PREFACE

This material is collected by Center of Excellence for Hydro Power Plant Project, Electricity Generating Authority of Thailand. The purpose of the material is to be a reference for Hydro Power Plant Engineering and Environment Impact Training Course on Capacity Building Programme for power industries in Cambodia, Laos, Vietnam, and Thailand (CLVT) countries under Initiative for ASEAN Integration (IAI) Project.

The material, for the optimum benefits and other usage, may need further revision. In the mean time, the collectors apologize for any mistake that may cause to you and also appreciate your advice.

Collectors Group

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I. Hydropower Plant Pre-feasibility and Feasibility Study

1. Introduction

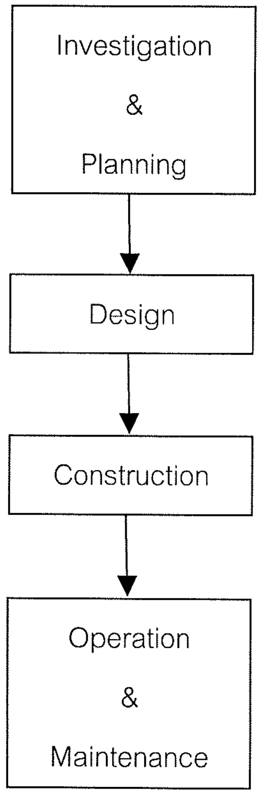
1.1 Hydropower Classification

Hydro power generation systems are mainly classified into the conventional and pumped storage types as described below.

- Hydro power generation
  - Conventional type
    - Run-of-river type
    - Reservoir type
    - Pondage type
  - Pumped storage type
    - Pure pumped storage type
    - Pumped and natural flow storage type

This section describes power generation systems of conventional and pumped storage types. For conventional type, development scale of 1 MW to 10 MW is classified as small scale hydro power and 10 MW to 500 MW as middle/large scale hydro power, and that of pumped storage type covers 100 MW to 1,000 MW. Civil structures of the projects mentioned above are to be newly constructed, however, projects utilizing existing irrigation facilities where a turbine and generator is newly installed are not described here because their development scales are mostly less than 1 MW.

The process from planning to operation of hydro power development projects is classified into investigation and planning, design, construction, and operation and maintenance stages as shown in the following flow chart.



- Reconnaissance study
- Feasibility Study

- Detailed design

- Civil works
- Hydro Mechanical and Electrical works

- Operation of hydropower
- Environment monitoring

Reconnaissance study is defined as investigation and planning based on topographic maps to scale 1:50,000~1:100,000 as these are easily acquired in the developing countries.

1.2 Hydropower Development Study Process

(1) Introduction

Significance of hydro power development, hydro power generation systems are explained as Basic knowledge for those engaged in development of hydro power projects.

The following are the major content.

- Concept of power output and electric energy of hydro power station
- Power generation systems such as run-of-river type, pondage type, reservoir type, and pumped storage type
- Positioning of hydro power as a supply source in response to the power demand

(2) Reconnaissance study

This Part describes the concept and methodology of hydro power planning in the reconnaissance study stage, and hydro power potential survey.

- Pre-investigation (collection of topographic and geologic maps and runoff data, etc.) prior to project study
- Calculation method of river flow at the planned site
- Selection of dam and powerhouse locations, waterway route, determination of power discharge, head calculation, selection of turbine and generator, calculation method of power output and energy generation
- Simplified method to calculate the work quantity for each structure such as the dam, waterway, and powerhouse, an their approximate construction cost
- Simplified benefit-cost analysis (B/C) using the approximate construction cost and generated energy, and economic analysis method using as indicator construction cost per kWh
- Main points for confirming the feasibility and suitability of a planned project from the site reconnaissance

(3) Feasibility study

This Part describes the concept of feasibility study. The following are the major content.

- Positioning of the planned hydro power project in the electric power system
- Concept and methodology of power demand forecast which is required to determine the development scale and commissioning time
- Investigation for feasibility study using topographic and geologic data, aerial photograph interpretation, physical prospecting, drilling, and exploratory adit
- Methodology of hydrologic and meteorologic study, and hydrologic analysis for feasibility study
- Significance of environmental impact survey and assessment, and environmental impact checklist

- Design concept of civil structures including the dam, intake facility, water conveyance facility, and powerhouse for feasibility study (hereinafter referred to as feasibility design)
- Concept of feasibility design for electric facilities including turbine and generator
- Concept of construction planning, construction schedule and construction cost estimate
- Concept of economic analysis using border price and shadow price to benefit-cost method and internal rate of return
- Concept of financial analysis and generation cost
- Concept of cost allocation for multi-purpose dam

(4) Case study, and operation and maintenance

The following are the major content.

- River flow data production in case the data is not available, and example of TANK model
- Case study on power development planning described in "Reconnaissance study"
- Items to be considered for operation and maintenance

2. Outline of hydro power generation

2.1 Hydro power generation

The waters of lakes, reservoirs located at high elevation and flowing in a river all provide potential energy or kinetic energy. These energy produced by water is termed water power. Power generation methods which produce electric energy by using water power are called hydro power generation.

