965 to 1967. Nippon Koei Co., Ltd. submitted the feasibility study report on the overall development scheme on the Kulekhani River in 1973 to 1974.

The overall development study on the Kulekhani River adopted a river diversion scheme by construction of a 114m high rockfill type dam in the Kulekhani River of a tributary of the Bagmati River, which flows through the central region of Nepal. The Kulekhani project is located about 30km southwest of Kathmandu. It incorporates a cascade plan for developing three hydropower projects, harnessing the river flow diverted from the Kulekhani River to the Rapti River as follows:

- the Kulekhani I hydropower station on the Mandu tributary, harnessing a water head of 600 m and having an installed capacity of 60MW and an annual energy production of 162GWh,
- the Kulekhani II hydropower station on the Khani tributary, having 310m water head, 32MW installed capacity and 105GWh annual energy, and
- the Kulekhani III hydropower station on the Kesadi tributary, having 130m water head, 17MW installed capacity and 50GWh annual energy at that time.



Kulekhani Overall Development Scheme **(*) Results of this Study**

The Kulekhani I hydropower station was constructed from 1977 to 1983 by co-finance of IDA, OECF, UNDP, EEC, and KF. The Kulekhani II hydropower station was constructed from 1982 to 1986 after the feasibility study from 1977 to 1987. The Kulekhani Disaster Prevention Project financed by JBIC was carried out from 1992 to 2000 through the experience of serious damage occurring from unprecedented heavy rainfall in central and southern Nepal in July 1993.

The Updated F/S prepared by the NEA in 1999 formulated the Kulekhani III Hydropower Project as a peak power station of 42 MW with a regulating pond of 500,000 m^3 effective volume for four hours, generating the annual power production of 49GWh.

1.4 Objectives of the Study

The Objectives of the Study are:

1) To review the updated Feasibility Study of the Kulekhani III prepared by the Nepal Electricity Authority (NEA),
2) To study the feasibility of the Project by carrying out supplementary geological investigation and environmental impact assessment, and to formulate an optimum development plan from technical, economic and

financial, and environmental viewpoints, and

3) To carry out the technology transfer to Nepalese counterpart personnel in the course of the Study.

1.5 Stages and Schedule of the Study

The Study is carried out three stages, Preliminary Investigation Stage, Detailed Investigation Stage, and Design and Economic Evaluation Stage with phases of field preparatory work, home preparatory work, five field investigations and three home office works during the period of 18 months from September 2001 to February 2003. The overall work schedule is summarized as follows:

Study Stage and Phase	Work Period	Report Submitted
Preliminary Investigation Stage		
• Field Preparatory Work	September to October 2001	
• Home Preparatory Work	October 2001	Inception Report
• First Field Investigation	November to December 2001	
• First Home Office Work	January 2002	Progress Report
Detailed Investigation Stage		
• Second Field Investigation	February to March 2002	
• Third Field Investigation	June to July 2002	
• Second Home Office Work	July 2002	Interim Report
Design and Economic Evaluation Stage		
• Fourth Field Investigation	August to November 2002	
• Third Home Office Work	December 2002	Draft Final Report
• Fifth Field Investigation	December 2002	
	February 2003	Final Report

1.6 Final Report

The Final Report summarizes the results of the Study carried out in the Field Preparatory Works, Home Preparatory Work, First to Fifth Field Works from September 2001 to February 2003, and First and Third Home Works from January to November 2002. The Final Report consists of twelve chapters.

Chapter 1 presents the conclusion and recommendation, background and objectives of the Study. Chapter 2 describes the socio-economic condition in Nepal, and social and economic forecast. Chapter 3 shows the natural conditions of topography, meteorology and hydrology, geology, landslides and sedimentation. Chapter 4 presents the results of the natural environmental assessment and social environmental assessment related to resettlement and land acquisition, and mitigation measures. Chapter 5 explains the existing power system and expansion plan and power demand forecast. Chapter 6 gives the study results on the optimum development scheme. Chapter 7 shows the optimum reservoir operation. Chapter 8 describes the preliminary design of main structures and generating equipment. Chapter 9 discusses the construction plan and cost estimate of the Project. Chapter

10 details the economic and financial evaluation of the Project. Chapter 11 briefs the status of transfer of technical knowledge. Chapter 12 recommends the further study of surveys and investigations required in the detailed design of the Project.

1.7 Acknowledgement

During the course of the Study, the JICA Study Team has been given a lot of helpful assistance and advice by the NEA and its counterpart personnel. The JICA Study Team highly appreciates the elaborated efforts of the counterpart personnel who participated in the field investigation works. The investigation had to be carried out under severe climate conditions in the rainy season in 2002. The JICA Study Team wishes to express grateful acknowledge to all personnel of the NEA and sincerely expresses many thanks to all of them.

Chapter 2

CHAPTER 2 SOCIO-ECONOMIC CONDITION

2.1 Geographic Features

The kingdom of Nepal is a land-locked country located between the great plains of India and the desert-like plateau of Tibet. Nepal stretches from north-west to south-east about 800km and varies in width from around 90km to 230km. Nepal is surrounded by China (Tibet) on its north and by India on its east, west and south. The area of the country is 147,181 km^2.

Ecologically the country is divided into three regions, running east to west. They are the Mountain, the Hill and the Terai (plain).

The Mountain Region

The region covers mountainous area of the great Himalaya mountain range, and the trans-Himalaya area. The altitude ranges between 4,877m to 8,848m above sea level. Although the region covers 35% of the whole land area of the country, its suitable land area for cultivation is limited to only 2%. Because of its geography and climatic conditions it is the most sparsely populated region which embraces 7.3% of the population of the country according to the 1991 census.

The Hill Region

The Hill region is located in the middle of the Mountain and the Terai regions, at altitude of 610m to 4,877m above sea level. The region comprises several attractive peaks, fertile and relatively densely populated valley and basins between Himalaya and Mahabharat ranges such as Kathmandu and Pokhara. The region covers 42% of the land area of the country with 46% of the country's population. About one tenth of its area is suitable for cultivation.

People living in its higher altitudes are mainly engaged in animal grazing, cottage industry and they cultivate high altitude cereals. People in lower altitude cultivate cereal crops and cash crops.

The Terai Region

The region of a low flat land lying on the southern part of the country is Terai (plain), which is an extension of the Gangetic plains of India. It extends 23% of the land area of the country and accommodates 47% of population in 1991. This area includes most of the fertile land and dense forest of the country with the arable area ratio of 40%. A wide variety of crops are cultivated in the Terai; such as paddy, maize, wheat, sugarcane, vegetables, tobacco and other crops. Population of this region is increasing at a faster ratio compared to ratios of other two regions partly due to migration inflow.

2.2 Administration Situation

Nepal is a constitutional monarchy with King Gyanendra as head of state. There is no significant restriction on political parties. The prime minister appointed from among the elected members of the House of Representatives presides over a Council of Ministers.

The central government comprises 18 ministries.

The country is divided into 5 development regions with total 75 administration districts. Names and accommodating district number of these regions are the following:

- the Eastern Development Region with 16 districts,
- the Central Development Region with 19,
- the Western Development Region with 16,
- the Mid-western Development Region with 15, and
- the Far-Western Development Region with 9.

Districts are further divided into number of Village Development Committees (VDC) and Municipalities as local units. There are 3,914 VDCs and 58 Municipalities including one Metropolitan and four Sub-metropolitan cities. VDC and Municipality are sub-divided into smaller units, called the Ward. There are 9 wards in each VDC and number of wards in a municipality ranges from 10 to 35. Each district is headed by a Chief District Officer (CDO). The CDO is mainly responsible to maintain law and order in the district and also to co-ordinate developmental works conducted by different ministries and local agency at the district level.

2.3 Population

According to the result of the 2001 census Nepal's population is 22.737million as an enumerated data. The population has grown from the previous census count of 18.491million people in 1991. An average growth ratio according to the enumerated data for the period is 2.1% per annum which is same level as the previous decade's average annual growth ratio, while the Government claims the ratio of 2.27% for the period in its Tenth Development Plan document.

Same as its geography, the population of Nepal is extremely diverse and highly complex in terms of ethnicity and caste.

The following table shows the ethnic groups in Nepal at the time of 1991 census. It has to be noted that among these ethnic groups, PARBATIYAS, NEWARS, and a major part of MADHESHIS (Terai Dwellers) consist of castes sub-groups.

Main Categories	Ethnic Groups	Percent
(1) PARBATIYAS (Hill People, Hindu-Caste)		***(40.3)***
(2) NEWARS		***(5.6)***
(3) OTHER HILL OR MOUNTAIN ETHNIC GROUPS ('TRIBES')		***(20.1)***
	MAGAR	7.2
	TAMANG	5.5
	RAI	2.8
	GURUNG	2.4
	LIMBU	1.6
	SHERPA	0.6
	Chepang	0.2
	Sunuwar	0.2
	Bhotiya	0.1
	Thami	0.1
(4) MADHESHIS (Terai Dwellers)		***(32.0)***
(a) Castes		[16.1]
(b) Ethnic Groups		[9.0]
Inner Tarai:	Kumal	0.4
	Majhi	0.3
	Danuwar	0.3
	Darai	0.1
Tarai Proper:	THARU	6.5
	Dhanuk	0.7
	Rajbanshi	0.4
	Gangai	0.1
	Dhimal	0.1
(c) Muslims		[3.5]
(d) Marwaris		[0.2]
(e) Sikhs		[0.1]
(5) OTHERS	(Tarai origin and below 0.1%)	(4.7)

Source: Census in 1991

Basically the Indo-Aryan people of India and the Tibet-Burmese of Himalaya live in Nepal. Ethnic groups, however, these people are adapted to the wide variety of natural environmental conditions or constraints respectively with their cultural and religious background. Migration from the impoverished hill and mountain areas to the Kathmandu valley and to the Terai has steadily been going on. Urban areas have had difficulty in absorbing the migrants and population growth of Terai has been faster than the other two regions. In addition there are Indian migrants coming across the open southern border. Creation of new dimension of population diversity and complexity is still ongoing.

2.4 Macro Economic Performance

(1) Basic Economic Profile

Nepal is one of the least developed countries of the world. Over 85% of 23 million people of the country live in the rural areas and mostly depend on subsistence farming. Estimated per capita GDP for the year 2000/01 is US$ 243. An average annual growth ratio of per capita GDP in terms of the US Dollar from the year 1990/01 to 2000/01 is 2.91%. (Refer to Table 2.4.1)

Although the contribution to real GDP of "Agriculture Fishery and Forestry" has slipped from 51.2% in fiscal year 1984/85 to 38.4% in 2000/01, this is still the largest sector as shown in the following table. "Community and Social Services," "Trade Restaurant and Hotel," "Finance and Real Estate," "Construction," "Manufacturing," and "Transport Communication and Storage" are the following sectors with the level of contribution to real GDP around 10%. Among them the fast growing sectors are "Manufacturing" in early 1990s, "Transport Communication and Storage" over 1990s, and "Community and Social Services" in recent years.

GDP Sectoral Contribution	
Agriculture Fisheries and Forestry	38.38%
Community and Social Services	11.29%
Trade Restaurant and Hotel	10.96%
Finance and Real Estate	10.05%
Construction	9.71%
Manufacturing	9.61%
Transport Communication and Storage	8.59%
Electricity Gas and Water	0.94%
Mining and Quarrying	0.47%
Total	100.00%

Source: Central Bureau of Statistics

As shown in the following table, even annual growth ratios for year 1999/2000 and year 2000/01 are close to 6% (5.73% and 5.87% respectively) average annual growth ratio for the first 4 years of the Ninth Five Year Plan (FY 1997 – 2002) period is 4.87% which is same level as the previous Five Year Plan (FY 1997 – 2002) period's annual growth ratio of 4.89%.

Average Annual Growth Ratio		Annual Growth Ratio	
FY92-97	FY97-01	1999/00	Jan-00
4.89%	4.87%	5.73%	5.87%

Nepal's economy involves a structural problem in savings and investment levels which are very low. Investment/GDP ratios were basically 20-25% level during the 1990s. Even in producer's current-price terms in 1990/91 Gross Domestic Saving was at just 9.6% of GDP. Although it had steadily risen until 2000/01 with Gross Domestic Saving/GDP ratio of 16.8%, it faced decrease to the ratio of 13.2% in 2001/02. (Refer to Table 2.4.2 - 2.4.6)

Even though a structural economic reform program was instituted in 1992, its progress has been slow and inefficient state-run firms are still big figures in non-agricultural economy. Government finance has basically been widening budget deficits except in 1999/2000 and been financing it mainly by foreign grants and loans. (Refer to Table 2.4.7)

Consumer price inflation during the 1999/2000 – 2000/01 period was 2.37%, though average annual inflation in the 1995/96 – 2000/01 period was 6.31%. (Refer to Table 2.4.8) While money supply (M2) expanded at 20% level for three consecutive years starting from year 1998, its expansion level was decreased to 15.3% in year 2001. (Refer to Table 2.4.9 for data on money supply and interest ratios.) External Trade and Foreign Reserve

(2) External Trade and Foreign Reserve

Nepal is a landlocked country with main transit routes which are limited only with India. Together with a condition of its difficult topography, merchandise trade is a difficult sector for Nepal to develop. Nepal relies on imported capital goods, while it has limited competitive export items. As a result, its base of external trade balance is deficit. In addition since its export industries have not grew fast enough to match with increasing imports in a liberalizing economy, its trade deficit was widen until year 1996/97. (Refer to Table 2.4.10)

After the trade dispute and incident of blockade in 1989/90, the Indian and Nepalese economies has strengthened trade ties and, in 2000/01, India accounted for about 41.6% of Nepal's total trade in the circumstance of synchronized liberalization of economies in both countries. The influence of Indian government's policy and Indian economy is considerable in Nepal's external trade. (Refer to Table 2.4.11)

Nepal experienced a slight current-account surplus in year 1998/99 followed by the much reduced level of deficit in year 1999/2000 comparing to the previous period. This current-account structure seems to continue in year 2000/01. The experience of current-account surplus was materialized mainly by rapid growth of exports and private remittance in the year. However, significant decrease in receipt by other services affected the current-account to back again to be deficit. (Refer to Table 2.4.10)

Despite the current-account deficits, Nepal has generally recorded a positive overall balance-of-payments position. Sources for financing these deficits have been almost foreign grants and concessional loans from donor governments and multilateral agencies. Since 1994/95 the debt-service ratio has been improving, while the debt/GNP ratio has been increasing. The debt/GNP and debt-service ratios in 1999/2000 were 61.5% and 4.7% respectively. (Refer to Table 2.4.12) These indexes show that the external debts, the dept-service ratios being less than 15 %, are considerably low while the foreign loans, the debt/GDP being more than 50 %, are high. This reveals that Nepal is financially capable to repay its debts.

Foreign-exchange reserves have been on the increasing trend with approximately 12% per annum growth ratio during the past decade and were more than US$1,400 million in 2001. (Refer to Table 2.4.13)

The US dollar and the Indian rupee are the two main currencies for Nepal's trade transaction. Since 1983 the Nepalese rupee has been tied, in principle, to a weighted currency basket with the US dollar as the intervention currency. However, in recent practice the exchange ratio is pegged against the Indian rupee. Since 1993 the ratio against the Indian rupee has been NRs1.6:Ts1. This is the signification of the high degree of integration between the Indian and Nepalese economies. The exchange ratio against the US dollar has gradually depreciated in line with the Indian rupee. On January, 2002 the exchange ratio is NRs76.30: US$1. (Refer to Table 2.4.13)

2.5 Status of National Development Plan

(1) Ninth Development Plan

Nepal commenced its national development plan in 1956 with the First Five Year Plan (1956 – 1961). Nine periodic plans have been implemented, and the Tenth Five-year Plan (2003 – 2007) has just commenced in July 16, 2002. Although some progress has been made towards laying socio-economic infrastructure, achievements of the previous nine plans do not measure up to the expectation.

The previous Ninth Five Year Plan which covered the period FY 1998 – FY 2002 prioritized the poverty alleviation and adopted it as the main objective. The plan focused on economic growth, sustainable development in agriculture and forestry, and reduction of regional and social imbalances. It also mentioned the following points as strategies: 1) decentralization for the local institutions' leadership, 2) lessening the dependence on external aids, 3) human resources development for sustainable and high economic growth, 4) reduction in population growth through education and family planning programs, and 5) coordination of organized modern sector and the unorganized, backward rural sector in development.

As shown in the following table, 6.00% was the target annual growth ratio of GDP for the Ninth Five Year Plan.

Gross Domestic Product and Sectoral Value added in the Ninth Plan
(At 1984/85 Constant Prices)

Sectors	1996/97 Baseline adjusted	2001/02 Target adjusted	2000/01 Attain. 1st 4 yrs	2001/02 Attain. Ttl 5 yrs	Av. Annual Growth		
					Target	Attain. 1st 4 yrs	Attain. Ttl 5 yrs
Agriculture, Irrigation and Forestry	32,529	39,577	36,853	37,632	4.0%	3.17%	2.96%
Non Agriculture	46,859	66,727	58,822	60,295	7.3%	5.85%	5.17%
Industry	7,437	11,495	9,677	8,922	9.1%	6.80%	3.71%
Electricity Gas and Water	646	1,059	906	1,055	10.4%	8.82%	10.31%
Construction	7,929	10,561	9,327	9,798	5.9%	4.14%	4.32%
Trade Restaurant and Hotel	8,755	12,511	10,522	10,602	7.4%	4.70%	3.90%
Transport Communication and Storage	6,266	9,509	8,251	8,509	8.7%	7.12%	6.31%
Finance and Real Estate	7,869	10,432	9,653	10,117	5.8%	5.24%	5.15%
Community and Social Services	7,957	11,160	10,844	11,292	7.0%	8.05%	7.25%
GDP at factor cost before deduction of bank service charges	79,388	106,304	96,033	97,927	6.0%	4.87%	4.29%

(In Million Rs)

Source: The Ninth Development Plan, Central Bureau of Statistics (modified by Study Team)

It expected higher growth ratios for the non-agricultural sectors, while the expectation of agricultural sector's development was steady as the annual growth ratio of 4.00%. Actual performance of GDP growth, however, was not as good as planned. GDP annual growth ratio for the first 4 years of the Plan was 4.87% due to slack in overall sectors in basic. According to the preliminary estimate, the final fiscal year's annual growth ratio of 2.0% was seriously affected by the internal and external abnormal circumstances. Owing to this sluggish economic performance, the estimated overall average annual growth ratio was lowered to 4.29%.

(2) The Tenth Development Plan

In the Tenth Plan poverty alleviation is still its main objective with the target to reduce the ratio of the population living below the poverty line from the current level of 38% to 30 %. Although it admits the importance of the economic growth, the Plan takes comprehensive approach for the poverty alleviation to improve the various aspects such as human development, social cohesion, empowerment and good governance as well as economic growth and its equitable distribution.

The Plan has four main strategies: 1) High, sustainable and broad-based economic growth for resurgence of broad-based economic activities, 2) Social sector and infrastructure development for enhancement of human resources and communities in a sustainable way, 3) Targeted programs for enhancement of the productive capacity of marginalized, deprived, ignored, remote, weak, and alienated communities and regions in a sustainable way, and 4) Good governance for establishment of sustainable good governance in the national development process on the basis of transparency, multi-faceted decision process, and decentralization.

The followings are the issues emphasized by these strategies.

- population control and good governance, promote economic opportunities through high, sustainable and broad-based economic growth, and creation of appropriate bases for the distribution of their opportunities to various sectors and classes;
- enhancing the capability of and mainstreaming of the down-trodden and backward communities, and strengthening women's empowerment through the expansion of investment in social services to ensure their access to the available opportunities;
- empowering the aforementioned people in the decision-making process of different programs including poverty alleviation to be implemented at local and national levels; and
- stressing on self-employment, income-generating and security-enhancing programs for the direct benefits of economically, geographically and socially backward classes and ethnicities, blind, disabled, weak and helpless as well as people living below the poverty line.

As shown in the following table, the Plan keeps almost as same target level for the macroeconomic growth rates as the previous Plan to be consistent with the long term target indicators. It has to be noted that the actual target annual growth ratios are higher than the above mentioned stated ones in the Plan, since the baseline figures taken for the estimated GDP in FY 2001/02 are derived from the three-year moving average to cope with the extraordinary low figures marked due to the internal and external abnormal circumstances in the respective fiscal year.

Gross Domestic Product and Sectoral Value Added in the Tenth Plan

(At 2001/02 Constant Prices)

Sectors	Estimated GDP in FY 2001/02 *		Projected GDP in FY 2006/07		Average annual growth rate (%)
	Production	Per cent	Production	Per cent	
Agriculture, irrigation and forestry	154,232	36.1	188,551	32.7	4.1
Non-agriculture	272,955	63.9	388,505	67.3	7.3
Industry and mining	414,94	9.7	60,406	10.5	7.8
Electricity, gas and water	84,072	2.0	13,706	2.3	10.1
Construction	83,815	10.3	62,028	10.7	7.2
Trade, hotel and restaurant	50,331	11.7	71,587	12.4	7.3
Transport and communications	36,798	8.6	52,583	9.1	7.4
Finance and real estate	47,282	11.1	61,504	10.7	5.4
Social Service	44,763	10.5	66,691	11.6	8.3
Gross Domestic Product (at factor cost)	427,187	100.0	577,056	100,0	6.2

* Estimates based on a three-year moving average. (In Million Rs)

Source: The Tenth Development Plan

Special attention has been paid for reducing the burden of foreign loans for the investment and development expenditure in the Tenth Plan. The expected share of the capital investment to be borne by national savings is 78.8% (Rs 535,080 million), which is 4.9 percent point higher the than the achievement of 73.9% by national savings during the Ninth Plan, while the expected one to be borne by the foreign assistance is 21.2% (Rs 143,590 million).

Succeeding the preferable achievement in reducing the average annual population growth ratio to 2.27%, which is 0.1% point less than the previous Plan's target, in the last decade according to the Tenth Development Plan document, the target for the population growth ratio is set at 2.1% as shown in the following table. The target for the total unemployed population is 10.5% including 1.8% of the fully unemployed population at the end of the Plan decreasing from the estimated ratios of 15.4% and 3.0% respectively at the end of the previous Plan.

	Annual Population Growth Ratio	Total Unemployed Population	Fully Unemployed Population
Targets	2.1%	10.5%	1.8%
Current Performance	2.27%	15.4%	3.0%

Source: The Tenth Development Plan

The electricity sector is apprehended as important sector to achieve both national economic development and nationwide equitable development in the Tenth Development Plan. It points out the necessity of expanding the supply of reliable and quality electricity services at reasonable price throughout the nation for integration of hydroelectricity with rural economic activities and for development of electricity as an exportable commodity. The plan also regards that the supply of reliable and quality electricity services is one of the most important infrastructure categories to be provided for the development of information technology, industry and commerce sectors.

For this purpose, emphasis will be laid on the activities such as expanding and strengthening electricity generation, transmission and distribution; making electricity tariffs more practical while considering the purchasing power of consumers; preparing long-term electricity generation plan for balancing the demand and supply of electricity; controlling electricity leakages; and attracting domestic and foreign investments in the electricity sector.

Following the attainment of the previous period's annual growth ratio of 10.31%, the sector's annual growth ratio target is set as 10.1% while the non-agricultural sector's target is 7.3%. In terms of investment the sector, of which projected proportion against the entire GDP is 2.3% at the end of the Plan, is intended to be allocated 11.9% of entire fixed capital investment and 15.4% of entire total development expenditure during the Plan period.

2.6 Macro Frame Analysis for Development Forecast

Macro framework for this study has to be based on the NEA's own load forecast study completed in July 2001 and the Power System Master Plan for Nepal in 1998 by ADB, since the power demand forecast for the Project adopted the same methodology as these studies. In this circumstance, verification of the indicators applied in the NEA study is herein conducted as configuration of macro framework for the Project.

The NEA study is based on the Power System Master Plan for Nepal in 1998 by ADB and applied socio-economic indicators for the demand forecasts are shown in the following table in the next page.

Indicators	Av. Annual Growth	
	ADB Study	NEA Study
Population	2.1%	2.1%
GDP	5.5%	**6.0%**
GDP/capita	3.3%	**3.8%**
Industry	7.3%	7.3%
Commerce	6.5%	6.5%
Other Sectors	5.5%	5.5%

The indicator for population growth in both studies is reasonable applicable for this study considering the current government's efforts and emphasis on mitigation of population growth, and last decade's growth ratios of the government claimed 2.27% and the enumerated data's 2.1% as stated in 2.4.1.

Annual growth ratio of the GDP and associating GDP per capita employed in the ADB study were increased for the NEA study. The adjustment is assessed as reasonable. As state in Section 2.5 and shown in the table 2.4.3 and table 2.4.6 together with the following table, the actual performances of the economic growth during the Ninth Five Year Plan period and the previous Eighth Five Year Plan are considerably low compared with the applied indicator of 6% per annum.

However, considering that the electricity sector is placed high priority in the Tenth Plan as the base for the national economic development, and the future Five Year Plans' targets as in the following table the raising of GDP annual growth ratio for the load and demand forecasts is reasonable. Relatively good economic performances observed in current three years except the latest year's extraordinary one support the application of the ratio of 6% per annum.

