12.3 Operation Plan of Reservoir and Power Plant

12.3.1 Basic Conditions for Reservoir Operation Plan

(1) Reservoir Operation Conditions provided by Hydrological Characteristics of the Basin

Rivers in areas affected by Asian tropical monsoons generally have vast differences in flow volumes from the dry season to the rainy season, and there are also significant differences from one year to the next. As outlined in chapter 9, the Se Kong Basin has typical characteristics of the basins in Asian tropical climate. In order to take full advantage of the hydropower potentials of a river with wide variances in flow volumes, it is necessary to fabricate an enough storage capacity of reservoir and regulate the natural inflow.

The necessary storage capacity of reservoir will naturally vary with the level of the flow volume variance of the river. According to the mass-curve analysis on 10 years inflow data estimated in Chapter 9 for each project site, it is expected that a reservoir storage capacity which is able to regulate varing inflow volume over several years (carry over reservoir operation) provides an efficient reservoir operation. Therefore, in the project scale optimization study in Chapter 13, the carry over operation rule is applied for the determination of effective storage capacity of the reservoirs.

(2) Reservoir Operation Conditions for Power Export

Since the main purpose of the hydropower development in the Se Kong Basin is electric power export, it is necessary to study power plant operation plan according to conditions required for electricity export.

Electric power export from Laos to Thailand is already taking place at the Nam Ngum and Xe Set hydropower plants. The Xe Set hydropower plant is a run-off-river type and therefore depends on the level of daily discharge, and production capacity drops off drastically in the dry season. For this reason, the Xe Set hydropower plant cannot be relied upon as a steady source of power supply. During the rainy season, in contrast, increased output is treated as secondary output and therefore export electric price has been set at a low level.

On the other hand, the Nam Ngum hydropower plant has a large-scale reservoir allowing for year-round moderation of flow volumes, and therefore it is treated as a reliable source of electric power even for the power system of Thailand. Here, electric prices are determined by demand times. The price of electricity at peak demand time is about 2.2 times of the price of off-peak time. However, the peak time lasts only for three hours, and therefore the amount of energy supply during peak hours does not account for a large percent of the whole amount of energy exported.

In this connection, in the study of hydropower development in the Se Kong Basin, the priority is given to securing a sufficient reservoir capacity which guarantees stable energy supply and to minimizing unit energy production cost per kWh for determination of optimum operation plan of each project.

(3) Reservoir Operation Conditions for Domestic Power Supply

In southern Laos, the region earmarked for domestic power supply in this study, demand is far below the output potential of the three priority projects being planned in the Se Kong Basin. In fact, two of the proposed projects, the Se Kong No. 4 and the Xe Kaman No. 1 projects will be able to satisfy total regional domestic power demand even during the dry season. The Xe Namnoy project, with its low flow levels during the dry season, requires a reservoir for annual wide flow regulation in order to secure stable energy supply. Given the low level of local demand, this project will easily be able to satisfy the demand of the entire southern region with a relatively small reservoir.

According to the conditions above, requirement for domestic power supply does not provide any restrictions on reservoir operation plan of each project. In this connection, any condition for domestic power supply is not considered in the optimization study on development scale.

12.3.2 Basic Conditions for Power Plant Operation Plan

(1) Power Plant Operation Conditions for Power Export

As outlined in 12.1.1, the practical turget of energy export by hydropower development in the Se Kong Basin is Thailand for the time being. Accordingly, the operation plan is studied assuming the energy export to Thailand.

Looking at changes in the demand load curve of Thailand's power system in recent years, dramatic changes commensurate to economic growth are occurring due to increased daytime power demand from industries and offices. The pattern of Thailand's power demand is shifting from a nighttime-peak to a daytime-peak year by year. In this connection, it is expected that increase of the demand load factor will continue for a while and the peak time will become longer. Further, Thailand has a development plan of a pumped storage hydropower plant to meet demand in peak hours.

In consideration of the above conditions, even for a reservoir type hydropower project, it is not appropriate to establish an operation plan for peak power supply in case of a project for power export to Thailand. In view of the recent daily load curve of Thailand, peak power duration of 8 hours is applied in the project scale optimization study.

(2) Power Plant Operation Conditions for Domestic Power Supply

To summarize the current power supply system of the four southern provinces in Loas, the system centering on Pakse City has achieved 24 hours power supply by the Xe Set (45 MW) and Selabam (5 MW) hydropower plants. However, in other areas including Attapu Town and Sekong Town, electricity is being supplied only for 3 hours of lighting at nighttime by independent diesel generators and mini-hydropower plants.

The projects selected for the pre-feasibility study are of large-scale projects in the Se Kong Basin. They will provide an important contribution to the electricity supply for the southern region of Loas. When these projects are implemented and the isolated power systems mentioned above are linked to an integrated transmission system, 24-hour electricity supply for those isolated areas will become possible. When this is achieved, latent demand for electric power will drive up electricity consumption in this region.

For domestic power supply from the Se Kong Basin, it is possible to apply the 24-hour operation. However, since domestic demand in this region is extremely small compared to the output potential of a large-scale hydropower project, any generating unit strictly for domestic purposes will be both inefficient and uneconomical.

The existing Xe Set and Selabam power plant are run-off river hydropower plants which operate 24 hours a day. They are able to meet domestic off-peak demand. However, when supply capability becomes insufficient during the driest months and when off-peak demand grows in southern Laos in the future, it will be better to develop additional resources to meet domestic demand. However, even without development of additional domestic resources, it is possible to continue the current convention of importing electric power from Thailand to meet domestic supply shortages.

On the other hand for peak power supply, medium to large-scale projects in the Se Kong Basin will play an important role in satisfying domestic demand. For this reason, it is required to establish a configuration of power generating units of each project applying operation conditions for securing a level of power system reliability.

Considering all of the above situations, the following conditions are applied to the power plant operation plan of three projects selected in the Se Kong Basin for pre-feasibility study;

a) Small-scale generator units for domestic supply will not be installed.

b) Transformers for connecting local power system to supply domestic power demand will be installed in addition to the main transformer.

c) Full day (24 hours) operation including off-peak hours is not applied as a condition of plant operation based on the assumption that the domestic power demand is supplied by entire power system of the southern region.

d) In consideration of power supply stability for domestic power demand during peak hours, each project has a configuration of at least two generating units.

(3) Power Plant Operation Conditions for Maintaining the Downstream River Functions

In consideration of the effects on the natural and social environment, it is necessary to maintain river flow conditions of project downstream in which fish and other organisms can live. It is also necessary to maintain water levels sufficient for shipping, irrigation, fishing and other social activities. These factors of river maintenance shall provide conditions for power plant operation of hydropower development project.

Regarding the actual levels and conditions of river flow to be discharged to downstream, detailed conditions shall be determined on a project-by-project based on an environmental impact assessment. However, since such detailed assessment has not been carried out, the operation conditions to be applied are not clear at present time. In this study in principle, a condition that at least two-thirds of monthly mean discharge during the driest month should be maintained at the project downstream throughout a day (24 hours) for maintaining river functions is applied for power plant operation of each project.

Based on this condition, the hydrological data for 10 years estimated in Chapter 9 provide levels of river flow to be maintained in downstream of projects. Regarding the method of releasing the discharges shown below, it is necessary to consider the conditions of each project individually. Chapter 13 addresses this issue.

Project	Catchment Area	Monthly Mean Discharge of Driest Month	Discharge for Maintaining River Functions
Se Kong No. 4	5,400 km^2	45 m^3/s	30 m^3/s
Xe Kaman No. 1	3,800 km^2	30 m^3/s	20 m^3/s
Xe Namnoy Midstream	531 km^2	1.5 m^3/s	1.0 m^3/s
Xe Namnoy Downstream	1,252 km^2	5.0 m^3/s	3.8 m^3/s

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13. Selection of Optimum Development Plan

13.1 Basic Policy for Optimization Study

In this section, the basic policies on the following items are determined for the optimization study on each development project.

- Basic data for the study
- Reservoir operation conditions
- Power plant operation conditions
- Conditions for construction cost estimation
- Conditions for project evaluation

The above conditions are determined based on the conditions regarding the reservoir operation plan and power generation operation plan described in Chapter 12.

(1) Basic Data

a) Topographic Maps

1/10,000 scale topographic maps developed in this master plan study, are used for the studies on the layout of major project structures.

For the Se Kong No.4 and Xe Kaman No.1 Projects, however, the reservoir area-storage volume curves estimated based on 1/50,000 scale maps are used in the optimization study. These storage volume curves may be used because the reservoirs of the two projects are extremely large and the reservoir storage volumes place no constraints on the power plant operation of the respective project.

b) Hydrological and Meteorological Data

The following hydrological and meteorological data, which were estimated for each project in Chapter 9, are used in the study;

- Reservoir inflow: monthly discharge data of a 10-year period from August, 1984 to July, 1994
- Evaporation: monthly reservoir surface evaporation

- Design flood: estimated design flood discharge at each dam site
- Sediment volume: accumulated sediment volume for 100 years

(2) Reservoir Operation Conditions

a) Reservoir Operation Rule

Since a series of discharge data for a 10-year period are available for each project, a reservoir operation rule which regulates a series of reservoir inflow over years (carry-over operation)is applied for the reservoir type projects. For the regulation pond type projects, the daily regulation rule is applied.

b) Effective Storage Capacity and Firm Discharge

Firm discharge is determined for a effective storage capacity by the mass-curve calculation with a series of inflow data for a 10-year period.

The firm discharge is used as the standard of minimum release from the reservoir in the calculation of the reservoir operation in the estimation of energy generation of each project.

In this study, 90% is applied as the firm discharge dependability.

c) Outflow for Downstream

The full day (24 hours) outflow discharge through the dam outlet or turbine is set, in principle, as a condition on the reservoir operation in order to maintain the original river function downstream of the project. In this study, 2/3 of the original mean flow of the driest month at a project site is applied as the full day outflow discharge as described in Chapter 12. This outflow is supplied as a part of the firm discharge.

(3) Power Plant Operation Conditions

a) Peak Power Duration

As described in Chapter 12, 8 hours is applied as a peak power duration for reservoir type projects.

Peak power duration of the regulation pond type project (Xe Namnoy Downstream Project) is determined by the optimization study.

b) Conditions of Outflow through the Turbine

Where the full day outflow condition set in (2) c) above is released through the turbine, that condition is applied for power plant operation.

(4) Conditions of Construction Cost Estimation

a) Total Construction Cost Configuration

The total construction cost applied to the optimization study includes the costs of preparatory works (includes construction road), civil works, hydraulic mechanical equipment, electro-mechanical equipment, physical contingencies, compensation, engineering fees and administration. The construction cost of the transmission line is excluded.

b) Estimation of Work Quantities

For civil structures and hydraulic mechanical equipment, work quantities are estimated based on the principle parameters of each structure determined with 1/10,000 scale topographical maps.

For the electro-mechanical equipment, the number and capacities of units and the turbine types are determined based on the maximum discharge, rated effective head, and power plant operation conditions.

For the construction road, an access road leading from an existing main road to the project site is counted based on the study in 8.5, Chapter 8.

c) Unit Costs of each Work

For civil works and hydraulic mechanical equipment, the unit costs listed in **Table 13.1-1** are used in the study.

For electro-mechanical equipment, the cost is estimated by individual study based on unit configuration and turbine type.

d) **Compensation Cost**

For compensation cost, the cost estimated in 11.3, Chapter 11, based on the results of environmental surveys performed in this Master Plan Study is used in the study.

e) **Others**

For other items, the costs are estimated by employing constant rates as follows;

- Physical contingency: 10% of civil works cost
- Engineering fee: 5% of costs of civil works and hydro and electro-mechanical works
- Administration cost: 5% of costs of civil works and hydro and electro-mechanical works

(5) **Economic Evaluation Index**

Regarding the economic evaluation of each case in the project scale optimization study, as the major purpose of the project development is energy export, unit energy cost per kWh (C/E), which is calculated by dividing annual cost (C) by annual energy (E), is used as the primary index.

In addition to the C/E, the benefit cost ratio (B/C), net benefit (B-C), and unit construction cost per kW are calculated and correctly employed.

Annual cost (C) and annual benefit (B) are calculated as follows;

a) **Annual Cost (C)**

The annual cost of the project is calculated by multiplying the annual cost rate with the total construction cost. In this study, an annual cost rate of 11% is applied, based on the conditions shown in **Table 13.1-2**.

b) **Annual Benefit (B)**

An alternative thermal plant method is applied for the calculation of the annual benefit of the project. The unit benefits listed below are calculated as shown in

Table 13.1-2, employing a gas combined cycle power plant as the alternative thermal plant.