2.1.1 Electric power output

Hydro power plants are equipped with turbines and generators which are turned by water power to generate electric power. Here, the water power is first converted into mechanical energy and hen into electric energy. In this form of energy conversion process, there is a certain amount of energy loss due to the turbine and generator. The power output is expressed by the following equation;

$$P = \rho g Q He \eta \times 10^{-3} \text{ [kW]}$$

Where,

P : Power output [kW]

ρ : Water density = 1,000 [kgf/m^3](1,000 kgf/m^3 at 4°C, elevation 0 m and 1 atm pressure)

g : Gravity acceleration [m/sec^2]=9.81 at Mean Sea Level

He : Effective head [m]

Q : Power discharge [m^3/sec]

η : Combined efficiency of turbine and generator

In this study, $\rho g \times 10^{-3} = 9.8$ is used as the approximate value.

1,000 kilowatt [kW] is equal to 1 megawatt [MW.] the MW unit is also used to express the power output.

Installed capacity, maximum output, rated capacity, firm output, and firm peak output are used to express the performance of the power plant.

2.1.2 Energy Generation

Power output (P) is the magnitude of the electric power generated per second. The electric energy (PxT) generated by continuous operation of P [kW] for T hours [h] is termed generated energy and is expressed by kilowatt hour [kWh].

The electric energy generated for one year at power plants is called annual energy generation or annual energy production. When electricity is continuously generated for one year at an output of 1 kW, the annual energy generation is expressed as follows.

Annual energy generation = 1 kW x 24 h / day x 365 days = 8,760 kWh.

2.2 Types of hydro power plant

Hydro power plant can be classified from view points of "power supply capability" and "measure to acquire the head for power generation"

2.2.1 Classification from view point of power supply capability

Typical examples of power supply in daily load curve are shown in Figure 2.4 (a) (b). Figure 2.4 (a) shows thermal power is the major source of supply in the power system and Figure 2.4 (b) shows hydro power is the major source of power supply.

(1) Conventional type

Run-of-river type

This type takes water within the range of the natural flow to generate electricity because it does not have a reservoir or pondage to regulate river flow. This type normally takes charge of the base load in the daily load curve shown in Figure 2.4 and is used frequently in hydro power plants of small scale. The waterway type is the category of this type.

Power plants having a reservoir or pondage are classified as a run-of-river type if peak generation is not feasible due to operating constraints by other water utilization purposes such as irrigation, water supply, etc.

Pondage type

As power demand fluctuates significantly during the course of one single day, power supply must be carried out in response to the demand. The pondage type has a pond which enables regulation of the river flow for one to several days. When the river flow is small, it is regulated and peak generation is conducted to allow a high power output in a short time in response to the peak load shown in Figure 2.4

Reservoir type

As river flow changes by season, a natural lake and a reservoir store water in the wet season and release it in the dry season thereby providing an even flow throughout the year. A power plant having a reservoir which enable annual or seasonal regulation of river flow is termed the reservoir type.

In case a power plant of the reservoir type is constructed upstream. The regulating effect extends to the power plants located downstream to enable more advantageous operation. Usually, this type takes charge of peak load in Figure 2.4 since it can supply relatively uniform power output throughout the year as well as enables response to the peak demand instantaneously . This type is widely used in power plants of large scale.

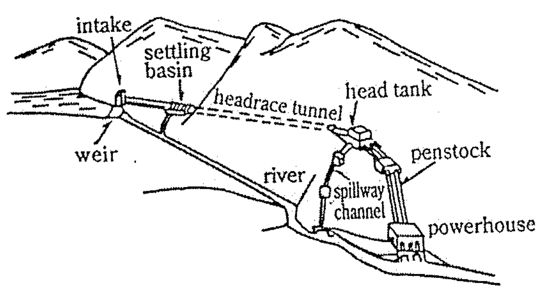


Figure 2.1 Run-of-River Type

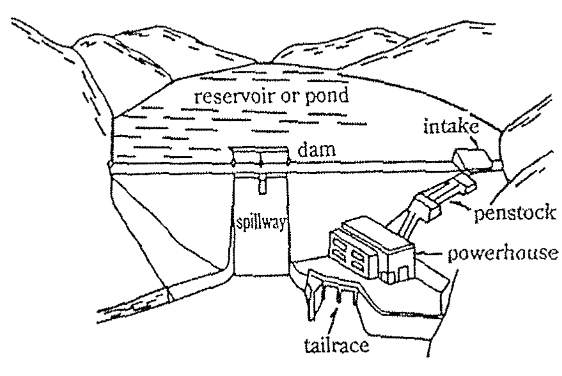


Figure 2.2 Reservoir Type or Pondage Type

(2) Pumped storage type

The pumped storage power plant consists of upper pond (upper reservoir), lower pond (lower reservoir), waterway and powerhouse as shown in Figure 2.3. It takes charge of the peak load in Figure 2.4 similar to the reservoir type. In this system, electricity is generated with the water stored in the upper pond in response to the peak demand in the daytime. Contrarily, during the night when the power demand drops, the water is pumped up from the lower pond to the upper pond using the excess energy generated by thermal power plants. Thus, the water is circulated to generate electric power.

Pumped storage power plants are classified into "pure pumped storage type" and "pumped and natural storage type" In the former type, there is no natural flow into the upper pond or is negligible and the water pumped up to the upper pond is circulated between two ponds for the power generation.

On the other hand, natural flow and pumped water into the upper pond is used for the power generation in the latter type, which means to save pumping energy corresponding to the natural flow into the upper pond.

Surplus electricity is sometimes produced during the wet season where hydro power is the major source in the power system, and is used for pumping energy in some pumped storage power plants.

