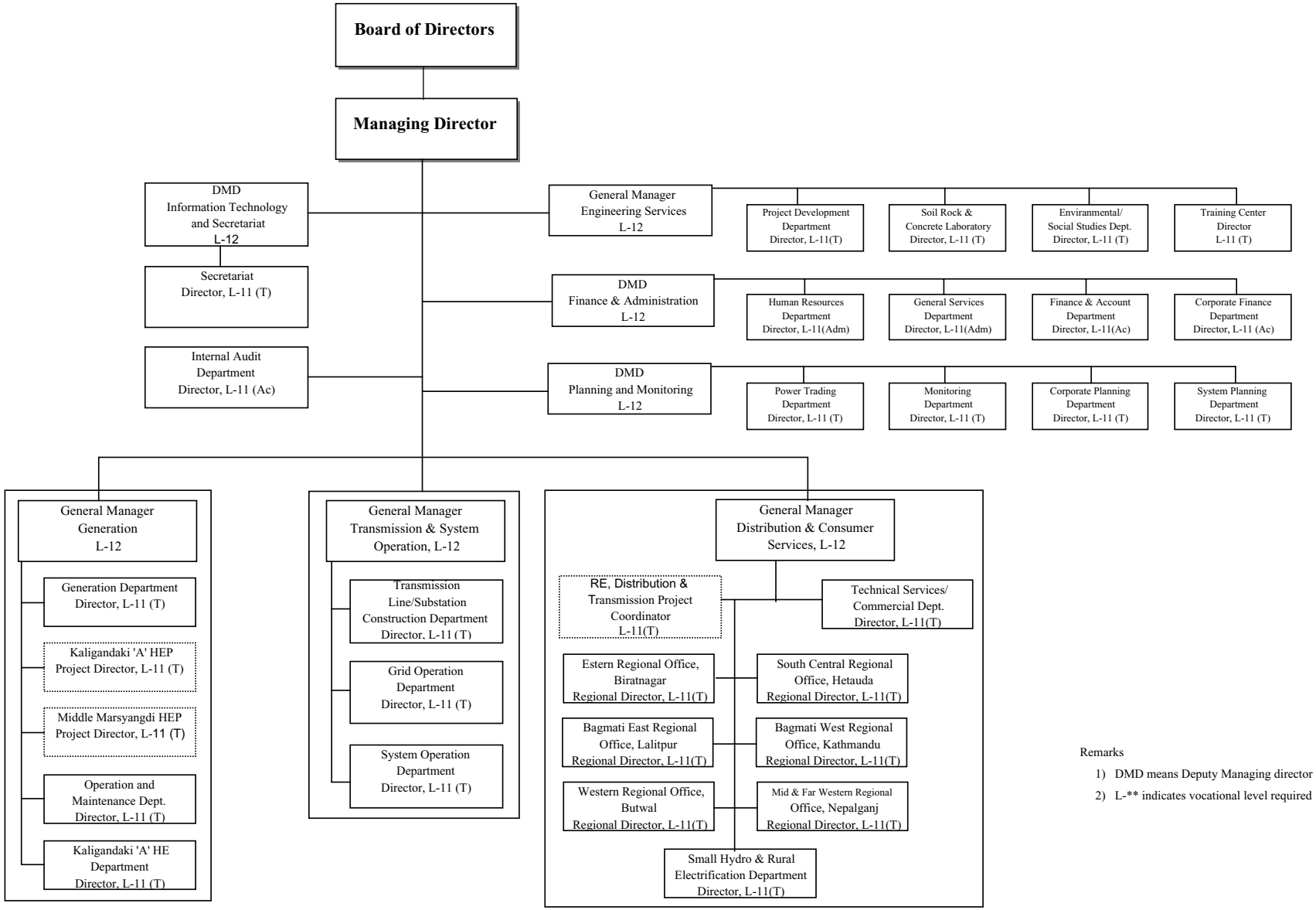
FIGURES

Chapter 5



Remarks

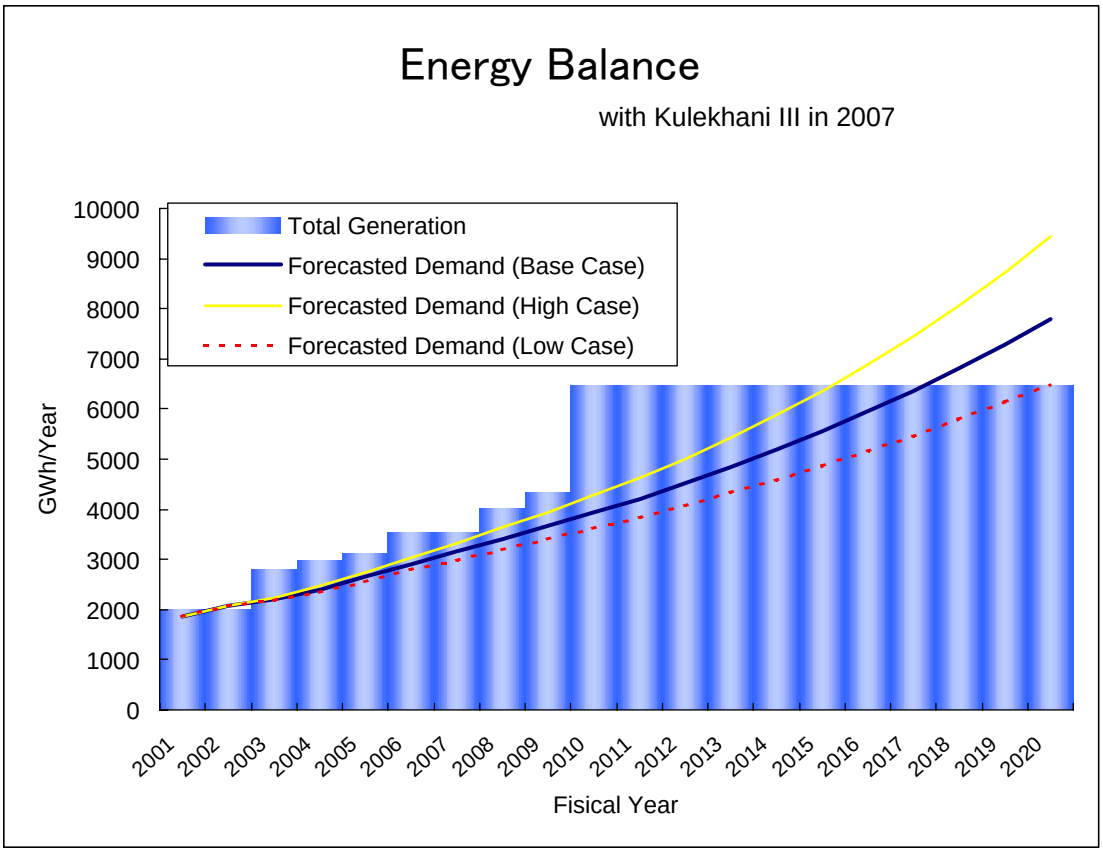
1) DMD means Deputy Managing director
2) L-** indicates vocational level required

Figure 5.1.1 Organization of NEA

Figure 5.2.1
Nepal National Grid

THE UPGRADING FEASIBILITY STUDY ON THE DEVELOPMENT OF THE KULEKHANI III HYDROPOWER PROJECT IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



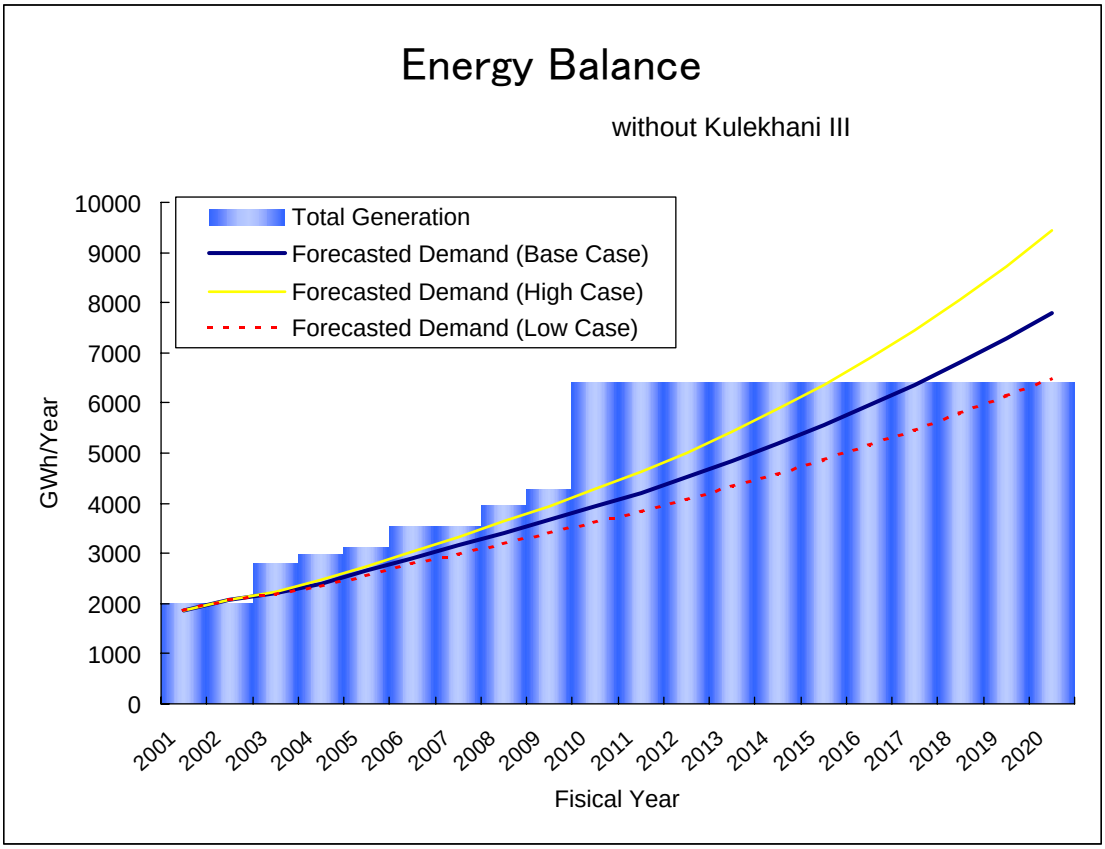
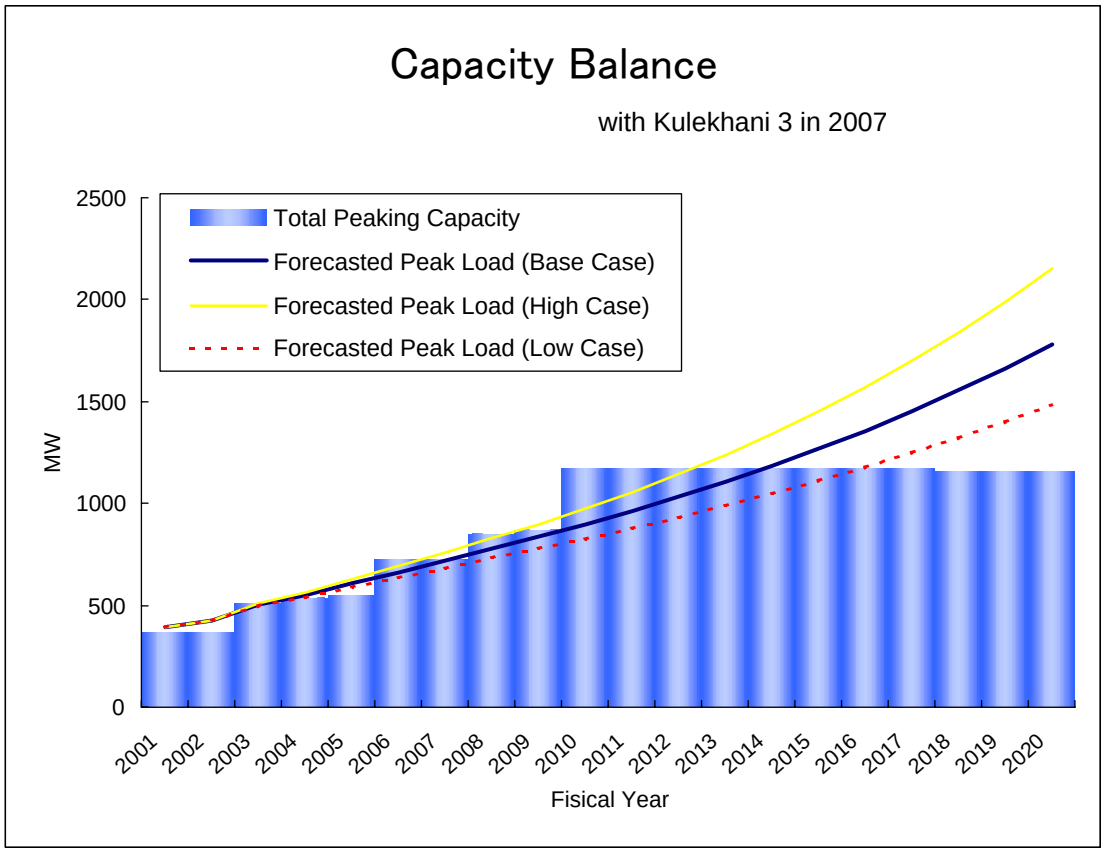