- Unit benefit per kW: 135 US$/kW
- Unit benefit per kWh: 19.20 US$/MWh

The annual benefit of a project is calculated by multiplying the above unit benefits to a 90% dependable peak power output (kW) and to the annual energy (kWh) at the generating end respectively, calculated by reservoir operation and power generation simulation respectively

The optimization studies on each project are conducted by applying the above conditions. The contents of the optimization studies on the Se Kong No.4, Xe Kaman No.1, and Xe Namnoy Projects are shown in the following sections.

Table 13.1-1 Project Cost Parameters for Optimization Study

Unit: US$

Item	Description	Unit	Unit Rate 1993
Excavation	Earth (Open)	m^3	4
	Rock (Open)	m^3	9
	Tunnel	m^3	50
	Shaft	m^3	100
	Underground	m^3	50
Embankment	Dam (Xe Namnoy Mid.)	m^3	7
	Dam (Others)	m^3	6
	Others	m^3	3
Concrete	Dam	m^3	100
	Facing	m^3	270
	Structure	m^3	150
	Lining	m^3	200
	Base	m^3	150
	Backfill	m^3	150
Reinforcement Bar		t	900
Hydro-mechanical Equipment	Gates	t	5,000
	Penstock	t	4,000
	Trashrack	t	5,000
Construction Road	Plain (unpaved)	km	50,000
	Mountainous (unpaved)	km	70,000
	Improvement	km	30,000
Concrete Bridge	W = 7 m, L = 25 m	m	5,000
	W = 7 m, L = 40 m	m	8,000
	W = 7 m, L = 80 m	m	11,000
	W = 7 m, L = 130 m	m	9,000

Table 13.1-2 Project Evaluation Parameters for Optimization Study

No.	Description	Unit	Conditions of Alternative Thermal		Conditions of Hydropower Projects	
(1)	Plant Type	-	Gas Combined Cycle		Hydropower Plant	
(2)	Plant Capacity	kW	1		by case	
(3)	Plant Factor	%	40.0%		by case	
(4)	Annual Energy Production	kWh	3468		by case	
(5)	Investment Cost	$/kW	772.5		by case	
(6)	Plant Service Life	years	25		50	
(7)	Construction Period	years	3		by case	
(8)	Discount Rate	%	10.0%		10.0%	
(9)	Capital Recovery Factor	%	11.0%		10.1%	
(10)	Average O & M Cost Rate	%	2.5%		0.9%	
(11)	Fueal Cost	$/M.Btu	2.427		-	
(12)	Fuel Heat Rate	Btu/kWh	7595.2		-	
	Fixed Cost					
(13)	Capital Cost	$/kW	85.10		by case	
(14)	O & M Cost	$/kW	19.31		by case	
(15)	Total Fixed Cost	$/kW	104.42		by case	
	Annual Coat Rate	%	13.5%		11.0%	
	Variable Cost					
(16)	Energy Cost	$/MWh	18.43		-	
	Adjustment Factor		kW	kWh	kW	kWh
(17)	Scheduled Outage Rate	-	0.173	0.000	0.020	0.000
(18)	Forced Outage Rate	-	0.090	0.000	0.005	0.000
(19)	Station Service Rate	-	0.050	0.050	0.003	0.003
(20)	Transmission Line Loss	-	0.020	0.010	0.030	0.015
(21)	Adjustment Factor	-	1.369	1.061	1.059	1.018
(22)	Net Adjustment Factor of Hydropower Plant	-			1.293	1.042
					$/kW	$/MWh
(23)	Unit Benefit of Hydropower Plant	-	-	-	134.97	19.20

13.2 Optimization Study of the Se Kong No.4 Project

13.2.1 Selection of the Basic Project Layout (Fig. 13.2-1)

(1) Dam Site Selection

Using 1/50,000 scale topographic maps, the dam site of the Se Kong No.4 Project selected in the study on the development plan inventory in Chapter 7, is located at where the Se Kong River flows onto the plain lying north to south along the eastern side of the Bolaven Plateau. At this site, the riverbed elevation site is approximately EL.140m and the catchment area is 5,400 km^2. The river gradient of the area upstream from this site is gentle until the site with a riverbed elevation of approximately EL.300m, which is the downstream of the Se Kong No.5 project site. A large reservoir could be constructed in this area.

From reviewing the above dam site using the 1/10,000 scale topographic maps developed in this Master Plan Study, it is confirmed that due to the topographic conditions of the canyon and the elevations of the right and left banks along the river there are no appropriate dam sites other than that described above. The geology of the dam site is mainly composed of sedimentary rocks such as sandstone and conglomerate stone with a partial distribution of limestone. A massive outcrop of hard sandstone is observed on the riverbed. Geological investigations show no serious geological problems for the dam's construction.

According to the above conditions, the dam site of the Se Kong No.4 Project is selected at the site shown in **Fig. 13.2-1**.

Here, a saddle is located upstream in the left bank water shade of the reservoir. The 1/10,000 scale map confirms that the bottom elevation of this saddle is approximately EL.340m, so that no problem in the reservoir's watertight integrity is expected when the reservoir HWL is EL.300m or lower.

(2) Type of Dam

Regarding the dam type, it is expected that a concrete gravity or rockfill dam will be applicable to the topographic and geological conditions of the site. According to the 1/10,000 scale maps, however, the dam becomes very large with a height of 170m and a crest length of 960m for a reservoir HWL of EL.300m Therefore, a rockfill dam is advantageous in terms of its construction cost.

In the case of a rockfill dam, however, the procurement of construction materials presents a problem because the dam volume is very large. Especially in the case of the impervious clay core type, due to the geological conditions around the dam site, some difficulty is expected in obtaining materials for the impervious core.

To overcome this problem, it is possible to employ a concrete or asphalt surface wall rockfill dam. The type of impervious wall or core is studied in the preliminary design stage. At this stage, however, the concrete facing type is temporarily selected for the optimization study.

(3) Layout of Waterway and Powerhouse

The river gradient is gentle in the downstream section of the Se Kong No.4 dam site, and a head cannot be expected to be developed by the waterway. Accordingly, other than the dam type scheme no alternative development scheme is available for the Se Kong No.4 Project. Its powerhouse site is selected immediately downstream from the dam site.

There are no geological constraints on constructing the major structures around the dam site. From the study of the structure layout, using 1/10,000 scale maps, a layout of an intake, headrace tunnel, open penstock and powerhouse is selected on and in the right bank side, as shown in **Fig. 13.2-1**. An optimization study on project scale is carried out based on this layout.

13.2.2 Basic Conditions for Optimization Study

(1) Reservoir Operation Conditions

a) Reservoir Operation Rule

For the reservoir operation, the carry-over type operation rule is applied as described in 13.1.

b) **Effective Storage Capacity**

Fig. 13.2-2 shows the reservoir area-storage volume curve at the Se Kong No.4 dam site as selected in 13.2.1. The gross storage volume at an HWL of EL.300m is estimated to be 7,776 MCM. This volume is extremely large against the mean annual inflow volume of 5,721 MCM at the dam site as estimated in Chapter 9. Even in the case of a lower HWL, a sufficient effective storage volume is available after considering the sediment volume and water depth for the installation of the intake.

Therefore, a limitation of effective storage volume provides no constraints on reservoir operation. The optimum effective storage volume is determined by comparative study in 13.2.3.

c) **Firm Discharge**

Fig. 13.2-3 shows the mass curve of the reservoir inflow volume for a 10-year period. **Fig. 13.2-4** shows the relationship between the effective storage capacity and firm discharge calculated by applying carry-over reservoir operation to the inflow mass curve above.

From this it is seen that the incremental amount of firm discharge becomes small at around 1,100 MCM of the effective storage capacity, which is approximately 20% of the annual inflow volume, although due to the application of carry-over operation, the firm discharge increases gradually with larger effective storage capacities.

d) **Discharge for Maintaining River Function**

In the case of the Se Kong No.4 Project, which is a dam type, there is no river section where the discharge is not supplied to the river. Accordingly, no conditions are set on the reservoir operation.

(2) **Power Plant Operation Conditions**

a) **Peak Power Duration**

As stated in 13.1, the peak power duration is set at 8 hours.

b) **Discharge for Maintaining River Function**

The Se Kong No.4 Project, which has a large reservoir, stores almost all the inflow and, except for the spilled flood, the outflow is discharged only through the turbine. Accordingly, if power generation is stopped during the off peak hours, no discharge is supplied to the downstream.

There are social activities such as navigation and fishing downstream from the dam site. In order to maintain the river function for these activities, a condition is set on the reservoir operation in order to supply a certain discharge to the downstream.

For this discharge, 30 m^3/s is applied, following the condition determined in 13.1.

c) **Maximum Discharge for Power Generation**

Maximum discharge (Qmax) is set by the following formula by applying the above conditions;

$$Qmax = (Qf - 30) \times 24/8 + 30 \quad (m^3/s)$$

d) **Turbine/Generator Configuration**

If the full day outflow determined in b) above is released directly from the dam outlet, the loss of energy generation becomes large. Therefore, partial power generation is applied by this outflow volume during the off peak hours, supplying downstream discharge through the turbine.

In this case, a configuration of power units able to achieve this operation is required. At this optimization study stage, a uniformed capacity is applied for all units of each case, setting the maximum discharge per unit at 90 m^3/s against the full day outflow of 30 m^3/s and taking into account that the minimum discharge for partial operation is, in general, approximately 30% of the maximum discharge in the case of a Francis turbine.

(3) Conditions for Construction Cost Estimation

a) Access Road

Regarding the route for the transportation of construction material and equipment to the Se Kong No.4 project site, as described in 8.5, Chapter 8, a national road is available from the border with Thailand. This road runs through Pakse to Ban Phon which is located approximately 10 km north of Sekong Town. Some improvement works are required for this road. Therefore, the dedicated access road for the Se Kong No.4 Project is an approximately 14 km section leading from Ban Phon to the project site. The construction of a new road or the reconstruction of the existing road are required for this section.

At this stage, the cost of the above works for the 18 km section is counted in the project construction cost. The constant access road cost is applied for each case of project scale.

b) Compensation Cost

The compensation costs by reservoir HWLs estimated based on the compensation survey in this Master Plan Study are as shown below;

HWL (m)	Compensation Cost (M.US$)
280	4.57
300	4.72
320	4.72

As shown above, there are only minimal differences in compensation costs between some HWLs. Therefore, a constant compensation cost is applied for each case of HWL. In this study, 4.72 M.US$, the compensation cost where the HWL is EL.300 m, is applied in project cost estimation.

13.2.3 Selection of Optimum Development Scale

In this section, the optimum development scale of the Se Kong No.4 Project is determined based on the basic layout selected in 13.2.1 and the basic conditions clarified in 13.2.2. To determine the optimum development scale, comparative studies are performed with varied reservoir HWLs and effective reservoir capacities.

(1) Study on Reservoir HWL

As described in 13.2.2 (1), the mean annual inflow volume for 10 years at the Se Kong No.4 dam site is estimated at 5,720 MCM, and annual wide flow regulation is achieved when the effective reservoir capacity is 20% or more of the annual inflow volume. Concerning this condition, a sufficient gross reservoir storage volume is available at a reservoir HWL of around EL.300m for the Se Kong No.4 Project, as shown in **Fig. 13.2-2**. Therefore, there are no constraints on setting an appropriate effective reservoir capacity.

In this connection, a comparative study on reservoir HWLs is first made with the conditions of a constant peak power duration of 8 hours and a constant effective reservoir capacity of 1,700 MCM, which is 30% of the mean annual inflow volume. This effective reservoir capacity provides a firm discharge of 143 m^3/s for all cases.

The study is made by varying the HWLs from EL.260m to EL.320m with the above conditions. This comparative study shows an HWL of EL.290m provides the best performance in unit energy cost, unit construction cost per kW, and B/C respectively, as shown in **Table 13.2-1**. Accordingly, EL.290m is selected as the optimum HWL for the Se Kong No.4 Project.

(2) Study on Effective Reservoir Capacity

With an HWL of EL.290m, a second comparative study is then made on the effective reservoir capacity by varying its ratio to the mean annual inflow volume to be 25, 30, 35, 40, and 45%, respectively. These cases provides firm discharges of 137, 143, 149, 155, and 161 m^3/s, respectively, as shown in **Fig. 13.2-4**. Accordingly also, the maximum discharge provided with the peak power duration of 8 hours varies in each case.