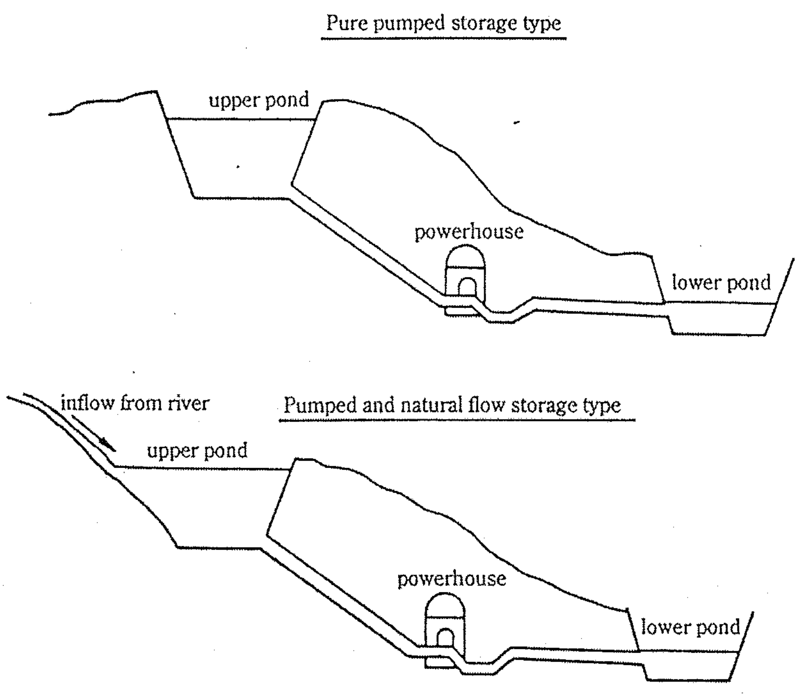


Figure 2.3 Pumped Storage Type

2.2.2 Classification by method of head acquisition

(1) Waterway type

Head of water of this is created by the difference in elevation between steep river gradient and gentle slope waterway, and is generally suitable for the upper or middle reaches of rivers which have relatively steep gradient.

It is classified into two types depending on the location of the powerhouse. In one type, the powerhouse is constructed along the same river where the intake is installed. In the other, it is constructed on a different river basin by construction of diversion facilities.

Since a dam is not constructed in this type of development, the flow cannot be regulated and the output fluctuates according to the natural river flow.

(2) Dam type

The head is acquired mainly by the height of a dam. The powerhouse is installed near a dam. A high dam is feasible where the river valley is narrow and the geologic condition is good. A reservoir created upstream of the dam provides the dam provides the regulation of the river flow, thus enabling regulation of the power output in response to load fluctuation. Generally, a site in the middle or lower reaches of a river where the flow is abundant is advantageous for the dam type.

(3) Dam and waterway type

This is a combination of the two types described above to create a head by the elevation difference between a dam and a waterway.

2.3 Power demand and supply

Power demand fluctuates according to the time of day and by season. The power demand to the power supplier is called load. The curve showing the load fluctuation status in timed sequence is called the load curve. In most cases, a load fluctuation curve is produced for one single day (24 hours) and is termed the daily load curve, an example is shown in Figure 2.4. The curve showing load fluctuation for one year is termed the annual load curve.

The characteristics of daily load fluctuation vary depending on the composition of the power demand. Generally, load increase in the daytime due to the operation of factories and offices, or in the evening when electricity is consumed for lighting. It drops off though the night to the early morning and again during the noon-time recess period.

In the load curve, peak load may include those areas before and after reaching its peak. The heavy load time zone is termed on-speak load time (peak time) while the light load time zone late at night and early in the morning is termed the off-peak load time (off-peak time)

Electric power supply in response to the power demand is depicted in the load curve show in Figure 2.4 described above. Figure 2.4 (a) show examples of power systems in which the major power source is thermal power. Figure 2.4 (b) shows the case where the major power source is hydro power. Of the hydro power plants, run-of-river plants takes charge of the base load in the daily load curve. The reservoir type, pondage type and pumped storage type power plants generally take charge of peak demand. Run-of-river plants do not have the capability to regulate the river runoff to generate electricity in response to peak power demand however the other three types of plants can regulate the river flow to generate peak power at the time and in the quantity as required by the system load.

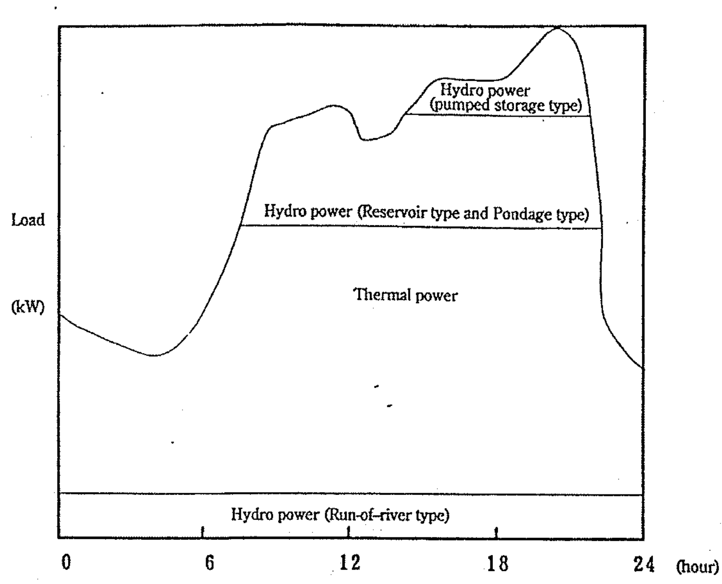


Figure 2.4 (a) Example of Daily Load Curve (System Composed Mainly of Thermal Power)