Figure 5.3.1 Energy Balance



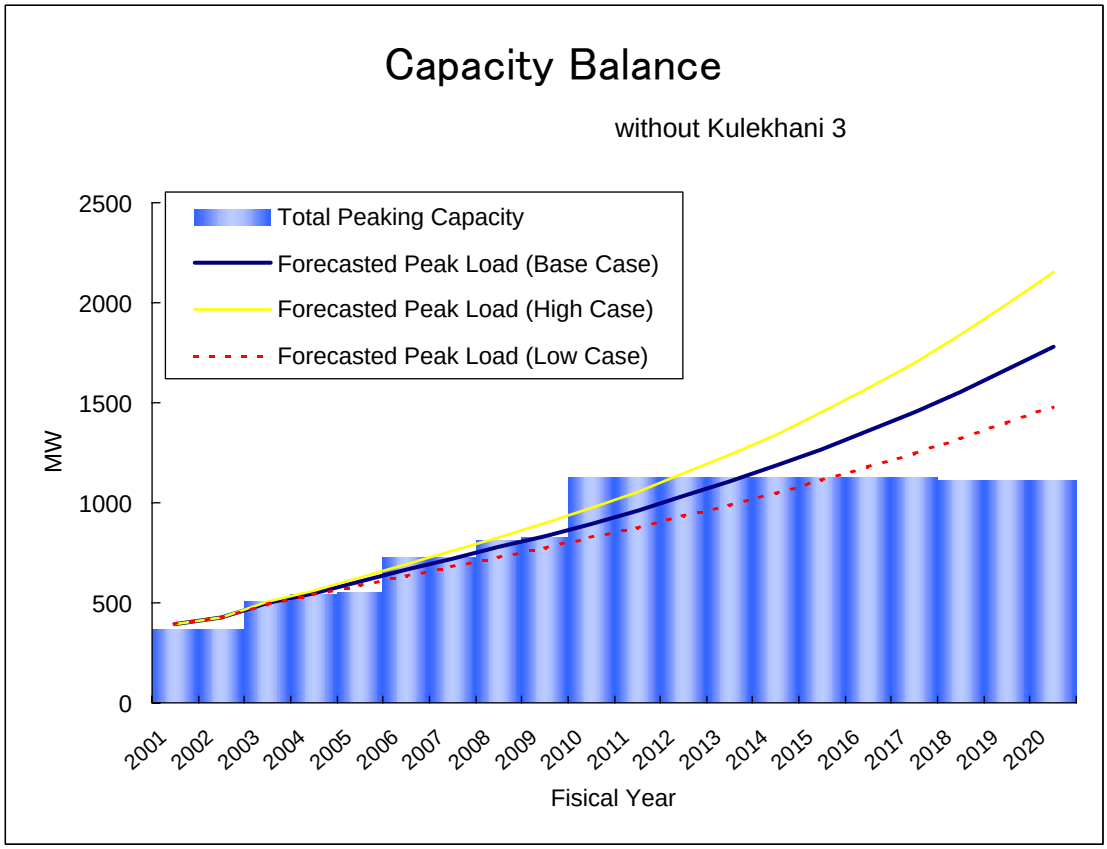
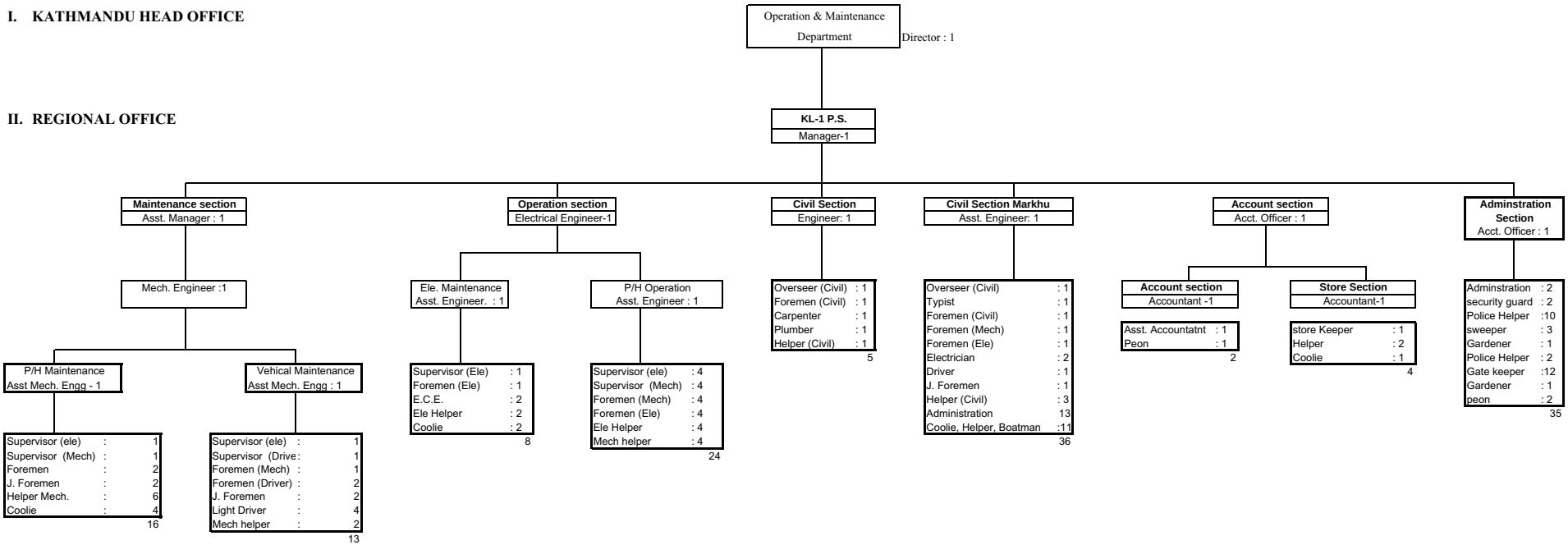


Figure 5.3.2 Capacity Balance

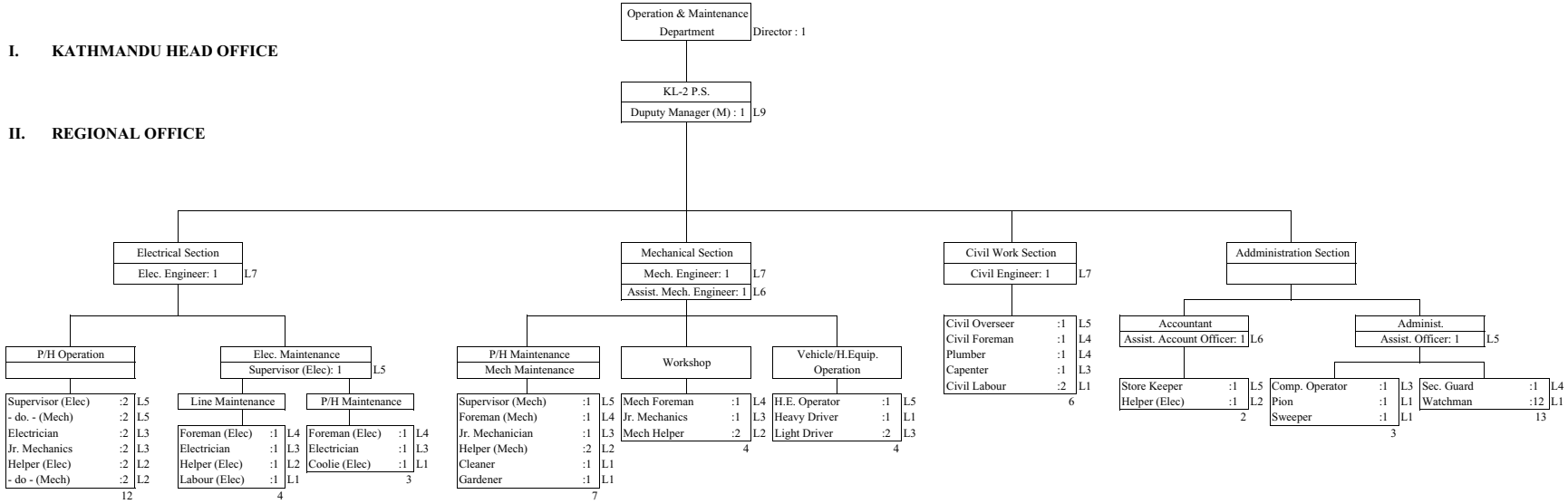


Note:
1. Parts and materials are kept at each P/S.
2. 2-days rotation in operation shift.
3. Total number of personnel: 151

Figure 5.5.1 Organization Chart for Kulekhani-I Power Station

I. KATHMANDU HEAD OFFICE

II. REGIONAL OFFICE



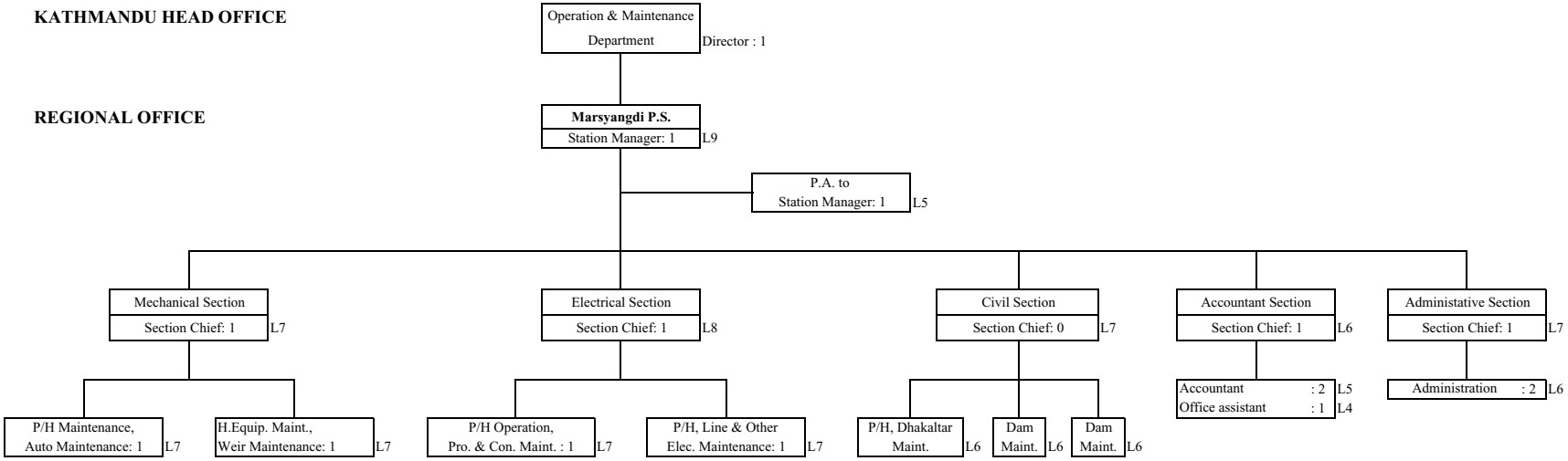
:

Note:
1. Parts and materials are kept at each P/S.
2. 2-days rotation in operation shift.
3. Total number of personnel: 66

Figure 5.5.2 Organization Chart for Kulekhani-II Power Station

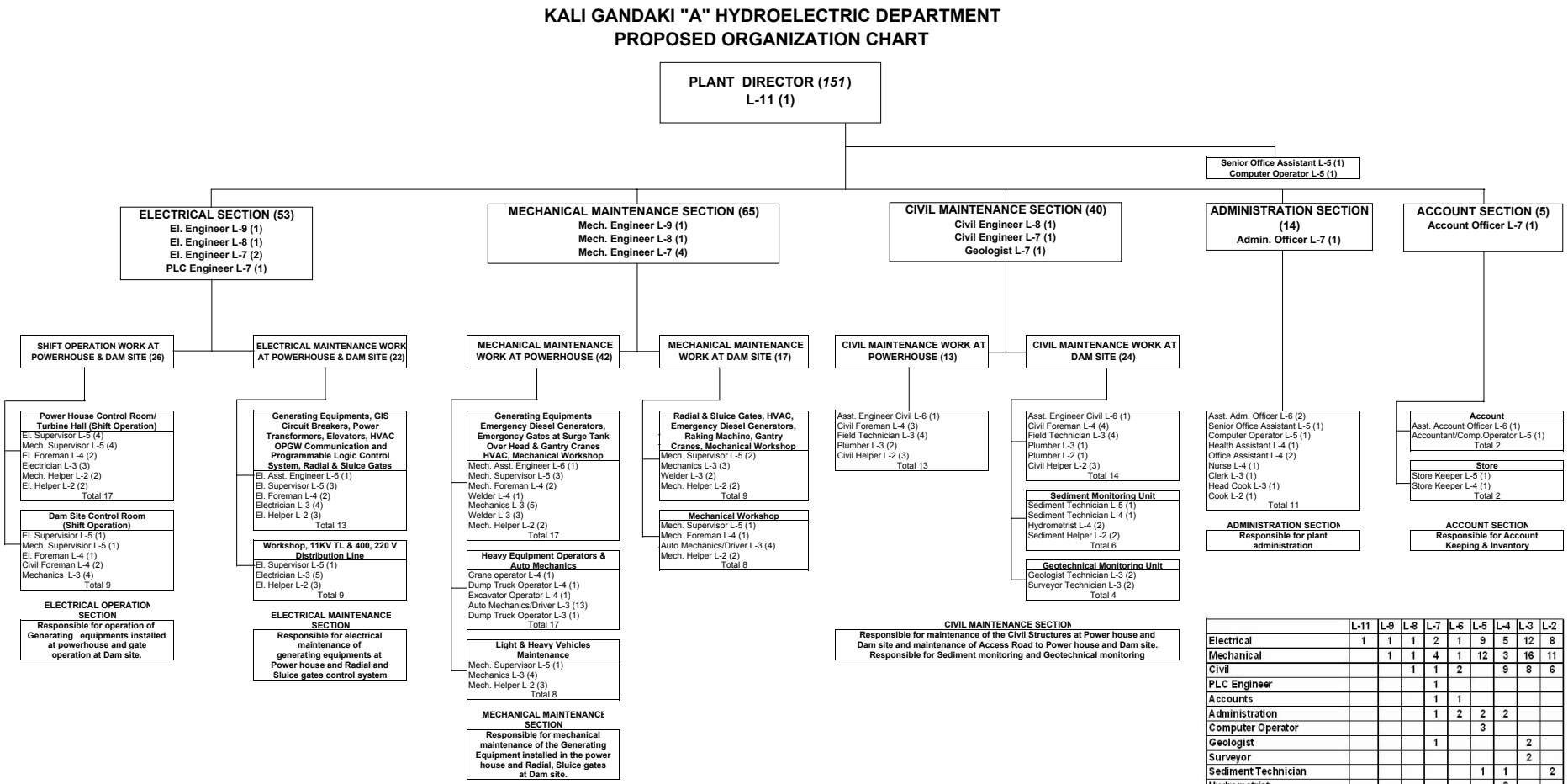
I. KATHMANDU HEAD OFFICE

II. REGIONAL OFFICE



Note:
1. Parts and materials are kept at each P/S.
2. 2-days rotation in operation shift.
3. Total number of personnel: 111