Sectors	Av. Annual Growth			Av. Annual Growth		
	9th Plan Target	Attain. 1st 4 years	Attain. Total 5 years	5 Year Plans 10th	11th	12th
Agriculture, Irrigation and Forestry	4.0%	3.17%	2.96%	4.1%	5.0%	5.0%
Non Agriculture	7.4%	5.85%	5.17%	7.3%	8.8%	9.7%
Industry	9.1%	4.79%	3.71%	7.8%		
Electricity Gas and Water	10.4%	6.50%	10.31%	10.1%		
Construction	5.9%	4.53%	4.32%	7.2%		
Trade Restaurant and Hotel	7.4%	4.80%	3.90%	7.3%		
Transport Communication and Storage	8.7%	6.82%	6.31%	7.4%		
Finance and Real Estate	5.8%	5.32%	5.15%	5.4%		
Community and Social Services	7.0%	8.81%	7.25%	8.3%		
GDP at factor cost before deduction of bank service charges	6.0%	4.78%	4.29%	7.2%	7.5%	8.3%

The other annual growth ratios adopted by the both studies are rational by the same reason as stated in the above.

Both the ADB and NEA forecasts incorporate real electricity tariff increase by average 4.5% per annum until FY 2003 following the ADB loan condition and recommendation, and a NEA's own policy. This tariff increase is expected to be sound.

As explained above, it is recommended that socio-economic indicators in the NEA study are applied to those used for the power demand forecast in section 5.3. (growth ratio of population, GDP and electricity tariff increase)

TABLES

Chapter 2

Table 2.4.1 Some Important Macro Economic Indicators, 1990/91 to 2000/01

Description	1990/91 (2047/48)	1991/92 (2048/49)	1992/93 (2049/50)	1993/94 (2050/51)	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00R (2056/57)	2000/01P (2057/58)
Consumption/GDP (%)	90.43	89.16	86.49	85.34	85.19	86.17	86.04	86.23	86.40	84.09	82.90
Investment/GDP (%)	20.83	21.15	23.12	22.40	25.20	27.21	25.34	24.84	20.47	24.09	25.34
Gross Domestic Saving/GDP (%)	9.57	10.84	13.51	14.66	14.81	13.83	13.96	13.77	13.60	15.91	17.10
Export/GDP (%)	11.82	15.99	18.05	24.01	24.22	22.26	26.33	22.82	22.85	23.51	23.13
Import /GDP (%)	23.08	26.30	27.66	31.60	34.61	35.75	37.71	33.89	29.72	31.68	31.36
Export/ Import	0.51	0.61	0.65	0.76	0.70	0.62	0.70	0.67	0.77	0.74	0.74
Overall GDP Deflator	194.30	231.78	256.01	274.93	292.25	315.11	338.05	351.93	383.15	406.28	210.68
Total population (in millions)	18.30	18.68	19.13	19.59	20.05	20.53	21.02	21.53	22.04	22.57	23.11
Per Capita GDP In NRs.	6577.24	8001.80	8964.46	10174.55	10929.55	12122.75	13342.86	13975.95	15515.98	16996.08	17937.31
Per Capita GNP in NRs.	6694.56	8147.13	9133.38	10371.78	11169.76	12296.43	13564.52	14255.82	16009.65	17577.66	18677.10
Average exchange rate (Rs./US$)	36.00	42.75	42.95	49.30	49.94	55.05	56.98	61.44	68.30	68.98	73.70
Per Capita GDP in US $	182.70	187.18	208.72	206.40	218.85	220.21	234.17	227.47	227.17	246.39	243.38
Per Capita GNP in US $	185.96	190.58	212.65	210.40	223.66	223.37	238.06	232.03	234.40	254.82	253.42

P: Preliminary estimates

R: Revised estimates

Source: Central Bureau of Statistics

Table 2.4.2 National Accounts Summary, 1990/91 to 2001/02
(At current prices)

(In Rs. Millions)

Description	1990/91 (2047/48)	1991/92 (2048/49)	1992/93 (2049/50)	1993/94 (2050/51)	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00 (2056/57)	2000/01R (2057/58)	2001/02P (2058/59)
GDP at producers prices	120370	149487	171474	199272	219175	248913	280513	300845	342036	379521	410194	428033
Plus Import of goods and non factor services	27785	39321	47429	62972	75850	88996	105775	101949	101648	123055	131403	123143
Total resources available = uses	148155	188808	218903	262244	295025	337909	386288	402794	443684	502576	541597	551176
Total consumption	108856	133280	148302	170052	186710	214487	241351	259407	295473	322526	350080	371495
Private Consumption	97771	121372	133402	154065	166443	191469	216364	231392	264944	287947	309107	326108
Public consumption	11085	11908	14900	15987	20267	23018	24987	28015	30529	34579	40973	45387
Total Investment	25074	31619	39653	44344	55231	68017	71084	74728	70061	91690	99696	101885
Gross fixed capital formation	22780	29277	37278	42032	48370	56081	60794	65375	65269	73314	78017	84165
Public sector	8683	10331	11769	13380	15070	17624	19392	22573	23888	26436	31290	31709
Private sector	14097	18945	25509	28652	33300	38457	41402	42802	41381	46878	46727	52456
Change in stock	2294	2342	2375	2612	6861	11636	10290	9353	4734	18376	21679	17720
Export of goods and non factor services	14226	23909	30948	47848	53084	55405	73853	68659	78150	88360	91821	77796
Memorandum Items:												
Gross domestic saving	11514	16207	23172	29220	32465	34426	39162	41438	46563	56995	69114	56538
Net factor income	2147	2715	3231	3863	4817	3566	4660	6025	10881	13125	16171	18186
Net current transfer	218	482	581	495	819	900	1009	1158	1205	1319	1456	1664
Gross national saving	13879	19404	26984	33578	38101	38892	44831	48620	58648	70120	76285	74724
GNP at current prices	122517	152202	174705	203135	223992	252479	285173	306870	352917	392646	426365	446219

Note: Change in stock onwards 1994/95 is derived residually
P: Preliminary estimates
R: Revised estimates
Source: Central Bureau of Statistics

Table 2.4.3 Gross Domestic Product by Industrial Origin at Constant Prices, 1990/91 to 2000/01
(1984/85 = 100)

(In Rs. Millons)

S. No.	Description	1990/91 (2047/48)	1991/92 (2048/49)	1992/93 (2049/50)	1993/94 (2050/51)	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00R (2056/57)	2000/01P (2057/58)	Av. Annl. Growth FY92-97	FY97-01
1	Agriculture Fisheries and Forestry	28371.9	28070.2	27896.0	30017.0	29917.0	31239.0	32529.0	32867.3	33761.3	35438.5	36852.5	2.99%	3.17%
2	Mining and Quarrying	271.4	293.4	299.8	318.0	329.0	371.8	397.0	402.0	417.0	436.0	453.0	6.23%	3.35%
3	Manufacturing	3756.3	4957.8	5266.5	5915.0	6031.0	6576.0	7040.0	7281.0	7666.0	8663.0	9224.0	7.26%	6.99%
4	Electricity Gas and Water	461.3	492.6	447.4	475.0	532.0	635.0	646.0	619.0	659.0	761.0	906.0	5.57%	8.82%
5	Construction	5532.3	5961.9	6250.0	6662.0	7008.0	7471.0	7929.0	8080.0	8621.0	9089.0	9327.0	5.87%	4.14%
6	Trade Restaurant and Hotel	6288.5	6657.9	7085.3	7685.2	8104.0	8446.0	8755.0	9233.0	9605.0	10184.0	10522.0	5.63%	4.70%
7	Transport Communication and Storage	3916.0	4256.1	4615.4	4986.0	5515.0	5816.0	6266.0	6736.0	7187.0	7726.0	8251.4	8.04%	7.12%
8	Finance and Real Estate	5654.2	5951.1	6298.0	6696.8	6985.0	7515.0	7869.0	8334.0	8752.0	9204.0	9653.0	5.75%	5.24%
9	Community and Social Services	5516.4	5890.4	6427.5	6931.0	7264.0	7703.0	7957.0	8564.0	9121.0	9205.0	10844.0	6.20%	8.05%
	GDP at factor cost before deduction of bank service charges	59768.3	62531.4	64585.9	69686.1	71685.0	75772.8	79388.0	82116.3	85789.3	90706.5	96032.9	4.89%	4.87%
	Less imputed Value of bank service charges	1178.0	1265.0	1399.0	1624.0	1818.9	2019.0	2050.0	2222.0	2376.0	2599.0	2815.0	10.14%	8.25%
	Total GDP at factor cost	58590.3	61266.4	63186.9	68062.1	69866.1	73753.8	77338.0	79894.3	83413.3	88107.5	93217.9	4.77%	4.78%
	Plus Indirect Taxes, net	3362.0	3230.0	3792.0	4420.0	5130.0	5238.0	5642.0	5589.0	5841.8	6298.0	6788.7	11.80%	4.73%
	GDP at producers prices	61952.3	64496.4	66978.9	72482.1	74996.1	78991.8	82980.0	85483.3	89255.1	94405.5	100006.6	5.17%	4.78%

P: Preliminary estimates

R: Revised estimates

Source: Central Bureau of Statistics

Table 2.4.4 Price Deflators of the Gross Domestic Product, 1990/91 to 2000/01
(1984/85 = 100)

S. No.	Description	1990/91 (2047/48)	1991/92 (2048/49)	1992/93 (2049/50)	1993/94 (2050/51)	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00R 2056/57)	2000/01P (2057/58)	Change %
1	Agriculture Fisheries and Forestry	195.15	232.12	251.25	268.48	286.02	310.18	334.42	342.27	392.09	403.26	391.89	-2.82
2	Mining and Quarrying	211.66	270.87	307.17	311.33	339.51	360.98	376.57	386.32	404.08	416.28	437.31	5.05
3	Manufacturing	210.15	258.62	277.57	301.96	324.24	341.64	352.50	370.65	395.73	408.48	419.71	2.75
4	Electricity Gas and Water	176.67	251.95	340.85	455.37	537.97	566.61	689.94	708.08	694.08	774.64	851.55	9.93
5	Construction	200.25	247.73	277.09	294.52	329.52	349.26	369.06	377.26	385.83	397.48	421.69	6.09
6	Trade Restaurant and Hotel	205.17	248.78	271.83	292.73	300.17	335.27	348.95	364.85	409.30	423.30	435.87	2.97
7	Transport Communication and Storage	167.52	201.07	234.41	253.21	253.76	273.35	308.25	335.48	342.72	378.99	403.83	6.55
8	Finance and Real Estate	193.56	222.49	249.03	270.61	293.96	312.99	345.11	357.31	379.38	401.12	419.63	4.62
9	Community and Social Services	181.12	200.12	235.16	247.12	260.52	275.96	298.24	325.01	335.29	411.97	423.24	2.73
	Overall GDP Deflator	194.30	231.78	256.01	274.93	292.25	315.11	338.05	351.93	383.15	406.28	414.18	1.94

P: Preliminary estimates
R: Revised estimates
Source: Central Bureau of Statistics

Table 2.4.5 Percentage Contribution to Total GDP by Sector, 1990/91 to 2000/01

S. No.	Description	1990/91 (2047/48)	1991/92 (2048/49)	1992/93 (2049/50)	1993/94 (2050/51)	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00R (2056/57)	2000/01P (2057/58)
1	Agriculture Fisheries and Forestry	47.47	44.89	43.19	43.07	41.74	41.23	40.98	40.03	39.35	39.07	38.38
2	Mining and Quarrying	0.45	0.47	0.46	0.46	0.46	0.49	0.50	0.49	0.49	0.48	0.47
3	Manufacturing	6.29	7.93	8.16	8.49	8.41	8.68	8.87	8.87	8.93	9.55	9.61
4	Electricity Gas and Water	0.77	0.79	0.69	0.68	0.74	0.84	0.81	0.75	0.77	0.84	0.94
5	Construction	9.26	9.53	9.68	9.56	9.78	9.86	9.99	9.84	10.05	10.02	9.71
6	Trade Restaurant and Hotel	10.52	10.65	10.97	11.03	11.31	11.15	11.03	11.24	11.20	11.23	10.96
7	Transport Communication and Storage	6.55	6.80	7.15	7.15	7.69	7.67	7.89	8.20	8.38	8.52	8.59
8	Finance and Real Estate	9.46	9.52	9.75	9.61	9.74	9.92	9.91	10.15	10.20	10.14	10.05
9	Community and Social Services	9.23	9.42	9.95	9.95	10.13	10.16	10.02	10.43	10.63	10.15	11.29
	GDP at factor cost before deduction of bank service charges	100	100	100	100	100	100	100	100	100	100	100

P: Preliminary estimates

R: Revised estimates

Source: Central Bureau of Statistics

Table 2.4.6 Annual Growth Rates of the Gross Domestic Product by Major Industrial Divisions, 1990/91 to 2000/01

(In percentage)

S. No.	Description	1990/91 (2047/48)	1991/92 (2048/49)	1992/93 (2049/50)	1993/94 (2050/51)	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00R (2056/57)	2000/01P (2057/58)
1	Agriculture Fisheries and Forestry	2.15	-1.06	-0.62	7.60	-0.33	4.42	4.13	1.04	2.72	4.97	3.99
2	Mining and Quarrying	8.92	8.11	2.18	6.07	3.46	13.01	6.78	1.26	3.73	4.56	3.90
3	Manufacturing	17.68	31.99	6.23	12.31	1.96	9.04	7.06	3.42	5.29	13.01	6.48
4	Electricity Gas and Water	34.44	6.79	-9.18	6.17	12.00	19.36	1.73	-4.18	6.46	15.48	19.05
5	Construction	8.05	7.77	4.83	6.59	5.19	6.61	6.13	1.90	6.70	5.43	2.62
6	Trade Restaurant and Hotel	11.48	5.87	6.42	8.47	5.45	4.22	3.66	5.46	4.03	6.03	3.32
7	Transport Communication and Storage	13.18	8.68	8.44	8.03	10.61	5.46	7.74	7.50	6.70	7.50	6.80
8	Finance and Real Estate	10.07	5.25	5.83	6.33	4.30	7.59	4.71	5.91	5.02	5.16	4.88
9	Community and Social Services	5.36	6.78	9.12	7.83	4.80	6.04	3.30	7.63	6.50	0.92	17.81
	All Industries	6.44	4.62	3.29	7.90	2.87	5.70	4.77	3.44	4.47	5.73	5.87

P: Preliminary estimates

R: Revised estimates

Source: Central Bureau of Statistics

Table 2.4.7 Overall Budgetary Position of His Majesty's Government, 1990/91 to 2000/01

Rs. in Million

Head	*1990/91*	*1991/92*	*1992/93*	*1993/94*	*1994/95*	*1995/96*	*1996/97*	*1997/98*	*1998/99*	*1999/00*	*2000/01*
Expenditure	**23549.8**	**26418.2**	**30897.7**	**33597.4**	**39060.0**	**46542.4**	**50723.7**	**56118.3**	**59579.0**	**66272.5**	**79835.1**
Regular	7570.3	9905.4	11484.1	12409.2	19265.1	21561.9	24181.1	27174.4	31047.7	34523.3	42769.2
Development	15979.5	16512.8	19413.6	21188.2	19794.9	24980.5	26542.6	28943.9	28531.3	31749.2	37065.9
Source of Financing	**12894.7**	**15156.5**	**18941.7**	**21974.4**	**28512.3**	**32718.2**	**36361.8**	**38340.5**	**41587.6**	**48605.5**	**55647.0**
Revenue	10729.9	13512.7	15148.4	19580.8	24575.1	27893.1	30373.5	32937.9	37251.0	42893.8	48893.6
Foreign Grants	2164.8	1643.8	3793.3	2393.6	3937.2	4825.1	5988.3	5402.6	4336.6	5711.7	6753.4
Surplus (+) of Deficit (-)	**-10655.1**	**-11261.7**	**-11956.0**	**-11623.0**	**-10547.7**	**-13824.2**	**-14361.9**	**-17777.8**	**-17991.4**	**-17667.0**	**-24188.1**
Foreign Loan	**6256.7**	**6816.9**	**6920.9**	**9163.6**	**7312.3**	**9463.9**	**9043.6**	**11054.5**	**11852.4**	**11812.2**	**12044.0**
Internal Loan	**4552.7**	**2078.8**	**1620.0**	**1820.0**	**1900.0**	**2200.0**	**3000.0**	**3400.0**	**4710.0**	**5500.0**	**7000.0**
Cash balance surplus	-154.3	2366.0	3415.1	639.4	1335.4	2160.3	2318.3	3323.3	1429.0	354.8	5144.1

Note: The Change in Foreign Exchange Rate is adjusted in Direct Payments.

Sources: Financial Comptroller General Office

Table 2.4.8 Urban Consumer Price Index by Group and Sub-group of Commodities, 1996/97 to 2000/2001
(Base year: 1995/96 = 100)
National

Description	1996/97	1997/98P	1998/99	1999/00	2000/01
All Items	**108.1**	**117.1**	**130.4**	**134.9**	**138.1**
Food and Beverages	***108.2***	***116.6***	***135.5***	***136.1***	***133.0***
Grains and Cereal Products	109.1	112.5	133.5	145.0	125.1
Rice	106.5	110.1	132.9	145.8	124.4
Pulses	106.1	103.6	123.6	118.7	121.6
Vegetable	103.7	121.0	145.1	120.6	125.6
Spices	105.7	113.8	139.3	141.2	153.0
Meat, Fish and Eggs	111.1	120.6	128.5	134.0	137.8
Milk and Milk Products	112.0	120.6	132.1	136.9	144.7
Oil and Clarified Butter	102.5	110.0	143.2	110.9	105.7
Sugar and Related Product	104.2	112.8	118.0	113.4	126.4
Beverages	109.2	125.3	136.2	141.2	144.0
Snacks	111.0	124.0	139.8	150.8	162.9
Other Goods and Services	***108.0***	***117.8***	***124.6***	***133.4***	***144.2***
Cloths & Readymade Garments	107.8	115.2	221.1	127.8	130.6
Cloths	104.9	107.6	112.5	120.2	123.4
Readymade Garments	108.6	116.7	123.4	127.7	130.3
Footwear	108.3	119.3	124.9	127.1	129.1
Housing Material	107.8	114.5	119.1	127.5	142.5
Fuel, Light and water	111.2	119.6	122.9	139.2	170.2
Transport and Communication	111.8	124.7	130.2	146.5	158.4
Medical and Personal Care	107.5	119.9	131.0	139.4	147.4
Education, Educational Materials & Recreation	107.6	120.4	128.9	141.6	161.4
Cigarettes	106.8	124.6	130.2	137.4	139.9

Source: Price Division, Nepal Rastra Bank

Table 2.4.9 Monetary Survey

Description		*1997*	*1998*	*1999*	*2000*	*2001*
1.	Net Foreign Assets	40191.1	55572.8	65027.6	80467.5	87798.0
2.	Domestic Credit	100916.7	115812.1	134832.7	158001.2	187337.9
3.	Net Claims on Government	29229.4	31753.1	34918.2	38242.6	48657.6
4.	Claims on Govt. Enterprises	7028.6	7228.9	9114.0	10310.9	11922.4
	(a) Financial	(5431.6)	(6170.4)	(7547.3)	(8502.8)	(9699.4)
	(b) Non-Financial	(1597.0)	(1058.5)	(1566.7)	(1808.1)	(2223.0)
5.	Claims on Private Sector	65658.7	76830.1	90800.5	109447.6	126757.9
6.	Fixed and Savings Deposits	65260.3	81298.8	101737.7	125141.1	143877.2
7.	Net Capital & Other Items	37387.2	44922.3	47060.1	52347.8	60481.8
	Money Supply, M1	**38460.3**	**45163.8**	**51062.4**	**60979.8**	**70776.9**
	(a) Currency	(27333.7)	(30893.2)	(34984.3)	(42143.0)	(48495.1)
	(b) Demand Deposits	(11126.6)	(14270.6)	(16078.1)	(18836.8)	(22281.8)
	Money Supply, M2	**103720.6**	**126462.6**	**152800.2**	**186120.9**	**214654.1**
	Money Supply, M1	(38460.3)	(45163.8)	(51062.5)	(60979.8)	(70776.9)
	Fixed & Savings Deposits	(65260.3)	(81298.8)	(101737.7)	(125141.1)	(143877.2)
	Net Domestic Assets	63529.5	70889.8	87772.6	105653.4	111971.2
	Change in Money Supply (%)					
	M1	**5.4**	**17.4**	**13.1**	**19.4**	**16.1**
	M2	**11.9**	**21.9**	**20.8**	**21.8**	**15.3**
			0.2192621	0.2082639	0.2180671	0.15330465

Compiled by Research and Information Division of Foundation of Nepalese Chambers of Commerce and Industry (FNCCI) from Economic Survey.

Table 2.4.10 Balance of Payments

Rs. in Million

Description	*1991/92*	*1992/93*	*1993/94*	*1994/95*	*1995/96*	*1996/97*	*1997/98*	*1998/99*	*1999/00*	*2000/01**
Exports F.O.B.	13725.6	17286.4	19316.0	17680.3	19912.7	22663.1	27540.2	35692.7	51645.0	28767.5
Imports C.I.F.	31987.0	39259.9	51628.7	63740.4	74570.8	93661.9	89153.8	87695.0	107086.3	56167.4
Trade Balance	**-18261.4**	**-21973.5**	**-32312.7**	**-46060.1**	**-54658.1**	**-70998.8**	**-61613.6**	**-52002.3**	**-55441.3**	**-27399.9**
Services, Net	**3893.1**	**5064.4**	**17476.5**	**23565.2**	**20922.7**	**39360.7**	**29127.5**	**30201.3**	**26445.7**	**11081.1**
Receipts	11756.7	14942.7	30000.1	37478.5	37178.5	53180.5	43495.8	45967.2	43084.9	19631.7
Travel	5016.9	5966.0	8251.7	8973.2	9521.2	8523.0	9881.6	12167.8	12073.9	5308.1
Investment Income	1123.3	1518.9	1768.6	2075.1	1685.8	1990.3	2377.2	3510.4	4569.3	2262.1
Others	5616.5	7457.8	19979.8	26430.2	25971.5	42667.2	31237.0	30289.0	26441.7	12061.5
Payments	7863.6	9878.3	12523.6	13913.3	16255.8	13819.8	14368.3	15765.9	16639.2	8550.6
Transfers, Net	**4294.3**	**6937.3**	**6809.0**	**10708.8**	**12193.2**	**15130.1**	**17297.9**	**22036.1**	**23368.2**	**11565.5**
Receipts	4489.9	7075.5	7003.9	11227.2	12766.3	16347.3	19065.3	23167.5	25267.3	12175.5
Private Remittances	2316.5	2994.3	3469.1	5063.6	4283.6	5595.0	6987.8	10314.6	12662.3	7307.5
Official Grants	1689.5	3498.5	3039.9	5339.1	7582.8	9743.2	10919.7	11648.3	11286.1	4347.5
Indian Excise Refund	422.0	561.8	494.2	819.0	899.9	1009.1	1157.8	1204.6	1318.9	520.5
Others	61.9	20.9	0.7	5.5	--	--	--	--	--	--
Payments	195.6	138.2	194.9	518.4	573.1	1217.2	1767.4	1131.4	1899.1	610.0
Current Account Balance	**-10074.0**	**-9971.8**	**-8027.2**	**-11786.1**	**-21542.2**	**-16508.0**	**-15188.2**	**235.1**	**-5627.4**	**-4753.3**
Official Capital Net	**7326.0**	**5474.2**	**10723.3**	**8804.7**	**7401.0**	**8390.2**	**10369.6**	**9100.7**	**8878.4**	**3803.1**
Foreign Loans	8710.3	6960.1	12974.7	11395.9	10284.7	11232.9	14236.1	13264.2	13453.5	6237.3
Amortization	-1384.3	-1485.9	-2251.4	-2591.2	-2883.7	-2842.7	-3866.5	-4163.5	-4575.1	-2434.2
Foreign Direct Investment	**--**	**--**	**--**	**--**	**387.8**	**1620.7**	**684.6**	**577.7**	**232.6**	**-33.0**
Miscellaneous Capital	**6142.4**	**12237.8**	**3587.2**	**2667.5**	**12672.9**	**9699.2**	**15099.9**	**-74.0**	**10950.6**	**4494.1**
Change in Reserves, Net	**3394.4**	**7740.2**	**6283.3**	**-313.9**	**-1080.5**	**3202.1**	**10965.9**	**9839.5**	**14434.2**	**3510.9**

Note: * Provisional, Figures for 2000/2001 are for First six month only.

Compiled by Research and Information Division of Foundation of Nepalese Chambers of Commerce and Industry (FNCCI) from Economic Survey.

Table 2.4.11 Direction of Foreign Trade

Value in Million Rs.