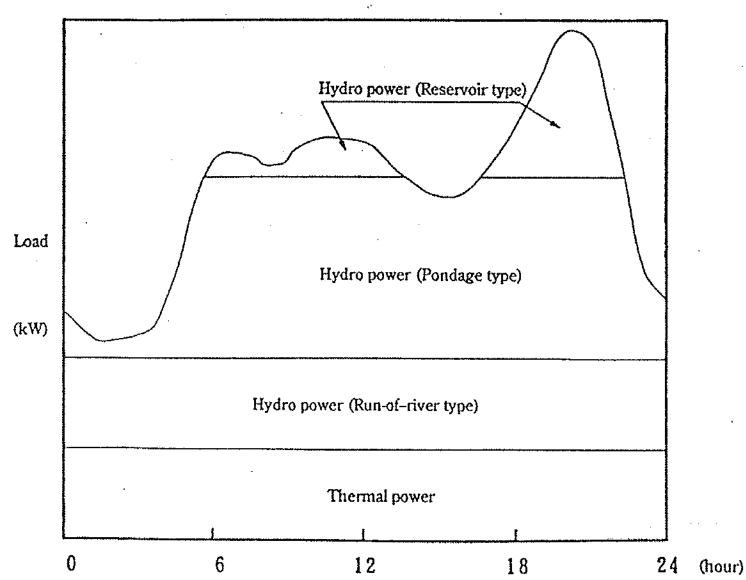


Figure 2.4 (b) Example of Daily Load Curve (System Composed Mainly of Hydro Power)

3. Project Planning and Pre-Feasibility Study

3.1 Flow of project planning

A feasibility study is conducted on promising projects which are selected from a reconnaissance study or master plan. The purpose of a feasibility study is to study project from technical, economical and environmental aspects and to obtain data to judge the possibility of development. A more detailed and latest data are used in the feasibility study to examine the necessity, development scale and commissioning time of the project from the aspect of power demand.

3.1.1 Review of basin master plan and pre-feasibility study

(1) Review of basin master plan

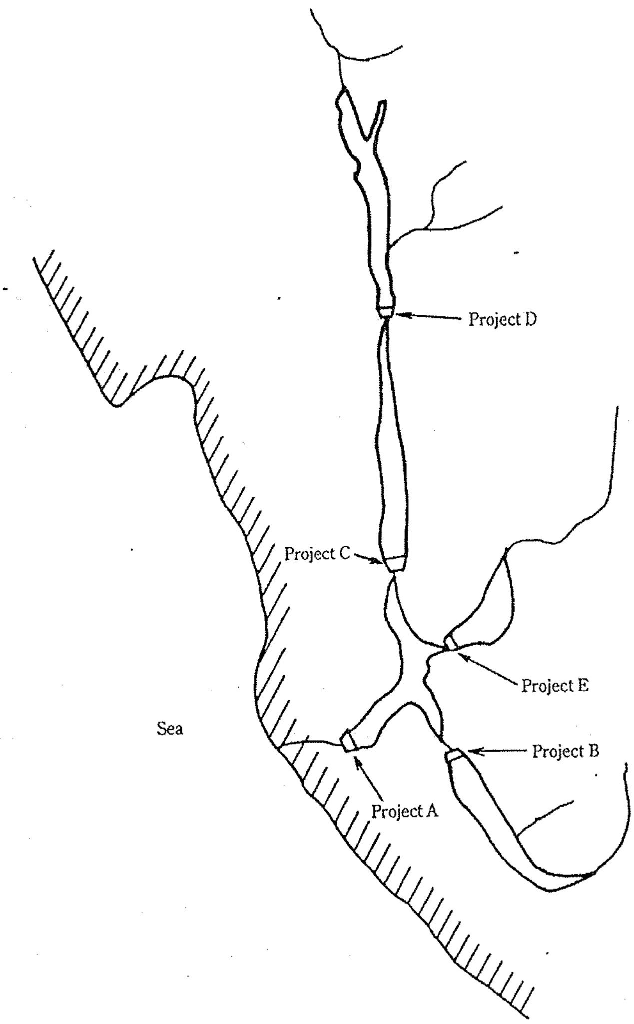
A basin master plan is usually formulated to study the most effective way to develop a river basin, before the feasibility study is conducted. An example of the master plan using topographic map of 1:50,000 scale is shown in Figure 3.1.1. Five sites are selected as development potential and a value of B/C for each project is obtained. Project A (162 MW, B/C = 1.52), Project B (117 MW, B/C = 1.31) and Project D (58 MW, B/C = 0.95) which give a benefit-cost ratio (B/C) of about 1.0 and above are deemed the most promising sites. Judging from the maximum output and economic aspects, Project A and B are selected as key projects which would be the core in the development of the basin. Topographic maps of approx. 1:10,000 – 1:50,000 scale are generally used in the master plan.

Promising projects registered in the master plan are compared from view points of future demand, access road, transmission lines, effects to other projects, land usage in the reservoir area, and overall economy and environmental impact, etc. The project judged to have the high priority is selected and the feasibility study is conducted. Therefore, the order of priority of each project should be identified in the master plan before conducting the feasibility study.

When the master plan contains multiple key projects, the development scale and order of development may mutually be affected by the regulating effect of upstream reservoirs and the advance construction of transmission lines. In this case, the feasibility study should be conducted of several projects.