Figure 5.5.3 Organization Chart for Marsyangdi Power Station



	L-11	L-9	L-8	L-7	L-6	L-5	L-4	L-3	L-2
Electrical	1	1	1	2	1	9	5	12	8
Mechanical		1	1	4	1	12	3	16	11
Civil			1	1	2		9	8	6
PLC Engineer				1					
Accounts				1	1				
Administration				1	2	2	2		
Computer Operator						3			
Geologist				1				2	
Surveyor								2	
Sediment Technician						1	1		2
Hydrometrist							2		
Auto Mechanics								17	
Welder							1	5	
Store Keeper						1	1		
Health Assistant							1		
Nurse							1		
Dump Truck Operator							1	1	
Crane Operator							1		
Excavator Operator							1		
Plumber								3	1
Clerk								1	
Cook								1	1
Total - 178	1	2	3	11	7	28	29	68	29

Note: Out of proposed 96 new applicants only 69 new applicants were approved by NEA board meeting on14 Sept., 2002 to hire in daily wage. So total number of the proposed staff is 151. (Level 5-13, Level 4-16, Level 4-36 and Level 2-4, totaling 69)

Figure 5.5.4 Organization Chart for Kali Gandaki A Power Station

Chapter 6

CHAPTER 6 OPTIMUM DEVELOPMENT PLAN

6.1 General

The study on the optimum development plan of the Kulekhani III Hydropower Project consists of:

1) A study of the adequacy of the development of the Kulekhani III Hydropower Project for the integrated power system in Nepal, and
2) A study on optimum layout
3) Optimization of Installed Capacity
4) Optimum Input Timing of the Kulekhani III Hydropower Project

The 42 MW scheme was proposed by NEA to cope with a deficiency in the peak power supply in the evenings during the dry season. The proposal was made in the "Updated Feasibility Study Report for 42 MW Option", prepared in September 1999. The purpose of the study on the adequacy of the development of the Project is to examine the possibility of power supply by the 42 MW scheme, taking into account the power demand forecast, the daily load, the development plan of the power supply system and the type of power supply source.

Based on the results of review of the existing feasibility study reports on the Kulekhani III Hydropower Project, promising alternatives for the optimum development plan are selected. In addition, these alternatives are taken into consideration about 1) measures against sedimentation of the Yangran regulating pond and a potential landslide area on the right bank of the regulating pond, 2) the construction of an underground powerhouse in the sound rock and 3) the construction of a tailrace crossing the Main Boundary Thrust (MBT). The optimum layout is determined through the comparing the alternatives from the economical and technical viewpoints.

The optimum installed capacity of the powerhouse is examined on the optimum layout mentioned above. Economical comparison with alternative thermal plants is carried out on three plant capacities, which have different peaking operation time. In this study, available discharge for the Kulekhani III hydropower Project is based on the results of the simulation study on the optimum operation of the Kulekhani Reservoir (refer to Chapter 7).

Finally, optimum input timing of Kulekhani III Hydropower Project is examined to minimize the capital cost and operation and maintenance cost of the whole Nepal electric system without inconvenience. Taking into consideration about conceivable candidate power plants, this analysis is carried out by using software package, "WASP III", which is owned by NEA. In addition, the results are checked by using EGEAS (Electric Generation Expansion Analysis System), which is developed by Massachusetts Institute of Technology (MIT) and Electric Power Research Institute (EPRI) in the United States.

6.2 Adequacy of the Development of the Kulekhani III Hydropower Project

6.2.1 General

The Kulekhani III Hydropower Project is the final power development plan in the Kulekhani series. The Kulekhani I power station has been operated since 1983 and the Kulekhani II power station has been operated since 1987. They were proposed as a cascade power development in an overall development study on the Kulekhani River in 1963. The Kulekhani I hydropower station is the only one in Nepal that has a reservoir for seasonal regulation (effective water storage volume of 73.3 million m^3). Although the Kulekhani II hydropower station is a run-of-river power station, it has been operating as a peak power station, supplying peak demand in the dry season by using the discharge from the Kulekhani I hydropower station.

Other power stations include the Marshyangdi hydropower station (69MW), which started in 1989, the Jhimruk hydropower station (IPP: 12.3 MW) in 1994, the Khimti Khola hydropower station (60MW) and the Upper Botekoshi hydropower station (36 MW) in 2000, all being middle scale run-of-river plants or peaking run-of-river plants. In addition there are other small-scale run-of-river plants, such as the Andi Khola hydropower station (5.1 MW) and the Ilam hydropower station (6.2 MW). The total installed capacity of electric power supply facilities in Nepal amounts to 585.0 MW (FY 2000/01). However, run-of-river type hydropower stations (436MW including peaking run-of-river power stations) account for 74% of the total installed capacity, and the total peak power output in the dry season falls to 286MW due to the reduced river flow. Although diesel power stations are added to the power supply system, the total peak power capacity is only 312 MW. To meet the peak load of 384 MW in the dry season, NEA is obliged to import electricity from India and carry out load shedding. It is estimated that the shortfall in peak power in the dry season will reach between 50 MW and 100 MW in the near future.

NEA plans to develop hydropower stations totaling 383 MW, including Kali Gandaki A (144 MW) and Middle Marsyangdi (70 MW), by 2007 (refer to Section 5.2.4). However, there will still be a peak power shortfall in the dry season in the latter half of the 2000s since the planned hydropower stations are run-of-river or peaking run-of-river power stations, with the exception of Kulekhani III hydropower station.

As mentioned above, all hydropower stations constructed in Nepal since the construction of Kulekhani I and II hydropower stations are run-of-river or peaking run-of-river power stations. However, there is a need for reservoir type power stations to cope with the increase in power demand in the evenings during the dry season. Therefore, NEA proposed the Kulekhani III hydropower station as a peak power station with an installed capacity of 42 MW in the Updated Feasibility

Study in order to meet the expected peak power shortfall in the second half of the 2000s. It is planned to utilize the discharge from Kulekhani I and II hydropower stations to supply electric power from 5 pm to 9 pm in the dry season.

The purpose of this study is to look at the role of the Kulekhani III power station in the overall power system, taking into account power demand forecast, daily load, and the power expansion plans of NEA.

6.2.2 Daily Load Curve

The daily load curve on January 18, 2001 and the allocation of each power station for power supply are shown in Figure 6.2.1. Points of interest include:

- Peak load reached 390MW from 5 pm to 9 pm, and load shedding of 16 MW was executed during the peak time.
- Run-of-river hydropower stations were allocated to base load.
- The Marsyangdi hydropower station, the Kulekhani I and II hydropower stations and the power imported from India supplied peak and off-peak power.
- The peak power in the morning was supplied by the Kulekhani I and II power stations. The peak power demand from 5 pm to 9 pm was covered by the Marsyangdi hydropower station, the Kulekhani I and II hydropower stations, the power imported from India, and diesel power stations.

Khimti Kohla (60 MW), the Upper Bhotekoshi (36 MW) and the Modi Kohla hydropower stations operating from 2000 contribute to the peak power supply. The load shedding of 16 MW in the dry season of 2001 was less than the load shedding of 65 MW for 350 MW of maximum peak load recorded on January 7, 2001.

According to the power demand forecast carried out in the First Field Investigation, the power demand grows at an annual rate of around 8%. It will reach 491 MW in 2003, 593 MW in 2005, 762 MW in 2008 and 878 MW in 2010 as shown below.

Fiscal Year	Power Demand (MW)	Energy Demand (GWh)
2001	391	1,868
2002	426	2,088
2003	502	2,198
2004	549	2,406
2005	606	2,652
2006	664	2,907
2007	720	3,154
2008	778	3,407
2009	835	3,659
2010	897	3,927

6.2.3 Adequacy of Input of the Kulekhani III Hydropower Project

According to the latest power development plan prepared in December 2001, NEA expects to bring on line the Middle Marsyangdi (70 MW), the Chilime (IPP: 20 MW), the Indrawati (IPP: 7.5 MW), the Piluwa (IPP: 3 MW), the Upper Modhi (IPP: 14 MW) hydropower stations and six other run-of-river or peaking run-of-river hydropower stations (total 15.5 MW) by 2006, having concluded an IPP contract. In addition, the Kali Gandaki A hydropower station (144 MW) was commissioned at the beginning of 2002 (refer to Section 5.2.4).

The Kulekhani III hydropower station is planned to come on line along with the Langtang hydropower station (10 MW) of IPP, the Chamelia hydropower station (30 MW) and the Khimti Khola II hydropower station (27 MW) in 2007. The Project is formulated as a four hours peak power station to cope with peak power demand in the dry season by utilizing the Kulekhani reservoir, which has seasonal regulating capacity, and the Yangran regulating pond, which has daily regulating capacity.

The adequacy of the input of the Kulekhani III hydropower station to the power supply in 2007 is studied in consideration of the power demand forecast carried out in Chapter 5 and the NEA power development plan mentioned above. The conditions of the study are as follows:

(1) The results of power demand forecast shown in Table 5.3.7 are used as peak demand.

(2) The existing generating facilities connected with the national grid system are as shown in Table 5.2.1.

(3) The input power supply facilities after 2002 refer to NEA's power development plan prepared in December 2001 as explained above and outlined in the table below. It is assumed that new power stations will start service from the year following commissioning.

Fiscal Year	Project	Installed Capcity (MW)	Remarks
2002	Kali Gandaki A	144.00	Commissioned in March 2002
	Syange	0.10	IPP, Signed PPA
2003	Chilime	20.00	IPP, Under construction
	Indrawati	7.50	IPP, Under construction
	Daram Khola	5.00	IPP, Signed PPA
	Piluwa Khola	3.00	IPP, Under construction
	Chaku Khola	0.91	IPP, Signed PPA
2004	Pheme	0.95	IPP, Signed PPA
	Upper Modi	14.00	IPP, Under construction
	Khudi	3.50	IPP, Signed PPA
2005	Mailung	5.00	IPP, Signed PPA
	Middle Marsyangdi	70.00	NEA, Under construction
2006	-	-	-
2007	Langtang	10.00	IPP, Signed PPA
	Chamelia	30.00	NEA, Under planning
	Kulekhani III	42.00	NEA, Under planning
	Khimiti 2	27.00	NEA, JV

(4) The Kulekhani III hydropower station is assumed to be completed in 2007 and to start power supply from FY2008.

(5) The daily peak load curve in FY2008 is based on that for January 18, 2001.

(6) The input of each power station for the daily load is as follows:

- First, run-of-river power stations are input for base load.
- The Kali Gandaki A, Marsyangdi and Middle Marsyangdi hydropower stations are input next. It is assumed that they are operated during peak time from 5 pm to 10 pm and off-peak time.
- It is assumed that the Kulekhani I and II power stations are operated during peak time from 6 am to 9 am and from 5 pm to 10 pm and off-peak time.
- Electric power imported from India is assumed to be 150 MW at a maximum, to make up for any shortfall in base power supply. However, the import from India is to be minimized by utilizing the hydroelectric power stations in Nepal as much as possible.
- The generated power of the Kulekhani III hydropower station is allocated for the shortfall of peak power from 5 pm to 10 pm.
- Any remaining shortfall will be made up using diesel power generators.

Based on the above conditions, each power station was allocated to the daily load curve for the dry season in FY2008 (peak demand 762MW). As a result of the study, a shortfall in the peak power supply between 5 pm and 9 pm was identified, indicating that the input of the Kulekhani III hydropower station is needed in FY 2007. The results of study are shown in Figure 6.2.2.

6.3 Optimum Development Plan

6.3.1 General

As for the development of the Kulekhani III Hydropower Project, six feasibility study reports have been issued in the past. The alternatives for optimum layout of the Project are selected by reviewing the existing feasibility study reports from both technical and economic viewpoints. The alternatives for the layout of the main structures are proposed by taking account of the countermeasures for sedimentation and potential landslide in the regulating pond, and the geological conditions in the underground powerhouse cavern and the tailrace tunnel crossing MBT. The optimum layout is determined through the comparison of these alternatives.

Subsequently, the development scale is examined on the optimum layout mentioned above. Alternatives for the development scale are set by varying the peak operation time. The optimum development scale is determined through the economical comparison study with alternative thermal plant.

6.3.2 Review of Existing Feasibility Study Report

NEA recommended the 42 MW plan with underground power station in the Updated Feasibility Study Report in September 1999. In this report, the Kulekhani III Hydropower Project is planned as follows:

- The outflow from the Kulekhani II hydropower station will be stored in a regulating pond to be constructed on the Yangran River, with an effective storage capacity of 500,000 m^3.

- The peak power output of 42 MW will be generated by utilizing the maximum plant discharge of 40.14 m^3/sec and an effective head of about 120 m.

In addition, other five alternatives were proposed in the existing feasibility studies. Since the 42 MW plan in NEA's report in September 1999 was not compared with the other alternatives, each plan is reviewed here from both technical and economic viewpoints, based on the available data. The installed capacity, type of generating and type of the powerhouse for each of the 6 plans are shown below.