Description	*1960/61*	*1965/66*	*1970/71*	*1975/76*	*1980/81*	*1985/86*	*1990/91*	*1991/92*	*1992/93*	*1993/94*	*1994/95*	*1995/96*	*1996/97*	*1997/98*	*1998/99*	*1999/2000*	*2000/2001*
Exports F.O.B.	**209.7**	**375.1**	**400.6**	**1185.8**	**1608.7**	**3078.0**	**7387.5**	**13706.5**	**17266.5**	**19293.4**	**17639.2**	**19881.1**	**22636.5**	**27513.5**	**35676.3**	**49822.7**	**55654.1**
	(100.0)	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**
India	209.2	370.5	395.2	893.7	992.4	1241.1	1552.2	1450.0	1621.7	2408.9	3124.3	3682.3	5226.2	8794.4	12530.7	21220.7	26030.2
	(99.8)	(98.8)	(98.7)	(75.4)	(61.7)	(40.3)	(21.0)	(10.6)	(9.4)	(12.5)	(17.7)	(18.5)	(23.1)	(32.0)	(35.1)	(42.6)	(46.8)
Other Countries	0.5	4.6	5.4	292.1	616.3	1836.9	5835.3	12256.5	15644.8	16884.5	14514.9	16198.5	17410.3	18719.1	23145.6	28602.0	29623.9
	(0.2)	(1.2)	(1.3)	(24.6)	(38.3)	(59.7)	(79.0)	(89.4)	(90.6)	(87.5)	(82.3)	(81.5)	(76.9)	(68.0)	(64.9)	(57.4)	(53.2)
Imports, C.I.F.	**398.0**	**782.0**	**699.1**	**1981.7**	**4428.2**	**9341.2**	**23226.5**	**31940.0**	**39205.6**	**51570.8**	**63679.5**	**74454.5**	**93553.4**	**89002.0**	**87525.3**	**108504.9**	**115687.2**
	(100.0)	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**
India	375.1	763.5	616.8	1227.1	2179.2	3970.9	7323.1	11245.5	12542.1	17035.4	19615.9	24398.6	24853.3	27331.0	32119.7	39660.1	45211.0
	(94.2)	(97.6)	(88.2)	(61.9)	(49.2)	(42.5)	(31.5)	(35.2)	(32.0)	(33.0)	(30.8)	(32.8)	(26.6)	(30.7)	(36.7)	(36.6)	(39.1)
Other Countries	22.9	18.5	82.3	754.6	2249.0	5370.3	15903.4	20694.5	26663.5	34535.4	44063.6	50055.9	68700.1	61671.0	55405.6	68844.8	70476.2
	(5.8)	(2.4)	(11.8)	(38.1)	(50.8)	(57.5)	(68.5)	(64.8)	(68.0)	(67.0)	(69.2)	(67.2)	(73.4)	(69.3)	(63.3)	(63.4)	(60.9)
Trade Balaance	**-188.3**	**-406.9**	**-298.5**	**-795.9**	**-2819.5**	**-6263.2**	**-15839.0**	**-18233.5**	**-21939.1**	**-32277.4**	**-46040.3**	**-54573.4**	**-70916.9**	**-61488.5**	**-51849.0**	**-58682.2**	**-60033.1**
	(100.0)	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**
India	-165.9	-393.0	-221.6	-333.4	-1186.8	-2729.8	-5770.9	-9795.5	-10920.4	-14626.5	-16491.6	-20716.0	-19627.1	-18536.6	-19589.0	-18439.4	-19180.8
	(88.1)	(96.6)	(74.2)	(41.9)	(42.1)	(43.6)	(36.4)	(53.7)	(49.8)	(45.3)	(35.8)	(38.0)	(27.7)	(30.1)	(37.8)	(31.4)	(32.0)
Other Countries	-22.4	-13.9	-76.9	-462.5	-1632.7	-3533.4	-10068.1	-8438.0	-11018.7	-17650.9	-29548.7	-33857.4	-51289.8	-42951.9	-32260.0	-40242.8	-40852.3
	(11.9)	(3.4)	(25.8)	(58.1)	(57.9)	(56.4)	(63.6)	(46.3)	(50.2)	(54.7)	(64.2)	(62.0)	(72.3)	(69.9)	(62.2)	(68.6)	(68.0)
Total Volume of Trade	**607.7**	**1157.1**	**1099.7**	**3167.5**	**6036.9**	**12419.2**	**30614.0**	**45646.5**	**56472.1**	**70864.2**	**81318.7**	**94335.6**	**116189.9**	**116515.5**	**123201.6**	**158327.6**	**171341.3**
	(100.0)	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**	**(100.0)**
India	584.3	1134.0	1012.0	2120.8	3171.6	5212.0	8875.3	12695.5	14163.8	19444.3	22740.2	28081.2	30079.5	36125.4	44650.4	60880.8	71241.2
	(96.1)	(98.0)	(92.0)	(67.0)	(52.5)	(42.0)	(29.0)	(27.8)	(25.1)	(27.4)	(28.0)	(29.8)	(25.9)	(31.0)	(36.2)	(38.5)	(41.6)
Other Countries	23.4	23.1	87.7	1046.7	2865.3	7207.2	21738.7	32951.0	42308.3	51419.9	58578.5	66254.4	86110.4	80391.1	78551.2	97446.8	100100.1
	(3.9)	(2.0)	(8.0)	(33.0)	(47.5)	(58.0)	(71.0)	(72.2)	(74.9)	(72.6)	(72.0)	(70.2)	(74.1)	(69.0)	(63.8)	(61.5)	(58.4)

Note: figures in the Paranthesis are percentage of the total.

Compiled by Sesearch and Information Division of FNCCI from Nepali's Foreign Trade and Economic Development 1956/57 to 1979/80 by Pushkar R. Reejal, a CEDA Publication and Various publications of Nepal Rastra Bank.

Table 2.4.12 Nepal: External Debt and Debt Service, 1994/95-1999/00

(In millions of US. dollars)

	1994/95 (2051/52)	1995/96 (2052/53)	1996/97 (2053/54)	1997/98 (2054/55)	1998/99 (2055/56)	1999/00 (2056/57)
Debt outstanding 1/	**2,295**	**2,370**	**2,483**	**2,612**	**2,729**	**3381**
Total Medium and Long-term	**2,295**	**2,320**	**2,362**	**2,415**	**2,532**	**3,112**
Multilateral	**1,842**	**1,940**	**1,983**	**2,090**	**2,169**	**2642**
AsDB	698	757	802	910	948	1216
EEC	10	9	8	8	7	8
IDA	1,002	1,052	1,059	1,080	1,107	1297
IFAD	58	57	57	44	58	68
IMF 2/	55	43	34	25	21	15
NDF	8	11	16	18	20	23
OPEC	12	10	7	6	9	15
Bilateral	**453**	**380**	**378**	**325**	**363**	**470**
Australia	0	0	0	0	0	6
Austria	0	6	5	5	4	5
Belgium	9	8	7	6	6	10
Finland	0	0	6	6	6	7
France	51	53	51	52	48	53
Korea	0	0	0	2	10	9
Kuwait	16	15	13	12	11	10
OECF	370	291	296	229	264	344
Saudi Fund	8	7	10	13	14	26
Short-term debt 3/	**...**	**50**	**121**	**197**	**197**	**269**
Total debt service	**82**	**84**	**83**	**87**	**84**	**83**
Amortization 4/	59	60	55	62	59	57
Of which : To IMF 2/	7	8	7	7	5	5
Interest 4/	23	24	28	24	25	26
Of which : To IMF	0.2	0.2	0.2	0.2	0.1	0.1
			(in percent)			
Debt service ratio 5/	**6.3**	**6.8**	**5.0**	**6.7**	**5.9**	**4.7**
Of which : To IMF	0.6	0.7	0.5	0.6	0.4	0.3
Outstanding debt/GDP	**52.1**	**52.4**	**50.5**	**53.8**	**54.2**	**61.5**
Of which: To IMF	1.3	1.0	0.7	0.5	0.4	0.3

1/ Consortium primarily of medium- and long-tem public and publicly guaranteed debt excluding foreign liabilities of the banking system other than liabilities to the IMF.
2/ Excluding IMF Trust Fund.
3/ Outstanding trade credits.
4/ Includes principal and interest repayments of public enterprises and some private entities, as well as The central government.
5/ In relation to exports of goods and services and private transfers

Source: IMF.

Table 2.4.13 Foreign Exchange Holidings

Year/ Month	Exchange Rate IUS$=NR	Gold+IMF Gold Tranche+ Special Drawing Rights Million Rs.	Million$	Foreign Exchange Million Rs.	Million$	Total Million Rs.	Million$	
1989 July	27.40	380.2	13.9	8310.8	303.3	8691.0	317.2	0.1332088
1990 July	29.10	424.6	14.6	11589.8	398.3	12014.4	412.9	0.1190179
1991 July	42.70	613.4	14.4	18656.6	436.9	19270.0	451.3	0.1216534
1992 July	42.60	630.9	14.8	24251.4	569.3	24882.3	584.1	0.1039558
1993 July	49.00	714.6	14.6	33510.4	683.9	34225.0	698.5	0.0929763
1994 July	49.11	732.6	14.9	42015.7	855.5	42748.3	870.4	0.0726949
1995 July	50.45	778.2	15.4	43084.9	854.0	43863.1	869.4	0.0855224
1996 July	56.25	832.1	14.8	44438.3	790.0	45270.4	804.8	0.1206574
1997 July	56.75	825.1	14.5	48541.4	855.4	49366.5	869.9	0.1308259
1998 July	67.60	956.3	14.1	65157.7	963.9	66114.0	978.0	0.1330206
1999 July	68.15	960.3	14.1	76650.8	1124.7	77611.1	1138.8	0.1176412
2000 July*	70.40	997.7	14.2	93858.1	1333.2	94855.8	1347.4	0.055737
2001 July*	74.65	1018.2	13.6	105172.5	1408.9	106190.7	1422.5	
2002 Jan.*	76.30	1049.6	13.8	103692.1	1359.0	104741.7	1372.8	0.0221031

Compiled by Research and Information Division of FNCCI from Economic Survey.

*: Compiled by the Study Team with Source from Quarterly Eonomic Bulletin, Mid-January 2002, by Nepal Rastra Bank

Chapter 3

CHAPTER 3 SITE CONDITIONS

3.1 Location and Topography

The project area of the development of the Kulekhani III hydropower station is located in the Rapti River basin along a reach of 6 km long from Bhaisedobhan to Hetauda in Makwanpur District. The Rapti River, which meets with the Khani River at Bhaisedobhan, flows from northeast to southwest. In the upstream stretch from Bhaisedobhan to the confluence of the Kesadi River, which is one of the tributaries of the Rapti River, the river slope is steep at 1/50 to 1/100. The slope of the river downstream of the confluence of the Rapti River and the Kesadi River to Hetauda is gentle in comparison with the upstream stretch affected by the geological characteristics of Siwalik.

A principal mountain ridge stretches in the direction of northeast to southwest, showing a rugged and steep relief. The highest peak rises to 1,300 m above sea level and the lowest point is approximately 500 m near the town of Hetauda.

Old terrace deposits, which are characterized by a flat, elevated topography above the present riversides, exist on the hillsides of both banks of the Rapti River and are used mostly for agricultural land.

Topographical maps collected in this investigation are as follows:

Type	Scale	Area	Published	Aerial Photo	Produced by	Nos.
Field Survey	500	Kulakhani III HPP Area	1998	—	Nepal Electricity Authority	36
Aerial Photgraphic Survey	5,000	Kulakhani III Regulating Pond Area - P/H Area - Sanutar - Tailrace	1996	—	Nepal Electricity Authority	1
	5,000	Area along Rapti River (Bhimphedi- Khani - Bhainse Dobhan- Hetauda)	1989	1978-1979 (1:25000)	Nepal Electricity Authority	9
	25,000	Kathmandu - Kulekhani Reservoir Area - Bhainse Dobhan- Hetauda Area along Bagmati River (Hariharpur Ghadi)	1995	1992 (1:50000)	Survey Department of His Majesty's Government of Nepal Finnish International Development Agency	18

3.2 Meteorology and Hydrology

3.2.1 Objectives

The main objectives of the studies on meteorology and hydrology for the Project are:

- review of relevant meteorological and hydrological data,
- review and estimation of long-term sequences of inflow into the Kulekhani reservoir and runoff of the upper Rapti tributaries,
- estimation of design discharges of major structures, and
- estimation of sediment load from the Yangran River basin.

For studies on meteorology and hydrology, observation data of the adjacent stations are used as basic information. An inventory of the related stations for this study is given in Table 3.2.1 and the location of each station is shown in Figure 3.2.1.

3.2.2 Climatic Conditions

The climate of Nepal is strongly influenced by the southwest monsoon during the wet season and the northwest monsoon during the dry season. The wet season generally lasts from June to September while the dry season lasts from November to April. May and October are transition periods between these seasons. In general, it is humid and hot in the wet season while it is dry and cold in the dry season. Approximately 80 % to 90 % of the annual rainfall occurs during the wet season due to the influence of the southwest monsoon.

The project area is located at a relatively high altitude between 600 m and 1,100 m, and the climate is generally moderate compared with that in the Terai and in the higher Mahabharat range.

With regard to past records of temperature and humidity, there is no meteorological station within the project area. Nearby stations are Daman and Hetauda N.F.I., situated at EL. 2,314 m and 474 m respectively. The general features of the climate in the project area seem not to deviate too far from their mean values.

Mean maximum, mean minimum and mean daily air temperatures recorded at these stations between 1985 and 2000 are summarized in Table 3.2.2[1)] on a monthly basis.

At Daman where the mountain climate is predominant, the mean air temperature is 14 °C. The maximum temperature occurs in October, occasionally rising to about 29 °C, while the minimum temperature rarely falls below freezing point during November to March. On the other hand, at Hetauda N.F.I., where the sub-tropical climate is predominant, the mean air temperature is 23 °C. The maximum temperature occurs in May, sometimes rising to about 41 °C while the minimum temperature occasionally drops to about 2 °C in January.

Evaporation, measured at Chisapani Gadhi for the period 1963 to 1965, is tabulated on a monthly basis in Table 3.2.3[2)]. According to the record, the monthly mean evaporation ranges from about 70 mm (2.3 mm/day) in December to 360 mm (11.7 mm/day) in May, and the annual mean is approximately 1,800 mm.

3.2.3 Rainfall

Monthly mean rainfall records at eight rainfall gauging stations around the project area are summarized in Table 3.2.4[3)4)]. Monthly variation at these stations indicates distinct sub-tropical weather in that approximately 90 % of the annual rainfall occurs during the wet season from May to October. July is generally the wettest month and November is the driest one.

Among these stations, Chisapani Gadhi and Hetauda N.F.I. are located near the project area and can be regarded as having rainfall patterns representative of the area.

Table 3.2.5[3)] shows the maximum daily rainfall of 300 mm at Chisapani Gadhi in July, 1965 and 453 mm at Hetauda N.F.I. in August, 1990. Due to the lack of records in and around the project area, details of the earlier storm are not available. During the 1990 storm, heavy rainfall was also observed at several stations located in the southern part of the project area, such as 248 mm at Makwanpur Gadhi[3)].

In July, 1993, an unprecedented storm hit the center and southern mountain regions of Nepal, including the project area. This storm caused substantial soil erosion and landslides, and transported a great deal of sediment along the rivers and tributaries in the project area and also into the Kulekhani reservoir.

Table 3.2.6[5)] summarizes rainfall during this storm. The one-day rainfall for both the 19th and 20th July over the project area is estimated to be 212 mm, using the arithmetic mean of records at six stations in and around the area. In addition, the maximum rainfall intensities of 70 mm/hr and 64 mm/hr were recorded at Tistung and Churibagaicha, respectively[5)].

Since this storm is regarded to be at the scale of the recorded maximum, thorough reviews are required for the flood and sediment analyses described later.

During the period of this study, in July, 2002, a heavy storm hit the vicinity of the project area. Debris flows triggered by this storm seriously damaged the surrounding areas, such as the Lothar River, the Manahari River, and the upper Rapti River. It was observed that the upper Rapti River basin was affected more severely than the Kulekhani River basin by this storm.

Table 3.2.7 summarizes rainfall during this storm. The one-day rainfall for the 22nd and 23rd July over the project area is estimated to be 294 mm and 353 mm respectively, using the arithmetic mean of records at five stations in and around the area. In addition, the maximum rainfall intensity of 32 mm/hr was recorded at

Tistung.

3.2.4 Sedimentation of Kulekhani Reservoir

The Kulekhani reservoir was created on a riverbed at EL.1427.0 m. The reservoir has a full supply water level (F.S.L.) at EL.1,530.0 m. In 1981 it had a gross storage of 85.3 x 10^6 m^3, including dead storage of 12.0 x 10^6 m^3 and live storage of 73.3 x 10^6 m^3.

After completion, the sediment survey has been conducted continuously by the Department of Soil Conservation (DSC) and the Nepal Electricity Authority (NEA) in order to manage the watershed and sediment inflow. A summary of the survey results[6) 7) 8)] is presented in Table 3.2.8 and tabulated below:

	Gross Storage ($10^6 m^3$)	Dead Storage ($10^6 m^3$)	Live Storage ($10^6 m^3$)	M.O.L. (EL. m)
1981 (Original)	85.30	12.00	73.30	1,476.0
Nov., 1995	63.50	4.60	58.90	1,476.0
Nov., 2001	62.36	6.79	55.57	1,483.5

Sediment deposition over 20 years after impounding of the reservoir reduced the storage capacity to a gross storage of 62.36 x 10^6 m^3 in November, 2001, including dead storage of 6.79 x 10^6 m^3 and live storage of 55.57 x 10^6 m^3. These reductions correspond to 73 % and 76 % of the original gross and live storage respectively.

The lowest intake level was changed to EL.1,480.0 m from the original 1,471.0 m after installation of a sloping intake in 1997. Following this installation, the minimum operation level (M.O.L) was raised to EL.1,483.5 m from the original 1,476.0 m.

Prior to analysis of the reservoir operation rules, it is necessary to revise the existing storage capacity curve with respect to the reservoir sedimentation in recent years. Figure 3.2.2 illustrates the original storage capacity curve and the one estimated by the Area-Increment method in 1995[6)]. Both of the curves are best represented by the polynomial equations given below:

$$Y = a_0 + a_1 \times (EL) + a_2 \times (EL)^2 + a_3 \times (EL)^3$$

Y : Storage capacity (10^6 m^3)

EL : Reservoir water level (EL. m)

Coefficients of polynomial equations;

For original curve : $a_0 = -226,544.6$, $a_1 = 471.98683$, $a_2 = -0.3280187$, $a_3 = 0.76041656 \times 10^{-4}$

For curve as of 1995 : $a_0 = -146,779.0$, $a_1 = 312.42454$, $a_2 = -0.2214828$, $a_3 = 0.52295988 \times 10^{-4}$

3.2.5 Runoff Analysis

In this section, the reservoir inflow and runoff of the upper Rapti tributaries are studied using runoff analyses over a period 1963 to 1995.

(1) Runoff Records

Runoff records at the adjacent stream gauging stations were collected as shown in Table 3.2.1. In this study, the runoff recorded at the Kulekhani gauging station (G.S.) and the Rajaya G.S. are used as the main data while the data from the Manahari G.S. and the Lothar G.S., located near the project area, are used as supplementary data. With regard to runoff records since 1996, those are still processed by DHM and were not collected in this study.

1) Runoff record at Kulekhani G.S.

The Kulekhani G.S., with a catchment area of 126 km^2, had been situated on the Kulekhani River 0.4 km upstream from the confluence with the Sim River and demolished prior to the dam construction. Daily mean runoff was recorded from 1963 to 1977 as shown in Table 3.2.9 on a monthly basis.

2) Runoff record at Rajaya G.S.

The Rajaya G.S. has a catchment area of 579 km^2 and is situated on the Rapti River 14 km downstream from Hetauda. Daily mean runoff was recorded from 1963 to 1995 as shown in Table 3.2.10 on a monthly basis. Records for some periods for which no data were collected were extrapolated using correlation with the records at the Manahari G.S. It should be noted that the records since 1983 were affected by outflow from the Kulekhani hydropower station series.

3) Runoff records at other G.S.

The Manahari G.S. and the Lothar G.S. are situated on the Manahari River and the Lothar River, close to the confluences with the Rapti River. These stations have drainage areas of 427 km^2 and 169 km^2 respectively. The former drains into the Rapti River at about 15 km downstream from the Rajaya G.S. and the latter at about 25 km downstream. Runoff was recorded at each G.S. since 1964.

Apart from these stations, runoff was recorded at some tributaries of the Kulekhani River, such as the Chakhel River, the Sim River and the Thado River, and those of the upper Rapti River. Those records are limited to short periods and are not used in this study. The runoffs of the Chakhel River and the Sim River are derived from that at the Kulekhani G.S. by means of the following equations[2)]:

Runoff of the Chakhel River : $Qc=0.18\ Qk$
Runoff of the Sim River : $Qs=0.0745\ Qk^{1.128}$
where, Qk; Runoff recorded at the Kulekhani G.S.

(2) Reliability of Runoff Records

The reliability of the runoff record at the Kulekhani G.S. was ascertained in the previous study.[2)] Consequently, the following examinations are carried out to assess the reliability of that at the Rajaya G.S.

- Examination of the consistency of the record by double mass curve
- Comparison of runoff coefficient and specific runoff with other adjacent basins

1) Consistency of record

The Manahari G.S. and the Lothar G.S. are selected as comparative stations for checking the consistency of the record at the Rajaya G.S. Since the river basins of these comparative stations are located close to that of the Rajaya G.S., basin characteristics of both rivers are considered to be geometrically, geologically and hydrologically similar to that of the upper Rapti River.

The accumulated annual runoff at the Rajaya G.S. is compared with that of both stations, as shown in Figure 3.2.3, for the period 1964 to 1982, before the Kulekhani I hydropower station commenced operation. Two straight lines give the relationships between the Rajaya G.S. and each selected station. Accordingly, the consistency of the record at the Rajaya G.S. is considered to be verified.

2) Runoff coefficient and specific runoff

To estimate the runoff coefficient of the upstream basin of the Rajaya G.S., the average value of rainfall records at Chisapani Gadhi and Hetauda N.F.I. is used. These stations are situated in the upper and the lower reaches of the basin, respectively. For the period 1967 to 1982, before the Kulekhani I hydropower station commenced operation, the runoff coefficients and specific runoffs are computed on an annual basis as shown in Table 3.2.11 and summarized below:

Annual Rainfall (mm)	Annual Runoff (mm)	Runoff Coefficient	Specific Runoff ($m^3/s/100\ km^2$)
2,189	1,451	0.67	4.60

Note: Average for the period 1967 to 1982 excluding years with missing rainfall data

The runoff coefficient of the upper Rapti River basin for the period is 0.67, which is greater than that of the Kulekhani River basin (0.56) [2)]. This is considered to be reasonable, taking into account the larger amount of rainfall over the upper Rapti River basin compared with the Kulekhani one and the mountainous topography.

The specific runoff at the Rajaya G.S. is 4.60 $m^3/s/100\ km^2$ and is comparable with those of the stations in the adjacent basins[9)]. Table 3.2.12 and Fig. 3.2.4 show the relationship between drainage area and specific runoff. In addition, the specific runoff at the Rajaya G.S. nearly corresponds to that at the Manahari G.S. (4.31 $m^3/s/100\ km^2$), which is located in the Rapti river basin and has a similar catchment area of 427 km^2 to the Rajaya G.S. (579 km^2).

On the basis of the above results, the reliability of the runoff record at the Rajaya G.S. is judged to be reasonable and can be used for the studies hereinafter.

(3) Inflow into Kulekhani Reservoir

Inflow into the Kulekhani reservoir is dominated by the runoff of the Kulekhani

River, which has a catchment area of 126 km^2. In addition to the Kulekhani River, the tributary intake discharge from the Chakhel River has been diverted to the reservoir and one from the Sim River has been directed to the pressure tunnel. The catchment areas of these intake sites are 22.8 km^2 and 7.1 km^2 respectively. The maximum discharge of the former was designed to be 4.1 m^3/s and the latter 3.3 m^3/s. The maximum plant discharge of the Kulekhani I hydropower station was set at 13.1 m^3/s, irrespective of the Sim River contribution.

Since daily mean runoff was measured at the Kulekhani G.S. for only 15 years over the period of 1963 to 1977, the reservoir inflow since 1978 is estimated by applying the tank model method and from the reservoir operation record as tabulated below:

Period	Reservoir Inflow	Estimated as
1) 1963 to 1977 (15 yrs.)	Computed from the runoff record at the Kulekhani G.S.	Daily mean
2) 1978 to 1982 (5 yrs.)	Estimated by the tank model method	- ditto -
3) 1983 to 1995 (13 yrs.)	Estimated from the reservoir operation record (Tributary intake discharges are included.)	5-day mean

1) Reservoir inflow computed from runoff record at Kulekhani G.S. (1963 to 1977)

The reservoir inflow for the period 1963 to 1977 is computed from the runoff record at the Kulekhani G.S. by including the diverted water from the Chakhel River and the Sim River.

2) Reservoir inflow estimated by tank model method (1978 to 1982)

The reservoir inflow for the period 1978 to 1982 is estimated by applying the tank model method, in which the model is composed of four tanks vertically combined as illustrated in Figure 3.2.5 and using the following conditions:

Rainfall : the weighted average of the daily rainfall records at Daman (0.3) and Markhu Gaun (0.7) by means of the Thiessen polygon

Evaporation Loss : 70 % of the daily mean evaporation record at Chisapani Gadhi is adopted, taking into the difference in altitude between the observatory station and the reservoir basin, as tabulated below:

Unit: mm/day

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Daily Evaporation	2.46	3.89	6.31	10.62	11.71	8.17	2.74	2.71	2.67	3.33	2.96	2.15	4.97
70% value	1.72	2.18	4.42	7.43	8.20	5.72	1.92	1.90	1.87	2.33	2.07	1.51	3.48

Calibration of the model is undertaken from the viewpoints of correlation, runoff coefficient and specific runoff, using comparisons with the runoff record at the Kulekhani G.S. for the 6 year period from 1972 through 1977.

Table 3.2.13 and Figure 3.2.6 show results of the calibration, which arrive at a runoff coefficient of 0.56 and a specific runoff of 3.20 $m^3/s/100\ km^2$. These results are almost the same as those in the previous study[2)] (0.56 and 3.10 $m^3/s/100\ km^2$). Furthermore, the results show a correlation coefficient of 0.86 and a ratio of the observed and estimated runoff to be approximately 1.0. Accordingly, it is judged that the runoff estimates are satisfactory and the reservoir inflow for the period can be computed from the runoff estimated by the model, adding the tributary intake discharges from the Chakhel River and the Sim River.