(2) Review of pre-feasibility study

When sufficient data are not available to conduct feasibility study, a pre-feasibility study may be made as a step before conducting the feasibility study.



Project Plan

Project name	Output (MW)	B/C
A	162	1.52
B	117	1.31
C	24	0.69
D	58	0.95
E	40	0.74

Figure 3.1.1 Example of Master Plan

3.1.2 Basic data for project planning

Nature of investigations and data required for project planning are described below. When these data are not available in the quality to conduct the feasibility study, a pre-feasibility study may be conducted using some of the data.

(1) Topographic map

Topographic maps of 1:50,000 – 1:100,000 scale are used in a reconnaissance study. Topographic maps of the following accuracy are usually required for a feasibility study.

Project site (reservoir and structures);

- About 1:5,000 – 1:10,000 scale
- About 1:25,000 for large reservoirs

Dam site and powerhouse site;

- About 1:1,000 scale

(2) Hydrologic data of runoff, evaporation, sedimentation, etc., at dam site

In the project study, it is preferable to use runoff data covering a period of over ten years. If this is unavailable, data are prepared for longer period. Study of reservoir type development requires monthly flow data. Pondage and run-of-river types require daily flow data. If flow data is not measured at or near the dam site, it is difficult to conduct feasibility study. Therefore, it is necessary to install a streamflow gaging station to obtain reliable flow data at the dam site.

For a study of reservoir type power plants, the reservoir operation should be studied taking the evaporation from the reservoir into consideration. Therefore, evaporation data should be prepared. Sedimentation data should also be prepared for reservoir and pondage types.

(3) Rating curve at powerhouse or tailrace site

In order to calculate the output and energy of the project and to design the powerhouse (or tailrace), rating curve at the site is necessary. Generally, as streamflows at the site are not observed, the rating curve at the site is made with a river cross section and river gradient of the site by assuming Manning' coefficient of roughness and uniform flow condition. If several river cross section are available downstream of the site, more accurate rating curve can be made by varied flow calculation.

(4) Geologic data on dam, powerhouse and main structure sites

Geologic data by surface reconnaissance, drilling, and other methods are required.

(5) Load curve of maximum load day and data of the power source.

These data are required to study the necessity of the project from the aspects of supply and demand.

(6) Information and data related to environmental regulations

3.1.3 Position as source of supply power

In the feasibility stage of project study, future demand and supply capability should be kept in mind so that project study is conducted clearly identifying its role.

(1) Electric power system where a new hydro power is proposed to be constructed

When studying a project, it is important to understand the characteristics of the electric power system from the aspect of both demand and composition of power source. Figure 3.1.2 gives examples of load duration curves in which demand are arranged in the order of magnitude. Figure (a) is for a system in which power is supplied mainly by thermal plants, and hydro power is used mainly for peak loads. Figure (b) is for a system in which power is supplied mainly by hydro power. The characteristics of this system is that the power capability is affected by wet and dry seasons. Figure (c) is an example of a small-scale isolated system where power is supplied by diesel and/or small hydro power plants.

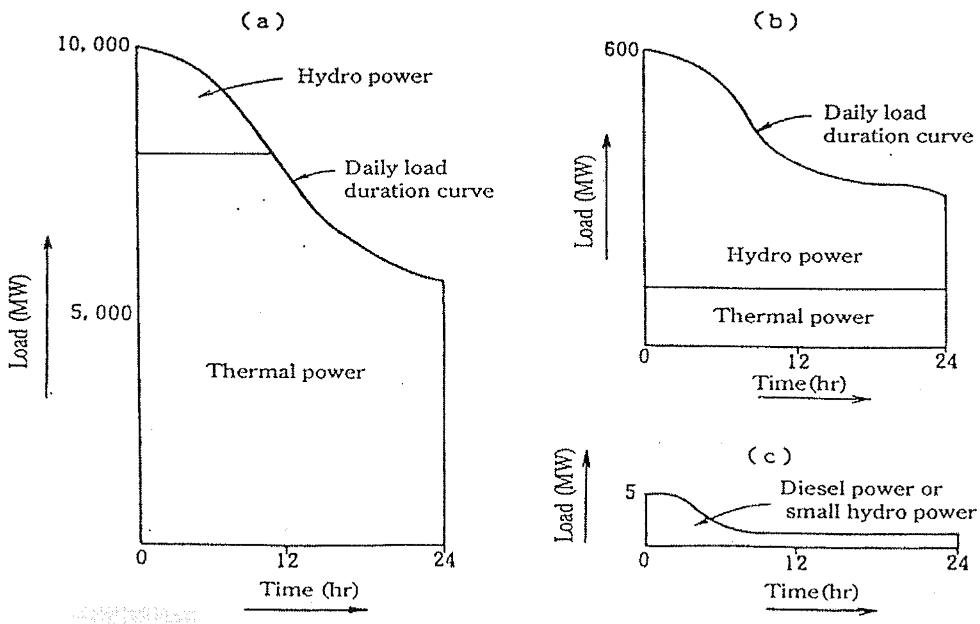


Figure 3.1.2 Examples of Daily Load Duration Curve and Supply Capability

(2) Load configuration

In the project study, the load configuration of the following particular day in a year is used.

- As shown in Figure 3.1.2 (a), where power is supplied mainly by thermal plants, supply capability is almost constant throughout the year, and the critical time of power supply is the day of maximum demand. The configuration of demand of that day is used to prepare load duration curve.
- In systems where power is supplied mainly by hydro-plants, as shown in Figure 3.1.2 (b), the supply capability is affected by seasonal conditions of river flow. Therefore, the load configuration is made for the day when maximum demand occurs during the dry season.