Alt. No.	Date of submission	Development scale	Report	Type of Generation	Type of Powerhouse	Executing Agency
1	May 1988	54 MW	Feasibility Study Report	Pondage	Surface	Nippon Koei
2	Mar. 1993	38 MW	Updated Study	Pondage	Surface	NEA
3	Jul. 1997	14 MW	Detailed Design Report	Run-of-river	Surface	NEA
4	Jul. 1998	16 MW	Supplementary Engineering Study Report	Run-of-river	Underground	NEA
5	Apr. 1999	48 MW	Kulekhani-III Hydroelectric Project	Pondage	Underground	NEA
6	Sep. 1999	42 MW	Updated Feasibility Study Report	Pondage	Underground	NEA

(1) Review of Technical Aspects for Each Alternatives

The main features and technical issues for the six alternatives proposed in the existing reports are shown in Table 6.3.1 and Table 6.3.2 respectively. In addition, the layout of structures for each plan is shown in Figure 6.3.1. The outline and technical issues of each alternative are explained below.

1) Alternative-1：54 MW Plan

Outline of Alternative-1

- The maximum discharge of 5.0 m^3/sec is taken from the Rapti headwork constructed at Bhainsedobhan, in addition to the maximum discharge of 13.3 m^3/sec from the Kulekhani II power station.
- The water is conveyed by gravity flow to the Yangran regulating pond (effective storage capacity 602,500 m^3) through a 3,400 m long connection tunnel.
- Alternative-1 is a regulating pond type power station that generates a power output of 54 MW for three hours peak time by utilizing the maximum plant discharge of 60.97 m^3/sec and effective head of 100.6 m. The surface type power station would be constructed at the confluence of the Rapti River and the Kesadi River.

Technical Examination

- There are no problems with technical aspects of the design of the tunnel and the powerhouse.
- The influence of the 1993 flood is not considered in this design since the study was carried out in 1988. It appears that the riverbank in the planned area of the Rapti headwork was eroded due to debris flow following the 1993 flood.
- Site reconnaissance of the riverbed observed deposited boulders as well as large and small gravel.

- If the Rapti headwork were to be constructed according to the original design, there is a strong possibility of damage to the intake structure similar to that at the Mandu headwork of the Kulekhnai II power station, due to debris flow and sedimentation. Therefore, the construction of check dams is required upstream of the Rapti headwork and dredging work is required to recover check dam function.

2) Alternative -2：38 MW Plan

Outline of Alternative-2

- The design concept of Alternative-2 is the same as Alternative-1 (54 MW), but it is modified as a 38 MW installed capacity for 4 hours peak time.

Technical Examination

- This plan does not consider the 1993 flood, similar to the 54 MW plan, and measures against sedimentation and debris flow are required.

3) Alternative-3：14 MW Plan

Outline of Alternative-3

- Considering the influence of the 1993 flood, Alternative-3 cancels the construction of the Yangran regulating pond and the intake from the Rapti River.
- This plan adds 0.2 m^3/sec taken from the Rapti pump intake facility to intake from the Mandu River and to the design discharge of the Kulekhani II power station. The maximum discharge of 1.5 m^3/sec is taken from the Khani headwork using a check dam constructed upstream of the Kulekhani II power station.
- Alternative-3 is planned as a run-of-river scheme. Water is directly conveyed to the surface type power station, which is constructed at the confluence of the Rapti River and the Kesadi River, through a 4,337m long pressure tunnel. Alternative-3 has a power output of 14 MW, utilizing the maximum plant discharge of 15 m^3/sec and an effective head of 103.45 m.

Technical Examination

- The maximum plant discharge of Alternative-3 is set at 15.0 m^3/sec by adding the maximum intake discharge of 1.5 m^3/sec taken from the Khani headwork to the 13.5 m^3/sec from the Kulekhani II power station. However, the 1.5 m^3/sec cannot be taken in the dry season due to low river flow.
- The lining of the pressure tunnel is shotcrete for the whole length. The designed effective head is not available due to large friction losses in the shotcrete lining section and the actual output of Alternative-3 is decreased to 11 MW.

- The use of shotcrete lining was proposed to decrease the construction cost of the pressure tunnel. However, concrete lining should be used to ensure the stability of the pressure tunnel in the 1800 m section where the Q value is less than 4.

4) Alternative-4：16 MW Plan

Outline of Alternative-4

- Alternative-4 is planned as a run-of-river scheme that is not accompanied by construction of the Yangran regulating pond, similar to Alternative 3 (14 MW).
- The water from the Kulekhani II power station and the Khani headwork is directly conveyed to the underground power station through a 3,883m long pressure tunnel.
- The discharge from the power station flows into the Rapti River through a tailrace tunnel.
- The power output of 16 MW is planned by utilizing 15 m^3/sec of maximum plant discharge and 123m of effective head.

Technical Examination

- Two types of lining system are used in the headrace tunnel of Alternative-4. One is concrete lining and another is shotcrete lining. Where the Q value is greater than 4 for the whole section, shotcrete is used. In the tailrace tunnel sections where the Q value is less than 4, joints may develop in the rock mass, especially the Slaty Phyllite sections. Some of the joints may be filled with erodible material such as clay, and if the external water pressure is high, there is a possibility that the material will be washed out and the rock mass may become unstable. Concrete lining should be used for the whole of the tailrace tunnel to ensure stability of the tunnel. In addition, it will be necessary to study the stability of the section of the excavated tailrace tunnel crossing the Main Boundary Thrust fault.
- A drop shaft having a head of 100 m connects the headrace tunnel and the underground powerhouse. Although high pressure is acts on the lining, it is designed using concrete lining instead of a steel liner in order to decrease construction cost. In this case, it is necessary to conduct studies on hydro jacking[1)] and hydro fracturing[2)] caused by leakage of high pressure water. In addition, the possibility of excessive leakage from the tunnel should be examined.

  It is also necessary to examine changes in the in-situ stress condition due to excavation of the underground powerhouse cavern, the permeability of the

1) Hydro jacking is a phenomenon in which cracks are widened by internal water pressure acting along crack surfaces when internal water pressure is beyond in-situ compressive stress in the direction perpendicular to the crack surface.
2) Hydro fracturing is a phenomenon in which rock is broken by tensile stress induced in the rock when tensile stress caused by internal water pressure acting on the tunnel surface is beyond the tensile strength of the rock.

rock and the groundwater level since the powerhouse cavern is to be constructed near the drop shaft.

- Rock bolts and 15 cm thick shotcrete are to be used as the supporting system for the underground power station cavern. However, the appropriateness of this support system has not been studied.

5) Alternative-5：48MW Plan

Outline of Alternative-5

- Alternative-5 is planned as a four hours peak power station using the Yangran regulating pond (effective storage capacity 602,500 m^3), similar to Alternative –1 (54 MW) and Alternative-2 (38 MW).
- The water is taken from the Rapti headwork proposed in Alternative-1 (54 MW) and Alterative-2 (38 MW) and the Khani headwork proposed in Altrenative-3 (14 MW) and Alternative-4 (16 MW) in addition to the outflow (13.3 m^3/sec) from the Kulekhani II power station.
- The water is conveyed to a regulating pond by gravity flow through a 3,400 m long connection tunnel.
- The powerhouse is an underground type. The discharge from the powerhouse is conveyed to the Rapti River through a 2,100 m long tailrace tunnel.
- The power output of 48 MW is planned by using the maximum plant discharge of 45.54 m^3/sec and 120 m of effective head.

Technical Examination

- Countermeasures against sedimentation and debris flow for the Rapti headwork may need to be considered, as mentioned in Alternative-1 (54 MW). The stability of the underground powerhouse cavern and the stability of the tailrace tunnel where it crosses the MBT fault should also be examined, as mentioned in Alternative-4 (16 MW).

6) Alternative-6：42 MW Plan

Outline of 42 MW Plan

- Alternative-6 is planned as a four hour peak power station using the Yangran regulating pond, similar to Alternative-5 (48 MW). The effective storage capacity of the regulating pond is 500,000 m^3.
- The Rapti headwork is cancelled in consideration of issues of sedimentation and debris flow. Water is taken from the Khani headwork in addition to the maximum discharge (13.3 m^3/sec) from Kulekhani II hydropower station.
- Water is conveyed to the Yangran regulating pond by pressure flow thorough a 3,300m long connection tunnel.

- The power output of 42 MW is planned by utilizing 40.14 m^3/sec of maximum plant discharge and 120 m of effective head at an underground power station constructed in the dolomite layer.

Technical Examination

- The connection tunnel between the Khani headwork and regulating pond is divided into concrete lining sections and shotcrete lining sections to decrease construction cost. In the section where Q value is less than 4, concrete lining is used, and in other sections where rock condition is good, shotcrete is used. At present, the design concept of the connection tunnel is acceptable. However, it should be reviewed using the results of core drilling, physical property tests and permeability tests planned in this feasibility study.
- The drop shaft, which conveys water to the underground powerhouse, is designed using concrete lining instead of a steel liner, similar to the 16 MW plan. In-situ stress condition, permeability and the groundwater level should be considered in the design of the drop shaft since high-pressure water acts on the excavated shaft surface.
- A stability analysis of the underground powerhouse cavern was carried out in an NEA report in 1999. However, the physical properties of the rock mass have yet to be confirmed. It is necessary to re-analyze the stability of the powerhouse cavern considering the results of various investigations of the rock mass planned in the exploratory adit.
- The stability of the tailrace tunnel crossing the MBT fault should be examined, as for Alternative-4 (16 MW).

In addition, for the six alternatives outlined above, there are common technical issues, as follows:

- The design flood is determined using river flow data at the Rajaya water level gauging station from 1963 to 1985. Accordingly, the results of the 1993 flood are not reflected in the design. The design flood for each structure should be reviewed based on the latest available data (at present, data until 1995 is available).
- At the site reconnaissance during the preliminary investigation and the first field investigation in this feasibility study, a potential landslide area, 150m wide and 150m long, was identified at the upstream end of the regulating pond. This potential landslide area is stable at present, but there is a possibility of it becoming unstable due to pore pressure along the sliding surface at impounding or during drawdown stage of the regulating pond. Therefore, for Alternatives 1, 2, 5 and 6, which all require the Yangran regulating pond, the stability of the potential landslide area should be established based on the results of a boring investigation.

- Riverbed observations indicate that the rate of sedimentation of the Yangran River is less than that of the Rapti, Khani and Mandu Rivers, and substantial sediment deposition was not identified, although a grain size analysis of the bedload is required. However, some indications of debris flow were observed in the upstream reaches of the Yangran River and, as for Alternative-1, 2, 5 and 6 a study on measures against debris flow is needed.

(2) Results of Review for Each Alternative

In this section, each alternative is compared on the basis of plant discharge, effective head, benefit, project cost and economic evaluation.

1) Plant Discharge

In accordance with the NEA report of September 1999, it is assumed that 6.2 m^3/sec is discharged from the Kulekhani I power station in winter (December to March) and 2.1 m^3/sec is discharged in summer (April to November). Each river flow is analyzed using monthly average flow data from 1963 to 1992 at the Rajaya water level gauging station.

2) Effective Head

Head loss is calculated for each alternative layout and effective head is reviewed. Firm peak output is calculated by using effective head and plant discharge mentioned above. For the calculation of friction head loss, the roughness coefficient for concrete lining is set at 0.014 and 0.022 for shotcrete lining

3) Benefit

The benefit of the generation is separately calculated as kW value and kWh value. Furthermore, kWh value is divided into peak time in the dry season (December to May) and peak and off-peak time in the wet season (June to November) plus the off-peak in the dry season. The kW value and kWh value for peak time in the dry season is 121 US$/kW and 6.1 US ¢ /kWh, based on Long Run Marginal Cost studies in "Power System Master Plan Nepal" by Technical Assistance Finance of ADB. Considering imports from India during shortfall and export to India of surplus electricity, the kWh value for peak and off-peak in the wet season and off-peak in dry season is 4US ¢ /kWh, based on the price of power exchange with India, effective from FY1996.

4) Construction Cost

The direct construction cost of the Project is reviewed in order to carry out an economic evaluation of each plan. For civil work and mechanical work, such as gate and penstock installation, the quantity is checked and the cost is then calculated using the unit prices used in the NEA report for the 42 MW plan in September 1999.

The design of electrical equipment such as turbines, generators, control devices

and mains transformers are reviewed. These costs are estimated using international prices.

For the transmission line, the unit price is reviewed and construction cost is estimated.

Administration costs and engineering costs are considered as 10% of the total direct cost mentioned above. In addition, it was assumed that the operation and maintenance cost is 2% of the direct cost.

A construction period of three years is assumed for the 16 MW plan and the 14 MW plan. For the other plans, construction time is assumed as four years.

To convert project cost to economic cost, a conversion factor of 0.9 is considered.

5) Comparison of Economic Evaluation for Each Alternative

The project life is 50 years after construction. The replacement cost of the electrical and hydro-mechanical equipment is set at 100%, incurred 30 years after commissioning, and that of the power transmission line, 90%. Net present value (NPV) for each alternative is compared. Details of economic analysis are shown in Table 6.3.3 and a summary is given in the table below.

Alt. No.	Installed capacity	Headwork	Type of generation	Type of powerhouse	Peak Time	NPV (Mil. US$)
1	54 MW	Rapti	Pondage	Surface	3 hours	5.737
2	38 MW	Rapti	Pondage	Surface	4 hours	2.337
3	14 MW	Khani	Run-of-river	Surface	-	-0.675
4	16 MW	Khani	Run-of-river	Underground	-	-6.844
5	**48 MW**	**Rapti Khani**	**Pondage**	**Underground**	**4 hours**	**4.785**
6	42 MW	Khani	Pondage	Underground	4 hours	3.510

The following points emerge from the comparison.