3) Reservoir inflow estimated from reservoir operation record (1983 to 1995)

The reservoir inflow for the period 1983 to 1995 is estimated from the reservoir operation record using the following method, of which details are presented in the Supporting Report (1), Appendix.A1.

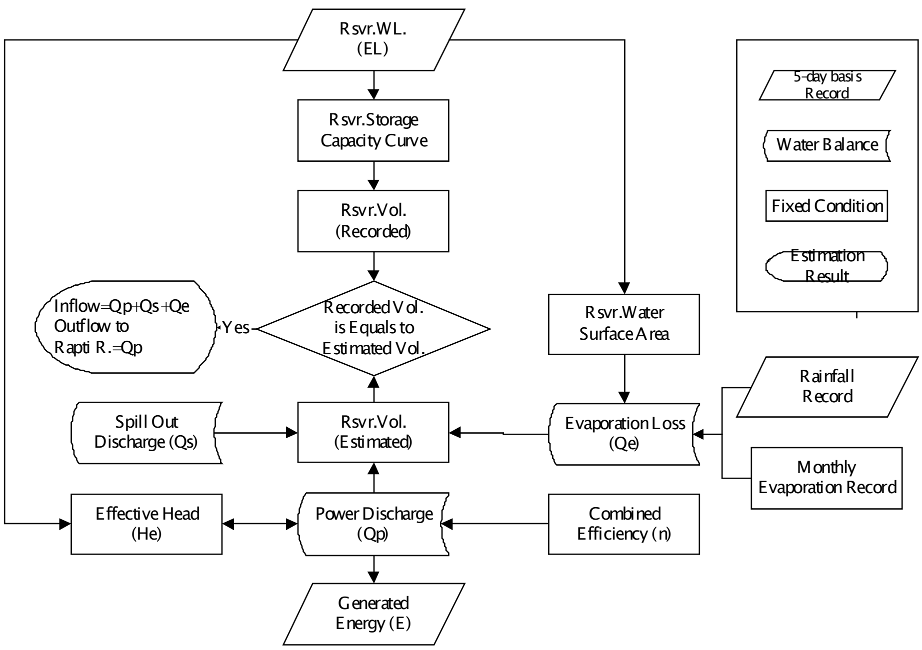
The reservoir inflow is estimated on a 5-day basis from the daily operation record, since daily fluctuations are inevitable due to recording inaccuracies.

i) Actual reservoir water volumes are computed from the water level record.

ii) Water balances in the reservoir, which is maintained by inflow, outflow and evaporation loss, is estimated from the records of water level, generated energy, spill out and rainfall.

iii) Based on the estimated water balance, the reservoir water volume is estimated.

iv) The reservoir inflow and the outflow are obtained when the estimated reservoir water volume is equivalent to the actual one.



4) Evaluation of reservoir inflow

The estimated reservoir inflow including the tributary intake discharges is summarized in Table 3.2.14. The reservoir inflows that are estimated by the three different methods are compared in Table 3.2.15 and summarized below. The annual rainfall is derived from the weighted average of the rainfall records at Daman and Markhu Gaun by means of the Thiessen polygon.

Reservoir Inflow	Annual Rainfall (mm)	Annual Runoff (mm)	Runoff Coefficient	Specific Runoff ($m^3/s/100km^2$)
1) Computed from the runoff record (1972 to 1977)	1,801	997	0.55	3.16
2) Estimated by the tank model method (1978 to 1982)	1,375	735	0.53	2.33
3) Estimated from the reservoir operation record (1983 to 1995)	1,527	846	0.55	2.68
Average	1,564	860	0.55	2.73

Note: The years of 1963 to 1971 are excluded in comparison due to missing rainfall data.

The runoff coefficients estimated by the three methods are almost consistent (0.53 to 0.55) while the specific runoffs range between 2.33 $m^3/s/100\ km^2$ and 3.16 $m^3/s/100\ km^2$, reflecting the different amounts of annual rainfall. These values also compare well with the runoff coefficient of 0.56 and the specific runoff of 3.10 $m^3/s/100\ km^2$ for the period 1963 to 1972[2)]. Therefore, the estimated reservoir inflow is judged to be reasonable and can be used for the studies hereinafter.

(4) Runoff of Upper Rapti Tributaries

Applying the method verified in the previous study[11)], runoff at each intake site of the upper Rapti River is derived from a simple area proportion of the runoff record at the Rajaya G.S.

Since the runoff recorded at the Rajaya G.S. after 1983 contains the outflow from the Kulekhani hydropower station series, subtraction of the outflow is necessary to obtain natural runoff. It is thought that the recorded runoff reflects river flow in daytime since level gauges measure it. The outflow is increased at night by peak operation of the hydropower stations. The natural runoff is calculated from the recorded runoff by subtracting the outflow during base operation in daytime, as estimated by conversion from the daily mean discharge on the basis of the basic daily discharge pattern outlined in the operation manual[10)].

1) Tributary Intake for Kulekhani II hydropower station

The Kulekhani II hydropower station is a run-of-river power station aiming at peak power supply by utilizing the outflow from the Kulekhani I hydropower station and the diverted water from the upper Rapti River. Tributary intake discharges from the Mandu intake, an infiltration type intake with a daily regulating pond, on the Mandu River and from the Rapti pump intake on the upper Rapti River. These intake sites have a catchment area of 20.0 km^2 and 28.5 km^2

respectively. The design intake discharges of both facilities were set at 0.2 m^3/s, applying the 90 % dependable discharge of the Mandu River for the former, and the available discharge of the upper Rapti River in the dry season for the latter. The maximum intake discharge of 1.0 m^3/s was recorded at the former during the monitoring period from January to April in 1998 while the latter is in operation from October to April[12)].

2) Tributary Intake for Kulekhani III hydropower station

To increase the available discharge in the dry season, the water taken from the Khani headwork on the Khani River and from the Yangran regulating dam on the Yangran River are led to the Kulekhani III hydropower station. These intake sites have a catchment area of 21.2 km^2 and 8.1 km^2 respectively.

The monthly mean runoff at the respective intake sites are shown below:

Monthly Mean Runoff from 1963 to 1995 Unit: m^3/s

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Mandu Intake	0.27	0.23	0.19	0.20	0.26	0.72	2.06	2.54	2.20	1.04	0.52	0.35	0.88
Rapti Pump Intake	0.39	0.32	0.28	0.28	0.36	1.02	2.94	3.62	3.14	1.48	0.74	0.50	1.26
Khani Headwork	0.29	0.24	0.21	0.21	0.27	0.76	2.19	2.69	2.34	1.10	0.55	0.37	0.93
Yangran Reg.Dam	0.11	0.09	0.08	0.08	0.10	0.29	0.83	1.01	0.88	0.41	0.21	0.14	0.35

Flow duration curves of the reservoir inflow and runoff at the respective tributary intake sites are illustrated in Figure 3.2.7 on both an annual and seasonal basis.

3.2.6 Flood Analysis

In this section, probable floods at adjacent stream gauging stations are used to calculate those at the major structure sites utilizing Creager's equation. In order to determine design floods, the probable floods at the respective sites are also evaluated by comparison with records of large floods experienced around the project area and the recorded maximum floods in Nepal.

(1) Probable Floods

1) Flood records

Flood study is required for determining the design floods of the major structures. There is no flood record in the project area. It is therefore necessary to assess floods in the area based on those flood records available at adjacent stream gauging stations (G.S.), such as the Rajaya G.S. with a drainage area of 579 km^2, and the Kulekhani G.S. with a drainage area of 126 km^2.

In addition to these two stations, flood record is available for the Darkot G.S., with a drainage area of 13.8 km^2, on the Thado River, a tributary of the Kulekhani River. However, taking into consideration the uncertainty of the record, as pointed out in the previous study[13)], the Darkot G.S. is excluded from the studies hereinafter.

Table 3.2.16 tabulates records of annual maximum flood at the Rajaya G.S. and the Kulekhani G.S. [14].

2) Probable floods at adjacent G.S.

a) Rajaya G.S.

Frequency analyses are carried out on the annual maximum flood record at the Rajaya G.S. by applying three distributions: Gumbel, Iwai and Log-Pearson type III. The results of the analyses are presented in Table 3.2.17 and Figure 3.2.8. The probable floods given by Iwai and Log-Pearson type III are almost the same. Though, that given by Iwai is generally larger than that by Log-Pearson type III for the low frequency portion of the distribution. Therefore, the probable flood given by Iwai is adopted as that at the Rajaya G.S. from a safety view point.

b) Kulekhani G.S.

Flood record exists only for the period 1963 to 1977 at the Kulekhani G.S. and the flood of July 1993 was not observed. Therefore, the probable flood at the station is estimated based on the results of the previous study[5].

- Results of the Master Plan Study on Sediment Control of 1994

In the Master Plan Study on Sediment Control, flood analysis was conducted utilizing a unit-hydrograph to estimate a peak discharge caused by the storm of July 1993 at the station. The unit-hydrograph was developed from an hourly rainfall distribution observed at Tistung during the said storm, as represented in Figure 3.2.9. It was confirmed that the developed unit-hydrograph well reproduced the peak discharge and the flood volume without sediment content in comparison with the reservoir operation record[5]. Prior to estimate the probable flood, rainfall probability was reviewed by utilizing the annual maximum daily rainfall at Daman in a period 1968 to 1993. The probable flood for each return period was obtained by the same unit-hydrograph, arranging the hourly rainfall distribution of the said storm proportionally to reach the respective probable rainfall. The obtained probable flood was considered to be reasonable compared with the estimates developed on the basis of the relationship between specific discharge and drainage area of adjacent rivers by DHM[5].

In this study, rainfall characteristics of the overall reservoir basin are reconsidered as described in the Supporting Report (1), Appendix A2. Consequently, basin rainfalls are computed from the weighted average of the rainfall records at Daman and Markhu Gaun by means of the Thiessen polygon, at which relatively longer sequences of record are available. The probable rainfall is estimated from the basin rainfall as shown in Table 3.2.18 and Figure 3.2.10. The probable flood for each return period is obtained by the same unit-hydrograph, arranging the hourly rainfall distribution of the said storm proportionally to reach the respective probable rainfall, as shown in Table 3.2.19.

Return Period (Yrs.)	Probable Flood (m^3/s)			
	Rajaya G.S. ($579 km^2$)	Kulekhani G.S.[5)] ($126 km^2$)		
5	793	562	548	440
10	947	717	700	600
20	1,201	890	872	-
50	1,475	1,151	1,139	1,025
100	1,690	1,374	1,379	1,240
200	1,912	1,624	1,653	1,470
1,000	2,460	2,331	2,471	2,100
Based on	Flood record (1963-1995)	Rainfall at Daman Unit-hydrograph (1968-1993)	Basin Rainfall Unit-hydrograph (1972-2002)	Specific discharge

3) Probable floods at major structure sites

The probable floods obtained at both stations are converted to those corresponding to the drainage area of the respective major structure sites utilizing Creager's equation and the results are presented below:

$$Q = 46\ C\ A^n$$

$$n = 0.894\ A^{-0.048}$$

where, Q: Flood peak runoff ($ft.^3/s$, $1\ ft.^3/s = 0.02832\ m^3/s$)

A: Drainage area ($mile^2$, $1\ mile^2 = 2.590\ km^2$)

C: A coefficient depending on the characteristic of the drainage

Unit: m^3/s

Return Period (Yrs.)	Khani H/W ($21.2km^2$)		Yangran Reg. Dam ($8.1km^2$)		Tailrace Outlet ($168.8km^2$)	
	Rajaya	Kulekhani	Rajaya	Kulekhani	Rajaya	Kulekhani
50	194	353	93	169	745	1,355
100	222	427	107	205	854	1,641
200	251	512	121	246	966	1,968
1,000	323	766	155	368	1,242	2,941

As shown in the above table, the probable floods converted from the record at the Rajaya G.S. are smaller than those at the Kulekhani G.S. The following reasons are proposed to account for this tendency:

a) Difference in method of estimation

The latter are estimated on the basis of the annual maximum daily rainfall records due to the lack of flood records while the former are based on the long-term sequence of flood records.

b) Difference in basin conditions

The Rajaya G.S. has a drainage area of 579 km^2. The lower reach of the upper Rapti River, downstream from Bhainsedobhan, is relatively gentle with an average river gradient of less than 1/50 and a low portion of mountain area. While the upper reach is in a steep mountain drainage system of 95 km^2 with an average river gradient of 1/5 and a mountain area of 78 %. The Kulekhani G.S. was located in a steep mountain drainage system of 126 km^2 with an average river gradient of 1/7 and a mountain area of 87 %.

Taking account of the above conditions and the locations where the major structures are planned, it is judged that the design floods should be obtained from the probable flood at the Kulekhani G.S. from a safety viewpoint.

Unit: m^3/s

Return Period	Creager's Coefficient	Khani H/W (21.2km^2)	Yangran Reg. Dam (8.1km^2)	Tailrace Outlet (168.8km^2)
50	49.3	353	169	1,355
100	59.7	427	205	1,641
200	71.6	512	246	1,968
1,000	107.0	766	368	2,941

(2) Design Floods of Major Structures

1) Record of large floods experienced around the project area

Although several large floods have been experienced around the project area, reliable records are limited as described below:

a) Flood of July 1970

The flood of July 1970, regarded to be the fifth largest from 1927 to 1987, was traced with relatively high reliability and its peak runoff was estimated to be 908 m^3/s at the existing bridge in Bhainsedobhan, which has a drainage area of 95.1 km^2 [13].

b) Flood of July 1993

The flood of July 1993, regarded to be the recorded maximum in the upper Rapti River and the Kulekhani River basins, was investigated and evaluated by several concerned authorities. A peak discharge of 1,340 m^3/s at the Kulekhani dam was estimated from the reservoir operation record during the event with verification by the flood volume[5)]. Accordingly, the estimate is considered to have relatively high reliability. The estimations of peak runoff in the upper Rapti River basin were undertaken by utilizing several methods, including the Slope-Area method based on flood marks. Peak discharges at the confluence of the Khani River, with a drainage area of 114 km^2, and at Bhainsedobhan, with a drainage area of 92 km^2, were estimated to be 1,929 m^3/s[15)] and 2,600 m^3/s[16)] respectively.

Flood Records	Drainage Area (km^2)	Peak Runoff (m^3/s)	Creager's Coefficient	Return Period (Yrs.)
Flood of July 1970				
Bhainsedobhan Existing Bridge	95.1	908	46.4	40
Flood of July 1993				
・Kulekhani Dam	126	1,340	57.6	90
・Confluence of Khani R.	114	1,929	88.3	500
・Bhainsedobhan	92	2,600	135.7	>1,000

Note: Return periods are roughly estimated from the probable floods at the Kulekhani G.S.

The estimate at the Kulekhani dam was derived from the reservoir operation record and verified by the flood volume without sediment content. Those at the other locations were mainly based on flood marks and seem to be evaluated as peak discharges of debris flows containing large amounts of sediment.

2) Recorded maximum floods in Nepal

To evaluate the design floods of the major structures, the recorded maximum floods in Nepal[14)] are plotted against their respective drainage areas as presented in Figure 3.2.11. Among the records for 75 stations, the longest duration of record is 34 years and the average is 19 years. As seen from the figure, the number of records is not sufficient for smaller drainage areas due to lack of stations.

3) Evaluation of design floods

Based on the records of large floods experienced around the project area and the recorded maximum floods in Nepal, the design floods of the major structures are evaluated as follows:

- Two envelope curves are drawn in Figure 3.2.11 so as to estimate floods of small drainage areas of less than 200 km^2, where the major structures are planned, from the available records of large drainage areas. Curve No.1 corresponds to Creager's coefficient of 45, and fits to the flood record of July 1970 at the existing bridge in Bhainsedobhan. Curve No.2 is drawn to include the recorded maximum floods in Nepal and corresponds to that of 90. These coefficients correspond to return periods of 40 years and more than 500 years respectively at the major structure sites.
- Curve No.2 is controlled by the flood records at G.S. with drainage areas of more than 1,000 km^2 while curve No.1 by those at G.S. with drainage areas of less than 1,000 km^2.
- Due to lack of records at G.S. with drainage areas of less than 200 km^2, the records of the large floods experienced around the project area are essential information for reference.
- It seems that the peak discharges during the flood of July 1993 at several locations, with the exception of the Kulekhani dam, were evaluated as peak discharges of debris flows containing large amount of sediment.
- Accordingly, the peak discharge of the flood of July 1993 that was estimated at the Kulekhani dam is considered to be a reliable maximum flood, without sediment content, for a drainage area of around 200 km^2.
- While the above-mentioned peak discharge corresponds to a 90-year probable flood at the Kulekhani G.S., 100-year probable floods at the respective major structure sites are adopted as design discharges for safety considerations. A 200-year probable flood is adopted as a design discharge for the Yangran regulating dam due to the importance of the structure.

- Furthermore, it is expected that some degrees of sediment are assumed to be contained in large floods, even in cases without debris flow. Therefore, the design discharges are increased by supposed sediment content of 10 % of flood volume.

As the results, the design floods of the major structures are determined as follows:

Evaluation Item	Creager's Coefficient	Khani H/W ($21.2km^2$)	Yangran Reg. Dam ($8.1km^2$)	Tailrace Outlet ($168.8km^2$)
Flood of July 1970	46.4	330	159	1,286
Flood of July 1993				
・Kulekhani Dam	57.6	410	198	1,597
・Confluence of Khani R.	88.3	629	304	2,447
・Bhainsedobhan	135.7	966	467	
Curve No. 1	45	322	155	1,237
Curve No. 2	90	644	310	2,474
Design Period	-	100	200	100
Design Discharge (without sediment content)	59.7	427	246	1,641
Design Discharge (with sediment content of 10 %)	-	470	280	1,810

3.2.7 Sediment Analysis

In this section, the sediment load from the Kulekhani reservoir basin is obtained by probabilistic analysis on the reservoir sedimentation records. The sediment load from the Yangran River basin, in which the regulating dam will be constructed, is estimated considering differences in basin characteristics between the reservoir and the Yangran River.

(1) Sediment Load from Kulekhani Reservoir Basin

The records of periodical reservoir sediment surveys are summarized in Table 3.2.8.

Average annual sediment loads are depended on the magnitude of floods that have been happened in evaluation periods when annual means of the accumulated sediment load are used. To reflect the sediment load due to the flood of July 1993 in the design, the average annual sediment load is obtained by probabilistic analysis on magnitude and occurrence probability of floods.

1) Relationship between annual sediment load and maximum daily rainfall

It is well known that there are strong relationships between sediment loads and peak flood discharges. However, lack of flood records after impounding of the reservoir makes it difficult to quantify the relationship between them. Accordingly, relationship between annual sediment loads and maximum daily rainfalls are used, based on the relationship between flood discharge and rainfall.

The annual maximum daily rainfalls are based on basin rainfalls that are computed from the weighted average of the rainfall records at Daman and Markhu Gaun, as described in the section 3.2.6 (1). The annual sediment load for 1993 is assumed to include those for 1994 and 1995 since they are regarded to have been triggered by the flood of July 1993.

The equation below, which is derived from the data presented in Figure 3.2.12, describes the relationship between the annual sediment loads and maximum daily rainfalls.

$SV = 0.0265\ e^{0.0168R}$ (R=0.96)

SV : Annual sediment load from the reservoir basin ($10^6 m^3$)

R : Annual maximum daily rainfall (mm)

As shown in Table 3.2.20, the cumulative sediment load over the period from impounding of the reservoir in 1981 to 2000 is estimated to be $19.98 \times 10^6\ m^3$ using the above equation. Taking into account the difference between the estimate and the sedimentation record of $22.92 \times 10^6\ m^3$, the equation is revised as follows:

$SV = 0.0304\ e^{0.0168R}$

2) Estimation of average annual sediment load

The average annual sediment load from the reservoir basin is obtained as shown in Table 3.2.21 using the above equation and the probable rainfall in the reservoir basin. Considering the design life of the regulating dam, the average annual sediment load for a return period of 100 years is generally used to determine the design sediment capacity.

Average Annual Sediment Load : 540,000 m^3/yr.

Annual Specific Sediment Load : 4,300 m^3/km^2/yr.

The resulting average annual sediment load is compared with the estimates from previous studies as follows:

	1994 M/P	1997 JICA Study	This Study
Average Annual Sediment Load (m^3/yr.)	355,000	1,180,000	540,000
Denudation Rate (mm/km^2/yr.)	2.8	9.37	4.29
Analysis Data	-	4 (1993 to 1995)	8 (1993 to 2000)

In the Master Plan Study of 1994[5)], the average sediment load was estimated to be 355,000 m^3/yr, corresponding to a denudation rate of 2.8 mm/km^2/yr. This assumed that future erosion from the reservoir basin would include soil that originated from landslides in 1993. The value was determined by reference to a study of erosion in the Phewa Valley where there was ongoing landslide activity (Ramsey, 1985). In the JICA Study of 1997[17)], the average sediment load was estimated to be 1,180,000 m^3/yr. based on the arithmetic mean of the reservoir sedimentation records over 4 years. In this study, the average sediment load estimate of 540,000 m^3/yr. is based on the probabilistic analysis of the reservoir sedimentation records for 8 years.

As is evident in the records presented in Table 3.2.8, the annual sedimentation volumes vary from year to year. It is considered that the average annual sediment load should be estimated by taking magnitude and occurrence probability of annual floods into account. Accordingly, applying probabilistic analysis, as described above, is considered to be a practical approach to estimation.

(2) Sediment Load from Yangran River Basin

The sediment load from the Yangran River basin is estimated by adjusting the sediment load from the reservoir basin, considering differences in basin characteristics between the both basins.

Factors that determine sediment loads include drainage size, soil type and geologic formation, topography, ground cover, rainfall amount and intensity, channel hydraulic characteristics, land use and so on. The degree of damage or devastation caused to a basin by a flood depends on the characteristics of the basin, and can be used as an adjustment factor. The ratio of the devastated area in a basin, the average collapse depth and sediment discharge ratio are considered to be the indices reflecting the devastation characteristics of each basin.

1) Ratio of devastated area

The devastated area in the reservoir basin due to the flood of July 1993 was estimated to be 6.81 km^2, based on the results of field surveys and aerial photographs which had been taken before and after the flood[5)]. The devastated area in the Yangran River basin is measured as 0.16 km^2 using topographical maps at a scale of 1/25,000 published in 1994. Accordingly, the ratios of devastated area in both basins are calculated as 5.4 % and 2.0 % respectively.

2) Average collapse depth

The average collapse depths that reflect the geology of each basin were estimated during field surveys after the flood of July 1993. An average collapse depth of 2.7 m was obtained for the whole reservoir basin[5)].

Geology	Granite	Schist	Schist & Hard Sandstone
Average Collapse Depth (m)	3.0	4.0	2.0

An average collapse depth of 2.0 m, equivalent to the value for schist and hard sandstone in the reservoir basin, is assumed for the Yangran River basin, based on the schist and phyllite dominated geology of the basin.

3) Rainfall Intensity

It seems that the devastation characteristics of both basins reflect differences in rainfall intensity during the flood of July 1993. Accordingly, those characteristics are adjusted by the ratio of the maximum rainfall intensity recorded at adjacent observatory stations, i.e. Tistung (70 mm/hr.) and Churibagaicha (64 mm/hr.) [5)].

4) Sediment Discharge Ratio

Sediment discharge ratio is derived from drainage area and basin slope based on the Kaki's formula regarding sediment discharge as follows:

$\dot{a} = I^{0.4} / A^{0.2}$ (A>1.0 km^2)

$\dot{a} = I^{0.4} / A^{0.3}$ (A≤1.0 km^2)

where, $\dot{a}$: Sediment discharge ratio, I: River gradient, A: drainage area (km^2)

The sediment discharge ratio of the reservoir basin was estimated to be 18 % [5)]. While that of the Yangran River basin at the regulating dam site is estimated to be 33 % from an average river gradient of 1/18 and a drainage area of 8.1 km^2.

Adjusting the specific sediment load from the reservoir basin by the ratio of devastation characteristics, the specific sediment load from the Yangran River basin is obtained as follows:

(Specific sediment load) = (Specific sediment load from the reservoir basin)
x (ratio of devastated area)
x (ratio of average collapse depth)
x (ratio of maximum rainfall intensity)
x (ratio of sediment discharge ratio)

$$= 4{,}300\ \text{m}^3/\text{km}^2/\text{year} \times \frac{2.0\ \%}{5.4\ \%} \times \frac{2.0\ \text{m}}{2.7\ \text{m}} \times \frac{70\ \text{mm/hr.}}{64\ \text{mm/hr.}} \times \frac{33\ \%}{18\ \%}$$

$$= 2{,}300\ \text{m}^3/\text{km}^2/\text{year}$$

Short-term measurements of suspended load were conducted at the Lothar G.S. Adding a bed load of 15 % of the suspended load, an average annual sediment load of 4,200 ton/year was estimated from an average of measurement records in the rainy seasons from 1975 to 1977[18)]. Accordingly, a specific sediment load of 1,770 m^3/km^2/year was obtained using a normal specific weight of soil of 1.4 ton/m^3. It seems that the upper Rapti River basin is similar to the Lothar River basin in topography and meteorological conditions. However, since the duration of measurement at the Lothar G.S. is relatively short, this value only provides a guideline for evaluating the specific sediment load in the Yangran River basin.

		Reservoir basin	Yangran R. basin	Lothar R. basin
Drainage Area	Km^2	126.0	8.0	169.0
Devastated Area	Km^2	6.81	0.16	-
Ratio of Devastated Area	%	5.4	2.0	-
Average Collapse Depth	.m	2.7	2.0	-
Maximum Rainfall Intensity	.mm/hr.	70	64	-
Sediment Discharge Ratio	%	18	33	-
Ratio of Adjustment	-	1.00	0.55	-
Average annual specific load	$m^3/km^2/yr.$	4,300	2,300	1,770

As a result, the average annual sediment load from the Yangran River basin is estimated to be 19,000 m^3/year.