This comparative study shows that an effective reservoir capacity of 30% of the mean annual inflow volume (Ve = 1,700 MCM) provides the best performance in unit energy cost although the case of 35% provides slightly better performance in B/C, respectively, as shown in **Table 13.2-2**. Accordingly, 1,700 MCM is selected as the optimum effective reservoir capacity of the Se Kong No.4 Project. In this case, the reservoir storage volume under the low water level (LWL) is 4,699 MCM, providing sufficient room against an estimated reservoir sediment volume of 226 MCM.

(3) Optimum Development Scale

According to the above comparative studies on reservoir HWLs and effective storage capacities, the optimum development scale of the Se Kong No.4 Project is determined as the plan below.

Reservoir HWL	290.0	m
Reservoir LWL	275.4	m
Effective Storage Capacity	1,700	MCM
Firm Discharge	143	m^3/s
Minimum Outflow (through Turbine)	30	m^3/s
Peak Power Duration	8	hours
Maximum Discharge	370	m^3/s
Rated Intake Water Level (IWL)	285.1	m
Rated Tail Water Level (TWL)	145.0	m
Rated Effective Head (He)	137.0	m
Installed Capacity	443	MW
Dependable Peak Capacity	406	MW
Annual Energy	1,816	GWh

13.2.4 Remarks on the Development Plan

The above development plan is proposed as the optimum plan of the Se Kong No.4 Project based on the technical studies with the data and information presently available. Several remarks requiring clarification in further stages are, however, indicated as follows;

a) Technical Matters

Although there are no specific geological problems, because the dam is quite large, investigations regarding the quantity of dam construction materials are required.

b) Environmental Impact Issues

The appropriate mitigation measures for an estimated 3,600 people requiring resettlement should be carefully studied.

Investigations and studies on the project impact on the ecology are required because the inundation area would be wide at approximately 130 km^2.

c) **Others**

A possibility of coal mining development is reported in the reservoir area. If this is clarified, adjustment or the priority of the development plans should be discussed.

Table 13.2-1 Study on Reservoir HWL (Se Kong No.4)

Description	Unit	Case-1	Case-2	Case-3	Case-4	Case-5	Case-6	Case-7
Reservoir HWL	m	260.0	270.0	280.0	290.0	300.0	310.0	320.0
Dam Crest Length	m	810	850	895	925	960	995	1,030
Dam Height	m	130	140	150	160	170	180	190
Reservoir Area	km^2	82	103	114	130	145	160.4	180.5
Gross Storage Capa.	MCM	3,217	4,142	5,180	6,399	7,776	9,305	11,035
Sediment Capa.	MCM	226	226	226	226	226	226	226
Net Storage Capa.	MCM	1,700	1,700	1,700	1,700	1,700	1,700	1,700
Reservoir LWL	m	233.9	249.6	262.9	275.4	287.4	298.8	310.2
Firm Discharge	m^3/s	143	143	143	143	143	143	143
River Maint.Release	m^3/s	0	0	0	0	0	0	0
Base Power Discharge	m^3/s	30	30	30	30	30	30	30
Max. Power Discharge	m^3/s	370	370	370	370	370	370	370
Rated IWL	m	251.3	263.2	274.3	285.1	295.8	306.3	316.7
Rated TWL	m	145.0	145.0	145.0	145.0	145.0	145.0	145.0
Gross Head	m	106.3	118.2	129.3	140.1	150.8	161.3	171.7
Effective Head	m	103.1	115.0	126.1	137.0	147.6	158.1	168.6
Installed Capacity	MW	336	374	409	443	477	510	543
Annual Inflow	MCM	5,721	5,721	5,721	5,721	5,721	5,721	5,721
Annual Evaporation	MCM	70	87	105	119	134	149	167
Annual Dam Outflow	MCM	152	113	78	26	21	21	21
Annual Turbine Out.	MCM	5,500	5,522	5,538	5,577	5,567	5,551	5,533
Firm Peak Capacity	MW	287	331	366	406	428	463	501
Annual Energy	GWh	1,358	1,522	1,660	1,816	1,934	2,066	2,246
Plant Factor	%	46	46	46	47	46	46	47
Construction Cost	M.US$	493.5	538.1	586.2	634.4	686.5	741.9	800.8
Annual Cost	M.US$	54.3	59.2	64.5	69.8	75.5	81.6	88.1
Annual Benefit	M.US$	64.8	73.8	81.3	89.7	94.9	102.2	110.7
Unit Energy Cost	$/MWh	40.0	38.9	38.8	38.4	39.0	39.5	39.2
B-C	M.US$	10.5	14.6	16.9	19.9	19.4	20.6	22.6
B/C	-	1.19	1.25	1.26	1.29	1.26	1.25	1.26
Const.Cost/kW	M.US$	1,468	1,440	1,434	1,432	1,440	1,455	1,475
Selected Case	-				*			

Table 13.2-2 Study on Effective Storage Capacity (Se Kong No.4)

Description	Unit	Case-1	Case-2	Case-3	Case-4	Case-5
Regulation Ratio	%	25	30	35	40	45
Reservoir HWL	m	290.0	290.0	290.0	290.0	290.0
Dam Crest Length	m	925	925	925	925	925
Dam Height	m	160	160	160	160	160
Reservoir Area	km^2	130	130	130	130	130
Gross Storage Capa.	MCM	6,399	6,399	6,399	6,399	6,399
Sediment Capa.	MCM	226	226	226	226	226
Net Storage Capa.	MCM	1,410	1,700	1,980	2,260	2,550
Reservoir LWL	m	278.1	275.4	272.7	270.0	266.9
Firm Discharge	m^3/s	137	143	149	155	161
River Maint.Release	m^3/s	0	0	0	0	0
Base Power Discharge	m^3/s	30	30	30	30	30
Max. Power Discharge	m^3/s	352	370	388	406	424
Rated IWL	m	286.0	285.1	284.2	283.3	282.3
Rated TWL	m	145.0	145.0	145.0	145.0	145.0
Gross Head	m	141.0	140.1	139.2	138.3	137.3
Effective Head	m	137.9	137.0	136.1	135.3	134.3
Installed Capacity	MW	424	443	462	480	498
Annual Inflow	MCM	5,721	5,721	5,721	5,721	5,721
Annual Evaporation	MCM	120	119	117	115	113
Annual Dam Outflow	MCM	80	26	16	0	0
Annual Turbine Out.	MCM	5,522	5,577	5,588	5,606	5,608
Firm Peak Capacity	MW	377	406	418	423	427
Annual Energy	GWh	1,781	1,816	1,818	1,807	1,794
Plant Factor	%	48	47	45	43	41
Construction Cost	M.US$	630.8	634.7	645.8	653.2	660.5
Annual Cost	M.US$	69.4	69.8	71.0	71.8	72.7
Annual Benefit	M.US$	85.0	89.7	91.4	91.8	92.1
Unit Energy Cost	$/MWh	39.0	38.4	39.1	39.8	40.5
B-C	M.US$	15.7	19.9	20.4	20.0	19.5
B/C	-	1.23	1.28	1.29	1.28	1.27
Const.Cost/kW	M.US$	1,487	1,432	1,399	1,361	1,327
Selected Case	-			*		

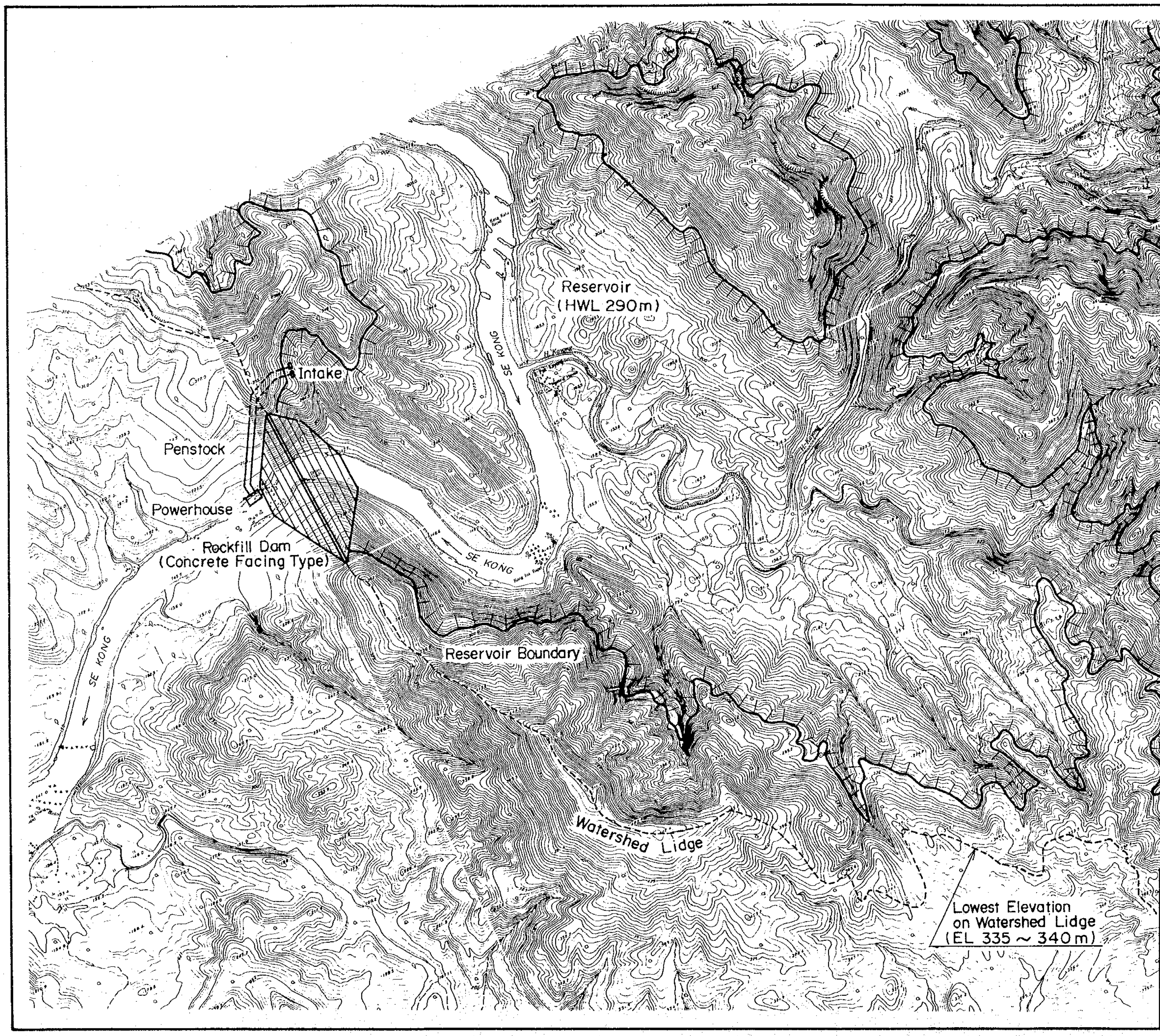
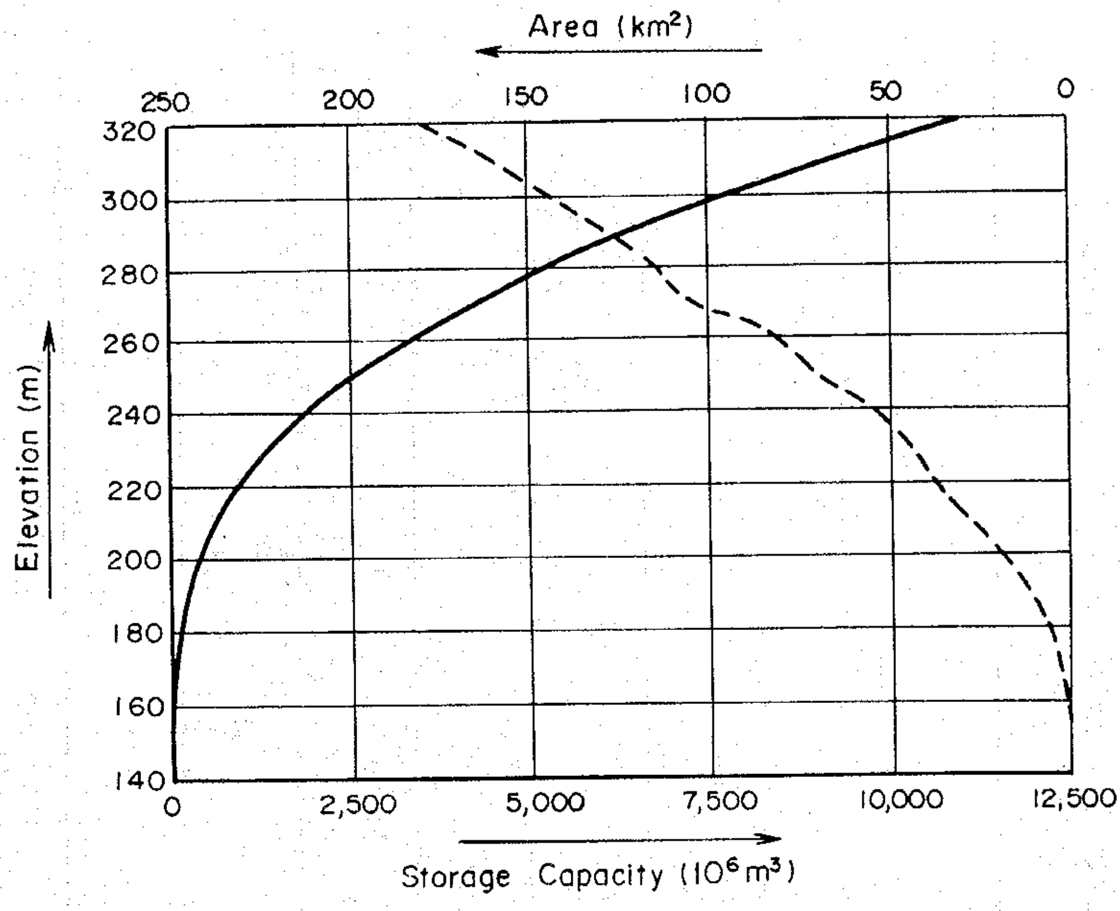