- The NPVs of the 14 MW and 16 MW plans, which are planned as run-of-river type, are negative. They are inferior to run-of-river type with regulating ponds on economic grounds. As explained in Section 6.2, there is a peak power deficiency of 40 MW for four hours from 5 pm to 9 pm. These plans do not cover this shortage of peak power, and an additional power station is needed to avoid load shedding. Therefore, a peak power station having a regulating pond is better for coping with the power deficit forecast.
- In the run-of-river type with regulating pond, the NPVs of underground powerhouse types is greater than those of surface powerhouse types.
- The 42 MW plan, which takes water from the Khani headwork, has a lower NPV than that of the 48 MW plan, which takes water from the Rapti headwork in addition to Khani headwork, since the energy benefit of the 48

MW plan increases in summer. However, as mentioned in section 6.3.2 (1), the Rapti headwork needs the provision of measures against debris flow and sedimentation, and this cost needs to be estimated in detail to evaluate the appropriateness of the construction cost for the 48 MW plan.

- Comparing four hours peak power generation with three hours peak power generation, the NPV of three hours peak power generation is greater. However, according to the power demand forecast for FY 2007, there is a shortfall in power generation from 5 pm to 9 pm and four hours peak generation is considered more appropriate.
- The economic evaluation above shows that a layout based on an underground powerhouse and a regulating pond is superior to the other alternatives.

6.3.3 Optimum Project Layout

The technical issues of each plan proposed in the existing feasibility study reports are explained in section 6.3.2. Among these issues, items with a major influence on the project cost are as follows:

- Countermeasures against sedimentation of the Yangran Regulating Pond
- Countermeasures against potential landslides in the Yangran Regulating Pond.
- Geological condition of the underground powerhouse
- The section of the tailrace tunnel crossing the MBT
- Sabo Works and the channel route for the Rapti Headwork

Alternative layouts for the regulating pond, the powerhouse and the tailrace tunnel are made taking into account the technical issues mentioned above. The optimum project layout is determined by comparing the NPV of the alternatives.

(1) Basic Assumption

The unit prices of major civil works are determined by referring to recent data for international competitive bidding on similar projects in Nepal and Asian Countries. Unit prices related to the electro-mechanical works are determined by referring to recent international competitive bidding.

The unit prices of the civil works for cost estimation are as follows:

Unit：US$

Work Item	Unit	Kulekhani III (NEA)	Middle Marsyandi	Kaligandaki A	Various Similar Project	Unit Price in this Study
Open Excavation (Common)	m^3	2.2	2.1	4.0	2.0 – 3.0	2.2
Open Excavation (Rock)	m^3	9.7	12.5	9.0	5.0 –11.0	9.7
Tunnel Excavation	m^3	32.0	20.0	33.7	40.0 – 50.0	45.5
Shaft Excavation	m^3	65.0	25.3	112.5	30.0 – 60.0	63.3
Underground Cave Excavation	m^3	30	25.4		40.0 – 50.0	26.4
Structural Concrete	m^3	77.0	70.0	63.2	70.0 – 80.0	67.8
RCC Concrete	m^3	65.0			50.0 – 60.0	44.9
Mass Concrete	m^3	66.0	62.8	34.3	60.0 – 70.0	66.0
Lining Concrete	m^3	180.0	94.8	186.5		66.2
Invert Concrete	m^3	112.5	62.8	101.5		65.5
Reinforcement Bars	ton	650.0	880.5	1049.3	450.0 – 900.0	559.0
Rockbolt, D25	m	34.0				18.1
Shotcrete (5cm)	m^2	17.2				16.9
Shotcrete (10cm)	m^2	22.5				25.5
Shotcrete (15cm)	m^2	32.0				32.0

The following projects are used to set unit prices for the Kulekhani III Project.

No.	Project Name	Country	Remarks
(1)	Kulekhani III HPP	Nepal	NEA report on September 1991.
(2)	Middle Marsyandi HPP	Nepal	Contract Price on November 2000
(3)	Kaligandaki A HPP	Nepal	Contract Price on January 1997
(4)	Various Similar Projects	Asian Countries	Bidding Price

The energy generation of the Kulekhani III hydropower station is governed by the discharge released from the Kulekhani reservoir. The reservoir simulation study is carried out to estimate the available discharge for the Kulekhani III hydropower station in Chapter 7. The optimum reservoir operation is determined so as to maximize a power benefit of a series of the Kulekhani hydropower stations. The optimum operation rule derived from the simulation study is as follows (refer to Section 7.2).

1) The period of dry season operation is four months from December to March.

The peak operation period of the Kulekhani I and II hydropower stations are 8 hours in the dry season and 4 hours in the wet season.

As examined in Section 6.2.3, a shortfall in the peak power supply will occur between 5 pm and 9 pm. For the comparison of the project layout, the peak operation period of the Kulekhani III hydropower station is assumed as 4 hours. A maximum plant discharge is estimated as 43.1 m^3/sec, which is determined so as to guarantee 90 % dependability from the results of the reservoir simulation study performed in accordance with the optimum operation rule mentioned above. A required storage volume of the Yangran regulating pond is 475,000 m^3, which is determined so as to minimize a spill out water in the energy simulation study on the Kulekhani III Hydropower Project. A full supply level (FSL) of the regulating pond is set at El. 597.0 m as high as possible to maximize an annual benefit. If dam type regulating pond is selected, a minimum operation level (MOL) of regulating pond shall be determined considering sedimentation. It is set at El. 577.0m to keep the effective regulating function. A tailwater level is set at 465.5 m, considering discharge rating curve and sedimentation around the tailrace outlet. The rated water level is set at the elevation of FSL minus one third a drawdown. The rated head of 117.5 m is calculated taking account of all kinds of headloss. Combined efficiency of a turbine and a generator is assumed as 0.902 from the recent generating equipment data. Dimensions of main structures for all alternatives are determined based on the above conditions.

(2) Comparison Study on Options for the Regulating Pond

Alternatives considered for the regulating pond are as follows:

Alternative A: Dam type regulating pond

Alternative B: Underground type regulating pond

Alternative C: Dispersion type regulating pond

Plans, profiles and details of each alternative are shown in Figures 6.3.2 to 6.3.10, and the principal features of the main structures are summarized in Table 6.3.4.

Alternative A: Dam Type Regulating Pond

A 50 m high RCC dam is to be constructed on the Yangran River. For the dam type regulating pond, countermeasures against sedimentation and debris flow are needed. By the study on the sedimentation of the Yangran regulating pond, the specific sediment yield is estimated at 19,000m^3/year (refer to section 3.2.7). There is a possibility that the regulating pond, with a gross storage capacity of 570,000 m^3 would be filled with sediment within 30 years. Accordingly, countermeasures against the sedimentation are also needed in Alternative A.

Huge boulders, found in the Kulekhani and the Mandu river basins, were not observed in the Yangran River. However, countermeasures against debris flow are necessary since the gradient of the Yangran River is steep, and some slope failures were observed in the upstream reach of the river.

As shown in Figure 6.3.2, two check dams are placed in the upstream reach as countermeasures against sedimentation and debris flow. One is constructed at 1,170 m and the other is 950 m upstream of the regulating dam axis to prevent sand and gravel from flowing into the regulating pond. Both check dams are concrete dam types of 15 m in height. In addition, a sand flush gate is provided at the regulating dam to remove any suspended load that the two check dams do not trap. The construction cost of the dam type regulating pond includes countermeasures against sedimentation and debris flow. Measures for the potential landslide area in the regulating pond are also required, as mentioned in section 3.4.2. Removal of the head and provision of a counterweight embankment at the toe are recommended as effective measures for the potential landslide area, based on the site reconnaissance and the stability analysis based on core drillings. These costs are also included in the construction cost of Alternative A.

A plan and sections of the regulating dam are shown in Drawing 5, and the proposed check dams are shown in Drawing 6.

Alternative B: Underground Regulating Pond

As shown in Figure 6.3.7, Alternative B plans to store the water in a large underground cavern in the limestone layer on the right bank of the Khani River. Five large caverns (17 m in diameter x 500m in length) store 500,000m^3 for the peak power generation. In this plan, countermeasures for debris flow, sedimentation and potential landslide are not necessary since all regulating pond structures are arranged underground. However, a sand flush tunnel is required to maintain the underground regulating pond. This cost is included in the construction cost of Alternative B.

Alternative C: Dispersion Type regulating Pond

As shown in Figure 6.3.10, Alternative C plans to store 500,000 m^3 for the peak power generation in two excavated ponds. One is an excavated headpond with 100,000 m^3 of storage capacity, which is planned to be constructed on the left bank of the Khani River at the confluence of the Khani and Rapti River. The other is an excavated regulating pond with a storage capacity of 400,000 m^3, constructed in the riverbed of the Yangran River. Countermeasures for sedimentation and the potential landslide area are not needed since the regulating pond structure is buried in the riverbed. However, diversion work is necessary for riverbed excavation along a 1,000 m long reach.

Direct construction costs of the civil works for the three alternatives are shown in the table below. They are calculated using the unit prices mentioned in Section 6.3.3 (1). This indicates that the dam type regulating pond is the most economical of the three alternatives, even when the countermeasures for debris flow and sedimentation are included. (Unit : mil US$)

	Alternative A	Alternative B	Alternative C
Direct Cost of Civil Works	35.2	69.1	49.5

(3) Measures against Potential Landslides in the Regulating Pond

The stability of potential landslides during water filling and drawdown for power generation (a daily fluctuation of water level of 20 m) is examined in section 3.4.2. As a result of the stability analysis, it is confirmed that the following measures are necessary to secure a safety factor of 1.10 for slope stability:

1) Removal of the top of the potential landslide area
   Excavation Length: 100 m, Height: 40 m, Volume: 31,900 m^3
2) Counterweight embankment
   Embankment Length: 150 m, Height: 20 m, Volume: 27,000 m^3
3) Riprap for slope protection
   Riprap Volume: 700 m^3

Drawings of above works are shown in Drawing 7 and 8.

(4) Optimum Layout of Powerhouse

According to the Updated Feasibility Study Report of NEA in September 1999, an underground power station is planned to be constructed in the dolomite layer at about 150m in width. Judging from the drilling investigation carried out in the exploratory adit, the existence of a hard and good dolomite layer was confirmed at the underground powerhouse location.

In general, the construction cost of underground powerhouses is higher than for other types of powerhouse because of the long construction period and the high unit cost of the works. Therefore, a semi-underground type powerhouse (Alternative A-1) is compared as an alternative. Profiles and details of the

powerhouse structures in Alternative A and Alternative A-1 are shown in Figures 6.3.11 to 14. Principle features of the main structures are shown in Table 6.3.5.

Two units of semi-umbrella type generators and vertical Francis type turbines are selected for the study. The required size of the powerhouse depends on the generator and turbine size.

The drilling investigation shows a river deposit layer of 33.5 m thickness at the semi-underground powerhouse site. If the semi-underground option is adopted, an open excavation of more than 100 m in height is required to establish the powerhouse on the slate layer foundation. A large cutting of this size induces a risk of slope instability. In addition, construction of the semi-underground powerhouse would require resettlement and land acquisition since it is planned to be constructed at Sanutar village. The semi-underground type powerhouse plan (Alternative A-1) will have an impact on the social environment.

Direct construction costs of the civil works for two alternatives are shown in the table below. They are calculated using the unit prices mentioned in section 6.3.3 (1). The cost of the semi-underground powerhouse (Alternative A-1) is higher than that of the underground powerhouse (Alternative A) due to the large open excavation.

During the heavy rain in July 2002, it was observed that the surface sliding and flushing out debris along the small stream occurred in the proposed area of semi-underground powerhouse. There is a possibility that a landslide will be caused by the large slope cutting. From a viewpoint of safety, underground powerhouse is recommendable.

(Unit: Mil US$)

	Alternative A	Alternative A－1
Direct Cost of Civil Works	35.2	36.3

(5) Optimum Layout Tailrace Tunnel crossing the MBT

From the results of the drilling investigation and the seismic refraction survey, it is confirmed that the Siwalic Sandstone is fractured for a 130 m section along the tailrace tunnel due to the Main Boundary Thrust (MBT). In this section, it is anticipated that difficult geological conditions and high levels of seepage might be encountered during tunnel excavation through the MBT. Instead of a tunnel, a culvert is considered as a means of crossing the MBT. For the culvert, the 350m long section crossing the Kesadi River would be excavated by open cutting. In this scenario, a large open excavation of 450,000 m^3 is necessary. Therefore, two alternatives are compared for selecting the optimum layout as follows:

Alternative A: Pressure Tunnel

Alternative A-2: Free Flow Tunnel + Culvert (Crossing the Kesadi River)

Profiles of Alternative A and Alternative A-2 are shown in Figure 6.3.11 and 15

respectively. The tailrace surge tank and chamber are shown in Figure 6.3.16. The principle features of the main structures are shown in Table 6.3.6. The lining thickness of Alternative A is set at 50 cm, since the lining thickness of pressure tunnels is generally required to be 1/8 to 1/10 of the inner diameter (inner diameter of tailrace tunnel: 4.5m). The free flow tunnel would be non-reinforced concrete, 20 cm in thickness. In the culvert section, the lining thickness is assumed to be 1 m to withstand earth pressure. For the pressure tunnel plan in Alternative 1, a tailrace surge tank of 12 m in width, 38 m length and 16 m in height is required.

Direct construction costs of the civil works for the two alternatives are shown in the table below. They are calculated using the unit prices mentioned in section 6.3.3 (1). The costs of both alternatives are the same. However, if the excavation face requires shoring due to seepage water in the fault zone, the construction period of the pressure tunnel plan (Alternative A) is affected. Accordingly, the Free Flow Tunnel + Culvert plan (Alternative A-2) is selected for further study.

(Unit：Mil US $)

	Alternative A	Alternative A－2
Direct Cost of Civil Works	35.2	35.2

(6) Rapti Headwork

An intake from the Rapti River (maximum 5 m^3/sec) is planned in the feasibility study report in 1988. Assuming the same arrangement of structures as Alternative 1, the installed capacity increases by 4 MW and the energy generation increases by 21 GWh/year through utilizing the water from the Rapti River.