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3.3 Geology

3.3.1 Introduction

The geological and geotechnical investigations for the Upgrading Feasibility Study have been done to deal with following items.

(1) Review of Existing Reports

Review of the existing geological investigation reports including the Upgrading Feasibility Study prepared by NEA was done prior to implementation of the geological investigation for this study. Results of the review are summarized as follows.

- According to the existing reports, the foundation of a semi-underground powerhouse is assumed to be more than 30m from the ground surface near the confluence of the Khani and Rapti Rivers. The use of an underground type powerhouse will be studied more closely in a future stage.
- The geological investigations of the regulating dam were carried out on a single dam axis. Additional geological investigation will be performed to deal with any future modification of the dam axis in order to meet results of the hydrological study and slope stability analysis in the reservoir area.
- The geotechnical investigation to clarify physical properties of rocks will be required in future stage.
- Exploratory adit has been excavated to clarify the geological and geotechnical condition of dolomite around the headrace tunnel level. The excavation work has been performed for three years. Deformation of tunnel supports and the collapse of excavation face were observed near the portal of the adit.

Results of the review of the existing geological and geotechnical information were utilized for planning of the additional geological investigation for this study.

(2) Geological Investigation for this Study

As a result of review of the existing geological and geotechnical information for this project, an additional investigation was planned, and carried out to clarify following items.

1) General as well as detailed geological condition of the project site to optimize project layout, and

2) Seismically risk for structural analysis based on existing data of earthquake occurrences around the project area.

The geological and geotechnical condition of the major structure sites was studied mainly on the basis of the results obtained during the site investigation period.

3.3.2 Regional Geology

(1) General

1) Topography

Nepal is situated in an active tectonic zone developed in the southern foothills of the Himalayan ranges where the Indian plate submerges northward under the Eurasian plate. Therefore, the geological setting of Nepal is characterized by discernible features of geomorphology. Himalayan ranges exist in the north and lowland plains occur near the southern border with India.

Nepal is composed of four topographical divisions bounded by major WNW-ESE trending thrust faults. Higher Himalayan mountains of more than 8,000 m in elevation lie in the north, Lower and Sub Himalayan ranges are located adjacent to its southern boundary in the central region, and Lowland plains lie in the southernmost part of Nepal. These mountain ranges and plains are bounded by major WNW-ESE trending thrust faults.

2) Geology

The Higher Himalayas are bounded by the Main Central Thrust (MCT) from the Lower Himalayas, and the Lower Himalayas are separated by the Main Boundary Thrust (MBT) from the Sub Himalayas. Himalayan Front Thrust (HFT) lies in the boundary between these Himalayas in the north and Lowland Plains in the south.

Geology of the zone in between the thrust faults is, in general, younger strata in the north and older in the south. The Higher Himalayas consist mainly of metamorphic rocks of Pre-Cambrian to Paleozoic age. The Lower Himalayas consists chiefly of unfossiliferous meta-sedimentary rocks of Pre-Cambrian to Paleozoic age with remnants of the Higher Himalayas. Sub Himalayas of Tertiary Siwalik sandstone extends in the south of the MBT and form the southern-most belt of the Himalayas. (See Figure 3.3.1)

(2) Tectonic Setting

Nepal is located in an active tectonic zone as mentioned above, and the geology of Nepal is chiefly bounded by these major thrust faults, such as the Main Central Thrust (MCT), the Mahabarat Thrust (MT), the Main Boundary Thrust (MBT), and the Himalayan Front Thrust (HFT) from north to south. Some sections of the Mahabarat Thrust lie on the Main Central Thrust (MCT). Distribution of these thrust faults is not always linear, but circular due to folding in some localities.

3.3.3 Geology of the Project Site

(1) Topography

The project area is located at around 30km southwest of Kathmandu in the zone of the Lower and Sub Himalayas. The project area is situated in the Rapti River basin, which is adjacent to the south of the Kulekhani river basin. The Rapti River originates in a ridge on the Mahabarat ranges around 4 km east of Bhimphedi and flows southwest to southward. The riverbed elevation of the Rapti River is 1,100m at Bhimphedi, 600m at Bhainsedobhan and 500m at Hetauda. Mountain ranges with a highest peak of 1,373m are confined in the direction of WNW to ESE reflecting the geology of the area. The Rapti River has an N-S trend and flows down to the south dissecting the said mountain ranges in the area.

(2) Geology

The project area consists of Redua Formation, Bhainsedobhan Marble, Kalitar Formation of Bhimphedi Group, Benighat Slate, Malekhu Limestone, Robang Formation of Upper Nawarkot Group and Siwalik Group overlain by Quaternary deposits of limestone breccias, terrace deposits, riverbed deposits and scree deposits.

The strike of formations is generally WNW-ESE. The boundary between the Upper Nawakot Group and the Bhimphedi Group is called the Mahabharat Thrust, and the Upper Nawakot Group and the Siwalik Group are bounded by the Main Boundary Thrust.

The geological Map of the project area is shown in Figure 3.3.2, and Figure 3.3.3. The geological profile along the waterway is shown in Figure 3.3.4.

The stratigraphy of the project area is described as follows and is shown in the following table.

Raduwa Formation consists of coarse-crystalline, highly garnetiferous mica schist, gneissic schist. Some quartzites are also seen in this formation.

Bhaise Dobhan Formation is consists of coarse crystalline marble, limestone with intercalation of thin schist. Marble and limestone are massive and well bedded.

Kalitar Formation is composed of dark green to gray colored two mica and biotite schist with intercalation of strongly micaceous quartzite and amphibole containing some garnets.

Benighat Formation is consists of dark gray slates and phyllites together with black carbonaceous slate. Intercalations of the limestone are often seen in this formation.

Malekhu Formation consists mainly of light-to-dark and greenish gray siliceous dolomites. Thin bands of fine crystalline limestone and calc-phyllites intercalate in dolomites.

Robang Formation is consists of Lower Robang and Upper Robang phyllites, and Dunga Quartzite. Robang phyllite consists of blue green phyllites and phyllites are chloritic in general. Dunga Quartzite is mainly composed of quartzite. Intercalations of thin phyllite beds are seen in this quartzite at some localities.

Siwalik Group consists of sandstone, mudstone, and small portion of conglomerates.

Recent Deposits is composed of riverbed deposits, talus deposits and terrace deposits. Decomposed limestone beds are also seen sporadically in higher elevation forming small terraces bounded by steep escarpment. These deposits are distributed over the said bedrocks.

River deposits: River deposits are mainly composed of non-consolidated sands and gravels.

Talus: Talus and terrace deposits consist loosely of well-consolidated sands and gravels. Decomposed limestone beds comprises chiefly of cobble to boulder sized limestone. The decomposed limestone has a silt or sandy matrix and is calcareous at places.

Stratigraphy of Project Area

AGE	GROUP	FORMATION	SYMBOL	ROCK TYPE	GEOLOGY
Cenozoic	Recent Deposits		Rd	Riverbed deposits	Sand and gravels with bolders
			Ta	Talus and/or Terrace	Talus deposits and terrace deposits.
		(Uncomformity)			
	Siwalik Group		Sw	Conglomerate, Sandstone, Mudstone	Sandstone, mudstone, and small portions of conglomerates. Relatively soft and fractured near MBT.
		(Main Boundary Thrust)			
Paleozoic	Upper Nawakot Group	Robang Formation	Phy (2)	Phyllite (2)	Blue green slatic phyllites, generally chloritic. Intercalation of calcalious beds. Relatively compact in general.
			Qz	Quartzite	Quartzite. Intercalation of thin phyllite at some localities. Massive and compact in general.
			Phy (1)	Phyllite (1)	Blue green phyllites, generally chloritic. Relatively compact in general.
		Malekhu Formation	Dl	Siliceous Dolomite	Light-to-dark and greenish gray siliceous dolomites. Intercalation of thin crystalline limestone and calc-phyllites. Massive and relatively well bedded.
		Berighat Formation	Sl	Slate(Phyllitic)	Dark gray slates and phyllites together with black carbonaceous slate. Fractured and weathered near MBT.
		(Mahabharat Thrust)			
Pre-Cambrian	Bhimphedi Group	Kalitar Formation	Sq	Schist, Quarzite	Dark green to gray colored two mica and biotite schist with intercalation of quartzite and garnets. Strongly folded and fractured at places.
		Bhaise Dobhan Formation	Mb	Limestone	Coarse crystalline marble, limestone with intercalation of thin schist. Marble and limestone are massive and well bedded.
		Raduwa Formation	Sch	Schist	Coarse-crystalline, highly garnetiferous mica schist, gneissic schist. Some quartzites are also seen in this formation.

(3) Geological Structure

The project area consists of Precambrian rock of Bhimphedi group of Kathmandu Nappe and Paleozoic rocks of Upper Nawarcot group as well as Cenozoic Siwalik group. The Mahabharat Thrust (MBT), which is said to be the basement thrust of Kathmandu Nappe, and the Main Boundary Thrust (MBT) are distributed in the area.

1) Main Boundary Thrust

The Main Boundary Thrust forms the boundary between the Lower Himalaya and the Sub Himalaya. The Siwalik sandstone of folded and faulted Tertiary sedimentary rock has been over-thrusted in the south of the Main Boundary Thrust (MBT).

2) Mahabharat Thrust

The Mahabharat Thrust can be considered as an extension of the Main Central Thrust (MCT). The Main Central Thrust (MCT) is formed due to collision of Indian plate during Cenozoic. Thrusting of the Main Central Thrust (MCT) appears to begin at 50 million years ago and continue today. The rate of northward movement is considered to be 5cm/year in recent years.

3) Discontinuity

Discontinuities of the rock mass are highly developed in the project area. In general, surface of the continuities of quartzite, dolomite and sandstone are fresh, rough and open, however those of phyllite and slate are weathered, relatively smooth, closed or partly filled with fine materials. Discontinuities along major thrusts of the Mahabharat Thrust and the Main Boundary Thrust are slickensided and filled with clayey materials in general. Some discontinuities of major thrusts are recrystallised with calcareous or siliceous materials.

3.3.4 Geological Investigation

The geological and geotechnical investigations were performed for this study. The investigation consists of core drilling, geophysical survey including seismic refraction as well as electrical resistivity prospecting, in-situ rock test, and laboratory tests. The location map of the geological investigation is shown in Fig. 3.3.5. Results of the geological investigation are mentioned in detail in the Volume II, Supporting Report (1), Appendix B.

(1) Core Drilling

The core drilling was performed covering the whole project area including powerhouse, connection and tailrace tunnels, regulating dam and other appurtenant structures, totaling 1,287 m. Results of the core drilling are mentioned in Section 3.3.5.

(2) Standard Penetration Test

Standard Penetration Tests were carried out to clarify engineering properties like bearing capacity of unconsolidated deposits of Holocene age and weathered zone of basement rock. Results were entered into the drill logs in the Volume II, Supporting Report (1), Appendix B, Section B3.3.

(3) Permeability Test

Lugeon tests were performed to obtain permeability data of the rock mass of the regulating dam foundation, the underground powerhouse and the tailrace tunnel. The results are summarized and mentioned in the Volume II, Supporting Report (1), Appendix B, Section B3.4.

(4) Seismic Refraction Prospecting

Seismic refraction prospecting were performed for the waterway of connection and tailrace tunnels. Some of the prospecting had done by NEA in 1988 and 1997. Results were utilized to evaluate the rock condition.

Seismic refraction method has been applied for analysis of geotechnical condition. Five (5) profiles of total 1,245 m in length were carried out. The arrangement of shots and detectors was laid out on a line. Ground surface profile were surveyed and shot and detector points were marked by stakes prior to the field recording.

Travel time of the seismic wave (primary wave) was read from recording paper to the accuracy of 1/1,000 second, and plotted on the time-distance curve. From this graph, the profile of velocity layers was drawn mainly by means of Hagiwara's method. Results of the prospecting are mentioned in detail in the Volume II, Supporting Report (1), Appendix B, Section B3.5.

a. Connection Tunnel

BCT-1 to BCT-2 Section

The geological data obtained through site reconnaissance as well as core drilling were also used to analyze velocity layer. Four velocity layers are confirmed along the connection tunnel.

First velocity layer	0.3 km/s
Second velocity layer	0.6 km/s to 0.8 km/s
Third velocity layer	1.2 km/s to 1.4 km/s
Fourth velocity layer	2.2 km/s to 2.4 km/s
Fifth velocity layer	5.5 km/s

Low velocity zones which are the segments of remarkably low speed such as 1.5 km/sec to 2.2 km/sec zone were observed in the highest velocity zone of 5.5 km/s. The low velocity zone may represent defects in the bedrock such as a fractured zone and other anomalies. In the case of the connection tunnel, several low velocity zones are distributed and they are regarded as fractured zone of Mahabharat Thrust and adjacent fractured zones.

Outlet of Connection Tunnel

The geological data of geological reconnaissance and drill logs were also used to analyze velocity. Three different velocity layers are confirmed near the outlet of the connection tunnel.

First velocity layer	0.3 km/s to 0.4 km/s
Second velocity layer	1.5 km/s to 1.7 m/s
Third velocity layer	3.0 km/s to 3.2 m/s
Fourth velocity layer	5.8 km/s to 6.0 km/s

b. Tailrace Tunnel

Outlet of Tailrace Tunnel

There are two velocity layers along this connection tunnel.

First velocity layer	0.4 km/s to 0.5 km/s
Second velocity layer	1.2 km/s to 1.4 km/s
Third velocity layer	2.7 km/s to 2.8 km/s

(5) Electrical Resistivity Prospecting

The electrical resistivity prospecting was performed around the important structure sites, such as the underground powerhouse site and the tailrace tunnel. Geological conditions of the said sites are to be crucial for technical feasibility of the project.

Electrical resistivity of the ground around the said site was measured and profiles were made as shown in Figure 3.3.6 to 3.3.9 and the Volume II, Supporting Report (1), Appendix B, section B.6.

a. Underground Structures

Two 700m long survey lines were placed at the top of the underground powerhouse site. As a result of prospecting, the distribution of dolomite was clearly indicated and the geological condition of dolomite and adjacent strata of slate and phyllite were clarified. The geological condition of dolomite is far better than the adjacent two strata and phyllite appears to be better than slate. Observation of outcrops of each stratum indicates the same conclusion.

b. Tailrace Tunnel

A survey line of 350m length was placed along the tailrace tunnel alignment. The boundary between Siwalik sandstone and Benighat slate was clearly indicated in the profile made by prospecting. Siwalik sandstone appears to be fractured in width of 130m due to the MBT. Slate might be fractured as well near the MBT.

(6) In-situ Rock Test

In-situ rock shear tests and loading tests were performed in the exploratory adit at an elevation of 577.6m, 115m above the powerhouse cavern. The tests were concentrated on the underground structure sites for their importance.

In-situ rock tests were carried out to measure the strength of the bedrock as a mass in the branch adit near the excavation face of the exploratory adit. Severe testing conditions, such as high humidity, unstable supply of electricity and hauling difficulty of testing materials caused inaccuracies in the testing results. Therefore, these test results have been judged to be used as reference data only, at this time.

a. Plate Loading Test

A plate loading test was carried out at three spots of the branch adit, around 10 m from the excavation face.

Both modulus of elasticity and modulus of deformation can be calculated with the same formula as follows.

$$EorD = \frac{(1-\mu 2) \quad x \ d F}{d S \ x 0.5a}$$

Where,

E: Modulus of elasticity (Kgf /cm^2)
D: Modulus of deformation (Kgf /cm^2)
a: Radius of steel loading plate (cm)
μ = Poisson's ratio (0.2 for hard rock and 0.25 to 0.3 for soft rock)
dF = increased load in a section of load-displacement curve
dS = increased displacement for the same section as above (cm)

If a gradient of the tangential line of the stress-displacement curve for the peak stress is placed in the place of dF /dS, the formula will give the modulus of elasticity. If a gradient of the line enveloping the stress-displacement curves of the initial stresses is used for dF /dS, it will give the deformation modulus. Results of the test are mentioned in detail in the Volume II, Supporting Report (1), Appendix B, Section B3.7.

TEST RESULT

Plate loading tests are performed at three locations for this study. Test results are summarized below. (See Figure 3.3.10 – 3.3.12)

Location	Modulus of Deformation (MPa)	Modulus of Elasticity (MPa)
PL-1	3,183.9	14,650.3
PL-2	9,366.9	25,340.5
PL-3	1,869.5	8,392.9

b. Rock Shear Test

The rock shear tests were performed at 3 spots inside the branch adit of the exploratory adit. They were performed in siliceous dolomite.

The procedure of conducting the in-situ shear tests is described in ISRM (1974) and IS 7746-(1975). The shear strength of rock mass depends upon a number of factors such as the direction of shear force relative to the direction of joints, foliations, strength of rock, saturation, rate of loading, rate of shearing etc.

This test measures peak and residual direct shear strength as a function of stress to the sheared plane.

TEST RESULT

The plots between shear stress and the horizontal displacements of 3 blocks are shown in figure below. The normal stress varies between 5 kg/cm^2, 7.5 kg/ cm^2 and 10 kg/ cm^2. The plot between normal stress and shear stress is shown in Figure 3.3.13 and the figures attached in the Volume II, Supporting Report (1), Appendix B, Section B3.7.

As a result of the testing, the following values are obtained.

C=0.3 to 0.5 Mpa, $\varphi = 45.0^{\circ}$

However, this result is discordant with the results of the plate loading tests. The results of the plate loading test indicate a hard and compact state of rock. The results of the shearing test, while both (plate loading and rock shear testing) tests were performed in adjacent location, indicate a relatively soft and poor rock condition.

Due to this inconsistency of the rock shear test results, these figures should be regarded reference data only, in this stage of the study.

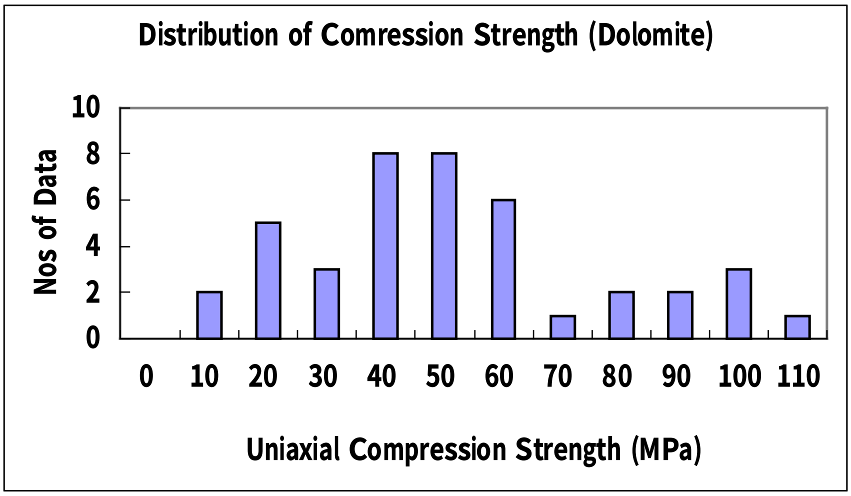
The utilization of test results to clarify the design value of rocks will be discussed in the following chapter.

(7) Laboratory Test

A series of laboratory test were carried out, using core samples to examine and clarify the characteristics of rock at the sites. These samples involved the measurement of specific gravity and water absorption, unconfined compression, super-sonic wave velocity, and splitting tensile strength to evaluate characteristics of rocks in each site. Results of the test are mentioned in detail in the Volume II, Supporting Report (1), Appendix B, Section B3.8.

Specified data of the rocks for design work can be obtained by those test results and the laboratory test of rock samples of varied strata is useful in this study.

The uniaxial compression strength of dolomite rock samples obtained through drill holes of BPV-1 and BPH-1 are shown below.



As a result of this analysis, uniaxial compression strength of dolomite in the exploratory adit is judged to be more than 50 MPa.

(8) Exploratory Adit

Excavation of the exploratory adit, 460 m long, had been completed as of March.08, 2001. The exploratory adit was used to check the actual condition of siliceous dolomite at the excavation face. The sectional area forms a 3.0m wide x 3.0m high section from the portal to a distance of 237m. The sectional area of the adit downstream from 237m is reduced to 1.7m wide x 2.0m high.

The geological condition along the exploratory adit is described as follows:

The boundary between slate and sericeous dolomite was observed at 380m from the adit portal. The rock condition in the section around 70 m to 90 m from the portal was assessed as relatively poor, however, moderately fair rock condition is confirmed in the rest of the section.

A groundwater ingress of approximately 150 to 200 l/min was observed near the end of the adit (320 m in total length) on September 28, 2001(approximately 310 to

315 m from the adit portal). Nearly the same amount of water flow was observed at the adit portal at that time. The groundwater inflow of less than 50 l/min (approximately) was observed at the same location at the beginning of July, 2002. The observation result of the exploratory adit is mentioned in detail in the Volume II, Supporting Report (1), Appendix B, Section B3.9.

A branch adit of 2.5m x 2.0m x 10.0m in size was excavated for an in-situ rock test. Siliceous dolomite in hard and compact state is predominantly distributed over the excavation face of the adit.

3.3.5 Engineering Geology

(1) Rock Classification

1) Discussion on Test Results

In-situ rock tests were carried out in the branch adit excavated around the excavation face of the exploratory adit. Results of the test were carefully examined and some discordances were found in comparison with results of the laboratory test and site observation. In the rock shear test, shear strength of 0.3 to 0.5 MPa and friction of 45 degrees were obtained. As discussed in the former chapter, these resulted figures should be used as reference data considering the differing results of the other tests.

In the laboratory tests of rock samples obtained from the BPV-1 and PPH-1 drill holes near the in-situ rock testing site, the uniaxial compression strength of dolomite appears to be more than 50 MPa.

According to a study on the relationship between uniaxial compression strength and shear strength for similar dolomite on the basis of numerous data of rock samples obtained in Japan (Journal of the Japan Society of Engineering Geology, 1983), the following correlation is proposed.

Uniaxial Compression Strength	Shear Strength
50 MPa	2 to 3 MPa

The modulus of deformation is assumed to be 2,000 to 3,500 MPa when the uniaxial compression strength of 50 MPa on the basis of the above study of correlation between the uniaxial compression strength and the modulus of deformation.

Uniaxial Compression Strength	Modulus of Deformation
50 MPa	2,000 to 3,500 MPa

In the plate loading test, 1,869.5 to 9,366.9 MPa were obtained. These figures are correlated to the modulus of deformation based on the uniaxial compression strength. Therefore, the shear strength is judged to be 2 to 3 MPa, not 0.3 to 0.5 MPa.

The modulus of deformation obtained as a result of the plate loading tests was carefully studied. The test result of PL-3 location, which shows 1,869.5 MPa, is judged to be too low a figure when compared with the average rock mass in the test adit. Discontinuities like joints and foliation were highly developed when the testing location was carefully observed after the site testing.

Therefore, the modulus of deformation obtained in the test at the points of PL-1 (3,1838.9 MPa) and PL-2 (9,366.9MPa) are considered to be the representative figures of the rock in the testing area, and the modulus of deformation of rock at the testing location is judged to be more than 3,000 MPa.

Considering the result of the in-situ rock tests and laboratory tests, the following figures for the physical properties of rock at the location of in-situ rock testing are assumed.

Shear strength	2 to 3 MPa
Friction angle	45 to 50 degrees
Modulus of Deformation	3,000 to 5,000 MPa

2) Classification by Q Values

Q value rock classification had been used for the Updated Feasibility Study done by NEA and this classification is applied on the basis of the Q classification system developed by Barton, Lien and Lunde (1974). The Q system is primary developed for tunnel design work. The main advantage of this Q classification system is its sensitiveness to minor variations in rock properties. One disadvantage of the Q system is difficulty for inexperienced users to apply.

Q value is calculated on the basis of a function of 6 independent parameters by using the following formula.

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

where,

RQD: Rock Quality Designation
Jn: Joints Set Number
Jr: Joints Roughness Number
Ja: Joints Alteration Number
Jw: Joints Water Reduction Number
SRF: Stress Reduction Factor

The Q system parameters are shown in Table 3.3.1.

3) Classification by CRIEPI

The Central Research Institute of Electric Power Industry (CRIRPI) of Japan has developed a rock classification system based on abundant research data collected over a long period of activity. The rock classification for the regulating dam is judged on the basis of this CRIEPI rock classification system.

The Q system and the CRIEPI system for rock classification are shown in Figure. 3.3.14.

(2) Geology and Physical Properties

The rock properties of the different grades of rock are proposed on the basis of the results of in-situ rock tests as well as laboratory tests performed for this study and the existing data of similar geological condition of other projects.

The physical properties of rock at the location of the in-situ rock testing are assumed to be 2 to 3 MPa of shear strength and more than 3,000 MPa of modulus of deformation.

According to the rock classification of the Q system and the CRIEPI system, the rock at the location of the in-situ rock testing is judged to be around Q2 and CH, respectively. The following physical properties are proposed on the basis of this judgment.

Rock Grade	Modulus of Deformation (MPa)	Shear Strength (MPa)	Friction Degree (degree)	Q value by Q system	CRIEPI system (reference)
Q1	> 3,000	> 2.4	> 50	> 40	B
Q2	3,000	2.4	50	10 to 40	CH
Q3	1,000	1.2	45	4 to 10	CM
Q4	500	0.6	40	1 to 4	CL
Q5	250	0.1	35	1 >	D

The Q classification system is developed mainly for tunneling work and is applied to the rock classification of the underground structures in this report. The CRIEPI classification system was first developed for the foundation of large structures and is used for evaluation of the dam foundation in this report. The rock grade of the CRIEPI classification system is assumed to be as shown in the above table referring to the Q classification system.