Fig. 13.2 - 1
Basic Layout of
Sekong No.4 Project

Fig. 13.2-2 Area and Storage Capacity Curve of Se Kong No. 4 Reservoir



Elevation (m)	* Area (km^2)	Storage Capacity (10^6 m^3)
320	180.5	11,035
310	160.4	9,305
300	145.4	7,776
290	129.6	6,399
280	114.2	5,180
270	103.0	4,142
260	82.1	3,217
250	70.3	2,471
240	55.4	1,843
220	37.0	920
200	19.7	353
180	7.1	86
160	1.2	3
140	0	0

* measured using 1/50,000 scale topographic maps

Fig. 13.2 – 3 Mass-curves at Se Kong No.4 Dam Site

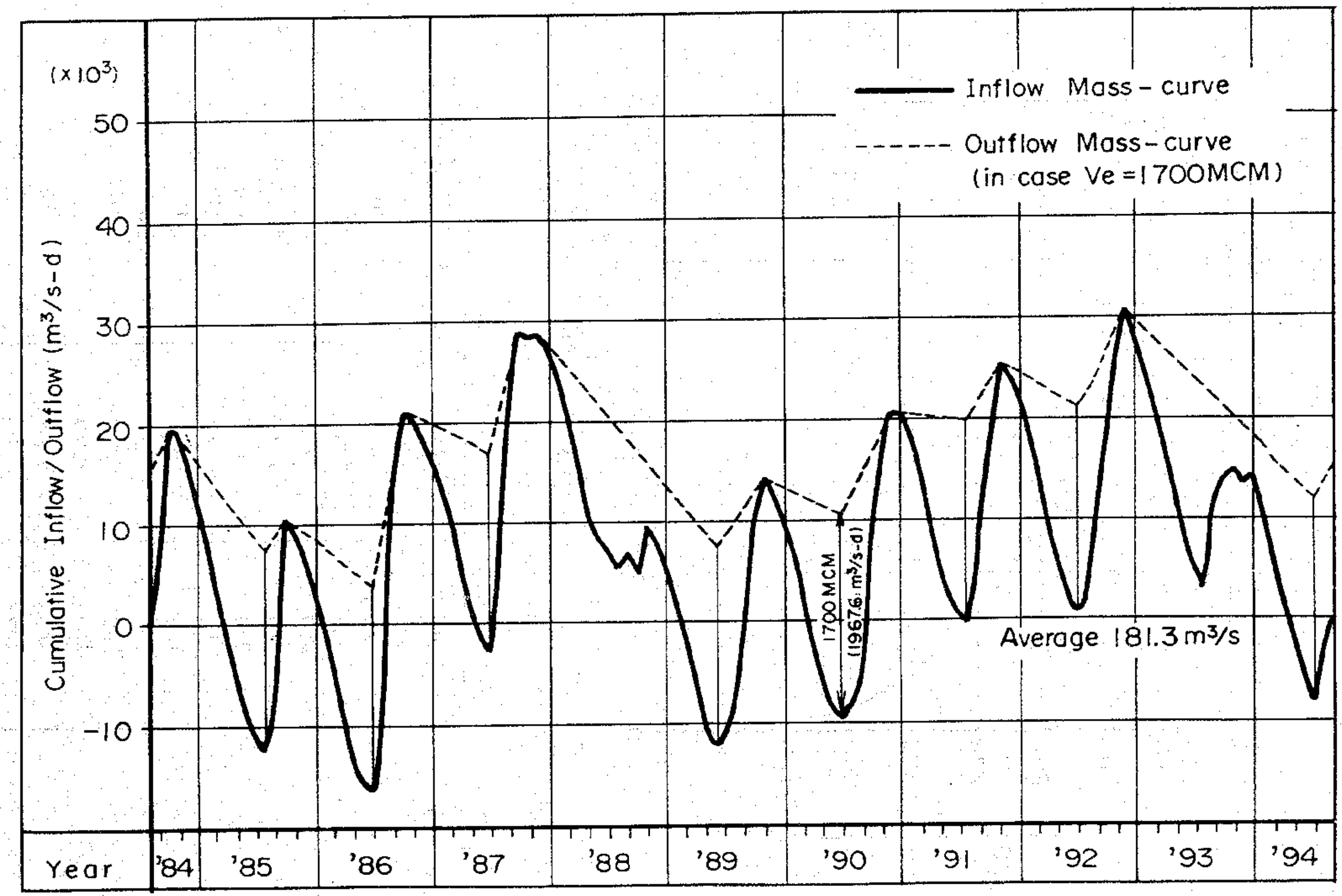
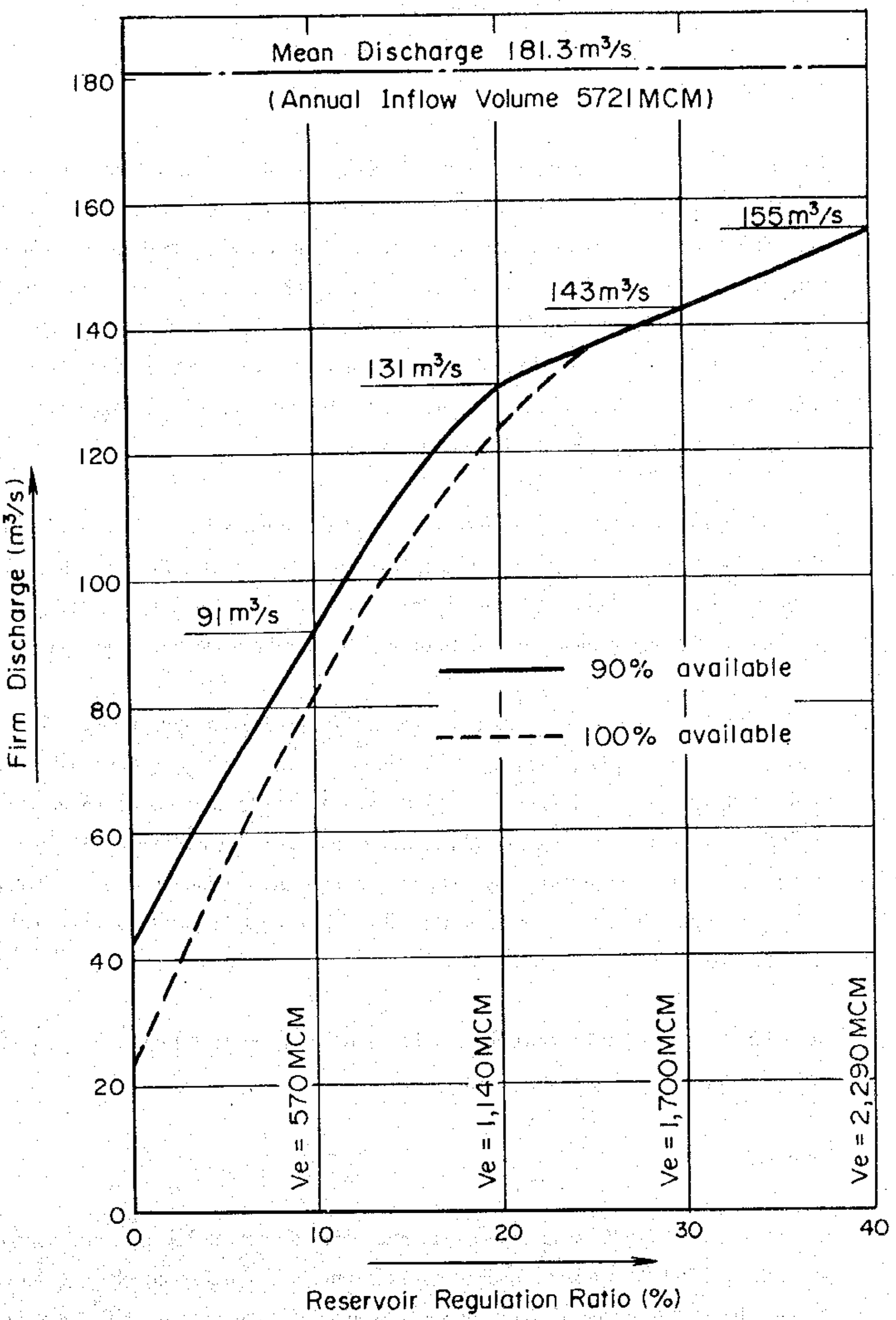


Fig. 13.2-4 Firm Discharges provided by Se Kong No. 4 Reservoir



Note) This figure is based on the mass-curve calculation for 10 years period with carry-over reservoir operation rule.

13.3 Optimization Study of the Xe Kaman No. 1 Project

13.3.1 Selection of Basic Project Layout (Fig. 13.3-1)

(1) Dam Site Selection

Using 1/50,000 scale topographic maps, the dam site of the Xe Kaman No.1 Project selected in the study on the development plan inventory in Chapter 7, is located approximately 12 km upstream from where the Xe Kaman river flows onto the plain lying north to south along the east side of the Bolaven Plateau. At this site, the riverbed elevation is approximately EL.120m and the catchment area is 3,800 km^2. The river gradient of the upstream area from this site is gentle until where the riverbed elevation is approximately EL.280m, and where the dam site of the Xe Kaman No.2 Project is located. A large reservoir could be established in this area.

Using the 1/10,000 scale topographic maps developed in this Master Plan Study, reviews of the above dam site confirm that with a reservoir HWL of EL.280m, which is of the inventory plan, the above dam site is the most appropriate due to the topographic conditions of the canyon and the elevation of the left and right banks along the river.

The geology of the dam site is mainly composed of unweathered shale stone. The right bank forms a steep cliff with outcrops. The left bank is also relatively steep and covered by thin weathered layer. Geological investigations at the site show no serious geological problems against dam construction. Although a limestone distribution which cannot be judged by the information presently available, is seen around the upstream end of the reservoir. It may, however, provide no critical problems regarding the watertight integrity of the reservoir.

According to the conditions given above, the dam site of the Xe Kaman No.1 Project is selected at the site shown in **Fig. 13.3-1**.

(2) Type of Dam

According to the 1/10,000 scale topographic maps, with a reservoir HWL of EL.280m, the height and the crest length of the dam would be 170m and 540m respectively. Regarding the dam type, it is expected that any types would be suitable to meet the geological conditions of the site. For the selection of a dam type, however, there are certain conditions to be met such as the availability of construction materials and the layout of the dam and spillway with regard to a small valley lying just downstream of the dam axis in the left bank side.

In the case of a rockfill type dam with an impervious clay core, some difficulty is expected in the availability of the materials for the core. The concrete facing type or asphalt facing type are also applicable. Even in these cases, however, the crest length and volume of the dam would be larger because the dam axis must have some upstream offset in its layout from the narrowest section to avoid the valley lying downstream. In the case of a concrete dam, however, although the procurement of cement may be a problem, there are no constraints on the layout of the dam.

As stated above, there are many factors in the selection of a dam type for the Xe Kaman No.1 project. The optimum dam type is selected in the preliminary design stage in Chapter 14. At this stage, however, the concrete gravity type is temporarily selected for the study on the optimum project scale.

(3) Waterway and Powerhouse Layout

The river gradient is gentle in the downstream section of the Xe Kaman No.1 dam site and cannot be expected to develop a head by the waterway. Accordingly, other than the dam type scheme, no alternative development scheme is available for the Xe Kaman No.1 Project. Its powerhouse site is selected just downstream of the dam site.