However, the Rapti headwork is planned to construct near the Bhainsedobhan. This area was severely damaged by the flood in 1993 and 2002. In addition, large quantities of disposal flow out from the Hetauda cement quarry located upstream of the Rapti headwork site. There is a possibility that the intake could be buried by sand and gravel washed down by flood.

The waterway conveying the water from the Rapti headwork to the headpond passes through Baisedobahan. It would be difficult to construct the Rapti headwork from the environmental viewpoint because the extensive resettlement and land acquisition will be required along the route of the waterway.

From the above reason, the Rapti headwork option is discarded in this study.

(7) Comparison Study of Economic Evaluation for Alternatives

Economic evaluation for each alternative is carried out assuming that the construction period is 3.5 years and the project life is 50 years after construction. The replacement cost of the electrical and hydro-mechanical equipment is set at 100%, incurred 30 years after commissioning, and that of the power transmission line at 90%. The net present value (NPV) for each alternative is computed.

1) Benefit

The benefit of the power generation is calculated by the same procedure mentioned in Section 6.3.2. It is based on Long Run Marginal Cost in "Power System Master Plan Nepal" prepared by Technical Assistance Finance of ADB and the price of power exchange with India, effective from FY1996.

2) Direct Construction Cost

The direct construction cost of the Project is calculated by the same procedure mentioned in Section 6.3.2. The unit price of each work item is shown in the table in Section 6.3.3 (2) "Basic Assumption".

The main structures and net present value (NPV) of each alternative are summarized in the table below.

	Headwork	Regulating Pond	Regulating Dm	Powerhouse	Tailrace	NPV (Mil US$)
Alternative A	Khani Headwork	Yangran Regulating Pond	Original Dam Axis	Underground	Tunnel	1.117
Alternative A-1	Khani Headwork	Yangran Regulating Pond	Original Dam Axis	Semi-underground	Culvert	－0.001
Alternative A-2	Khani Headwork	Yangran Regulating Pond	Original Dam Axis	Underground	Culvert	**1.119**
Alternative B	Khani Headwork	Underground Regulating Pond	w/o Dam	Underground	Tunnel	-36.218
Alternative C	Khani Headwork	Dispersion Type Regulating Pond	w/o Dm	Underground	Tunnel	-14.596

The result of the economic evaluation indicates that Alternative A-2 is the most economical layout.

(8) Summary of Study on Optimum Project Layout

Based on the comparison of the alternatives on technical and economical grounds, Alternative A-2 is considered to be the optimum layout. Alternative A-2 is composed of a dam type regulating pond and underground powerhouse. This layout has the following advantages:

- In consideration of the characteristics of slope failure in the Yangran watershed, two check dams are recommended to be placed in the upstream reach of the Yangran River in order to trap sand and gravel. The dam type of the regulating pond, including the measures for sedimentation, is the most economical of the three alternatives.

  In addition, this plan can be expected to be constructed in 3.5 years since there are few difficulties in construction compared with the other alternatives.

- The semi-underground powerhouse option requires a large open excavation of more than 100m in height, whereas the underground powerhouse has a much lower natural environmental impact. The social environmental impact

will also be reduced by adopting the underground powerhouse since resettlement and land acquisition can be minimized.

- It is anticipated that the geological conditions around the MBT will become worse. If the riverbed section of the tailrace crossing the MBT is constructed as a culvert type, it is easier to take measures against changes in geological condition compared to a tunnel. The tailrace tunnel can be constructed within 3.5 years by using a culvert in the MBT section.

Although the selected alternative (Dam type regulating pond + Underground powerhouse) has the advantages mentioned above, it is still necessary to consider the natural environmental impact on the Yangran River Basin imposed by the construction of the regulating dam. Accordingly, it is necessary to determine the river maintenance flow in the Yangran River, taking into account the natural environment in the Yangran River and the irrigation water supply to Sautar and Ghumaune villages.

6.3.4 Optimum Development Scale

As mentioned in the previous section, Alternative A-2 consisting of dam type regulating pond and underground powerhouse is selected as the optimum layout. To determine the optimum development scale, an economical comparison study with alternative thermal plant was carried out on basis of the optimum layout mentioned above. Various installed capacities were set as alternatives by changing the duration of peaking operation time.

(1) Available Discharge

As explained in the section 6.3, the available discharge for the Kulekhani III hydropower station will be calculated based on the optimum operation rule of the Kulekhani reservoir, which is examined in Chapter 7. The optimum operation of the Kulekhani reservoir for a series of the Kulekhani power stations is proposed as follows:- Seasonal operation pattern : 4-month dry season operation

: 8-month wet season operation

- Peak operation hour in dry season : 8-hour
- Peak operation hour in wet season : 4-hour

The optimum installed capacity of the Kulekhani III power station was examined by referring to the optimum reservoir operation rule mentioned above.

In addition, the maximum intake discharge of 2.0 m^3/sec can be taken from the Khani River in the wet season and added to the available discharge released from the Kulekhani II hydropower station. The river maintenance flow of 0.1 m^3/sec in the dry season and 0.3 m^3/sec in the wet season is deducted from the discharge released from the Yangran regulating pond. The available discharge for the Kulekhani III hydropower project, which is calculated by the reservoir simulation study based on the hydrology data from 1963 to 1995, is summarized in the table below:

Available Discharge for KL-III

90 % dependable discharge in the dry season	m^3/sec	7.18
90 % dependable discharge in the wet season	m^3/sec	1.55
Average available discharge in the dry season	m^3/sec	7.36
Average available discharge in the wet season	m^3/sec	4.37

(2) Alternatives for Optimum Development Scale

The cases of installed capacity are set by varying peaking operation time of 3, 4 and 5 hours as shown in the table below:

Alternatives of Installed capacity

	Unit	Case-1	Case-2	Case-3
Plant Discharge	m^3/s	57.5	43.1	34.5
Installed Capacity	MW	59.6	44.8	35.8
Peaking hour	hour	3	4	5

(3) Power Generation

The calculated energy outputs to be produced by the Kulekhani III are based on the available discharge obtained by the reservoir simulation study mentioned in Chapter 7. The energy output of each case is summarized in the table below:

Power Generation for Alternatives

Case	Installed Capacity (MW)	Peak hour (hour)	Firm Peak Energy (GWh)	Secondary Energy (GWh)	Total Energy (GWh)
Case-1	59.6	3	29.43	17.27	46.70
Case-2	44.8	4	29.42	18.16	47.58
Case-3	35.8	5	29.49	18.37	47.86

(4) Capacity Value and Energy Value of Alternative

A 25 MW gas turbine power plant was selected as the alternative thermal plant for the estimation of capacity value and firm peak energy value. As a secondary energy value, LRMC (Long Run Marginal Cost) for peak energy in the dry season was selected. Capacity value and energy value based on the alternative thermal plant are as follows:

Capacity and Energy Value based on the Thermal

Thermal Plant	Unit Const.Cost (US$/kW)	Oil Price (HSD) (US$/liter)	kW-value (US$/kW)	kWh-value (US$/kWh)
Gas Turbine	660	0.34	1,003	0.119

(5) Economic Project Cost

The project cost estimate for optimization of the installed capacity was calculated from unit prices mentioned in Chapter 9. The construction period is considered to take 4 years for Case-1 and 3.5 years for case 2 and 3.

(6) Results and Conclusion

The EIRR for each case was calculated for the basic condition mentioned above and the results are shown in Figure 6.3.17. In this figure, EIRR of Case-1 (3 hour peaking operation: 59.6 MW) and Case-2 (4 hour peaking operation: 44.8 MW) is higher than Case-3 (5 hour peaking operation: 35.8MW). It means that Case 1 and Case 2 is economically superior to Case-3.

Case-1 and Case-2 are almost same EIRR value. However, as the installed capacity is smaller, profit of the project become higher since energy production increases and construction cost decrease on the contrary. Therefore, it is considered that the Case-2 is financially superior to Case-1. In addition, comparing with daily load curve in 2008 shown in Figure 6.2.2, the 4 hour peaking operation is appropriate to cover the power deficit of peaking time in the dry season. From the reason above, the installed capacity of 44.8 MW with 4 hour peaking operation is selected as optimum project scale.

6.4 Study on Optimum Input Timing

6.4.1 Long-term Power Source Development Plan

Based on the long-term power demand forecast prepared in Section 5.3, the long–term power source development plan covering the period up to 2012 was examined using the "WASPIII" software, owned by NEA. Furthermore, the results of study were re-examined using "EGEAS"software, which presents the optimum power development plan to meet the power demands over the evaluation period. The study was carried out on the basis of the following criteria:

1) A constant ratio of the reverse capacity to the total power demand was maintained throughout the evaluation period.
2) Power plants to be put into operation during the evaluation period and year of commissioning were determined to meet the power demand of the power system so that the present worth of all capital cost and operation and maintenance (O&M) costs of the power system were minimized.

The software package was applied to find the optimum commissioning year of the Kulekhani III hydroelectric power station, and the least cost sequence of the candidate power plants to be added to the whole power system of Nepal.

6.4.2 Conditions and Assumptions

The studies to search for the optimum commissioning years of the Kulekhani III hydropower station were carried out using the following conditions and assumptions:

1) The power demands of the whole Nepal power system until year 2012 are met through the integrated operation of the candidate power plants, and the existing already commissioned power. The candidate power plants were selected from among those listed in the Corporate Development Plan prepared by NEA in FY2001. Their features are summarized in the table below:

No.	Project Name	Type	Installed Capacity (MW)	Average Annual Energy (GWh)	Earliest Commissioning Year (Year)
1.	Chameriya	PROR	30	196	2007/08
2.	Kulekhani III	PROR	45	47.5	2007/08
3.	Khimti II	PROR	27	157	2008/09
4.	Rahughat	PROR	27	165	2008/09
5.	Kabeli-A	PROR	30	164	2008/09
6.	Budhi Ganga	PROR	20	106	2008/09
7.	Upper Marsyandi-3	ROR	70	409	2008/09
8.	Upper Modi-A	PROR	42	285	2008/09
9.	Lower Modi	ROR	19	123	2008/09
10.	Upper Karnali	PROR	300	2133	2009/10

ROR: Run-of-river Type, PROR: Peaking Run-of-river Type

2) Power outage rate or loss of load probability (LOLP) set 5 days per year.

3) Installed power facilities required to meet the growing demands of power (MW) and energy (GWh), which is estimated in Chapter 5.

4) Minimum reserved margin was assumed to be 10% with reference to the power source development plan analysis carried out by WASPIII in the Updated Feasibility Study on Middle Marsyandi Hydropower Project.

5) Assumed that 100 MW and 150 MW imported from India as mentioned in Sub-section 5.3.2.

6) The average project life of hydropower plants fixed at 50 years.

7) According to the construction plan in Chapter 9, the Kulekhani III hydropower project is scheduled to be completed in 2007. Therefore, the Kulekhani III hydropower station can be committed to commence power generation in 2007 as the earliest possible timing. Accordingly, the Kulekhani III hydropower project can become one of the possible candidate projects to meet the power demand in 2007.

8) The year of 2002 was set as the base year, and the present worth of whole capital and O&M costs for the 5 years from 2007 to 2011 was estimated by running WASPIII and EGEAS.

The optimum power development plan which would have the least total cost among the numerous conceivable development alternatives was derived by applying EGEAS. This procedure involved Dynamic Programming (DP).

6.4.3 Optimum Input Timing of the Project

Though the current ceiling of power exchange with India is 50 MW as mentioned in Chapter 5, there is a plan to increase the ceiling to 150 MW. Taking into account of the possibility that power imports from India will increase, the analysis was carried out for the case of 100 MW and 150 MW of power import.

The results of the analysis are shown in the table below.

Optimum Input Timing of Kulekhani III Hydropower Project
In the Case of the 100 MW Import from India

Year	Project Name	Installed capacity (MW)	Peak Power In the Dry Season (MW)	Remarks
FY 2003/04	Syange	0.1	0.1	IPP, PPA signed
	Chilime	20.0	20.0	Under Construction
	Indrawati	7.5	3.0	IPP, PPA signed
	Daram	5.0	5.0	IPP, PPA signed
	Piluwa	3.0	2.0	IPP, PPA signed
	Chaku	0.91	0.90	Under Construction
FY 2004/05	Pheme	0.95	0.90	IPP, PPA signed
	Upper Modi	14.0	8.0	IPP, PPA signed
	Kudi	3.5	2.2	IPP, PPA signed
FY 2005/06	Mailung	5.0	4.0	IPP, PPA signed
	Middle Marsyandi	70.0	70.0	Under Construction
FY 2006/07	-	-	-	-
FY 2007/08	Kulekhani III	45.0	45.0	NEA Planned
	Chamelia	30.0	30.0	NEA Planned
FY 2008/09	Upper Modi-A	42.0	42.0	NEA Planned
FY 2009/10	Upper Marsyandi	70.0	21.0	NEA Planned
FY 2010/11	Upper Karnali	300.0	300.0	NEA Planned
FY 2011/12	-	-	-	-
Present worth of capital and O&M Cost			(Mill. US$)	349

Optimum Input Timing of Kulekhani III Hydropower Project
In the Case of the 150 MW Import from India

Year	Project Name	Installed Capacity (MW)	Peak Power In the Dry Season (MW)	Remarks
FY 2003/04	Syange	0.1	0.1	IPP, PPA signed
	Chilime	20.0	20.0	Under Construction
	Indrawati	7.5	3.0	IPP, PPA signed
	Daram	5.0	5.0	IPP, PPA signed
	Piluwa	3.0	2.0	IPP, PPA signed
	Chaku	0.91	0.90	Under Construction
FY 2004/05	Pheme	0.95	0.90	IPP, PPA signed
	Upper Modi	14.0	8.0	IPP, PPA signed
	Kudi	3.5	2.2	IPP, PPA signed
FY 2005/06	Mailung	5.0	4.0	IPP, PPA signed
	Middle Marsyandi	70.0	70.0	Under Construction
FY 2006/07	-	-	-	-
FY 2007/08	-	-	-	-
FY 2008/09	Kulekhani III	45.0	45.0	NEA Planned
FY 2009/10	Khimti II	27.0	53.0	IPP, Joint Study with NEA
FY 2010/11	Chameliya	30.0	30.0	NEA Planned
FY 2011/12	Upper Karnali	300.0	300.0	NEA Planned
Present worth of capital and O&M Cost			(Mill. US$)	328

For the case in which 100 MW is imported from India, the optimum input timing of the Kulekhani III Hydropower Project is set FY2007/08. If 150MW is imported from India, the Kulekhani III Hydropower Project is required in FY 2008/09.