(3) Geological Condition

The geological and geotechnical condition of the sites is summarized as follows.

1) Underground Structures

An underground or semi-underground type of powerhouse is planned to be built. The geological investigation of BS-1 drill hole was carried out for this study in the semi-underground type powerhouse site on the right bank of the Rapti River near the confluence with the Kesadi River. According to the results of the geological investigation, including existing investigation results, the foundation of this site will be weathered slate and it is covered by unconsolidated deposits in thickness of 33.5m (416.9m in elevation).

Five holes of core drilling for underground powerhouse were executed. Two holes were carried out from the exploratory adit. Long drilling works would have bean required, due to limited working space for drilling works in the adit, therefore three drill holes were executed on the ground surface.

Enlargement of the exploratory adit was performed for execution of drilling work in the adit. Results of the drilling carried out from the exploratory adit identified sound rock condition in and above the underground cavern. Thickness of the dolomite layer is judged to be around 150m as a result of other executed drillings for the underground powerhouse.

The underground structures including the powerhouse cavern are planned to be placed in siliceous dolomite layer of around 150 m in thickness, which was confirmed by drill holes of BPV-2, 3, and 4 in the right bank of the Rapti river. General trend and dips of the siliceous dolomite are N60° W and 60° N respectively. The drill hole of BPV-1 indicates that the siliceous dolomite is hard and has no solution cavity below the connection tunnel level of around 580m down to the powerhouse section of around 460m in elevation. Rock mass of the siliceous dolomite is not homogeneous, but platy joints of 10 to 30 cm interval were frequently observed in the drill hole of BPV-1. A sufficient water-tightness of less than 5 lugeon was generally confirmed in the drill hole of BPV-1 and BPH-1.

As a result of the geotechnical investigation, a modulus of deformation of more than 3,000 MPa, cohesion strength of 2 to 3 MPa and a friction angle of 45 to 50 degree are judged to be adequate in the rock mass around the powerhouse. The geological condition between the siliceous dolomite and the slate was confirmed to be poor as a result of the excavation of the exploratory adit. Attention should be paid to the lithological boundary between the dolomite and the slate lager, even if the geological condition around the underground powerhouse, which is to be built over 100 m below the exploratory adit level, assumes to be better than that of the exploratory adit. Attention shall be also paid to the groundwater inflow toward the underground cavern considering the elevation of the powerhouse, which is to be excavated at the elevation below the Rapti and Kesadi Rivers. (See Figure 3.3.15

and 3.3.16)

2) Regulating Dam

The bedrock of the proposed dam site consists of phyllite. The phyllite was fresh and hard below 3 to 5 m from the rock surface.

According to the core drilling carried out along the downstream dam axis near the proposed axis in 2002, the surface of the bedrock is moderately weathered to a thickness of 1 to 5 m, and fresh and compact bedrock is distributed underneath. Permeability of the phyllite appears to be relatively low, varying from less than one (1) to around twenty (20) lugeon.

Sufficient bearing capacity for the proposed dam could be obtained in the riverbed section. However weathered and relaxed portions should be expected at the abutments. Permeability of phyllite bedrocks is low, at less than 5 lugeon in general. Lugeon values of 5 to 10 are confirmed in the upper parts of the bedrock. (See Figure 3.3.17, 3.3.18, 3.3.19, 3.3.20)

3) Regulating Pond

A gentle slope of land at 15 degrees or less from the horizontal is developed in a 150 m wide and 150 m long area for the pondage of regulating dam. It is located on the right bank of the Yangran River near the upstream-end of the pondage. Potential landslide area (Landslide R-1) was suspected in previous study and drill holes of LS-1 and LS-2 were allocated.

Topsoil of around 1 m thick is distributed covering the whole gentle slope area. Relaxed rock mass and debris of 23m and 2m in thickness are found at LS-1 and LS-2 points respectively. Stable rock mass is confirmed below these debris zones. The foot of this potential landslide area is submerged during times of high water level. Daily fluctuation of water level of the pondage is expected to be 10 m. Careful attention shall be paid to the distribution of this potential landslide area.

The landslide block of relatively large scale is located in the upstream (Right bank) of the reservoir. The capacity of the reservoir likely decreases in some extent when the landslide occurs. The geological investigation will be required to perform to clarify the landslide block and to propose the countermeasures.

Analysis of the slope stability and countermeasures were described in Section 3.4 of "Landslide and Sedimentation in Project Area". (See Figure 3.3.9)

4) Connection Tunnel

The proposed alignment of the 3.5 km connection tunnel is planned on the right bank of the Rapti River. The tunnel drives through marble, schist, slate, quartzite, and phyllite. The drill hole BI-2 was placed at the inlet portal, holes BCT-1, BMT-1, and BCT-2 were placed along the tunnel route, and hole BO-1 was at the outlet of connection tunnel. As a result of drilling, relatively fair rock condition was confirmed. However, the length of drill holes along the tunnel was insufficient to reach the tunnel level. Geological condition along the connection tunnel is confirmed to be generally good considering the results of the drilling and site reconnaissance. Marble (0.7km in length), schist (0.3km), phyllite (2) (0.7km), quartzite (1.0km) and phyllite (1) (0.8km) are supposed to be encountered during the excavation period.

No serious problem is envisaged on the stability of the tunnel faces. However, careful attention shall be paid to the lithological boundaries including the Mahabharat Thrust (MT), where they might be fractured and altered to clay in some extent. The groundwater ingress may also be encountered in such boundary sections and in high groundwater table sections. (See Fig. 3.3.4, 3.3.21)

5) Headrace Tunnel

The proposed route of the headrace tunnel is 0.4km in length and is planned on the right bank of the Rapti River. Phyllite and siliceous dolomite may be encountered along the tunnel route. The lithological boundary of these two strata might be fractured, judging from the excavation face of the exploratory adit and from the outcrops observed along the river. Careful attention will be paid on excavation works in this section. The groundwater inflow may be small and no serious problem might be envisaged during the excavation work. (See Figure 3.3.4)

6) Tailrace Tunnel

The tailrace tunnel of 2.1 km in length is planned in the right bank of the Rapti River crossing the Main Boundary Thrust. Slate of Paleozoic, Tertiary Siwalik sandstone of Cenozoic may be encountered in the course of excavation work. Drill holes of DHT-4, DHT-6 were located along the tunnel route, and BOT-1 at the portal.

According to the results of drilling, bedrock of Siwalik sandstone was confirmed in all three drill holes. Sandstone distributed in the tunnel elevation was confirmed to be of poor geological condition according to a result of drill hole DHT-4. The geological condition of sandstone is relatively fair in the downstream part of the tunnel according to the results of core drilling of holes DHT-6 and BTO-1. The slate is confirmed at depth of 33.5m of the drill hole BS-1.

The slate and sandstone are fractured and in poor condition in and around the Main Boundary Thrust. The fractured zone of the MBT appears to be around 200m in width. Open excavation for the culvert in the section of the MBT should be considered as an alternative. Large amount of groundwater might be encountered in the river section. Therefore, drainage work for open excavation and backfilling needs to be carefully prepared. (See Fig. 3.3.4, 3.3.22)

7) Head Works

The headwork site is located around the tailrace of the KL-II powerhouse site in the

Khani River. Present river deposits of sand and gravels are distributed underlain by the limestone bedrock.

Drill hole BI-2 was executed at the planned intake site for the connection tunnel. Relatively massive limestone is confirmed to be distributed below the unconsolidated riverbed deposits. Sound foundation can be expected in the limestone.

8) Access Bridge

Construction of a bridge is planned for crossing the Rapti River immediately upstream of the confluence with the Kesadi River. The foundation of the bridge was investigated by the three drill holes BA-1, BP-1, and BA-2. Two holes are located at both the right and left banks and one hole at the river section. The foundation of the bridge is weathered bedrock of slate, which is confirmed by all three drill holes. The bedrock is judged to be sound enough for foundation of piers of the bridge, and some parts of the unconsolidated layer might have sufficient bearing capacity. However, careful attention will be paid to the slope stability of the foundation of abutment at both sides of the bridge.

(4) Geotechnical Condition of Waterway Tunnels and Underground Structures

The geological profile with rock classification along the waterway including the connection, headrace, underground powerhouse, and tailrace tunnels is shown Figure 3.3.23. The length of the rock mass of the different rock grade is summarized in the following table.

The geology and rock grades of the strata that are expected to be encountered along the tunnels and underground powerhouse structures are estimated and presented below. The rock grades that were used for the Upgrading Feasibility Study done by NEA are applied for this report. Rock grade of Q1 is expected in some sections of the connection tunnel, but may be intercalated with Q3 and/or Q4. The rock grade of Q2 is applied for such sections. The distribution of rock grades is shown in the following table.

Rock Grade for Structure Sites (Unit: m)

Structure Site	Total Distance	Q1	Q2	Q3	Q4	Q5
Connection Tunnel	3,475	-	1,685	1,495	220	75
Headrace Tunnel	389	-	54	315	20	-
Underground P/H Structures	132	-	132	-	-	-
Tailrace Tunnel	2,149	-	79	1,245	520	305
Total	6,145	-	1,950	3,055	760	380

Fair to good rock condition (Q2 to Q3 in rock grade) is expected along more than 90% of the total length of the connection tunnel as well as the headrace tunnel.

The underground powerhouse is planned to be built in the dolomite of Q2 in rock grade. However, the poor condition of less than Q2 in rock grade might be encountered in some area of the excavation face considering the results of the borehole BPV-1.

Around 40% of the tailrace tunnel is in the rock grade of Q3, and remaining 60% are Q4 and Q5 in rock grade. Relatively poor rock condition might be encountered during the excavation work of the tailrace tunnel.

3.3.6 Seismicity and Seismic Risk

Numbers of earthquakes have been occurred and the seismicity has been recorded in Nepal. Limited numbers of the reliable seismic records are available in prior to the development of seismographs in the late 19th centuries. The seismograph network has been gradually well facilitated and large numbers of earthquakes have been recorded since then.

The seismicity in Nepal including northern part of India has been studied in various fields. The relationships between the occurrence of earthquakes and the faulting have also been studied. As a result of the study, the major earthquakes occurred in Nepal are said to be related to the inferred subsurface faulting, not to the surface faulting.

Therefore, seismicity records collected through one of the most well facilitated seismograph network of United States Geological Survey (USGS) are utilized for seismicity analysis.

For evaluation of the seismic risk of the project area, all data earthquakes over 1.0 of Magnitude in the Richter scale with epicenters within a 300 km of distance from the project site, was collected from than United State Geological Survey (USGS) service. A total number of 153 data items were obtained after screening the said conditions of seismicity in the period between 1973 and 1991. (See Figure 3.3.24)

The seismic risk was mainly evaluated by using formulae according to Cornell. A second formula according to Kawasumi was also applied, and the resulting calculated figures used as reference data. The formula proposed by Kawasumi is developed on the basis of the seismic data of earthquakes occurring in Japan, where the earthquake occur frequently and the seismic risk is high, when compared with other countries.

The Cornell's formula (Cornell, C.A., 1968, Engineering seismic analysis, Bull. Seism. Soc. Am.Vol.58, pp.1583-1606) and the Kawasumi's formula is described as follows.

<u>The Cornell 's formula</u>

$$I = 8.0 + 1.5 M - 2.5 \mathrm{Ln}\, r$$

where,

I : Earthquake Intensity in Modified Mercalli Scale felt at the dam site
M: Magnitude in Richter Scale
r : Focal distance in kilometer $r = (d^2 + h^2 + 400)^{0.5}$
d : Epicentral distance (km)
h : Focal depth (km)

$\log A = 0.014 + 0.30\ I$ *

where,

A : Peak horizontal acceleration (cm/sec^2 or gal)

(* Trifunac, M.D. and Brady, A.G., 1975, On the correlation of seismic intensity scales with the peak of recorded strong ground motion, Bull. Seism. Soc. Am. Vol.65, pp.139-162)

<u>The Kawasumi's Formula</u>

(Kawasumi, H., 1951, Measures of earthquake danger and expectancy of maximum intensity throughout Japan as inferred from the seismic activity in historical times, Bull. Earthq. Res. Inst., 21, pp 469- 482.)

$Ij = 2\ M - 4.6052 \log d - 0.00183\ d - 0.307$ (when d is not less than 100 km)

$Ij = 2\ (M - \log r) - 0.01668\ r - 3.9916$ (when d is less than 100 km)

$A = 0.45 \times 10^{(Ij/2)}$ (when Ij is not more than 5.5)

$A = 20 \times 10^{(Ij/5)}$ (when 5.5 $<$Ij $<$7.0)

where,

Ij : Earthquake intensity in Japan Meteorological Agency Scale (JMA)
M : Magnitude in Richter Scale
D : Epicentral distance (km)
R : Focal distance (km)
A : Peak ground acceleration (cm/sec^2 or gal)

The number of earthquake events were counted for each intensity step, i.e., Intensity 1 (0.5 to 1.4), Intensity 2 (1.5 to 2.4), Intensity 3 (2.5 to 3.4), etc., and then accumulated to obtain the number of events in 25.5 years exceeding the given intensity for each of the same intensity steps. The number for each step was divided by 25.5 (years) to obtain the number of events per year exceeding the given intensity (Nc).

According to Gutenberg, the earthquake intensity (I) has a linear relationship with the logarithm of the number of earthquakes exceeding that intensity, that is,

$\log Nc = p + q.\ I$,

where, p and q are constants. The values of I and Nc were plotted on a graph, and the point where the I - log Nc line intersects the horizontal line for 0.01 of Nc indicates the probable maximum earthquake intensity for the return period of 100 years (and 0.005 of Nc for 200 years) (See Fig.3.3.25). The results are as follows:

	Maximum Intensity in MM Scale	Maximum Intensity in JMA Scale	Maximum Peak Acceleration
According to Cornell's	7.3	-	160 gal
According to Kawasumi's	-	3.3	20.1 gal

Kawasumi's formula is used in high seismic risk areas like Japan, therefore the seismic factors of maximum probable intensity obtained by Kawasumi's formula could be different from other calculated results, when seismic risk is relatively low.

On the other hand, it is assumed that the Maximum Credible Earthquake is generated at the distance of 10 km on the Main Mantle Thrust (This thrust fault is distributed in between the earth crust and mantle in the globe, and located deeper than any other thrust faults like the MCT and MBT etc.) and has a Magnitude of 7.0 and focal depth of 40 km. The intensity and peak acceleration are estimated at 9 and 500 gal respectively.

The peak acceleration applies only for a fraction of a second and is virtually unable to create any damage upon dam structures while the substantially durable acceleration is far lower than the peak value, for example a third of the peak acceleration value. From this viewpoint, the practically damaging acceleration level from the maximum credible earthquake would be 170 gal. The maximum credible earthquake, however, is the conceivable strongest earthquake of which the probability of occurrence is very low. It is defined that some damage upon the structures by the Maximum Credible Earthquake can be accepted if that damage does not lead to serious hindrance of the function.

A seismic risk study was done in the 1988 feasibility study by NEA. According to a calculation using a total earthquake of 281 events from 1913 to 1987, a probable maximum intensity of 8.4 and a probable maximum acceleration of 0.21 g in a 100 years return period was obtained, with a design seismic coefficient of 0.15 to 0.20 recommended.

With all the above results of evaluation in mind, the appropriate design earthquake acceleration is considered to be 0.15g.

3.3.7 Further Study

A geological investigation for the major structure sites has been done for this study. Additional geological investigation will be required to obtain further geological information for the detailed design of this project.

(1) Powerhouse

The underground structures including the powerhouse have been placed in a siliceous dolomite layer. Distribution of the dolomite has been clarified as a result of the geological investigation performed for this study. According to the outcrops observed in the adit, the dolomite layer is folded and tilted to some extent and platy joints of 5 to 10cm thick are developed locally, therefore it appears not to be a massive rock mass. Further geological and geotechnical investigation, such as additional drilling and rock testing will be required to clarify the rock property of the dolomite and neighboring layers (phyllite and slate) for stability of the excavation face. The initial stress of the rock mass around the underground powerhouse site also needs to be measured for design during the detailed design stage. Attention shall be paid to the groundwater inflow toward the underground cavern considering the elevation of the powerhouse, which is located below the Rapti and Kesadi Rivers. The hydrogeological survey including the measurement of the groundwater pressure will be performed to evaluate the inflow of the groundwater.

(2) Regulating Dam

Further core drilling will be required for the dam foundation and appurtenant structures after the dam layout is fixed during the detailed design stage.

The core recovery of some of the existing drill holes was so poor that it is clear that drilling technology and techniques need to be improved. The actual geological condition of the site can be clarified when the full core recovery is achieved in the future.

(3) Regulating Pond

The possible landslide area is distributed at several localities in the basin. The geological investigation was done in one of the possible landslide area. If necessary additional geological investigation will be required to enable the identification of counter measures.

(4) Connection Tunnel

No serious difficulties are envisaged during the excavation works, however, serious attention should be paid to the tunneling work at geological boundaries including the Mahabharat Thrust. Measurement of the groundwater pressure along the tunnel level will required the drill holes reaching to the tunnel level to estimate the volume of the groundwater inflow in the construction stage.

(5) Tailrace Tunnel

A fractured zone, including the MBT, will be encountered during the excavation works. The slate is extremely fractured and deteriorated near the MBT. Further core drilling with high core recovery will be required to clarify the actual geological condition of the slate along the tunnel alignment.

Special attention should be paid to core recovery of the drill holes due to the poor core recovery of the existing drill holes to enable better clarification of the actual geological condition along the tunnel where slate is distributed.

3.4 Landslides and Sedimentation in Project Area

3.4.1 Introduction

Possible landslide topography was found along the right bank of the Yangran River where the regulating reservoir is planned. An abundance of debris and boulders exists in the riverbed of the Yangran River. In the rainy season, many boulders and debris will be washed into the regulating pond and will progressively reduce its capacity.

During the study period, site investigations in the Yangran River watershed were carried out to prepare countermeasures against landslides for preventing sedimentation of the regulating pond.

3.4.2 Landslides in Regulating Pond

(1) Geology in the Yangran River Basin

The Yangran watershed is composed of Dunga Quartzite and Robang Formation, which are members of the Upper Nawakot Group (Upper Paleozoic). The Robang Formation consists of green chloritic and partly tuffaceous phyllites. The upper part of the phyllites is highly to moderately weathered, and landslides have developed in these areas. Upper Robang Slate is distributed in the upper basin area of the Yangran River, and Dunga Quartzite in the middle basin area. The lower basin area consists of Lower Robang Phyllite. The upper and middle basin areas form steep slopes and collapses of a small size occur along the steep slopes. The lower basin area forms a gentle slope on the right bank. Landslide and collapse were observed in the lower basin area of phyllite. The geology of the Yangran River basin is shown in Figure 3.4.1.

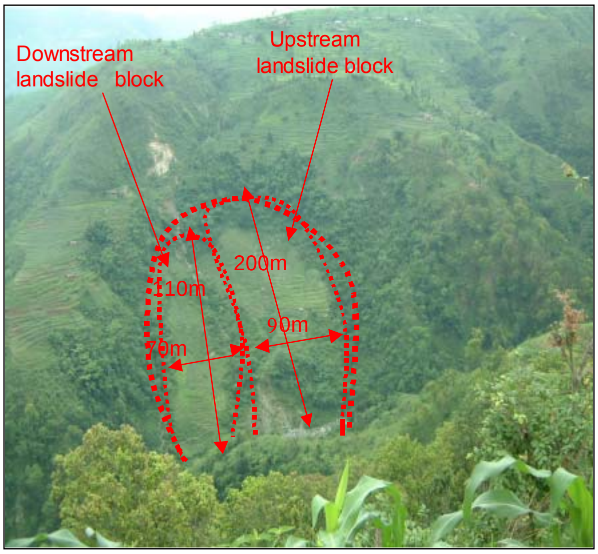
(2) Landslide and Collapse in the Yangran River Basin

There are three landslide blocks and many collapse areas in the Yangran watershed where the regulating pond is planned. Two of the landslides are located in the backwater of the regulating pond, one on either side of the river (Landslide R-1 and L-1). The other is located 1.5 km upstream from the backwater of the regulating pond (Landslide R-2). A collapse is also situated at the left abutment, just upstream of the regulating dam. The locations of the landslide and collapse areas are shown in Figure 3.4.2. Landslide and collapse were developed in the Yangran River basin by unexpected heavy rainfall in July 2002.

1) Landslide R-1

The size of Landslide R-1 is estimated at 150m in width and 200m in length. Landslide R-1 is divided into two blocks by a small valley in the center, consisting of a downstream block and an upstream block. The small valley was hardly eroded by the heavy rainfall in July 2002. Collapses are observed at the toe portions of both upstream and downstream blocks.

The upstream landslide block is larger than the downstream block. Greenish clay and spring water can be seen at the toe of the collapsed slope from 1.5 m above the riverbed and higher. The downstream block is composed of hardly weathered phyllite. A sketch of Landslide R-1 is shown in Figure 3.4.3.



Landslide R-1 in Regulating Pond

Two core drillings (LS-1 and 2) were carried out in the downstream landslide block, which will be heavily affected by impoundment. According to the results of LS-1 at the upper part of landslide slope, topsoil is distributed to about 1.0 m in depth and colluvial gravel and soils are distributed to 23.8m in depth. Base rock is developed below 23.8m. The results of LS-2 at the lower part of landslide slope shows that topsoil is distributed about 1.0m depth. Colluvial gravel and soils are distributed to 13.5m depth and base rock is developed deeper than 13.5 m. The drilling investigations reveals that the landslide mass consists of thick beds of colluvial gravels and soils.

Fig 3.4.4 shows the geological condition of the downstream landslide block revealed from the core drillings. It also shows the outline of the landslide as assumed from the topographic features and the outcrop of the clayey slip surface.

The stability of the downstream and upstream landslide blocks was studied to consider the effect of a drawdown in the water level of the regulating pond. The analysis suggests that the downstream landslide block will become unstable during drawdown when the residual pore water pressure is 100%. It is therefore necessary to implement some countermeasures against landslide. For protection against sliding and collapse, it is proposed that some of the earth from the upper part of the landslide mass be removed and formed into an embankment counterweight to keep a safety factor of 1.10. The surface water above Landslide R-1 needs to be diverted by a drain ditch to avoid further erosion. It is necessary to provide slope protection works at the toe portion of Landslide R-1.

The upstream landslide block will not be affected much by water level drawdown since the fluctuation of water level is less than 5 m. The lower slope should be protected by riprap to avoid possible occurrence of collapse.

The geological investigations and stability analysis were conducted under the conditions of this landslide before the storm in July, 2002. Therefore, in the detailed design study, it is necessary to consider its latest conditions.

2) Landslide R-2

Landslide R-2 is located at the right bank, 1.2 km upstream from R-1 as shown in Figure 3.4.2. A sketch of landslide block R-2 is shown in Figure 3.4.5. Landslide R-2 is composed of Phyllite. Four collapses are observed within Landslide R-2, each 400m wide. Out of the four collapses, the most downstream block is the largest collapse, being 150m wide and 150m long. Sound Phyllite was observed at its lower part. The other three blocks are hardly [S1]weathered. According to the site reconnaissance, there is a possibility of large scaled landslides developing behind the Landslide R-2 point. Further detailed topographic survey and geological investigation is needed to find the potential size of landslide and prepare the appropriate countermeasures.

Landslide R-2 of 1.5km upstream from Regulating Pond

3) Landslide L-1

Landslide L-1 is located at the left bank of the regulating pond as shown in Figure 3.4.2. The result of the site reconnaissance revealed that this appears stable.

4) Collapse at Left Abutment of Regulating Dam

The collapse of 30m wide and 30m high is located 0.5 km upstream of the left abutment of the dam. A 3 m high secondary collapse was observed behind the collapsed area of L-1 in July 2002, and its sides have deteriorated. Accordingly, there is a possibility of a secondary collapse in the wet season, similar to that occurred in July 2002. The volume of secondary collapse will be about 200m^3. It is recommended to remove this collapse to prevent further collapsed materials from filling the regulating pond. Slope protection of shotcrete and reinforcement anchors need to be provided at the excavated surface for weathering.

3.4.3 Slope Failure in Yangran Watershed

There is little slope failure in the Yangran watershed judging from aerial photography taken after the 1993 flood. The photo shows the existing condition of bed load in the Yangran riverbed. The volume of materials in the riverbed is relatively large in comparison with the volume of the regulating pond and the slope of the river is comparatively steep. Therefore, construction of two check dams upstream of the regulating pond is recommended to reduce sedimentation of the regulating pond.

Fig.3.4.2 shows the most suitable positions for the check dams considering the topographical and geological conditions.

Downstream check dam site of Yangran River

Upstream check dam site of Yangran River

3.5 Erosion and Sediment Control in the Kulekhani Watershed

A disastrous flood occurred in 1993 in the Kulekhani Dam watershed and the Rapti River watershed. Many slope failures and debris flows also occurred in this area. The 1993 flood seriously damaged important structures of the Kulekhani Power Station.

After this disaster, the "Master Plan of Sediment Control for the Kulekhani Watershed" was implemented in November 1993. Three check dams were constructed following the recommendations of the Master Plan. The first is No.1 check dam located in the back water of the Kulekhani reservoir, the second is the No.5 check dam located upstream of Palung Bridge, and the third is the D1 check dam located in the Darkot river.