There are no geological constraints on situating the major structures around the dam site. Using 1/10,000 scale maps and assuming a concrete gravity dam type, the study on the layout of structures, and the layout of the intake, headrace tunnel, open penstock and powerhouse are selected on and in the left bank, as shown in **Fig. 13.3-1**. An optimization study on project scale is carried out based on this layout.

13.3.2 Basic Conditions for Optimization Study

(1) Reservoir Operation Conditions

a) Reservoir Operation Rule

Regarding the reservoir operation, the carry-over type operation rule is applied as described in 13.1.

b) **Effective Storage Capacity**

Fig. 13.3-2 shows the reservoir area-storage volume curve at the Xe Kaman No.1 dam site selected in 13.3.1. The gross storage volume at an HWL of EL.280m is estimated to be 16,208 MCM. This volume is extremely large against a mean annual inflow volume of 4,245 MCM at the dam site as estimated in Chapter 9. Even in the case of a lower HWL, sufficient effective storage volume is available after considering the sediment volume and water depth for the installation of the intake.

Therefore, a limitation on the effective storage volume provides no constraints on reservoir operation. The optimum effective storage volume is determined by comparative study in 13.3.3.

c) **Firm Discharge**

Fig. 13.3-3 shows the mass curve of the reservoir inflow volume for a 10-year period. **Fig. 13.3-4** shows the relationship between the effective storage capacity and firm discharge calculated by applying carry-over reservoir operation to the above inflow mass curve.

From this it is seen that the incremental amount of the firm discharge becomes small at around an effective storage capacity of approximately 20% of the annual inflow volume, although the firm discharge gradually increases with the larger effective storage capacities because carry-over operation is applied.

d) **Discharge for Maintaining River Function**

In case of the Xe Kaman No.1 Project, which is a dam type project, there are no river sections where the discharge is not supplied to the river. Accordingly, no conditions are set on reservoir operation.

(2) **Power Plant Operation Conditions**

a) **Peak Power Duration**

As described in 13.1, peak power duration is set at 8 hours.

b) **Discharge for Maintaining River Function**

The Xe Kaman No.1 Project, which has a large reservoir, stores almost all the inflow. Except for spilled flood, the outflow is only discharged through the turbine. Accordingly, if power generation is stopped during the off-peak hours, no discharge is supplied to the downstream.

There are social activities such as navigation and fishing in the downstream area of the Xe Kaman River. To maintain the river function for these activities, a condition is set on the reservoir operation to supply a certain discharge to the downstream.

Following the conditions determined in 13.1, 20 m^3/s is applied for this discharge.

c) **Maximum Discharge for Power Generation**

Applying the above conditions, the maximum discharge (Qmax) is set by the following formula;

$$Qmax = (Qf - 20) \times 24/8 + 20 \quad (m^3/s)$$

d) **Turbine/Generator Unit Configuration**

If the full day outflow determined in b) above is released directly from the dam outlet, the loss of energy generation become large. Therefore, partial power generation is applied by this outflow volume during the off-peak hours, supplying downstream discharge through the turbine.

In this case, a configuration of power units able to achieve this operation is required. At this optimization study stage, a uniformed capacity is applied for all units of each case by setting the maximum discharge per unit at 60 m^3/s against the full day outflow of 20 m^3/s, taking into account that the minimum discharge for partial operation is generally approximately 30% of the maximum discharge in the case of the Francis turbine.

(3) Conditions of Construction Cost Estimation

a) Access Road

Regarding the route for the transportation of construction materials and equipment to the Xe Kaman No.1 Project site, as described in 8.5, Chapter 8, a route lying to the north of the Bolaven Plateau and passing Sekong Town and Attapu Town is seen as the most practical. For this route, national roads are available from the border with Thailand to Sekong Town, although some imrovement work is required. There is also a national road improvement plan from Sekong Town to Attapu Town. Therefore, the dedicated access road for the Xe Kaman No.1 Project is a section of approximately 50 km running from Attapu Town to the project site. A new road or the reconstruction of the existing road are required for this section.

At this stage, the cost of the above works for the 50 km section is counted in the project construction cost. The constant access road cost is applied for each case of project scale.

b) Compensation Cost

The compensation costs by reservoir HWLs estimated based on the compensation survey in this Master Plan Study are shown below;

HWL (m)	Compensation Cost (M.US$)
260	0.90
280	0.90
300	0.90

As shown above, there are only minimal, negligible differences in the compensation costs between some HWLs. Therefore, the constant compensation cost is applied for each HWL. In this study, a constant compensation cost of 0.90 M.US$ is applied in the project cost estimation.

13.3.3 Selection of Optimum Development Scale

In this section, the optimum development scale of the Xe Kaman No.1 Project is determined based on the basic layout selected in 13.3.1 and the basic conditions clarified in

13.3.2. To determine the optimum development scale, comparative studies are performed by varying the reservoir HWLs and effective reservoir capacities.

(1) Study on Reservoir HWL

As described in 13.3.2 (1), the mean annual inflow volume for 10 years at the Xe Kaman No.1 dam site is estimated to be 4,245 MCM, and annual wide flow regulation is achieved when the effective reservoir capacity is 20% or more of the annual inflow volume. In this situation, an adequate gross reservoir storage volume is available at a reservoir HWL of approximately EL.280m for the Xe Kaman No.1 Project, as shown in **Fig. 13.3-2**, and there are no constraints on setting an appropriate effective reservoir capacity.

In this connection, a comparative study on reservoir HWLs is made first under the conditions of an 8-hour constant peak power duration and a constant effective reservoir capacity of 1,270 MCM, which is 30% of the mean annual inflow volume. This effective reservoir capacity provides a firm discharge of 89 m^3/s in all cases.

The study is made by varying the HWLs from EL.250m to EL.280m with the above conditions. From this comparative study, an HWL of EL.260m is seen to provide the best performance in unit energy cost, unit construction cost per kW, and B/C respectively as shown in **Table 13.3-1**. Accordingly, EL.260m is selected as the optimum HWL for the Xe Kaman No.1 Project.

(2) Study on Effective Reservoir Capacity

With an HWL of EL.260m, a second comparative study is then made on the effective reservoir capacity by varying its ratio to the mean annual inflow volume to be 20, 25, 30, 35, and 40%, respectively. These cases provide firm discharges of 83, 86, 69, 92, and 95 m^3/s, respectively as shown in **Fig. 13.3-4**. Accordingly, the maximum discharge provided with a peak power duration of 8 hours varies in each case.

This comparative study shows that an effective reservoir capacity of 30% of the mean annual inflow volume (Ve = 1,270 MCM) provides the best performance in unit energy cost, although the cases of 35% and 40% provide slightly better performances in B/C, as shown in **Table 13.3-2**. Accordingly, 1,270 MCM is selected as the optimum effective reservoir capacity of the Xe Kaman No.1 Project. In this case, the reservoir storage volume under the low water level (LWL) is 10,791 MCM, thereby providing adequate room against an estimated reservoir sediment volume of 160 MCM, at a negligible level.

(3) Optimum Development Scale

According to the above comparative studies on reservoir HWLs and effective storage capacities, the optimum development scale of the Xe Kaman No.1 Project is determined as the plan below.

Reservoir HWL	260.0	m
Reservoir LWL	253.2	m
Effective Storage Capacity	1,270	MCM
Firm Discharge	89	m^3/s
Minimum Outflow (through Turbine)	20	m^3/s
Peak Power Duration	8	hours
Maximum Discharge	228	m^3/s
Rated Intake Water Level (IWL)	257.7	m
Rated Tail Water Level (TWL)	125.0	m
Rated Effective Head (He)	129.9	m
Installed Capacity	256	MW
Dependable Peak Capacity	245	MW
Annual Energy	1,137	GWh

13.3.4 Remarks on Development Plan

The above development plan is proposed as the optimum plan of the Xe Kaman No.1 Project, based on the technical studies with the data and information presently available. Several remarks to be clarified in further stages, however, are indicated as follows;

a) Technical Matters

Although no specific geological problems is observed in the dam site, there are alternative dam types from the viewpoint of the topographic conditions at the site and the availability of construction materials.

Investigation and study is also required on the distribution of limestone in the upstream area of the reservoir in order to confirm the watertight integrity of the reservoir.

b) **Environmental Impact Issues**

Although the number of people who would require resettlement is estimated as approximately 600, fewer than those related to the Se Kong No.4 Project, further investigation and studies on the impact to the natural environmental are required because of the extremely wide inundation area which would be approximately 193 km^2.

Table 13.3-1 Study on Reservoir HWL (Xe Kaman No.1)

Description	Unit	Case-1	Case-2	Case-3	Case-4
Reservoir HWL	m	250.0	260.0	270.0	280.0
Dam Crest Length	m	410	440	480	540
Dam Height	m	140	150	160	170
Reservoir Area	km^2	177	193	210	222
Gross Storage Capa.	MCM	10,195	12,061	14,074	16,208
Sediment Capa.	MCM	160	160	160	160
Net Storage Capa.	MCM	1,270	1,270	1,270	1,270
Reservoir LWL	m	242.5	253.2	263.7	274.0
Firm Discharge	m^3/s	89	89	89	89
River Maint.Release	m^3/s	0	0	0	0
Base Power Discharge	m^3/s	20	20	20	20
Max. Power Discharge	m^3/s	228	228	228	228
Rated IWL	m	247.5	257.7	267.9	278.0
Rated TWL	m	125.0	125.0	125.0	125.0
Gross Head	m	122.5	132.7	142.9	153.0
Effective Head	m	119.7	129.9	140.1	150.2
Installed Capacity	MW	236	256	276	296
Annual Inflow	MCM	4,245	4,245	4,245	4,245
Annual Evaporation	MCM	188	207	224	239
Annual Dam Outflow	MCM	335	316	299	284
Annual Turbine Out.	MCM	3,722	3,722	3,722	3,722
Firm Peak Capacity	MW	224	245	265	286
Annual Energy	GWh	1,045	1,137	1,227	1,318
Plant Factor	%	51	51	51	51
Construction Cost	M.US$	361.1	387.7	424.1	470.3
Annual Cost	M.US$	39.7	42.6	46.6	51.7
Annual Benefit	M.US$	50.4	54.9	59.4	63.9
Unit Energy Cost	$/MWh	38.0	37.5	38.0	39.2
B-C	M.US$	10.6	12.3	12.8	12.2
B/C	-	1.27	1.29	1.27	1.24
Const.Cost/kW	M.US$	1,531	1,514	1,536	1,589
Selected Case	-		*		

Table 13.3-2 Study on Effective Storage Capacity (Xe Kaman No.1)

Description	Unit	Case-1	Case-2	Case-3	Case-4	Case-5
Reguration Ratio	%	20	25	30	35	40
Reservoir HWL	m	260.0	260.0	260.0	260.0	260.0
Dam Crest Length	m	440	440	440	440	440
Dam Height	m	150	150	150	150	150
Reservoir Area	km^2	193	193	193	193	193
Gross Storage Capa.	MCM	12,061	12,061	12,061	12,061	12,061
Sediment Capa.	MCM	160	160	160	160	160
Net Storage Capa.	MCM	850	1,060	1,270	1,490	1,700
Reservoir LWL	m	255.5	254.3	253.2	252.0	250.9
Firm Discharge	m^3/s	83	86	89	92	95
River Maint.Release	m^3/s	0	0	0	0	0
Base Power Discharge	m^3/s	20	20	20	20	20
Max. Power Discharge	m^3/s	209	220	228	236	245
Rated IWL	m	258.5	258.1	257.7	257.3	257.0
Rated TWL	m	125.0	125.0	125.0	125.0	125.0
Gross Head	m	133.5	133.1	132.7	132.3	132.0
Effective Head	m	130.6	130.3	129.9	129.6	129.2
Installed Capacity	MW	236	248	256	265	273
Annual Inflow	MCM	4,245	4,245	4,245	4,245	4,245
Annual Evaporation	MCM	208	207	206	205	204
Annual Dam Outflow	MCM	485	377	317	261	324
Annual Turbine Out.	MCM	3,552	3,661	3,722	3,780	3,718
Firm Peak Capacity	MW	229	238	245	252	258
Annual Energy	GWh	1,095	1,124	1,137	1,149	1,139
Plant Factor	%	53	52	51	50	48
Construction Cost	M.US$	379.6	384.2	387.7	392.5	396.9
Annual Cost	M.US$	41.8	42.3	42.6	43.2	43.7
Annual Benefit	M.US$	51.9	53.7	54.9	56.0	56.7
Unit Energy Cost	$/MWh	38.1	37.6	37.5	37.6	38.3
B-C	M.US$	10.1	11.5	12.3	12.9	13.1
B/C	-	1.24	1.27	1.29	1.30	1.30
Const.Cost/kW	M.US$	1,606	1,552	1,512	1,482	1,452
Selected Case	-			*		