(3) Power source for future demand

A model of future power demand and supply capability is shown in Figure 3.1.3 (b). Future demand (a) is obtained by extrapolating the current demand (b) by the estimated growth rate. If the current load curve is deformed due to deficiency of power supply capability, it is necessary to correct the load curve by taking latent demand into consideration. Shaded part in Figure

3.1.3 (b) indicates the supply capability of existing power plants. The white part at the top of the figure (b) indicates the shortage of supply capability, and this part is taken care by most appropriate combination of hydro power, thermal power and other power sources. For hydro power which is judged the most appropriate, the project to cope with the load (mainly peak load) is selected from among projects identified as promising in the master plan and/or hydro power potential survey, and a feasibility study is conducted for that project.

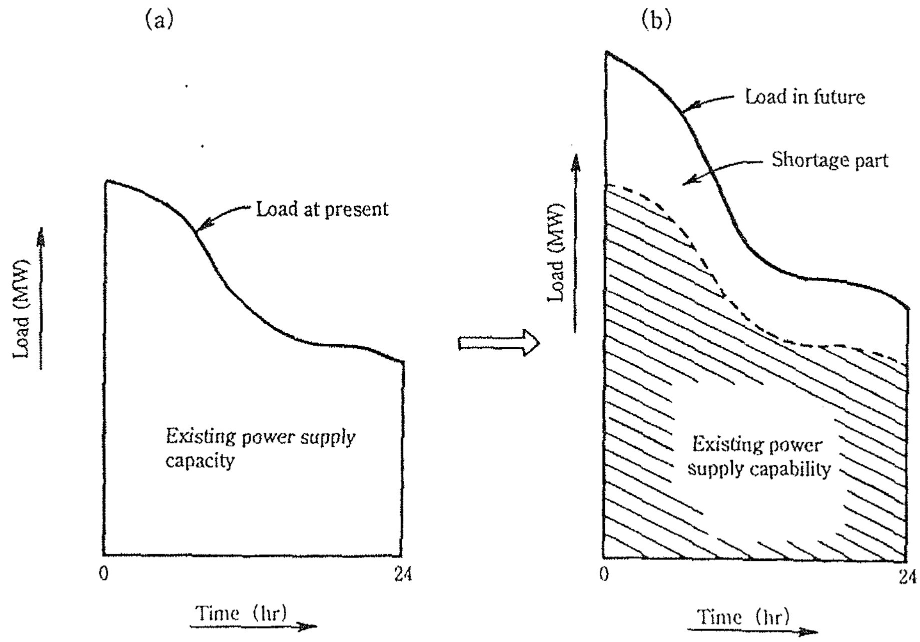


Figure 3.1.3 Relation between Future Demand and Planned Project

3.1.4 Methodology of the Study

Determination of type of power generation

The types of power source required from the standpoint of demand is described in Section 3.1.3(3). Determination of type of power generation is made after confirming the topography and geology at the project site from among run-of-river, reservoir and poundage types.

Optimization of scale of development

The waterway route, dam and powerhouse sites are compared and studied, and then storage capacity of reservoir and pond and maximum plant discharge are studied. The optimum development scale is determined by the economic analysis method described in Item (4).

The typical parameters in this study are;

Reservoir and pondage types

High water level (dam height), active storage capability, maximum plant discharge, waterway route (location of powerhouse), intake of water from tributary.

Run-of-river type

Maximum plant discharge, waterway route (location of intake weir and powerhouse), intake of water from tributary.

Number of units of turbine/generator and unit capacity

Generally, the larger the unit capacity, the trend is that project economics can be anticipated by merit of scale from the overall consideration of cost of electromechanical equipment and civil works. Therefore, the unit capacity should be as large as possible bearing in mind reliability, manufacturing technology and transportation. Although a large unit does give certain merits, outage of the unit causes large frequency fluctuations in the electric power system, and a larger reserve capacity is required in the event of outage of the equipment. These factors should be considered when determining the unit capacity.

The plant discharge of run-of-river type that fluctuates greatly according to the river flow, turbine efficiency drops and energy generation decrease significantly when the river flow is small. For these consideration, this problem can be solved by increasing the number of units.

Study of timing of implementation

The implementation time including stage development is determined by economic analysis described in Item (4), using the discounted cash flow method.

Peak duration hours

The concept of peak duration hours is used to study reservoir, pondage and pumped storage type projects. When a hydro power plant is continuously operated to supply the energy (E, kWh) at the maximum output (P kW), the concept is expressed as T = E/P. Peak duration hours is generally about 4 to 8 hours, which can be obtained by analyzing the load duration curve of a power system.