Since the flood of 1993, no large floods have occurred in this area apart from some rainfall events of about 150 mm/day. No debris disasters have occurred. There is no plan for construction of any other sabo facilities. If a huge flood occurs, a large amount of debris would flow into the Kulekhani reservoir and cause serious problems.

Existing condition of D1 check dam

The site investigation of the Kulekhani Dam watershed and the Rapti watershed was carried out in June 2001 and the existing conditions were clarified as follows:

(1) The D1 check dam located in the Darkot River was filled with sediment and debris. The reach downstream of the check dam has also been filled with sediment. There is a lot of debris upstream of the D1 check dam in the riverbed. It appears that large quantities of debris are transported as bedload when heavy rain occurs. The debris is mostly composed of granite boulders, cobbles and pebbles.

(2) There is little debris deposit in the riverbed of the Chalkhu River, a tributary of the Kulekhani reservoir.

(3) The Palung River from No.1 check dam to Palung Bridge has a lot of debris deposits in the riverbed. Most of the boulders are granite.

(4) The condition of the Kiteni River, the

Sediment condition upstream of No.1 check dam

Khaiti River, the Gauti River and their right tributaries are similar to the tributaries of the Palung River. The bed of these rivers is filled with many granite boulders and it appears that these granite boulders will migrate to the Kulekhani Reservoir.

(5) The frequency of slope failure on the left bank slope of the Kulekhani Reservoir is comparatively low, and there is little debris deposit in the left tributaries.

(6) The Chulipran River, Bisinkhel River and Kunchhal River have relatively low debris loads.

(7) A large collapse and debris flow occurred in the Phedigaon River upstream of Palung at the time of the 1993 flood. Debris deposits occur near Palung. The debris flow is mainly composed of decomposed phyllites. Small amounts of large boulders also exist.

Figure 3.5.1 shows the geology, and distribution of slope failures in the watershed of the Kulekhani Reservoir and the Rapti River based on the results of site inspections and interpretation of aerial photographs taken in 1994.

The geology of the area near the Daman ridge consists of granite, which is naturally highly susceptible to weathering. It can easily yield excessive volumes of sediment, especially during the rainy season. The Bhimphedi Group (Precambrian formation), Phulchauki Group (Lower Paleozoic formation), and Nawakot Group (Upper Paleozoic formation) surround this granite rock. These groups consist of schist, limestone quarzite, phyllite and siliceous dolomite. Large boulders from Daman ridge can be seen in the valley, and large numbers of collapse are located in the Palung River watershed.

Considering the above, this investigation concludes that the frequency of debris flows in the Palung River and Darkot River are remarkably high in comparison with the other watersheds of the Kulekhani reservoir. It is recommended that new check dams be constructed upstream of the existing check dams No. 1 and D1 to detain the sediment flow in the river.

3.6 Construction Materials

The construction material survey of concrete aggregate is carried out around the Project area during the field investigation of the Study to clarify the available volume of aggregate for construction of the Kulekhani III Hydropower Project (KL-III). Test pits of 2 m in width and 2m in depth were excavated at the riverbed. Grain-size distribution of riverbed material was investigated by sieve analysis.

The investigation of concrete aggregate was carried out around the Project area at the design and construction stage of the Kulekhani-I and II Hydropower Project (KL-I and KL-II), and the Kulekhani Disaster Prevention Project-II (KDPP-II). Borrow areas for the concrete aggregate including the location of test pits are shown in the Figure 3.6.1, referring the existing borrow areas. The results of the sieve analysis are summarized in Table 3.6.1.

(1) Borrow Pits in front of KL-I Powerhouse in the Rapti River Basin

The riverbed material in the Rapti river basin near the KL-I powerhouse site was used as coarse aggregate for concrete during the construction of the KL-I and II. Fine aggregate was also produced from the riverbed material in this borrow area by using a rod mil during the construction of the KL-II.

This borrow area is located at the 1 km upstream from the confluence between the Rapt and the Mandu Rivers. The distance between the borrow area and the batcher plant of KL-III, which is planned at Ghumaune village, is about 10 km.

Samples were taken for sieve analysis at the 1m in depth in two test pits. As a result of sieve analysis, the available volume of coarse aggregate from 5 mm to 40 mm is estimated at 50 to 60 % of total. The grain-size distribution for both coarse and fine aggregate doesn’t meet with the standard value recommended by the Japan Society of Civil Engineering. Therefore, the grain-size distribution needs adjusting for using as the concrete aggregate. The rod mill is also required for the production of fine aggregate.

Judging from the observation of the test pits, the volume of the concrete aggregate obtained from this borrow area is estimated at 200,000 m^3.

(2) Bhimphedi Site in the Rapti River Basin

The riverbed material in the Rapti river basin near the Bhimphedi village was used as the coarse aggregate for the concrete during the construction of the KDDP-II. The distance between the borrow area and batcher plant of KL-III is about 13 km.

The test result of sieve analysis shows that the available volume of coarse aggregate from 5 mm to 40 mm is 65 % of total. It is necessary to adjust the grain-size distribution, and use a rod mill for the production of the fine aggregate.

The volume of the concrete aggregate obtained from this borrow area is estimated at 100,000 m^3.

(3) Ratomati Site in the Rapti River Basin

Ratomati site in the Rapti River basin is located at 2 km downstream from the confluence between the Rapti and the Khani River. The distance between the borrow area and the batcher plant of KL-III is about 2 km.

The available volume of coarse aggregate from 5 mm to 40 mm is 40 % of total. The adjustment of grain-size distribution is needed for coarse aggregate, and a rod mill is required for the production of the fine aggregate.

The volume of the concrete aggregate obtained from this borrow area is estimated at 40,000 m^3.

(4) Churiya Site in the Chure River Basin

Churiya site is located in the Chure River basin, being a tributary of the Rapti River. The distance between the borrow area and the batcher plant of KL-III is about 16 km. The riverbed materials in this borrow area were used as the concrete aggregate for the construction of temporary facilities and minor structures at the construction of the KL-II.

Local contractors obtain the concrete aggregates from the Churiya borrow area at present. The available volume of coarse aggregate from 5 mm to 40 mm is 40 %, and fine aggregate below 5 mm is 25 % of total. According to the results of the sieve analysis for the fine aggregate, the grain-size distribution meets with the standard value recommended by the Japan Society of Civil Engineering. However, the result of the visual inspection shows that the quality of the fine aggregate varies from place to place and much contamination of fine particles was observed in some places.

The volume of the available coarse and fine aggregate is estimated at 160,000 m^3 and 100,000 m^3 respectively. As far as judging from the test results, the sufficient volume of aggregate can be obtained from this borrow area. However, further investigations are needed in order to confirm whether the required volume of the fine aggregate can be obtained, since 1) the quality of the aggregate varies from place to place and 2) the local contractors have obtained the aggregate from the Churiya site over a long time period.

The required volume of the concrete aggregate is estimated at 150,000 m^3. Therefore, the borrow areas mentioned above are enough to supply the concrete aggregate for the Project.

Churiya site is considered as the candidate of the borrow area obtained the fine aggregate. There is suspicion whether the good quality of the concrete aggregate can be obtained sufficiently. It is recommended that the fine aggregate should be produced by using a rod mil.

TABLES

Chapter 3

Table 3.2.1 Record at Adjacent Observatory Stations ("○": all data available, "△": some data available, "X": no data, ←→: collection period)

No.	Station Name	Latitude Longitude	Elevation (m)	C.A. (km^2)	Estd. Date	Record (63, 65, 70, 75, 80, 85, 90, 95, 00)
Rainfall Gauging Station (Daily Record)						
0904	Chisapani Gadhi	27 33 N. 85 08 E.	1706	-	May 1956	From 57 ←○ △ ○ ○ ○ ○ ○→
0905	Daman	27 36 N. 85 05 E.	2314	-	Sep.1965	←△ ○ △ ○ ○ ○ ○ ○→
0906	Hetauda N.F.I.	27 25 N. 85 03 E.	474	-	Aug.1966	←△ ○ ○ △ X △ ○ ○ △ ○→
0915	Markhu Gaun	27 37 N. 85 09 E.	1530	-	Dec.1971	←○ △ ○→
0917	Hetauda (Ind. Dis.)	27 26 N. 85 02 E.	466	-	Jan.1974	←○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○→
0919	Makwanpur Gadhi	27 25 N. 85 10 E.	1030	-	Dec.1974	←○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ △ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○→
1038	Dhunibesi	27.43 N. 85.11 E.	1085	-	Apr.1971	←△ ○ △ △ ○→
1039	Panipokari (Kathmandu)	27.44 N. 85.20 E.	1335	-	Apr.1971	←△ △ △ ○ ○ ○ ○ ○ ○ ○ △ ○ ○ ○ ○ ○ △ △ X △ ○ ○ △ ○ ○ ○ ○ △ ○ ○→
NEA	Nibuwatar	-	Not collected			←○ ○ ○ ○ △ △ △ △ △ △ △→
NEA	Kulekhani	-	Not collected			
Rainfall Gauging Station (Hourly Record)						
DSC	Tistung		Not collected			
HZM	Churibagaicha		Not collected			
Stream Flow Gauging Station (Daily Record)						
0460	Rapti R. at Rajaya	27 26 30 N. 84 58 15 E.	332	579	Jan.1963	←○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ △ ○ ○ ○ △ ○ ○ ○ ○ ○ ○ ○ △ ○ ○ ○ ○ ○→
0465	Manahari R. at Manahari	27 33 00 N. 84 48 10 E.	305	427	Jun.1963	←○ ○→
0470	Lothar R. at Lothar	27 35 40 N. 84 43 00 E.	336	169	Nov.1963	←○ △ ○ ○ ○ ○ △ ○ ○ ○ ○→
0560	Thado R. at Darkot	27 36 20 N. 85 09 00 E.	1830	14	Jan.1964 Closed	○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○
0570	Kulekhani R. at Kulekhani	27 35 10 N. 85 09 30 E.	1480	126	Dec.1962 Nov.1977	←○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○→

Table 3.2.2 Temperature at Daman and Hetauda N.F.I.
(Monthly mean of 1985 to 20000)

(Unit : °C)

Month	Daman					HetaudaN.F.I.				
	Mean Temp.	Maximum Temp.		Minimum Temp.		Mean Temp.	Maximum Temp.		Minimum Temp.	
		Mean	Extr.	Mean	Extr.		Mean	Extr.	Mean	Extr.
Jan.	6.8	12.6	19.0	1.0	-5.0	15.0	22.4	27.6	7.4	2.0
Feb.	7.9	13.3	24.5	2.4	-5.0	17.0	25.0	31.5	9.1	2.6
Mar.	11.6	17.0	23.9	6.0	-0.3	21.5	29.9	37.5	13.0	6.0
Apr.	14.9	20.3	27.3	9.5	2.4	25.6	33.9	39.8	17.3	9.2
May	16.4	21.6	26.6	11.3	5.0	27.5	33.9	40.6	21.1	12.2
Jun.	17.6	22.0	26.8	13.3	6.9	28.4	33.0	39.4	23.7	16.0
Jul.	17.9	21.7	25.2	14.1	8.1	27.8	31.6	36.0	23.9	12.0
Aug.	17.9	21.9	28.0	14.0	8.1	27.9	31.9	37.6	23.7	16.2
Sep.	17.3	21.9	25.3	13.0	7.5	27.0	31.4	36.6	22.5	16.0
Oct.	15.0	20.9	28.6	9.5	1.5	24.2	30.2	36.2	18.1	10.6
Nov.	10.9	17.4	23.0	4.7	-2.1	19.9	27.4	34.0	12.4	7.5
Dec.	7.8	14.2	19.3	1.8	-4.0	16.6	24.4	32.5	8.8	3.6
Mean	13.5	18.7	-	8.5	-	23.2	29.6	-	16.8	-
Extr.	-	-	28.6		-5.0	-	-	40.6	-	2.0

Source: Ref. 1)

Table 3.2.3 Monthly Evaporation Record at Chisapani Gadhi

(Unit: mm)

Month	1963	1964	1965	Mean
Jan.	-	63.5	89.1	76.3
Feb.	48.4	96.7	121.2	109.0
Mar.	169.1	214.7	203.1	195.6
Apr.	326.5	310.9	-	318.7
May	392.7	333.2	-	363.0
Jun.	198.6	291.8	-	245.2
Jul.	87.0	82.5	-	84.8
Aug.	48.3	119.6	-	84.0
Sep.	69.3	90.6	-	80.0
Oct.	81.9	124.3	-	103.1
Nov.	68.8	108.6	-	88.7
Dec.	59.0	74.6	-	66.8
Annual	-	-	-	1815.2

Source: Ref. 2)

Table 3.2.4 Monthly Mean Rainfall

(Unit: mm)

Month	Chisapani Gadhi	Daman	Hetauda N.F.I.	Markhu Gaun	Hetauda Ind. Dis.	Makwanpur Gadhi	Dhunibesi	Panipokari (Kathmandu)
Jan.	20.8	17.7	16.1	19.7	6.7	16.9	13.1	12.6
Feb.	20.3	25.0	18.6	25.6	11.8	11.8	15.0	16.0
Mar.	43.9	33.6	28.0	35.2	21.6	21.0	27.6	29.6
Apr.	77.9	79.4	57.2	60.8	56.6	53.4	44.9	73.5
May	159.8	155.8	167.3	131.8	135.0	157.1	131.1	114.9
Jun.	368.6	319.6	380.3	247.9	344.9	337.0	266.9	266.3
Jul.	587.1	455.9	617.3	376.0	572.2	610.2	422.3	375.7
Aug.	493.9	358.9	536.5	288.4	476.1	529.3	378.7	357.1
Sep.	288.8	229.2	367.1	212.5	411.5	337.2	217.0	186.1
Oct.	73.6	61.5	88.4	55.3	75.1	80.9	57.7	61.5
Nov.	8.3	10.5	11.7	11.3	4.6	15.2	9.4	8.7
Dec.	16.3	14.8	15.1	24.5	14.0	20.2	15.1	12.6
Annual	2159.3	1762.0	2303.5	1489.1	2130.1	2190.0	1598.5	1514.7
May to Oct.	1971.8 (91 %)	1580.9 (90 %)	2156.9 (94 %)	1312.0 (88 %)	2014.8 (95 %)	2051.6 (94 %)	1473.6 (92 %)	1361.6 (90 %)
Analysis Record	Mean of 44 yrs. 1957 – 2000	Mean of 34 yrs. 1967 – 2000	Mean of 35 yrs. 1966 – 2000	Mean of 29 yrs. 1972 – 2000	Mean of 17 yrs. 1974 – 1990	Mean of 26 yrs. 1975 – 2000	Mean of 30 yrs. 1971 – 2000	Mean of 28 yrs. 1971 – 2000

Source: Ref. 3), 4)

Table 3.2.5 Maximum Daily Rainfall

(Unit: mm)

Year	Chisapani Gadhi		Hetauda N.F.I.	
1958	83.3	07/31	-	
1959	90.8	07/22	-	
1960	80.8	05/21	-	
1961	76.4	07/28	-	
1962	233.0	06/28	-	
1963	65.0	08/20	-	
1964	49.0	08/17	-	
1965	300.0	07/07	-	
1966	223.0	08/28	196.0	08/24
1967	256.4	07/10	172.0	07/10
1968	145.0	07/23	262.0	08/27
1969	70.3	08/21	80.6	08/20
1970	280.2	07/16	-	-
1971	134.3	06/11	153.2	06/13
1972	162.2	07/27	105.6	07/27
1973	125.2	06/18	171.6	06/28
1974	218.0	09/02	279.2	08/31
1975	210.0	07/28	200.1	07/28
1976	162.0	06/10	220.2	07/11
1977	77.0	06/20	107.4	06/22
1978	173.0	07/16	247.6	07/16
1979	198.9	08/19	145.2	08/21
1980	84.1	05/11	157.5	06/19
1981	154.0	09/29	260.6	07/31
1982	133.0	08/27	148.2	09/18
1983	131.5	07/17	98.2	07/06
1984	228.3	09/17	116.9	09/17
1985	131.0	09/05	158.7	09/05
1986	157.0	08/27	190.3	09/15
1987	126.0	07/24	223.0	07/24
1988	106.8	09/08	103.5	07/06
1989	84.0	07/06	152.0	09/06
1990	137.0	08/27	453.2	08/27
1991	106.0	07/07	94.4	07/11
1992	58.0	05/15	115.2	08/25
1993	295.0	07/20	257.0	07/21
1994	96.4	09/10	124.0	09/10
1995	116.0	08/13	170.0	06/29
1996	150.2	07/14	115.4	09/24
1997	146.0	07/01	189.2	08/13
1998	98.3	07/25	181.2	07/21
1999	262.1	07/03	197.8	06/28
2000	162.0	08/03	142.4	07/10
Max.	300.0	-	453.2	-

Source: Ref. 3)

Table 3.2.6 Daily Rainfall during Storm of July 1993

No.	Station Name	Daily Rainfall (mm)					Total (mm)		
		7/18	7/19	7/20	7/21	7/22	1-day	3-day	5-day
904	Chisapani Gadhi	58	295	65	45	29	295	418	492
905	Daman	56	373	8	5	4	373	437	446
906	Hetauda N.F.I.	38	4	257	14	51	257	322	364
919	Makwanpur Gadhi	40	78	205	30	25	205	323	378
HZM	Churibagaicha	29	289	376	172	63	376	837	929
NEA	Nibuwatar	38	234	362	106	46	362	702	786
	Average of Pjt. Area	43	212	212	62	36	311	507	566
915	Markhu Gaun	5	386	44	38	33	386	468	506
DSC	Tistung	4	540	40	66	30	540	646	680

Source: Ref. 5)

Table 3.2.7 Daily Rainfall during Storm of July 2002

No.	Station Name	Daily Rainfall (mm)				Total (mm)	
		7/21	7/22	7/23	7/24	1-day	4-day
904	Chisapani Gadhi	22	148	443	210	443	823
905	Daman	102	403	255	101	403	861
906	Hetauda N.F.I.	31	218	302	95	302	646
919	Makwanpur Gadhi	27	210	311	123	311	671
NEA	Nibuwatar	169	490	455	111	490	1225
	Average of Pjt. Area	70	294	353	128	390	845
915	Markhu Gaun	79	284	145	34	284	542
DSC	Tistung	81	288	143	67	288	579

Source: DHM

Table 3.2.8 Sedimentation of Kulekhani Reservoir

Surveyed in	Hydro-logical Year	Dead Level (EL.m)	Dead Storage (10^6 m^3)	Live Storage (10^6 m^3)	Gross Storage (10^6 m^3)	Annual Sedimentation (10^6 m^3)	Accumulated Sedimentation (10^6 m^3)	Sedimentation Rate (m^3/ km^2/yr.)
1981	0	1,471.0	12.00	73.30	85.30	0.00	0.00	-
1993/03	11	1,471.0	10.80	72.30	83.10	2.20	2.20	1,588
1993/12	12	1,471.0	7.60	70.70	78.30	4.80	7.00	4,630
1994/09	13	1,471.0	6.50	61.30	67.80	10.50	17.50	10,684
1995/11	14	1,471.0	4.60	58.90	63.50	4.30	21.80	12,358
1996/12	15	1,471.0	2.80	60.60	63.40	0.10	21.90	11,587
1997/11	16	1,480.0	7.60	55.59	63.19	0.21	22.11	10,967
1998/11	17	1,480.0	7.42	55.87	63.30	-0.11/*1	22.00	10,271
1999/11	18	1,480.0	6.98	55.66	62.64	0.66	22.66	9,992
2000/11	19	1,480.0	6.80	55.58	62.38	0.26	22.92	9,574
2001/11	20	1,480.0	6.79	55.57/*2	62.36	0.02	22.94	9,103
Mean	-	-	-	-	-	1.15	-	-

Source: Ref. 6),7), 8)

/*1 An annual sedimentation was estimated to be -0.11x10^6 m^3 in Nov. 1998 due to differences in estimation method.
/*2 Live storage above M.O.L. is estimated to be.55.51x10^6 m^3

Notes;
1) Hydrological Year: Number of rainy seasons after reservoir impounding
2) Dead Level: The highest elevation of sediment
3) Dead Storage: Storage below the dead level
4) Live Storage: Storage between the F.S.L.(EL.1,530.0 m) and the dead level
5) A heavy storm and flood hit the central and southern mountain regions of Nepal in July 1993.
6) A sloping intake was completed in 1997.

Table 3.2.9 Monthly Runoff at Kulekhani G.S.

(Unit: m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1963	1.17	1.06	1.13	1.15	1.64	1.13	6.60	7.64	5.75	3.53	2.16	1.75	2.89
1964	1.47	1.39	1.16	0.91	1.26	2.21	7.24	11.87	15.23	4.48	1.84	1.50	4.21
1965	1.32	1.29	1.22	1.76	1.47	3.74	19.54	18.36	5.71	3.10	2.86	1.75	5.18
1966	1.55	1.41	1.14	0.75	1.12	1.14	10.38	20.78	10.29	3.33	2.20	1.70	4.65
1967	1.08	0.94	0.86	1.01	0.65	4.52	11.80	6.92	5.67	3.36	2.32	1.68	3.40
1968	1.66	1.46	1.63	1.21	1.10	2.52	5.72	6.33	2.62	7.12	2.25	1.47	2.92
1969	1.18	0.89	0.87	0.92	0.95	0.88	3.10	6.89	4.18	1.91	1.10	0.83	1.98
1970	0.82	0.72	0.64	0.61	0.64	3.42	21.29	8.98	5.26	3.30	2.18	1.47	4.11
1971	1.15	1.11	1.10	1.98	2.13	21.64	5.08	7.68	4.27	3.82	2.22	1.86	4.50
1972	1.72	1.78	1.62	1.41	1.38	4.54	28.27	6.15	8.36	2.49	1.85	1.58	5.10
1973	1.38	1.24	1.58	0.96	1.29	10.24	7.34	7.97	9.51	9.51	5.14	2.75	4.91
1974	1.59	1.33	1.13	1.16	1.26	1.66	7.15	15.61	20.65	3.50	1.96	1.50	4.88
1975	1.28	1.18	0.88	0.76	1.07	2.11	14.76	10.99	11.69	4.70	2.35	1.67	4.45
1976	1.46	1.25	1.02	1.09	1.44	7.96	6.04	4.75	3.94	2.30	1.75	1.45	2.87
1977	1.28	1.22	1.07	1.40	1.64	1.57	3.16	3.47	2.31	1.80	1.60	1.63	1.85
Mean	1.34	1.22	1.14	1.14	1.27	4.62	10.50	9.63	7.70	3.88	2.25	1.64	3.86

Source: electric files of daily runoff record prepared by DHM

Table 3.2.10 Monthly Runoff at Rajaya G.S.

(Unit: m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1963	7.86	6.77	5.63	5.10	6.07	21.36	65.55	91.79	70.86	33.15	16.30	9.58	28.34
1964	7.59	6.43	5.29	4.97	5.64	11.16	74.35	55.53	69.10	44.55	13.35	8.06	25.50
1965	7.16	6.63	6.74	4.45	3.82	17.49	84.26	170.49	73.43	28.93	20.62	10.88	36.24
1966	8.26	6.88	5.91	5.09	6.83	11.90	51.83	157.51	92.62	20.29	12.53	9.42	32.42
1967	7.55	6.27	6.69	6.72	6.32	14.40	93.67	74.28	72.04	21.12	10.01	6.69	27.15
1968	5.77	4.56	3.90	3.26	3.59	33.37	89.38	135.89	44.91	42.16	19.07	12.34	33.18
1969	10.17	7.68	6.91	6.11	7.29	13.88	44.82	81.47	64.28	28.03	14.81	10.25	24.64
1970	7.99	6.98	5.34	5.04	4.76	22.45	132.41	95.46	68.10	44.74	18.18	11.10	35.21
1971	7.33	5.62	4.66	7.86	22.21	90.28	67.89	89.87	59.29	34.72	17.11	11.39	34.85
1972	8.69	7.93	6.47	4.88	5.11	16.13	66.96	63.76	61.53	29.56	15.83	10.33	24.77
1973	8.61	6.69	5.80	3.13	6.25	43.72	45.30	64.43	77.47	55.33	24.50	15.10	29.69
1974	11.74	8.81	7.15	6.40	7.59	14.88	64.09	110.96	120.43	34.23	15.69	13.30	34.61
1975	9.81	7.94	5.92	5.48	6.76	18.13	109.72	54.49	45.43	23.58	12.56	9.37	25.77
1976	8.01	6.69	5.39	5.43	8.80	19.32	53.33	52.39	48.77	24.11	13.38	9.37	21.25
1977	7.38	6.18	4.87	7.49	8.65	14.43	48.04	63.02	45.50	29.85	20.62	13.05	22.42
1978	9.93	8.08	7.45	14.54	12.19	48.47	106.17	65.81	52.00	33.10	19.07	12.60	32.45
1979	8.08	8.10	5.86	5.25	4.56	11.79	76.45	81.28	35.72	25.17	14.38	11.10	23.98
1980	8.38	7.23	6.29	4.70	6.88	24.28	47.28	66.13	60.19	29.75	16.52	11.49	24.09
1981	9.57	6.98	5.55	6.71	9.67	14.84	61.90	82.83	73.99	40.86	19.53	13.32	28.81
1982	10.72	9.34	9.75	11.78	9.24	10.65	43.50	59.54	88.76	30.70	16.70	12.45	26.09
1983	11.49	10.41	9.25	9.09	11.63	10.76	47.16	46.05	46.16	17.70	10.62	9.33	19.97
1984	8.88	8.08	7.20	6.82	7.03	17.15	34.37	35.75	80.26	18.19	12.53	9.65	20.49
1985	8.66	7.81	6.73	6.98	8.74	16.44	44.91	42.35	72.34	30.75	14.83	11.02	22.63
1986	9.20	8.68	7.85	7.25	7.60	15.74	40.69	67.15	65.53	20.76	12.56	10.28	22.77
1987	10.38	8.07	7.11	7.28	6.98	8.16	46.10	79.19	65.29	38.64	17.72	11.22	25.51
1988	8.27	6.10	5.96	5.97	9.67	26.11	45.39	74.12	74.46	25.19	14.53	13.98	25.81
1989	13.62	10.82	7.47	9.13	8.20	20.51	90.10	64.34	129.99	43.48	17.19	13.35	35.68
1990	12.02	13.03	9.46	-	-	-	83.53	129.69	67.87	49.44	16.02	11.97	43.67
1991	12.55	10.36	8.98	7.69	7.79	15.49	38.92	43.24	57.20	18.11	13.91	12.10	20.53
1992	11.78	10.55	8.66	7.67	8.58	13.41	27.19	38.35	31.64	16.55	10.26	8.09	16.06
1993	7.45	7.10	6.61	7.27	6.93	9.73	44.46	43.66	34.85	21.15	13.00	8.50	17.56
1994	12.60	8.14	5.27	5.82	4.60	18.62	15.86	33.07	31.71	14.69	12.26	11.31	14.50
1995	10.28	9.60	6.44	6.19	10.07	23.76	19.42	48.97	47.18	25.60	17.98	11.58	19.76
Mean	9.33	7.90	6.62	6.61	7.81	20.90	60.76	74.63	64.51	30.13	15.58	11.02	26.32

Source: electric files of daily Runoff record prepared by DHM

Complemented runoff from the Manahari G.S. record

($Q_{Rajaya} = 2.0296 \times Q_{Manahari}^{0.8927}$, R = 0.885)

Table 3.2.11 Runoff Coefficient and Specific Runoff at Rajaya G.S.