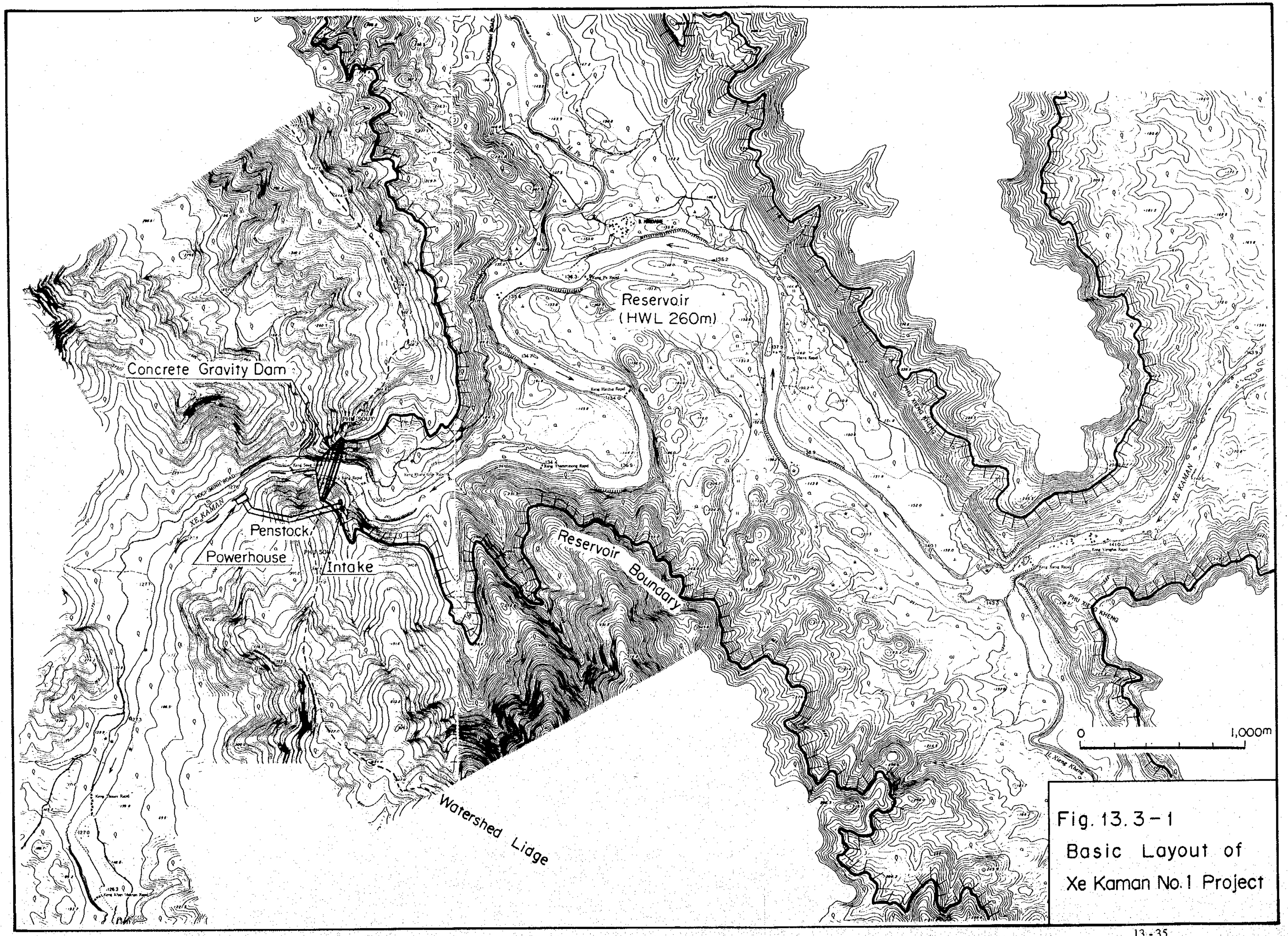
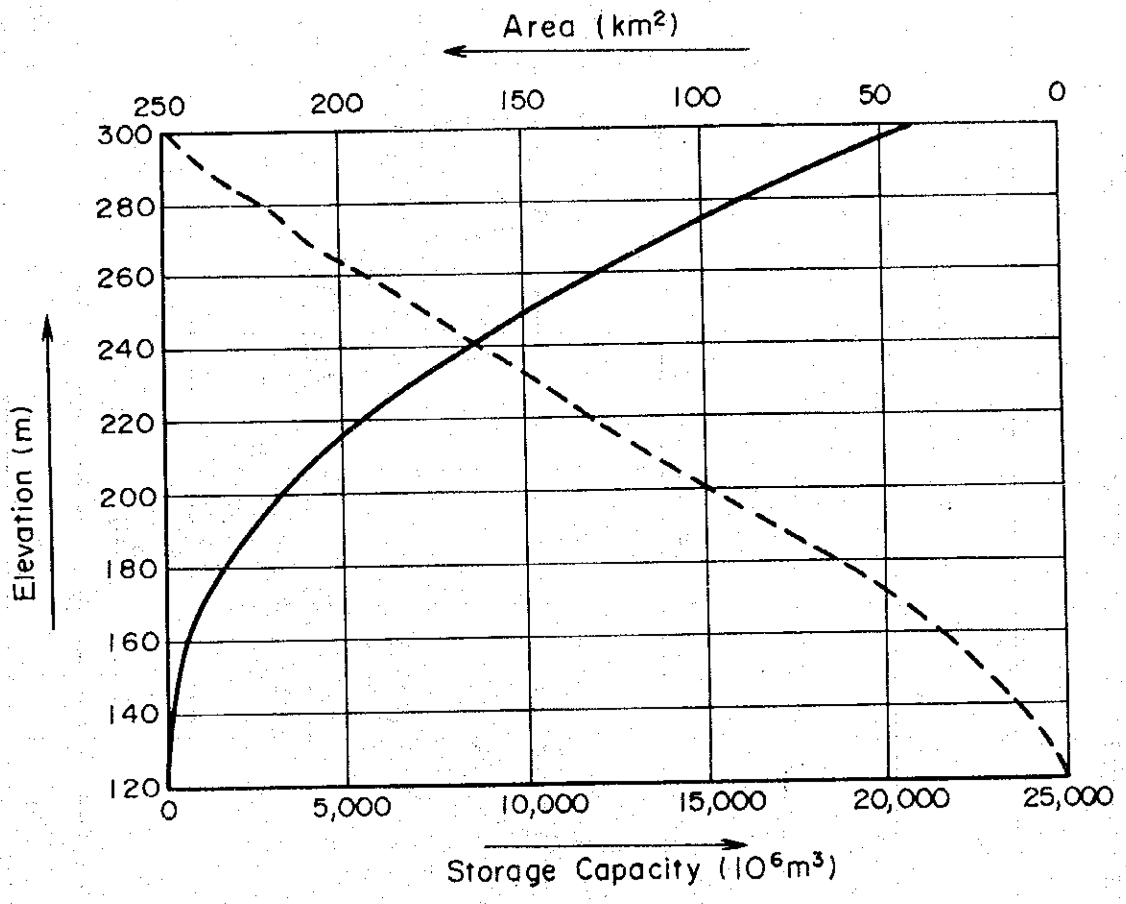


Fig. 13.3-1
Basic Layout of
Xe Kaman No.1 Project

Fig. 13.3-2 Area and Storage Capacity Curve of Xe Kaman No. 1 Reservoir



Elevation (m)	* Area (km^2)	Storage Capacity (10^6 m^3)
300	248.3	20,905
290	236.9	18,500
280	221.5	16,208
270	209.5	14,074
260	193.2	12,061
250	176.9	10,195
240	163.9	8,490
230	145.7	6,916
220	132.8	5,523
200	99.0	3,205
180	64.0	1,575
160	33.9	596
140	11.6	141
120	0	0

* measured using 1/50,000 scale topographic maps

Fig. 13.3 – 3 Mass-curves at Xe Kaman No.1 Dam Site

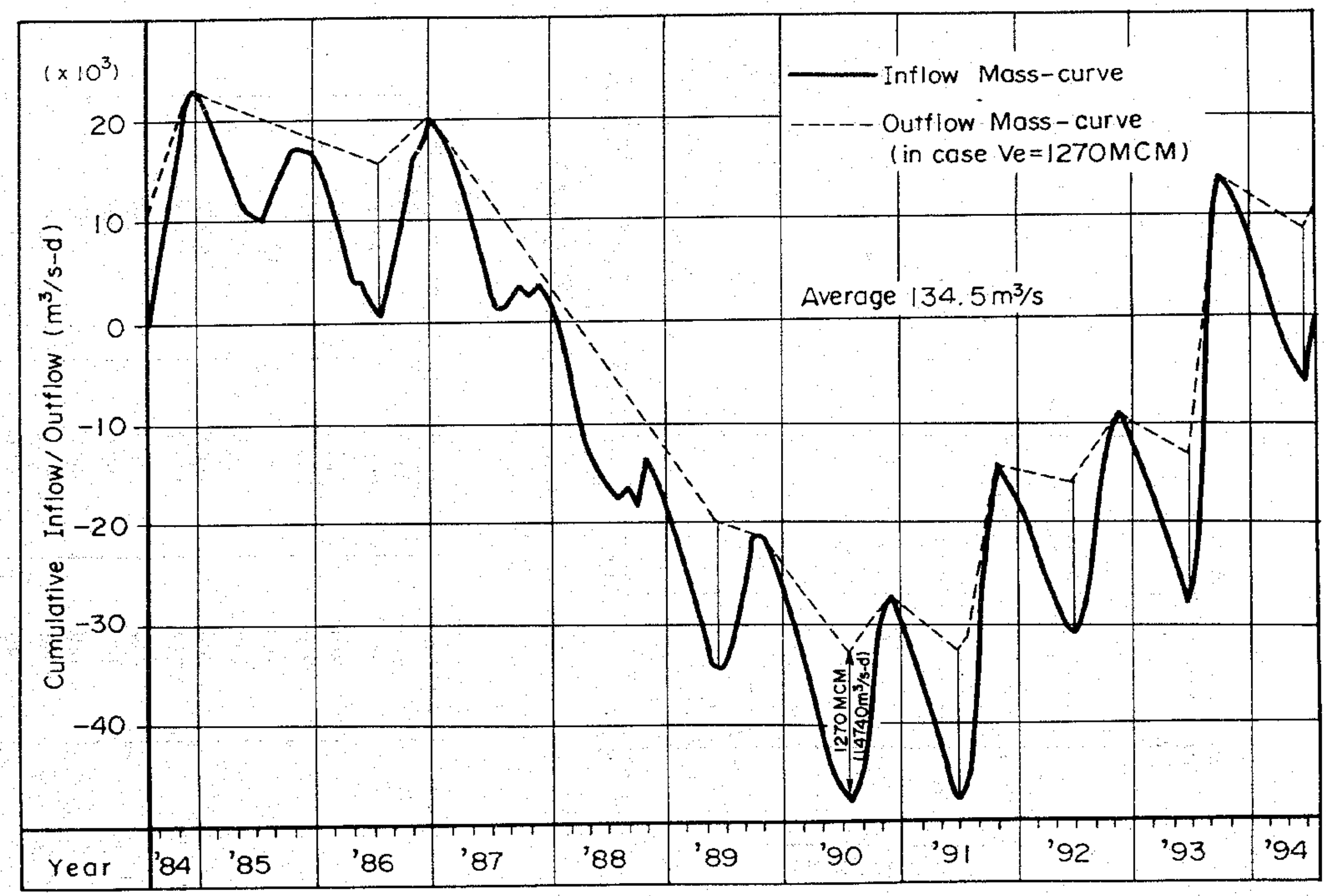
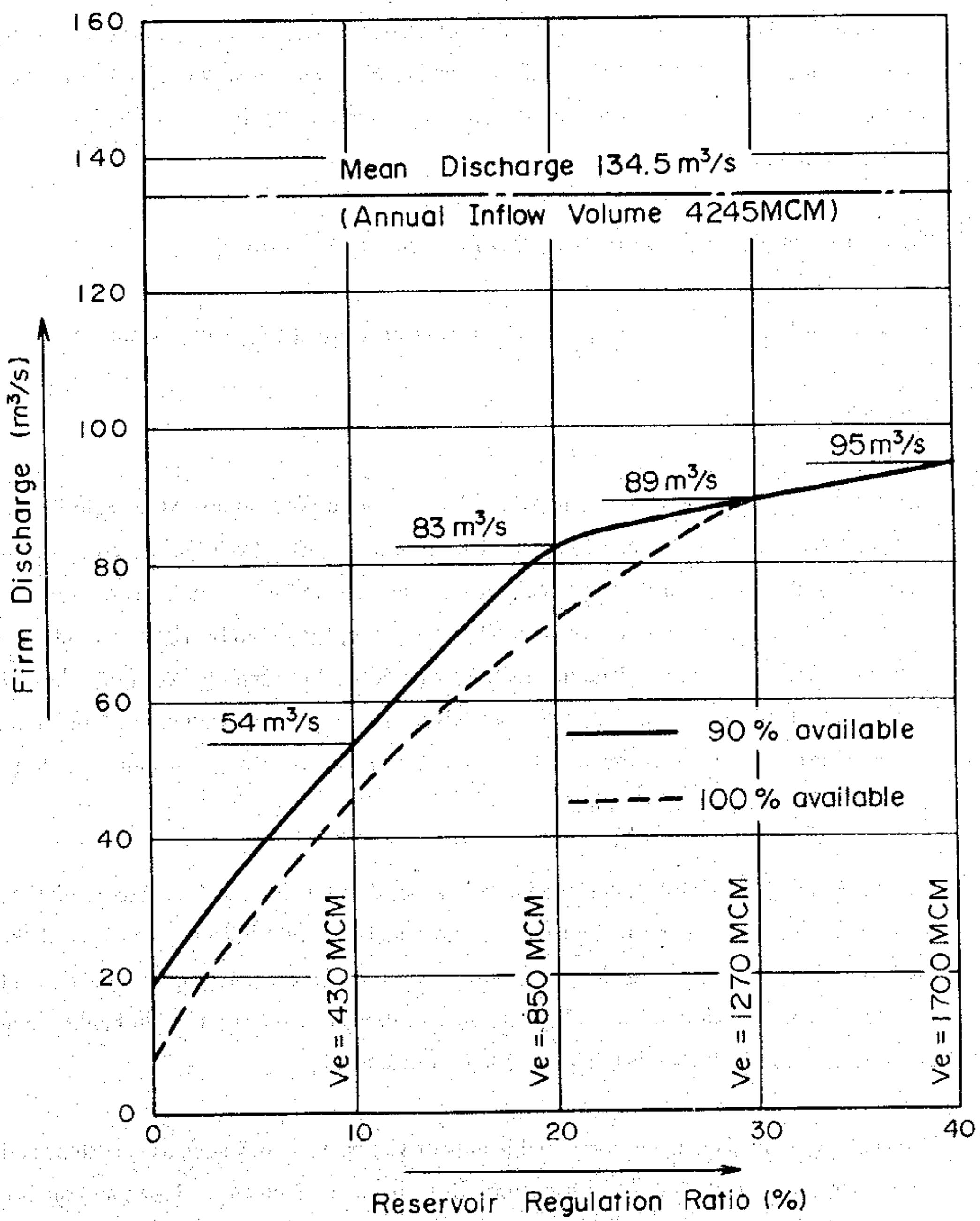