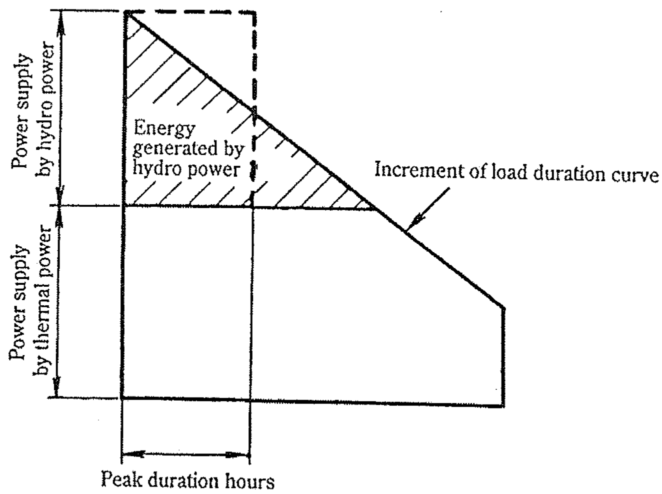


Figure 3.1.4 Peak duration hours

Maximum output and energy generation

Maximum output

Maximum output is calculated using the following formula.

$$P = 9.8 \times Q_{max} \times H_{es} \times \eta_t \times \eta_g$$

Where,

P	: Maximum output (kW)
Q_{max}	: Maximum plant discharge (m^3/s)
H_{es}	: Effective head (m)
η_t	: Turbine efficiency
η_g	: Generator efficiency

Head loss and effective head

Figure 3.1.5 and Figure 3.1.6 are schematic diagrams of the effective heads of the Francis turbine, including propeller turbine and Pelton turbine. After the head loss is calculated for each facility indicated in the diagram, the effective head is calculated by subtracting the head loss from gross head.

Effective head is expressed by the following equation

Francis turbine and propeller turbine :

$$H_e = H_g - (H_{L1}+H_{L2}+V_2^2/2g+H_{L3})$$

Pelton turbine:

$$H_e = H_g - (H_{L1}+H_{L2}+ H_s +H_{L3})$$

Where,

H_g : Gross head (Difference in elevation between intake water level and tailwater level)

H_e : Effective head

H_{L1} : The sum of head loss of intake, headrace and other waterway structures between intake and tank (surge tank or head tank)

H_{L2} : Head loss of penstock between head tank and turbine inlet

H_{L3} : Head loss of tailrace channel between tailrace bay and tailrace

$V_2^2/2g$: Velocity head of draft tube outlet flow velocity V_2 (Discharge head loss for reaction turbines)

H_s : Pelton turbine installation height

Calculation of output and energy generation

Output and energy generation are calculated from the turbine efficiency, plant discharge and effective head considering fluctuation of flow and head due to fluctuation of reservoir water level.

Primary energy and secondary energy

Primary energy and secondary energy should be accounted separately if their values differs in the power system. The concept of these energies are defined in this Manual as follow.

- Run-of-river type : Energy generation corresponding to firm discharge is termed primary energy, and the other energy is termed secondary energy.
- Reservoir and pondage types: Energy generation corresponding to the firm plant discharge during peak duration hours is termed primary energy, and other energy is termed secondary energy.

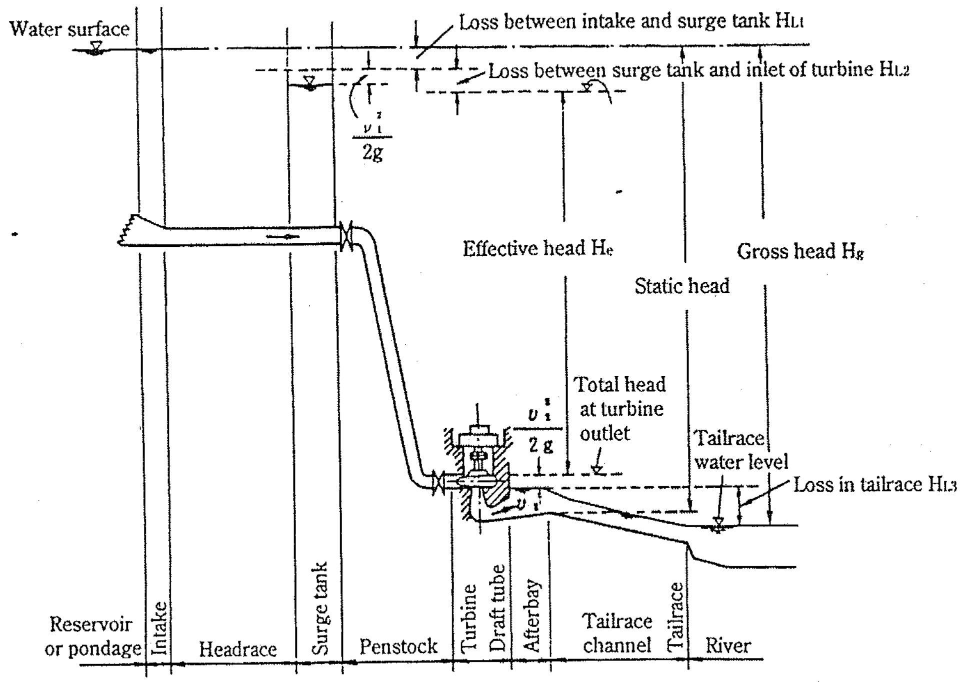


Figure 3.1.5 Schematic Diagram of Effective Head (Francis turbine)