As a result of analysis, it is confirmed that the input of the Kulekhani III hydropower project at an early stage would contribute to minimizing the capital cost of power development and the operation and maintenance cost of the whole Nepal power system. Even if the power exchange with India increases up to the upper limit in the future, the Kulekhani III hydropower project will still be needed.

As mentioned in Section 6.2.3, the peak power is required from 5pm to 9pm in the dry season. However, it is difficult to deal with peak demand by power imported from India for the following reason:

1) The capacity of the transmission line system is insufficient to send the power imported from India to the demand center.
2) Imported power from India could not follow the rapid increase of power demand since it is generated by coal thermal power plants which supply base power.

Consequently, Kulekhani III is required in order to deal with the deficiency of peak power, especially in Kathmandu, as early as possible.

TABLES

Chapter 6

Table 6.3.1 Main Structures of Each Alternative Scheme

	Alternative-1 (54 MW, 1988)	Alternative-2 (38 MW, 1993)	Alternative-3 (14 MW, 1997)	Alternative-4 (16 MW, 1998)	Alternative-5 (48 MW, 1999)	Alternative-6 (42 MW, 1999)
Headwork Q_{max}: Maximum intake discharge	Rapti Q_{max}: 5.0 m^3/sec	Rapti Q_{max}: 5.0 m^3/sec	Khani Q_{max}: 1.5 m^3/sec	Khani Q_{max}:1.5 m^3/sec	Khani Q_{max}: 1.5m^3/sec Rapti Q_{max}: 5.0m^3/sec	Khani: Q_{max}: 1.5 m^3/sec
Connection Tunnel	Length: 3,400 m Q_{max}: 18.3 m^3/sec	Length: 3,400 m Q_{max}: 18.3 m^3/sec	N/A	N/A	Length: 3,400 m Q_{max}: 20.5 m^3/sec	Length: 3,400 m Q_{max}: 15 m^3/sec
Regulating Dam V_{eff}: Effective reservoir capacity	V_{eff}: 602,500 m^3	V_{eff}: 602,500 m^3	N/A	N/A	V_{eff}: 602,500 m^3	V_{eff}: 500,000 m^3
Headrace Tunnel	Length: 1,000 m	Length: 1,000 m	Length: 4337 m	Length: 3,883 m	Length: 350 m	Length: 350 m
Penstock	Length: 222 m	Length: 222 m	Length: 345 m	Length: 50 m	Length: 200 m	Length: 80 m
Powerhouse	Surface type	Surface type	Surface type	Underground type	Underground type	Underground type
Tailrace	Open Channel	Open Channel	Box Culvert	Tunnel Length: 2,100 m	Tunnel Length: 2,100 m	Tunnel Length: 2,100 m
Full Supply Level	EL. 599.24 m	EL. 599.24 m	EL. 601 m	EL. 601 m	EL. 599.24 m	EL. 598 m
Tail Water Level	EL. 488 m	EL. 488 m	EL. 491.3 m	EL. 467.5 m	EL. 467.5 m	EL. 467.5 m
Gross Head	111.2 m	111.2 m	109.8 m	133.5 m	131.7 m	130.5 m
Net Head	101.8 m	101.3 m	97.8 m	122.8 m	120.1 m	119.4 m
Maximum Plant Discharge	60.87 m^3/sec (3 hours)	42.84 m^3/sec (4 hours)	15.0 m^3/sec	15.0 m^3/sec	45.54 m^3/sec (4 hours)	40.14 m^3/sec (4 hours)
Installed capacity	54 MW (3 units)	38 MW (3 units)	14 MW (2 units)	16 MW (4 units)	48 MW (4 units)	42 MW (3 units)

Table 6.3.2 Technical Issues of Each Alternative

Alternative	Technical Issues
Alt.-1 54MW (1988)	1) Not study measures against debris flow and sedimentation the for the Rapti headwork. 2) Not study measures against debris flow and sedimentation for the Yangran Regulating Pond. 3) Not consider the flood in 1993 for design of main structure.
Alt.-2 38MW (1993)	1) Not study measures against debris flow and sedimentation the for the Rapti headwork. 2) Not study measures against debris flow and sedimentation for the Yangran Regulating Pond 3) Not consider the flood in 1993 for the design of main structure.
Alt.-3 14MW (1997)	1) The lining of pressure tunnel applied is only shotcrete lining in the section where Q value is less than 4. 2) Designed effective head is not available due to large friction loss in the shotcrete lining section. 3) Require studying the support system for the powerhouse cavern. 4) Not consider the flood in 1993 for design of main structure.
Alt.-4 16MW (1998)	1) Drop shaft, on which high water pressure act, is designed with concrete lining, not with steel liner. Require examination of possibility of hydro fracturing and hydro jacking. 2) The lining of pressure tailrace tunnel applied is only shotcrete lining in the section where Q value is less than 4. 3) Require studying the support system for the powerhouse cavern. 4) Not consider the flood in 1993 for design of main structure. 5) Require examination of tailrace tunnel crossing MBT fault.
Alt.-5 48MW (1999)	1) Not study measures against debris flow and sedimentation the for the Rapti headwork. 2) Not study measures against debris flow and sedimentation for the Yangran Regulating Pond. 3) Not consider the flood in 1993 for design of main structure. 4) Require examination of tailrace tunnel crossing MBT fault.
Alt.-6 42MW (1999)	1) Drop shaft, on which high water pressure act, is designed with concrete lining, not with steel liner. Require examination of possibility of hydro fracturing and hydro jacking. 2) Not study measures against debris flow and sedimentation for the Yangran Regulating Pond. 3) Require studying the support system for the powerhouse cavern. 4) Not consider the flood in 1993 for design of main structure. 5) Require examination of tailrace tunnel crossing MBT fault.

Table 6.3.3 Comparison Study on Existing Alternative Option

Descriptions	Unit	Alternative Options											
		Alt.-1 54 MW (1988)		Alt.-2 38 MW (1993)		Alt.-3 14 MW (1997)		Alt.-4 16 MW (1998)		Alt.-5 48 WM (1999)		Alt.-6 42 MW (1999)	
		Dec-Mar	Apr-Nov	Dec-Mar	Apr-Nov	Dec-Mar	Apr-Nov	Dec-Mar	Apr-Nov	Dec-Mar	Apr-Nov	Dec-Mar	Apr-Nov
Full Supply Level of Reservoir	m	599.24	599.24	599.24	599.24	601	601	601	601	599.24	599.24	598	598
Rated water level of Reservoir	m	593.16	593.16	593.16	593.16	598.25	598.25	598.25	598.25	593.16	593.16	592	592
Tail water Level	m	488	487.5	488	487.7	491.2	490.9	467.5	467.2	467.5	466.8	467.5	466.7
90 % Dependable Discharge	m^3/sec	7.27	3.23	7.27	3.23	6.65	2.57	6.65	2.57	7.52	3.50	6.73	2.66
Mean Discharge	m^3/sec	7.94	6.41	7.94	6.41	6.95	3.81	6.95	3.81	8.34	7.39	7.08	4.30
Required Volume of Regulating Pond	m^3	549,898	244,547	518,475	232,902	-	-	-	-	533,748	252,342	481,075	191,376
Water Volume for Plant Operation	m^3	628,454	279,482	628,454	279,482	-	-	-	-	639,382	302,810	578,016	229,651
Maximum Plant Discharge	m^3/sec	60.97		42.84		15.00		15.00		45.54		40.14	
Firm Plant Discharge	m^3/sec	58.19	25.88	41.56	19.41	13.50	7.22	13.50	7.22	45.54	21.03	40.14	15.95
Gross Head	m	111.2	111.7	111.2	111.6	109.8	110.1	133.5	133.8	131.7	132.5	130.5	131.3
Head Loss	m	3.08	0.74	3.60	0.96	9.26	1.59	7.97	2.23	5.53	1.38	5.09	0.95
Net Head	m	102.1	104.9	101.6	104.5	97.8	105.7	122.8	128.9	120.1	125.9	119.4	124.4
Rated Efficiency		0.89	0.89	0.89	0.89	0.85	0.85	0.84	0.84	0.89	0.89	0.89	0.89
Installed Capacity	MW	54.4		37.9		12.2		15.2		47.6		41.7	
Firm Peak Output	MW	51.9	23.7	36.7	17.7	11.0	6.3	13.7	7.7	47.6	23.0	41.7	17.3
Generator Unit	Unit	3	3	3	3	2	2	4	4	4	4	3	3
Peaking Hours	hr	3	3	4	4	4	4	4	4	4	4	4	4
Primary Energy (Winter Season)	GWh	18.84	4.34	18.67	4.31	5.30	1.55	6.63	1.87	22.45	5.62	20.20	4.22
Primary Energy (Summer Season)	GWh		13.02		12.92		4.64		5.62		16.85		12.65
Primary Energy (Yearly)	GWh	36.20		35.91		11.48		14.13		44.92		37.07	
Secondary Energy (Winter Season)	GWh	1.71	4.26	1.70	4.23	11.08	3.35	13.84	4.06	2.85	6.23	1.19	2.61
Secondary Energy (Summer Season)	GWh		12.78		12.68		10.04		12.19		18.70		7.82
Secondary Energy (Yearly)	GWh	18.75		18.61		24.47		30.09		27.79		11.61	
Energy Output (Winter Season)	GWh	20.55	8.60	20.37	8.54	16.38	4.89	20.47	5.94	25.30	11.85	21.39	6.82
Energy Output (Summer Season)	GWh		25.80		25.61		14.68		17.81		35.56		20.47
Energy Output (Yearly)	GWh	54.95		54.51		35.96		44.21		72.70		48.68	
Benefit (Accumulative 50 years)	10^3 USD	453,969		368,025		147,116		182,306		469,658		381,632	
Power Benefit	10^3 USD	313,944		229,125		66,300		82,825		287,768		252,526	
Energy Benefit	10^3 USD	140,025		138,900		80,816		99,481		181,890		129,106	
Dry Season	10^3 USD	76,485		75,839		22,602		28,053		92,611		80,580	
Wet Season	10^3 USD	63,540		63,061		58,214		71,428		89,279		48,526	
Cost (Accumulative 50 Years)	10^3 USD	140,377		118,406		48,763		79,807		145,323		120,873	
Capital Cost	10^3 USD	80,565		67,651		25,777		45,521		82,216		69,317	
OMR Cost	10^3 USD	59,812		50,755		22,986		34,285		63,107		51,556	
Net Benefit	10^3 USD	313,592		249,619		98,353		102,499		324,335		260,759	
NPV	10^3 USD	5,737		2,337		-675		-6,844		4,785		3,510	

Table 6.3.4 Alternatives of Regulating Pond

Item	**Alternative A**	**Alternative B**	**Alternative C**
Type of Regulating Pond	Dam Type Regulating Pond	Underground regulating Pond	Dispersion Type regulating Pond
Structure of Regulating Pond	RCC Concrete Gravity Dam Dam Height: 50 m, Length:105m	Underground Regulating Pond 17m(H)×17m(W)×500m(L)×5nos.	Excavated Headpond Excavated Regulating Pond
Effective Storage Volume	V=514,000m^3	V=500,000m^3	HeadpondV=100,000 m^3 Regulating Pond V= 400,000 m^3
Measures for Debris Flow	Check Dam Dam Height: 15 m	N/A	Check Dam Dam Heighjt: 15m
Measures for Sedimentation	• Siltation Dam Dam Height: 15 m • Sand Flush Gate 5 m (W)×5 m (H)	N/A	N/A
Measures for Potential Landslide	• Cutting top of Potential landslide 40m (H)×100m (L) • Counterweight Embankment 20m (H)×150m (L)	N/A	N/A
Waterway	• Connection Tunnel (Horseshoe) D=3.2 m, L=3500 m • Headrace Tunnel (Circular) D=4.4m, L=400m	Headrace Tunnel (Circular) D=4.3 m, L=4000 m	• Connection Tunnel (Horseshoe) D= 4.8 m, L= 3500m • Headrace Tunnel (Circular) D= 4.4 m, L= 400m
Powerhouse	Underground Type (Generator : 2 units) 17m (W)×74m (L)×30m (H)	Underground Type (Generator : 2 units) 17m (W)×74m (L)×30m (H)	Underground Type (Generator : 2 units) 17m (W)×74m (L)×30m (H)
Tailrace	D=4.7m, L=2,100 m (D-shape)	D=4.7 m, L= 2,100 m (D-shape)	D=4.7 m, L=2,100 m (D-shape)
Environmental Impact	Large	Small	Medium
Direct Cost of Civil Works	35.2 mil US$	69.1 mil US $	49.5 mil US $