Fig. 13.3-4 Firm Discharges provided by Xe Kaman No. 1 Reservoir



Note) This figure is based on the mass-curve calculation for 10 years period with carry-over reservoir operation rule.

13.4 Optimization Study of the Xe Namnoy Project

The Xe Namnoy river forms a rapids in its midstream section between the sites with riverbed elevations of approximately 700m and 200m. A hydropower project could be proposed in this section using the head of approximately 500m available here. In the development plan inventory, the Xe Namnoy Project was proposed using this head as a two stage development scheme which combines the Xe Namnoy Midstream and Downstream Projects. In this Chapter, study on the optimum development plan is conducted, based on this development scheme.

13.4.1 Selection of Basic Project Layout (Figs. 13.4-1, 2, 3 and 4)

(1) Selection of Layout for the Xe Namnoy Midstream Project (Figs. 13.4-1 and 2)

(1.1) Dam Site Selection

Using 1/50,000 scale topographic maps, the dam site of the Xe Namnoy Midstream Project selected in the study on the development plan inventory in Chapter 7, is located upstream from where the Xe Namnoy River becomes a rapids, located in the midstream section of the river. At this site, the riverbed elevation is approximately EL.720m and the catchment area is 531 km^2. The upstream section of the Xe Namnoy river flows through an area which presents gentle terrain. The river gradient of this section is gentle and a reservoir providing an adequate storage volume for annual wide flow regulation could be developed in the upstream section.

Using the 1/10,000 scale topographic maps developed in this Master Plan Study, reviews of the above dam site confirm that with a reservoir HWL of EL.760m, which is of the inventory plan, the above dam site is the most appropriate for the topographic conditions of the site such as the width of the valley and the elevations of the left and right banks along the river, and for the layout of the intake and headrace tunnel.

The geology of the dam site is composed mainly of sedimentary rock such as sandstone and conglomerate. Hard, massive sandstone lies on the riverbed. However, highly permeable basalt is distributed on the sedimentary rocks in the area from the riverbed to the left bank. This geological condition presents a problem in the watertight integrity of the reservoir for the dam construction. Regarding this, according to geological studies, the range of the basalt distribution is limited to an area with a plains topography at the left bank, and the watertight integrity of the basalt could be improved by grouting in the section of the dam axis. Other than these, no serious geological problems are seen to prohibit dam construction.

According to the conditions described above, to minimize the dam volume, the dam site of the Xe Namnoy Midstream Project is selected at the site shown in **Fig. 13.4-1**. In addition, the downstream axis plan shown in **Fig. 13.4-1**, indicated by a broken line, could be proposed as an alternative site. According to geological studies, however, the wider distribution of high permeable basalt in that area is seen to provide disadvantage to this alternative. Also, this alternative plan would require the inundation of almost all the village area of Ban Latsasin. In view of these factors, this alternative dam site is cancelled.

(1.2) Type of Dam

For the dam type of the Xe Namnoy Midstream Project, a rockfill type is considered the most appropriate due the topographical conditions which include a wide valley.

According to the 1/10,000 scale topographic maps, in the case of a reservoir HWL of EL.760m, the dam would be 55m high with a 740m long crest. In the case of a rockfill dam, the availability of construction materials should be considered. In this regard, considering the site's geology and the size of the dam, it is expected that clay materials for the impervious core are available around the site. The type of impervious core will be studied again in the preliminary design stage in Chapter 14. At this stage, however, a rockfill dam with a central impervious clay core is temporarily selected for the study on optimum project scale.

(1.3) Waterway and Powerhouse Layout (Fig. 13.4-1)

The layout of the waterway and powerhouse of the Xe Namnoy Midstream project is studied using 1/10,000 topographic maps to utilize the available head as efficiently as possible and by taking the topographic conditions which provide possible construction sites of headrace tunnel, penstock, and powerhouse into consideration. From this, the layout shown in **Fig. 13.4-1** is selected based on the topographic condition of the waterway route and the river gradient distribution. In this layout, the intake site is selected in the right bank tributary located immediately upstream from the dam site. The powerhouse site is selected at the right bank of the site with a riverbed elevation of EL.265m. The intake and powerhouse are connected by a headrace tunnel.

Considering the layout of the Xe Namnoy Downstream Project, there is no appropriate alternative layout. In this stage, an optimization study on project scale is conducted based on the above layout plan.

(1.4) **Layout of Diversion Scheme from Neighboring Rivers (Figs. 13.4-2 and 3)**

The Xe Namnoy Midstream Project in the development plan inventory is planned to incorporate a river diversion scheme to divert water from the Xe Pian River located west of the Xe Namnoy River. In this stage, the layout of the diversion scheme is studied using 1/10,000 topographic maps. The study shows, as seen in **Fig. 13.4-2**, that a layout with two intake weirs on the Xe Pian mainstream and the Houay Liang River, a tributary, and a diversion channel connecting these intake weirs and the reservoir of the Xe Namnoy Midstream Project is selected, being the same as the plan in the development plan inventory. As no other appropriate alternative layout is available, study on the optimum project scale of the Xe Namnoy Midstream Project is conducted based on the above layout.

In addition to the diversion scheme from the Xe Pian River, a diversion scheme from the Houay Makchan river, which is a tributary flowing into the Xe Namnoy river downstream from the Midstream dam site, has been studied with a diversion scheme through the Houay Liang River. However, as seen in **Fig. 13.4-3**, this scheme requires a rather large volume of open channel works due to the relationship between the riverbed elevations of both the Houay Makchan and Houay Liang rivers. These works could provide certain environmental impacts around the site and downstream. Taking these conditions into account, the diversion scheme from the Houay Makchan River is not applied in the development of the Xe Namnoy Midstream Project.

(2) **Selection of Layout for the Xe Namnoy Downstream Project (Fig. 13.4-4)**

The Xe Namnoy Downstream Project in the development plan inventory as proposed in Chapter 7, is planned to utilize the head available downstream from the powerhouse of the Xe Namnoy Midstream Project on the rapid section of the Xe Namnoy river. It being difficult to construct a dam with a large reservoir due to the topographic conditions of the project site, this project is planned as a regulation pond type project. The catchment area of the Downstream Project, however, is 1,475 km^2 including 223 km^2 of indirect basin provided by the Xe Pian River diversion scheme. As approximately 50% of the total catchment area is shared by that of Midstream Project, 754 km^2 (including the Xe Pian basin), more than 50% of inflow volume is shared by the discharge regulated by the reservoir of the Midstream Project. This inflow provides the capability of stable power generation without a large reservoir for the Downstream Project.

Considering the above characteristics, the layout of the Xe Namnoy Downstream Project is studied below.

(2.1) Dam Site Selection (Fig. 13.4-4)

The dam site of the Xe Namnoy Downstream Project is selected in the section downstream from the confluence of the Houay Katak Tok River which flows into the Xe Namnoy mainstream 1 km downstream from the powerhouse site of the Midstream Project, as proposed in the development plan inventory, in order to utilize the discharge from the Houay Katak Tok river basin. Using 1/10,000 scale topographic maps and based on this layout as shown in **Fig. 13.4-4**, the study shows that the site with a riverbed elevation of approximately 245m which provides the minimum sized dam due to the topography, is selected as the dam site of the Downstream Project. In this case, a regulating reservoir with a storage capacity for daily flow regulation is available between the dam site and the powerhouse site of the Midstream Project.

Regarding the dam type, a concrete gravity type is selected due to the size of the dam and the flood discharge.

(2.2) Waterway and Powerhouse Layout (Fig. 13.4-4)

The layout of the waterway and powerhouse of the Downstream Project is selected to utilize the head available in the rapids downstream from the dam site as effectively as possible. Using 1/10,000 scale topographic maps, the study shows that the layout shown in **Fig. 13.4-4** is selected for the Downstream Project. In this layout, the powerhouse site is selected at the left bank of the site with a riverbed elevation of 180m. The headrace tunnel route is selected along the left bank of the Xe Namnoy River to connect the intake at the dam site with the powerhouse.

13.4.2 Basic Conditions for Optimization Study

(1) Reservoir Operation Conditions

(1.1) Xe Namnoy Midstream Project

a) Reservoir Operation Rule

Regarding the reservoir operation of the Xe Namnoy Midstream Project which is a reservoir type project, the carry-over type operation rule is applied, as described in 13.1.

b) Effective Storage Capacity

Fig. 13.4-5 shows the reservoir area-storage volume curve at the Xe Namnoy Mid-stream dam site selected in 13.4.1.

The reservoir storage volume at a water level estimated with 1/10,000 scale topographic maps is slightly smaller than that estimated with the 1/50,000 scale maps applied in the study of the development plan inventory. This new curve provides a gross storage volume of 237 MCM at a reservoir HWL of EL.760m against an annual reservoir inflow volume of 761 MCM (excluding diversion volume from the Xe Pian river). Therefore, the available effective storage capacity (annual regulation ratio) is limited to approximately 20% of the annual inflow volume, taking the reservoir sediment volume of 23 MCM and water depth required for installation of the intake into consideration. The annual regulation ratio against the inflow volume, including diversion flow from the Xe Pian River becomes less.

However, as the Xe Namnoy Midstream Project is a dam and waterway type, the head created by the height of the dam is only approximately 40m against the gross head of 475m. Therefore, the effect of reservoir drawdown is minimal for power generation.