Year/*	Annual Rainfall (mm)	Annual Runoff (m^3/s)	Annual Runoff (mm)	Runoff Coefficient	Specific Runoff ($m^3/s/100\ km^2$)
1967	2,335	27.15	1,479	0.63	4.69
1968	2,231	33.18	1,807	0.81	5.73
1972	2,056	24.77	1,349	0.66	4.28
1973	2,623	29.69	1,617	0.62	5.13
1975	2,693	25.77	1,404	0.52	4.45
1976	2,237	21.25	1,157	0.52	3.67
1977	1,964	22.42	1,221	0.62	3.87
1978	2,489	32.45	1,767	0.71	5.60
1979	1,853	23.98	1,306	0.70	4.14
1980	1,756	24.09	1,312	0.75	4.16
1981	2,142	28.81	1,569	0.73	4.98
1982	1,889	26.09	1,421	0.75	4.51
平均	2,189	26.64	1,451	0.67	4.60

/* the years with lacks of rainfall data are excluded.

Table 3.2.12 Specific Runoff at Adjacent G.S.

No.	Gauging Station	River Basin	Drainage Area (km^2)	Mean Discharge (m^3/s)	Specific Runoff ($m^3/s/100\ km^2$)	Analysis Period
420	Kali Gandaki at Kota Gaon	Narayani	11,400	470.8	4.13	1964-85
446.8	Phalandu Khola at Betrawati	Narayani	162	13.2	8.12	1971-85
447	Trisuli River at Betrawati	Narayani	4,110	183.8	4.47	1967-85
448	Tadi Khola at Tadi Pool, Belkot	Narayani	653	39.9	6.10	1969-85
450	Narayani River at Narayan Ghat	Narayani	31,100	1,583.1	5.09	1963-87
460	Rapti River at Rajaya	Rapti	579	26.6	4.60	1967-82
465	Manahari River at Manahari	Rapti	427	18.4	4.31	1963-85
470	Lothar Khola at Lothar	Rapti	169	9.6	5.65	1964-85
505	Bagmati River at Sundarijal	Bagmati	17	1.1	6.28	1963-85
536.2	Bishnumati Khola at Budhanilkantha	Bagmati	4	0.3	7.95	1969-85
550	Bagmati River at Chovar	Bagmati	585	15.5	2.65	1963-80
590	Bagmati River at Karmaiya, Mangalpur	Bagmati	2,720	159.9	5.88	1965-79
589	Bagmati River at Pandhera Dovan	Bagmati	2,700	120.8	4.48	1979-85

Source; Ref.

Table 3.2.13 Calibration of Tank Model

Calibration Item	1972	1973	1974	1975	1976	1977	Mean
Annual Rainfall (mm)	1,657	2,034	1,974	1,954	1,774	1,419	1,802
Estimated Annual Runoff (mm)	983	1,044	1,131	1,160	1,073	667	1,010
Observed Annual Runoff (mm)	1,286	1,232	1,223	1,122	720	464	1,008
Correlative Coefficient(R value)	0.90	0.91	0.89	0.53	0.95	0.91	0.86
Runoff Coefficient	0.59	0.51	0.57	0.59	0.60	0.47	0.56
Specific Runoff ($m^3/s/100\ km^2$)	3.12	3.31	3.59	3.68	3.40	2.11	3.20

Table 3.2.14 Monthly Inflow into Kulekhani Reservoir

(Unit: m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1963	1.46	1.33	1.42	1.44	2.07	1.42	8.45	9.77	7.33	4.47	2.73	2.21	3.68
1964	1.85	1.75	1.46	1.14	1.59	2.79	9.19	15.57	19.41	5.70	2.32	1.90	5.39
1965	1.66	1.63	1.54	2.22	1.85	4.72	21.91	22.61	7.27	4.01	3.62	2.21	6.27
1966	1.95	1.78	1.43	0.94	1.41	1.44	12.49	24.33	12.88	4.22	2.77	2.14	5.65
1967	1.36	1.18	1.08	1.27	0.82	5.56	14.06	8.82	7.22	4.26	2.93	2.12	4.22
1968	2.10	1.84	2.05	1.52	1.39	3.19	7.24	8.07	3.31	8.66	2.84	1.85	3.67
1969	1.49	1.12	1.09	1.16	1.19	1.10	3.94	8.81	5.31	2.41	1.39	1.05	2.51
1970	1.03	0.90	0.80	0.76	0.80	4.36	24.11	11.49	6.69	4.18	2.75	1.85	4.98
1971	1.45	1.40	1.38	2.50	2.69	24.40	6.47	9.82	5.42	4.81	2.81	2.34	5.46
1972	2.17	2.25	2.04	1.78	1.74	5.59	31.70	7.84	10.50	3.14	2.33	1.99	6.09
1973	1.73	1.56	2.28	1.21	1.62	12.22	9.38	10.19	11.92	11.98	6.55	3.48	6.18
1974	2.00	1.67	1.42	1.46	1.58	2.10	9.14	18.21	23.97	4.44	2.47	1.88	5.86
1975	1.62	1.49	1.11	0.95	1.35	2.68	17.15	13.94	14.71	5.97	2.96	2.10	5.50
1976	1.83	1.58	1.28	1.37	1.81	9.79	7.70	6.05	5.00	2.90	2.21	1.82	3.61
1977	1.62	1.53	1.35	1.76	2.06	1.98	4.00	4.40	2.91	2.26	2.02	2.06	2.33
1978	2.12	1.96	2.00	2.16	2.71	5.78	18.50	10.65	6.31	6.64	2.78	2.54	5.35
1979	2.37	2.30	2.00	1.74	1.59	4.11	13.01	9.11	3.61	2.27	1.89	2.15	3.85
1980	1.71	1.57	1.44	1.25	1.14	9.44	8.78	6.57	6.97	2.21	1.80	1.63	3.71
1981	1.52	1.40	1.19	1.80	1.14	1.32	2.78	4.41	11.41	2.81	1.43	1.30	2.71
1982	1.16	1.11	1.05	0.84	0.83	2.81	2.17	7.38	8.73	1.91	1.28	1.15	2.54
1983	0.76	0.99	0.76	0.93	1.86	1.48	10.24	6.20	9.56	5.53	3.70	1.98	3.67
1984	1.48	1.34	1.05	0.67	0.71	2.34	7.80	6.73	12.72	5.75	2.47	2.19	3.77
1985	1.43	0.97	1.47	0.47	2.97	1.81	6.84	7.39	17.54	9.96	3.32	2.96	4.76
1986	2.23	1.85	1.34	1.96	3.50	6.30	7.28	13.12	11.36	7.00	2.95	2.46	5.11
1987	1.93	1.67	1.75	1.21	1.07	0.73	16.10	12.31	6.69	7.85	3.28	2.04	4.72
1988	1.84	1.46	1.78	1.04	1.68	4.60	7.15	12.50	9.04	3.42	2.14	2.41	4.09
1989	2.65	1.52	1.08	0.82	2.15	2.35	12.67	6.69	6.32	4.27	2.55	1.50	3.71
1990	1.29	1.35	1.50	1.23	2.17	2.18	12.80	12.35	10.15	4.24	2.42	2.00	4.47
1991	1.98	1.33	1.27	1.56	1.10	2.57	4.96	9.69	7.57	2.35	1.73	1.68	3.15
1992	1.45	1.00	0.62	0.58	1.77	1.23	3.68	4.68	3.31	1.98	1.35	1.19	1.90
1993	0.99	0.72	0.86	1.27	1.69	4.35	30.98	12.24	4.01	3.16	2.01	1.42	5.31
1994	2.41	2.08	1.59	2.16	2.00	2.71	3.01	5.00	8.05	2.36	1.70	2.09	2.93
1995	1.91	1.81	1.35	1.14	1.23	7.87	10.38	8.48	5.93	3.18	26.65	11.42	6.78
Mean	1.71	1.50	1.39	1.34	1.68	4.46	11.09	10.16	8.88	4.55	3.28	2.28	4.36

1963 to 1977; Computed from runoff record
1978 to 1982; Estimated by tank model
1983 to 1995; Estimated from reservoir operation record

Table 3.2.15 Evaluation of Reservoir Inflow

Year	Rainfall (mm)		Inflow (mm)		Runoff Coefficient		Specific Runoff ($m^3/s/100km^2$)	
	Annual	Average	Annual	Average	Annual	Average	Annual	Average
1972	1,657		1,232		0.75		3.91	
1973	2,034		1,250		0.62		3.96	
1974	1,973		1,185		0.60		3.76	
1975	1,954		1,113		0.57		3.53	
1976	1,773		730		0.41		2.32	
1977	1,418	1,801	471	997	0.33	0.55	1.49	3.16
1978	1,865		1,082		0.58		3.43	
1979	1,320		779		0.59		2.47	
1980	1,388		750		0.54		2.38	
1981	1,145		548		0.48		1.74	
1982	1,159	1,375	514	735	0.44	0.53	1.63	2.33
1983	1,516		742		0.49		2.35	
1984	1,545		763		0.49		2.42	
1985	1,989		963		0.48		3.05	
1986	1,889		1,034		0.55		3.28	
1987	1,606		955		0.59		3.03	
1988	1,451		827		0.57		2.62	
1989	1,210		750		0.62		2.38	
1990	1,643		904		0.55		2.87	
1991	1,140		637		0.56		2.02	
1992	1,075		384		0.36		1.22	
1993	1,936		1,074		0.55		3.41	
1994	1,147		593		0.52		1.88	
1995	1,700	1,527	1,371	846	0.81	0.55	4.35	2.68
Mean	-	1,564	-	860	-	0.55	-	2.73

1963 to 1971; Excluded due to lacks of rainfall record
1963 to 1977; Computed from runoff record
1978 to 1982; Estimated by tank model
1983 to 1995; Estimated from reservoir operation record

Table 3.2.16 Annual Maximum Floods at Rajaya G.S. and Kulekhani G.S.

(unit: m^3/s)

	Rajaya G.S.			Kulekhani G.S.		
Year	Date	Gauge Height (m)	Discharge (m^3/s)	Date	Gauge Height (m)	Discharge (m^3/s)
1963	09/16	3.77	691	09/29	1.60	40.0
1964	09/02	2.68	368	07/15	2.71	148
1965	07/07	4.64	971	07/07	4.20	304
1966	08/27	4.62	964	08/24	3.25	202
1967	07/10	4.10	798	07/10	3.95	277
1968	08/26	4.91	1,050	10/04	2.63	141
1969	08/19	2.47	310	08/21	1.31	32.6
1970	07/17	3.48	604	07/16	5.35	571
1971	06/13	2.50	318	06/13	5.24	305
1972	07/27	2.64	357	07/24	4.56	251
1973	09/26	2.72	356	06/17	2.67	99.6
1974	09/01	4.24	933	08/30	4.38	236
1975	07/28	3.30	547	07/27	3.21	143
1976	07/02	2.88	343	06/10	3.28	148
1977	08/18	2.15	179	08/17	0.98	8.64
1978	07/15	3.30	540	-	-	-
1979	07/24	3.90	780	-	-	-
1980	06/19	3.08	463	-	-	-
1981	07/31	3.70	700	-	-	-
1982	09/21	3.10	470	-	-	-
1983	07/16	2.20	210	-	-	-
1984	09/17	4.51	1,070	-	-	-
1985	09/05	4.94	1,290	-	-	-
1986	09/14	3.40	580	-	-	-
1987	09/02	2.49	277	-	-	-
1988	07/06	2.40	250	-	-	-
1989	09/06	3.30	540	-	-	-
1990	08/27	3.99	821	-	-	-
1991	07/08	2.00	180	-	-	-
1992	08/28	2.10	205	-	-	-
1993	07/21	3.70	660	***07/19***	-	***1,340-***
1994	09/10	2.60	220	-	-	-
1995	??	4.06	714	-	-	-

Source; 1963 to 1990: Ref. 14)
1991 to 1995: Electric files of DHM
Estimate in Mater Plan Study 5)

Table 3.2.17 Probable Floods at Rajaya G.S.

(Unit: m^3/s)

Return Period	Probable Flood (m^3/s)		
	Gumbel	Iwai	Log-Pearson Type III
1.01	24	105	117
2	523	503	501
5	822	793	798
10	1,019	997	1,004
20	1,209	1,201	1,207
30	1,318	1,321	1,325
40	1,395	1,408	1,409
50	1,454	1,475	1,474
100	1,638	1,690	1,678
200	1,821	1,912	1,885
1000	2,246	2,460	2,374
10000	2,852	3,338	3,103

Table 3.2.18 Probable Rainfall of Kulekhani Reservoir Basin

Return Period	Probable Rainfall (Log-Pearson Type III, mm)		
	Daman	Daman	Reservoir Basin
1.01	42	46	49
2	108	113	107
5	166	179	162
10	212	237	207
20	263	304	258
30	296	349	291
40	320	383	317
50	340	412	337
100	407	510	408
200	481	626	489
1000	694	985	731
10000	1120	1,812	1,253
Analysis Period	1968-1993	1968-2000, 2002	1972-2000, 2002

Table 3.2.19 Probable Flood at Kulekhani G.S.

Return Period	Probable Flood (m^3/s)	Creager's Coefficient
1.01	166	7.2
2	362	15.7
5	548	23.7
10	700	30.3
20	872	37.8
30	984	42.6
40	1,071	46.4
50	1,139	49.3
100	1,379	59.7
200	1,653	71.6
1000	2,471	107.0
10000	4,235	183.5

Table 3.2.20 Estimated Sediment Load from Kulekhani Reservoir Basin

Year	Annual Sediment Deposition (10^6 m^3)	Annual Max. Rainfall (mm)	Estimated Sedimentation (10^6 m^3)		Estimated Sdimnt. (Revised equation) (10^6 m^3)	
			Annual	Cmltv.	Annual	Cmltv.
1981	-	169.3	0.46	0.46	0.52	0.52
1982	-	70.6	0.09	0.54	0.10	0.62
1983	-	133.7	0.25	0.79	0.29	0.91
1984	-	102.1	0.15	0.94	0.17	1.08
1985	-	113.9	0.18	1.12	0.21	1.29
1986	-	107.6	0.16	1.28	0.19	1.47
1987	-	114.4	0.18	1.46	0.21	1.68
1988	-	90.6	0.12	1.58	0.14	1.82
1989	-	76.1	0.10	1.68	0.11	1.93
1990	-	90.1	0.12	1.80	0.14	2.06
1991	-	55.3	0.07	1.87	0.08	2.14
1992	-	44.6	0.06	1.92	0.06	2.21
1993	4.80	381.9	16.21	18.13	18.59	20.80
1994	10.50	75.2	0.09	18.22	0.11	20.91
1995	4.30	127.3	0.23	18.45	0.26	21.16
1996	0.10	90.2	0.12	18.57	0.14	21.30
1997	0.21	91.4	0.12	18.69	0.14	21.44
1998	-0.11	119.0	0.20	18.89	0.22	21.67
1999	0.66	172.6	0.48	19.37	0.55	22.22
2000	0.26	186.7	0.61	19.98	0.70	22.92
	22.92 /*			19.98		22.92

/* Actual sediment deposition as of 2000

Table 3.2.21 Estimated Average Annual Sediment Load from Kulekhani Reservoir Basin

Return Period	Probable Rainfall (mm)	Sediment Load ($10^6 m^3$/yr.)	Excessive Probability	Frequency	Average Sediment Load ($10^6 m^3$/yr.)	Average Annual Sediment Load ($10^6 m^3$/yr.)	Cumulative Annual Sediment Load ($10^6 m^3$/yr.)
2	107	0.18	0.5000	-	-	-	-
5	162	0.46	0.2000	0.3000	0.32	0.10	0.10
10	207	0.98	0.1000	0.1000	0.72	0.07	0.17
20	258	2.32	0.0500	0.0500	1.65	0.08	0.25
30	291	4.04	0.0333	0.0167	3.18	0.05	0.31
40	317	6.25	0.0250	0.0083	5.14	0.04	0.35
50	337	8.74	0.0200	0.0050	7.50	0.04	0.39
60	355	11.83	0.0167	0.0033	10.29	0.03	0.42
70	370	15.22	0.0143	0.0024	13.53	0.03	0.45
80	384	19.26	0.0125	0.0018	17.24	0.03	0.48
90	396	23.56	0.0111	0.0014	21.41	0.03	0.51
100	408	28.82	0.0100	0.0011	26.19	0.03	0.54

Table 3.3.1 Rating for the Six Q System Parameters

	1. Rock Quality Designation	RQD
A	Very poor	0 - 25
B	Poor	25 - 50
C	Fair	50 - 75
D	Good	75 - 90
E	Excellent	90 - 100
Note: (i) Where RQD is reported or measured as $\leq$ 10(including 0), a nominal value of 10 is used to evaluate Q. (ii) RQD intervals of 5, i.e. 100, 95, 90 etc. are sufficiently accurate.		

	2. Joint Set Number	Jn
A	Massive, no or few joints	0.5 - 1.0
B	One joint set	2
C	One joint set plus randam joints	3
D	Two joint sets	4
E	Two joint sets plus randam joints	6
F	Three joint sets	9
G	Three joint sets plus randam joints	12
H	Four or more joint sets, random, heavily jointed,"sugar cube", etc	15
J	Crushed rock, earthlike	20
Note: (i) For instance, use (3.0 x Jn) (ii) For portals, use (2.0 x Jn)		

	3. Joint Roundness Number	Jr
a) Rock wall contact, and b) Rock wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
c) No rock-wall contact when sheared		
Note: (i) Descriptions refer to small scale features and intermediate scale features, in that order.		
H	Zone containing clay minerals thick enough to prevent rock wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1.0
Note: (i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m. (ii) Jr = 0.5 can be used for planar slickensided joints having linearions, provided the lineations are orientated for minimum strength.		

	4. Joint Alteration Number	Φr (approx.)	Ja
(a) Rock wall contact (no mineral fillings, only coatings)			
A	Tightly healed, hard, non-softening, Impermeable filling, I.e. quartz or epidote		0.75
B	Unaltered joint walls, surface staining only	25 to 35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock etc.	25 to 30°	2.0
D	Silty-, or sandy-clay coatings, small clay fraction (non-softening)	20 to 25°	3.0
E	Softening or low friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1-2 mm or less in thickness)	8 to 16°	4.0
(b) Rock wall contact before 10 cm shear (thin mineral fillings)			
F	Sandy particles, clay-free disintegrated rock, etc.	25 to 30°	4.0
G	Strangely over-consolidated, non-softening caly mineral fillings (continuous, but <5mm in thickness)	16 to 24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm in thickness)	12 to 16°	8.0
J	Swelling-clay filling, i.e., montmorillonite (continuous, but <5mm in thickness). Value of Ja depends on percent of swelling clay-size particles, and access to water etc.	6 to 12°	8.0 to 12.0
(c) No rock wall contact when sheared (thickness mineral fillings)			
KL M	Zones or bands of disintergarated or crushed rock and clay (see G.H. J for description of clay condition)	6 to 24°	6.0, 8.0 or 8.0 to 12.0
N	Zones or bands of silty or sandy clay, small clay fraction (non-softening)	-	5.0
OP R	Thick, continuous zones or bands of clay (see G,H,J for description of clay condition)	8 to 24°	10.0,13.0 or 13.0 to 20.0

Note (i) Values of (ϕ) γ are intended as an approximate guide to the mineralogical properties of the alteration products, if present.

	5. Joint Water Reduction Factor	Approx. Water pressure(kg/cm2)	Jw
A	Dry excavation or minor inflow, i.e. 5l/min locally	<1.0	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	1.0 to 2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	2.5 to 10.0	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	2.5 to 10.0	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	>10.0	0.2 to 0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	>10.0	0.1 to 0.05
Note: (i) Factors C to F are crude estimates. Increase Jw if drainngs measures are installed (ii) Special problems caused by ice formation are not considered.			

	6. Stress Reduction Factor	SRF
a) Weakness zones intersting excavation, which may causes loosening of rock mas when tunnel is excavated.		
A	Multiple occurrences of weakness zones containing clay or chemically distintigrated rock, very loose surrounding rock. (any depth)	10.0
B	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation $\leq$ 50m))	5.0
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50m))	2.5
D	Multiple shear zones in competent rock (clay-free) loose surrounding rock (any depth)	7.5
E	Single shear zones in competent rock (clay-free), (depth of excavation $\leq$ 50m))	5.0
F	Single shear zones in competent rock (clay-free), (depth of excavation > 50m)	2.5
G	Loose, open joints, heavily jointed or "sugar cube", etc. (any depth)	5.0
Note: (i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.		

	b) Competent rock, rock stress problems	σ_c/σ_1	σ_t/σ_1	SRF
H	Low stress, near surface, open joints	>200	>13	2.5
J	Medium stress, favorable stress condition	200 to 10	13 to 0.66	1.0
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability.	10 to 5	0.66 to 0.33	0.5 to 2.0
L	Moderately stabbing alter > 1 hour in massive rock	5 to 2.5	0.33 to 0.16	5.0 to 10.0
M	Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock	<2.5	<0.16	10.0 to 20.0

Note: (i) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$ reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When $\sigma_1/\sigma_3 > 10$ reduce σ_c, σt to $0.6\sigma c$, $0.6\sigma_t$ respectively. Where: σ_c = unconfined compression strength、σ_t = tensile strength (point load), σ_1 and σ_3=major and minor principal stress (estimated from elastic theory).
(ii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H).

	c) Squeezing rock : plastic flow of incomptetent rock under the influence of high rock pressure	SRF
N	Mild squeezing rock pressure	5.0 to 10.0
O	Heavy squeezing rock pressure	10.0 to 20.0
Note: (iv) Cases of squeezing rock may occur for depth $H>350.0^{1.3}$ (Singh et al., 1992). Rock mass compression strength can be estimated from $Q=0.7\gamma Q^{1/3}$(MPa) where γ = rock density in kN/m^2 (Singh, 1993)		
d) Swelling rock: chemical selling activity depending on presence of water		
P	Mild swelling rock pressure	5.0 to 10.0
R	Heavy swelling rock pressure	10.0 to 15.0

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Table 3.6.1 Results of Sieve Analysis

Coarse Aggregate

Sieve Mesh (m/m)	Site	100	80	60	50	40	30	25	20	15	10	5	PAN
Accumulation Retained (%)	Churiya A	7.7	14.2	20.2	23.6	33.5	42.0	49.8	55.9	59.2	66.5	73.5	100.0
	Churiya B	8.0	9.1	28.1	29.2	38.4	44.9	51.0	55.6	58.8	66.0	75.1	100.0
	KL-I Power House A	16.2	18.2	19.9	26.2	31.7	37.4	43.6	52.2	61.5	73.8	85.8	100.0
	KL-I Power House B	8.5	18.7	20.0	27.6	33.9	40.2	47.8	60.3	67.5	81.4	91.4	100.0
	Ratomate	0.0	15.0	17.8	23.3	28.8	32.2	37.0	44.5	49.9	69.0	85.1	100.0
	Bhimphedi	0.0	6.4	12.7	23.1	26.9	29.9	36.9	45.0	50.5	61.0	70.8	100.0

Fine Aggregate

Sieve Mesh (m/m)	Site	10	5	2.5	1.2	0.6	0.3	0.15	PAN
Accumulation Retained (%)	Churiya A	-	4.2	21.0	40.2	58.0	73.4	99.0	100
	Churiya B	-	5.4	19.2	35.8	54.6	72.0	91.0	100
	KL-I Power House A	-	3.2	24.2	38.6	42.4	44.0	50.0	100
	KL-I Power House B	-	10.4	54.6	67.6	72.4	74.6	77.4	100
	Ratomate	-	11.0	21.0	35.0	59.0	80.8	94.6	100
	Bhimphedi	-	4.0	27.4	58.4	72.0	77.6	84.4	100