Table 6.3.5 Alternatives of Powerhouse

Item	Alternative A（Underground Type）	Alternative A-1（Semi-Underground Type）
Type of Regulating Pond	Dam Type	Dam Type
Structure of Regulating Pond	RCC Concrete Gravity Dam Dam Height: 50 m, Length:105m	RCC Concrete Gravity Dam Dam Height: 50 m, Length:105m
Powerhouse Type	Underground Powerhouse	Semi-Underground Powerhouse
Structure of Powerhouse	• Powerhouse Cavern 17 m (W)×74 m (L)×30 m (H) • GIS 12 m (W)×20 m (L)×10 m (H)	• Powerhouse Pit 17 m (W)×37 m (L)×43 m (H) • Control Building 16 m (W)×37 m (L)×9 m (H) • GIS 12 m (W)×20 m (L)×10 m (H)
Waterway	• Connection Tunnel （Horseshoe） D=3.2 m, L=3500 m • Headrace Tunnel（Circular） D=4.4m, L=400m	• Connection Tunnel（Horseshoe） D= 3.2 m, L= 3500m • Headrace Tunnel（Circular） D= 4.4m, L=1,150 m • Headrace Surge Tank D＝15m, H＝50 m
Penstock	Vertical Shaft D= 3.6 m, L=150 m	Inclined Shaft D= 3.6 m, L= 200 m
Tailrace	Pressure Tunnel （D-shape）, D= 4.5 m, L=2,100 m	Free Flow Tunnel（D-shape）, D= 4.7 m, L= 1,000 m Culvert, D= 4.7m, L= 350m
Environmental Impact	Small	Large
Direct Cost of Civil Works	35.2 mil US$	36.3 mil US$

Table 6.3.6 Alternatives of Tailrace

Item	Alternative A（Pressure Flow）	Alternative A-2（Free Flow）
Type of Regulating Pond	Dam Type	Dam Type
Structure of Regulating Pond	RCC Concrete Gravity Dam Dam Height: 50 m, Length:105m	RCC Concrete Gravity Dam Dam Height: 50 m, Length:105m
Powerhouse Type	Underground Powerhouse	Underground Powerhouse
Structure of Powerhouse	• Powerhouse Cavern 17 m (W)×74 m (L)×30 m (H) • GIS 12 m (W)×20 m (L)×10 m (H)	• Powerhouse Cavern 17 m (W)×74 m (L)×30 m (H) • GIS 12 m (W)×20 m (L)×10 m (H)
Waterway	• Connection Tunnel （Horseshoe） D=3.2 m, L=3500 m • Headrace Tunnel（Circular） D=4.4m, L=400m	• Connection Tunnel（Horseshoe） D= 3.2 m, L= 3500m • Headrace Tunnel（Circular） D= 4.4m, L=1,150 m
Penstock	Vertical Shaft D= 3.6 m, L=150 m	Vertical Shaft D= 3.6 m, L=150 m
Tailrace	• Pressure Tunnel （D-shape） D= 4.5 m, L=2,100 m • Tailrace Surge Tank 12m(W)×38m(L)×15m(H)	• Free Flow Tunnel（D-shape） D= 4.7 m, L= 1,750 m • Culvert D= 4.7m, L= 350m
Environmental Impact	Small	Large
Direct Cost of Civil Works	35.2 mil US$	35.2 mil US$

FIGURES

Chapter 6

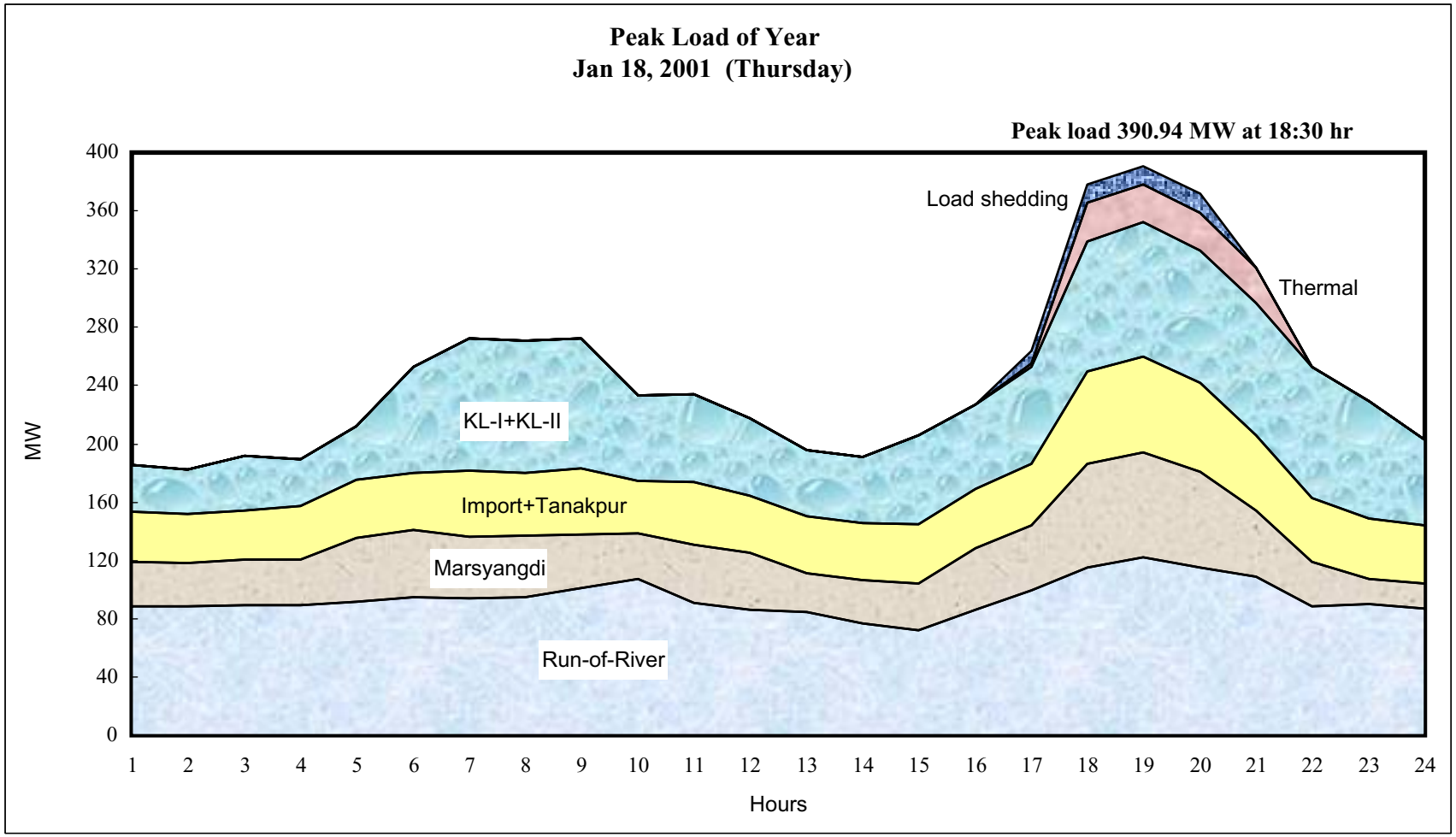


Figure 6.2.1 Daily Load Curve and Power Supply on January 18, 2001

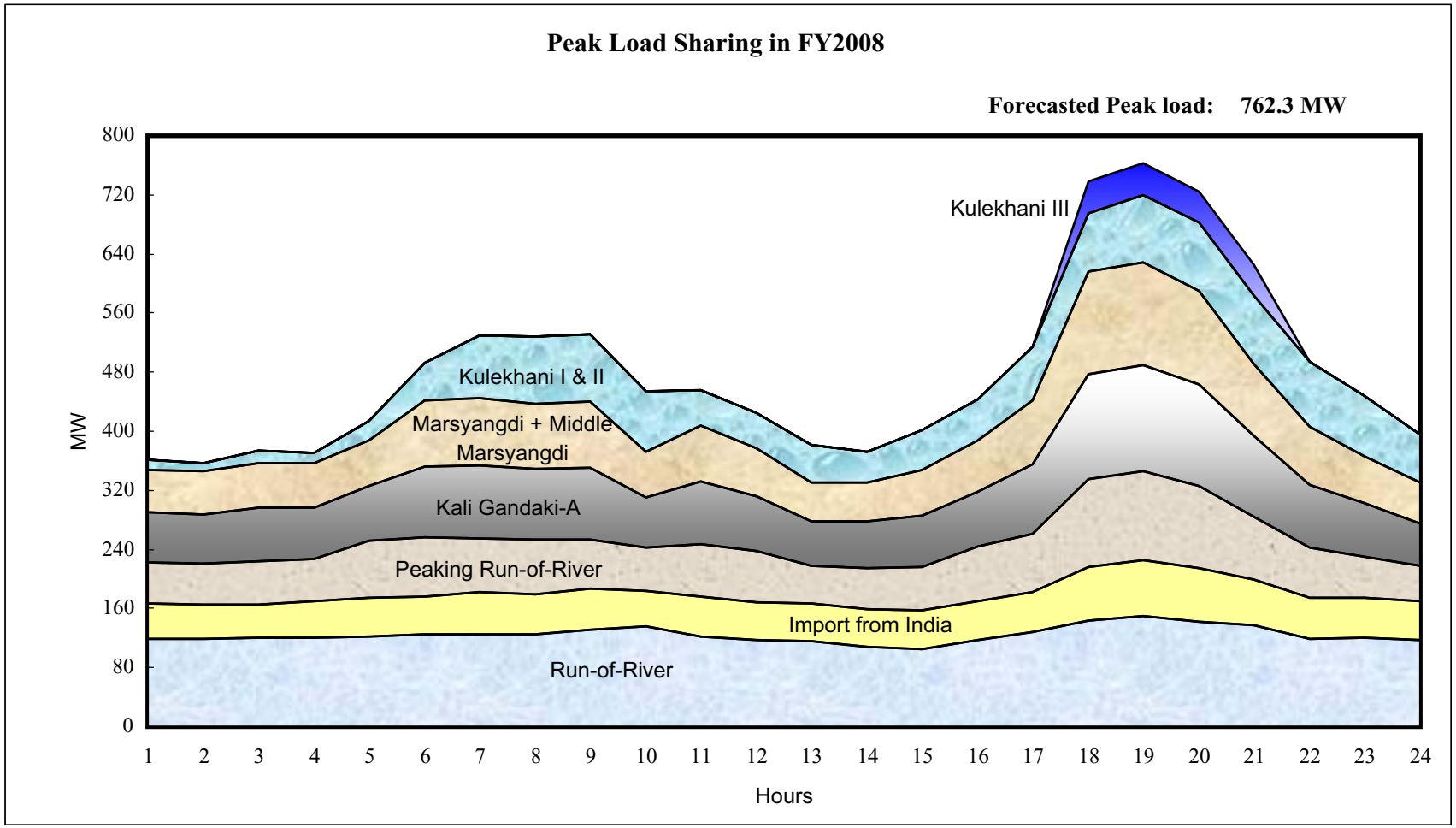


Figure 6.2.2 Daily Load Curve and Power Supply in FY2008

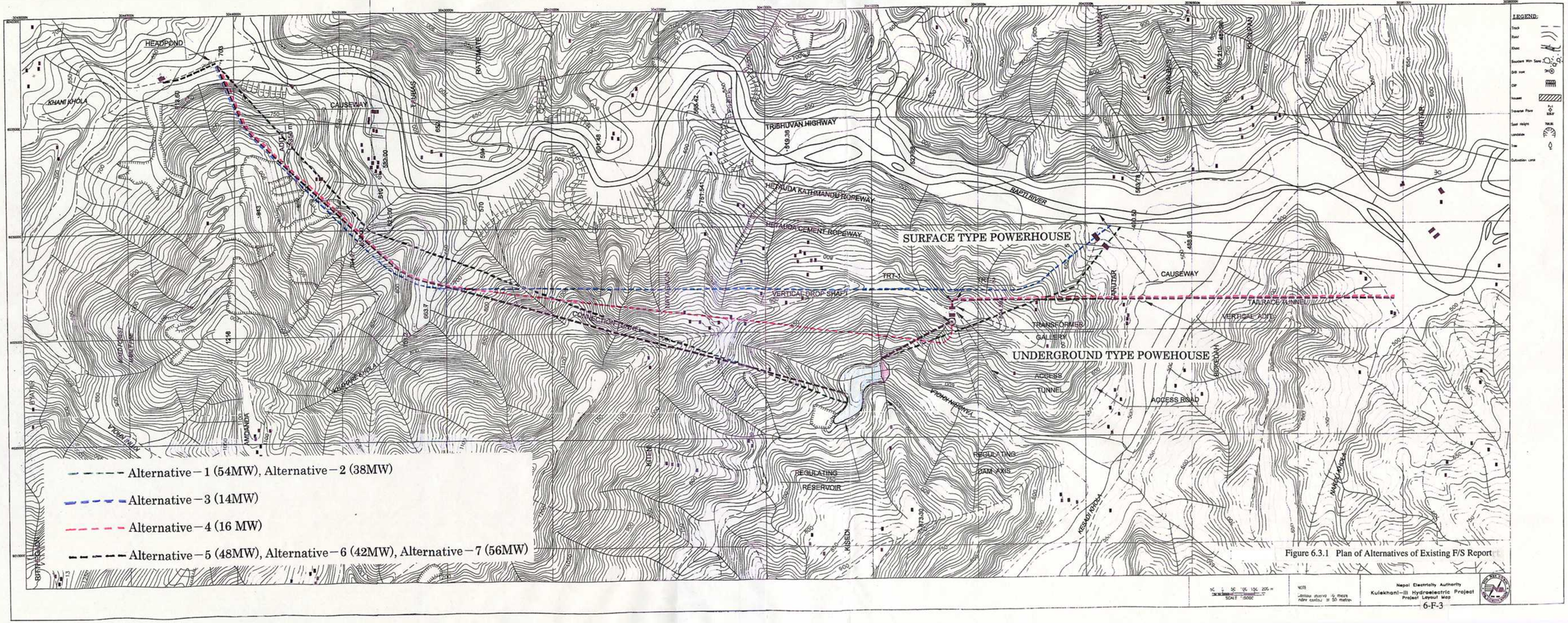


Figure 6.3.1 Plan of Alternatives of Existing F/S Report