Taking the above conditions and the conditions of firm discharge described below into account, the maximum effective storage capacity physically available for each case is applied in the study of the Xe Namnoy Midstream Project.

c) **Firm Discharge**

Fig. 13.4-6 shows the mass curve of reservoir inflow volume for 10 years. **Fig. 13.4-7** shows the relationship between the effective storage capacity and the firm discharge calculated by applying carry-over reservoir operation to the above inflow mass curve. From this it is seen that the available firm discharge becomes increasingly larger until around an effective storage capacity of 230 MCM, being approximately 30% of the annual inflow volume.

In the comparative study on effective reservoir capacities, the firm discharges for each capacity is applied in setting the maximum discharge of each case.

d) **Discharge for Maintaining River Function**

In the case of the Xe Namnoy Midstream Project which is a dam and waterway type, a river section where the discharge is not supplied to the river will be provided in the 20 km section between the dam and powerhouse. It is, therefore, necessary to supply a discharge to maintain the river function of this section.

For this discharge, a direct release of 1.0 m^3/s from the dam outlet is applied, following the condition determined in 13.1. This discharge amount is provided from a part of the regulated firm discharge.

The amount of released discharge determined above is small. However, there is almost no water usage from the mainstream of the Xe Namnoy River at Ban Latsasin located immediately downstream from the Midstream dam site. Thus, no serious problem is expected. Also, as the Houay Makchan River flows into the mainstream 5 km downstream from the Midstream dam site, river flow is supplied for the downstream from the confluence.

Regarding the river maintenance discharge for the downstream area from the intake on the Xe Pian River, approximately 1.0 m^3/s of that discharge is required if the condition determined in 13.1 is applied. However, as there are very few domiciles in the downstream area, no conditions of river maintaining discharge is set on the Xe Pian Diversion Scheme in this study. It does appear necessary, however, that this matter be re-studied in further stages, including the aspect of potential impacts upon the natural environment.

(1.2) Xe Namnoy Downstream Project

a) Reservoir Operation Rule

Due to its characteristics, the Xe Namnoy Downstream Project is planned as a regulation pond type. Accordingly, a daily flow regulation but not an annual flow regulation is applied as the operation conditon.

b) Effective Storage Capacity

The effective storage capacity is provided within a range required for the daily regulation.

Fig. 13.4-8 shows the reservoir area-storage volume curve at the Xe Namnoy Downstream dam site selected in 13.4.1.

c) Inflow Data

The reservoir inflow volume of the Xe Namnoy Downstream Project consists of the total outflow of the Midstream Project including the outflows from the turbine, dam outlet and spillway, and the natural discharge from the sub-basin which consists the downstream areas of the Midstream Project and the Houay Katak Tok Project. Here, it is assumed that all the reservoir inflow of the Houay Katak Tok Project is diverted to the mainstream of the Se Kong River.

Accordingly, the reservoir inflow data of the Downstream Project is calculated based on the natural discharge data of the sub-basin estimated in Chapter 9, and the calculation results of the reservoir and power plant operation of the Midstream Project.

d) Firm Discharge

The firm discharge of the Xe Namnoy Downstream Project is calculated based on the inflow data as a mean inflow of the driest month without regulation of the inflow.

e) **Discharge for Maintaining River Function**

In the case of the Xe Namnoy Downstream Project, which is a dam and waterway type, a river section where the discharge is not supplied to the river will be provided in the 4 km section between the dam and the powerhouse. As there are no river usage activities in this section which forms a rapids, a plan without discharge for maintaining river function for this section is not applied in this study.

(2) Power Plant Operation Conditions

(2.1) Xe Namnoy Midstream Project

a) **Peak Power Duration**

As described in 13.1, peak power duration is set at 8 hours.

b) **Discharge for Maintaining River Function**

In the case of the Xe Namnoy Midstream Project, 1.0 m^3/s of the discharge for downstream water supply determined in item d) of (1.1) is released directly from the dam outlet, consuming a part of the firm discharge.

c) **Maximum Discharge for Power Generation**

Applying the conditions of the firm discharge and the discharge for maintaining river functions determined above, the maximum discharge (Qmax) is set by the following formula.

$$Qmax = (Qf - 1.0) \times 24/8 \quad (m^3/s)$$

d) **Turbine/Generator Unit Configuration**

In case of Xe Namnoy Midstream Project, the discharge for the river section between the dam and powerhouse sites is releaswed directory from the dam outlet. Also, since the discharge for power generation is released directly into the regulation pond of the Downstream Project, there is no constraints on power plant operation for downstream river use.

In this connection, there are no particular constraints on the configuration of the power units. The configuration is set based only on the maximum discharge determined by the above formula and applying the conditions provided in 13.1.

(2.2) Xe Namnoy Downstream Project

a) Peak Power Duration

As the Xe Namnoy Downstream Project is a daily regulation type developed for peak power supply, peak power durations are applied by individual cases, depending on the ratio of maximum discharge against the firm discharge in the calculation of project benefit for economic evaluation.

b) Discharge for Maintaining River Function

If power generation is stopped during the off-peak hours, no discharge is supplied to the approximately 20 km section from the powerhouse site to the confluence with the mainstream of the Se Kong River. However, it is expected that there will be no significant impact even without a continuous supply of discharge as there are no large villages and almost no river usage activities in this section, and also because the river gradient is gentle and the river is wide here except for some parts. Therefore, no condition of full day discharge through the turbine is set in this study. It does appear necessary, however, that this matter be re-studied in further stages.

c) Maximum Discharge

In the case of the Xe Namnoy Downstream Project, the optimum maximum discharge (Qmax) is not determined by firm discharge and peak power duration, but by comparative study.

d) Turbine/Generator Unit Configuration

In the case of the Xe Namnoy Downstream Project, as the discharge for maintaining the original river function is not applied and as there are no operational constraints on discharge through the turbine, power unit configuration is set based on the maximum discharge of each case and based on the conditions provided in 13.1.

(3) Conditions for Construction Cost Estimation

a) Access Road

Regarding the route for the transportation of the construction materials and equipment to the Xe Namnoy Midstream and Downstream project sites, as stated in 8.5, Chapter 8, a road for vehicle traffic is available until Ban Latsasin located downstream from the Midstream dam site, although this road does require some renovation work. Therefore, the dedicated access road for the Xe Namnoy Project is a section approximately 57 km long overall including the sections from Ban Latsasin to the construction site of the major structures of the Midstream and Downstream Projects. Of these sections, the construction of 41 km of new road and the reconstruction of 16 km of existing road is required.

At this stage, as the two project sites are located in close proximity, the cost of the above works for the 57 km section is counted in the project construction cost of the Midstream Project. The constant access road cost is applied for each case of project scale.

b) Compensation Cost

The compensation costs of the Xe Namnoy Midstream Project by reservoir HWLs estimated based on the compensation survey in this Master Plan Study, are shown below;

HWL (m)	Compensation Cost (M.US$)
740	0.9
760	1.5
780	1.8

In the case of the Xe Namnoy Midstream Project, the compensation cost of a case with the nearest reservoir HWL is applied for each study case.

For the Downstream Project, the compensation cost is neglected as no reason for compensation is expected.

13.4.3 Selection of Optimum Development Scale

In this section, the optimum development scale of the Xe Namnoy Project consisting of the Midstream and Downstream Projects is determined based on the basic layout selected in 13.4.1 and the basic conditions clarified in 13.4.2.

(1) Study on the Reservoir HWL of the Xe Namnoy Midstream Project

In the case of the Xe Namnoy Midstream Project, attention should be paid to assure that a sufficient effective reservoir storage capacity is available in view of the topographic conditions of the dam site and upstream area and the hydrological characteristics with a large seasonal inflow gap. As described in 13.4.2, as this project is a dam and waterway type, the ratio of reservoir drawdown against the gross head is small. The gross storage capacity of the reservoir is also small. Accordingly, the effective storage capacity of the reservoir is set at the maximum capacity physically available in each case of reservoir HWL. (Therefore, no comparative studies on the effective reservoir capacities as a parameter are conducted in this study.)

The studies are conducted for those cases without and with the Xe Pian diversion scheme (for a case with a maximum diversion capacity of 15 m^3/s) respectively, varying HWLs of EL.750, 755, 760, 765, and 770m with the above conditions. Here, for the case with the Xe Pian diversion scheme, the reservoir HWL is limited at EL.765m or less due to the riverbed elevation at the intake site of the Xe Pian River.

As shown in **Table 13.4-1 (1/2)**, this comparative study shows that an HWL of EL.760m provides the best performance in unit energy cost and B/C in the case without the Xe Pian diversion scheme. For the case with the Xe Pian diversion scheme, as shown in **Table 13.4-1 (2/2)**, although a reservoir HWL of EL.760m provides the best performance in unit energy cost, the HWL of 765m provides the best performance in B/C and B-C respectively and provides the better performance in B/C and B-C than the performance provided by the best case of the without Xe Pian diversion scheme.

The Xe Namnoy Midstream Project provides a significantly lower level of unit energy cost of approximately 30 US$/MWh, than provided by the Se Kong No.4 and Xe Kaman No.1 Projects. Accordingly, EL.765m is selected as the optimum HWL of the Xe Namnoy Midstream Project, giving priority to the case with Xe Pian diversion scheme and to the B/C and B-C indexes in this study.

(2) Study on the Maximum Capacity of the Xe Pian Diversion Scheme

In addition to the above study, a comparative study on the maximum diversion capacity of the Xe Pian diversion scheme is conducted by varying the maximum capacities to be 10, 15, 20, and 25 m^3/s respectively for the case with a reservoir HWL of EL.765m.

From this, as shown in **Table 13.4-2**, no significant difference is seen between the cases with maximum diversion capacities of 15, 20, and 25 m^3/s in their economic performance. The case with a maximum diversion capacity of 20 m^3/s which provides slightly better performance in B/C among the cases is selected as the optimum case.

Here, it should be remarked that the discharge data of the Xe Pian River is less reliable. Further, the discharge calculation with monthly inflow data is applied in this study due to the lack of daily data observed in the basin, although a calculation with daily inflow data is required because the diversion scheme is planned as a run-of-river type. (In this study, adjustment is made on the monthly inflow data based on the relationship between the monthly volume of diverted discharge estimated with daily discharge data available for two years and the monthly mean inflow volume.)

(3) Development Scale of the Xe Namnoy Downstream Project

The study on the optimum development plan of the Xe Namnoy Downstream Project is conducted based on the study results of the Midstream Project which provides the following conditions for the Downstream Project;

a) Inflow Data

Reservoir inflow is calculated with the operation condition of the Midstream Project determined in the previous section (2).

b) Firm Discharge

The firm discharge of the Downstream Project is calculated to be 24 m^3/s as the mean inflow of the driest month based on the above inflow data.

c) **Effective Storage Capacity**

Based on the above firm discharge including allowance, the effective storage capacity for daily inflow regulation is set at 2.0 MCM.

(3.1) **Reservoir HWL**

The studies are conducted for those cases with peak power duration of 6 hours varying the HWLs to be EL.265, 270, 275, and 280m with the above conditions. This comparative study shows, as seen in **Table 13.4-3**, an HWL of EL.270m provides the best performance in unit energy cost and B/C in the independent evaluation of the Downstream Project.

Evaluation is also made on the overall performance of both the Midstream and Downstream Projects as one project. From this it is seen that the HWLs of EL.265m and 270m provide almost the same economic performance as shown in **Table 13.4-4**. The HWL of EL.270m, which has an advantage in the amount of energy generation is selected as the optimum reservoir HWL of the Downstream Project in this study.

Here, the tail water level (TWL) of the Midstream Project is varied depending on the reservoir HWLs of the Downstream Project with the condition that the minimum TWL is EL.270m due to the riverbed elevation of the powerhouse site of the Midstream Project.

(3.2) **Maximum Discharge**

In addition to the above study, a comparative study on the maximum discharge is conducted by varying the maximum discharges to be 2.4, 3, 4, 5, and 6 times the firm discharge of 24 m^3/s respectively for the case with a reservoir HWL of EL.270m. In the evaluation of this comparative study, different peak power durations are applied for each case based on the ratios of maximum discharge against the firm discharge (10, 8, 6, 4.8, and 4 hours for each case respectively).

From this it is seen that a maximum discharge of 5 times the firm discharge (peak power duration is 4.8 hours) provides the best performance in B/C as shown in **Table 13.4-5**. However, it also provides the second highest unit energy cost of all the cases. On the other hand, although the maximum discharge of 3 times the firm discharge (peak power duration is 8 hours) provides the best performance in unit energy cost, it providdes a B/C less than 1.0. Accordingly, this case is not selected as an optimum scale. In this study, the maximum discharge of 4 times the firm discharge (peak power duration is 6 hours)