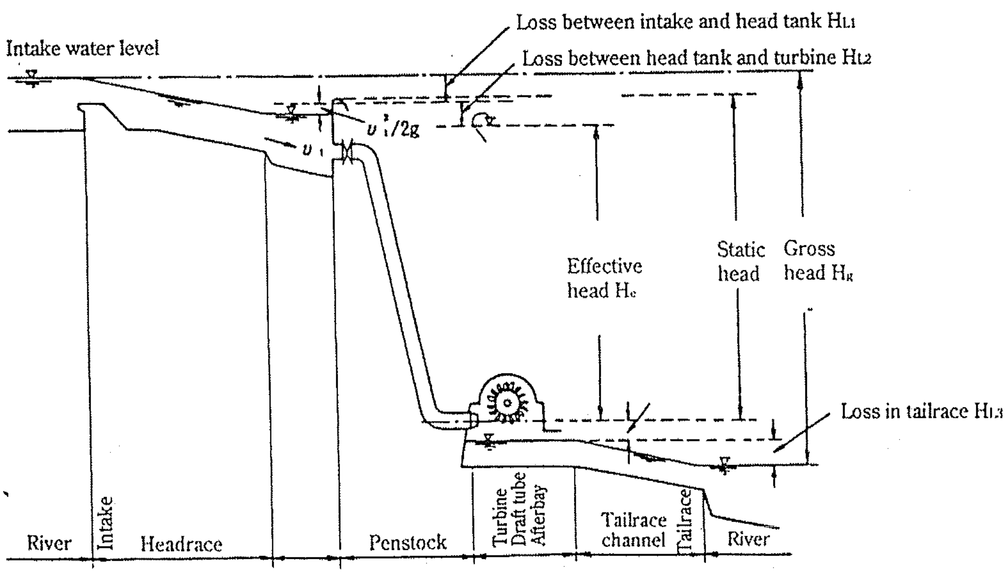


Figure 3.1.6 Schematic Diagram of Effective Head (Pelton turbine)

Economic analysis

The cost (C) of a hydro power plant and the cost (B) of an alternative thermal power plant having a supply capability comparable to the hydro power plant / are analyzed using the "discounted cash flow method" and compared. Then, the net present value of (B-C), benefit-cost ratio (B/C), and internal rate of return (IRR) are calculated. The analysis giving the highest value is adopted as the optimum plan.

3.2 planning of development scheme

In the study, the required supply capability for the deficiency of capacity indicated in Figure 3.1.3 is analyzed, and then the type of power generation demanded of hydro power is confirmed. Generally, a reservoir or pondage type capable of supplying peaking power is necessary for the system described in Figure 3.1.2 (a). A run-of-river, reservoir or pondage type is usually necessary for the system indicated in Figure (b). A run-of-river or pondage type is usually necessary for Figure (c). The type of power generation for the proposed project is decided with consideration given to the supply capability of the existing power source and the planned new thermal power and hydro power plants.

3.2.1 Run-of-river type

(1) Required supply capability

The run-of-river type is mainly used to supply power to areas remote from large scale power sources where the capacity of transmission line system is not adequate, or to supply power to isolated power systems. In case a run-of-river type power plant is connected to the large scale power system, it can contribute to reduce the fuel consumption of thermal power plants. Run-of-river type as source of supply for a small scale system is explained below.

Figure 3.2.1 shows the relation between the power supply capability (P) newly required by the system and the firm power (P_f) of the proposed hydro project. Figure (a) is the case when the P_f is larger than P, which means that a run-of-river plant is appropriate because the power plant has sufficient supply capability to satisfy the demand. When the P_f is significantly larger than P, turbines / generators may be installed in stages corresponding to the growth of future demand. Figure (b) is the case when P_f is smaller than P. When developing this project site, a pondage type is adopted to regulate the river flow by a pond so that Pf is equal to P, or to develop another run-of-river type project capable of making up the difference.

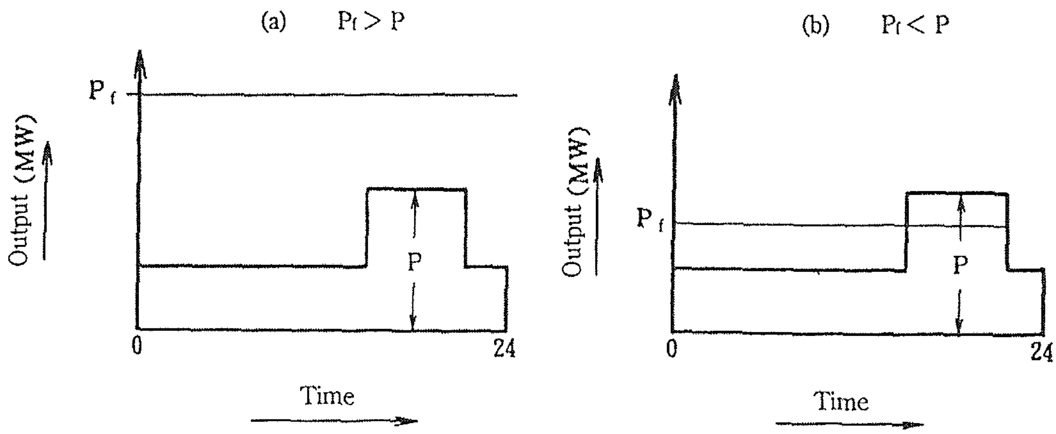


Figure 3.2.1 Relation between Required Supply Capability and Firm Output

(2) Optimization study of development scale

Waterway route

The topography and geology of possible sites are confirmed using topographic maps of scale 1/5,000-1/10,000 before proceeding to the feasibility study. Alternative plans changing the sites of intake weir and powerhouse are prepared, and the waterway route selected in the reconnaissance study is re-studied using the latest data such as topographic map, geology, runoff data. If both an open channel and tunnel are possible for the headrace, the final decision is made by economic comparison.

Maximum plant discharge

Alternative plans are prepared varying the maximum plant discharge for the selected waterway route and preliminary designs are made for the major plans. The turbine type is selected with consideration given to the conditions in the proposed plan, and then the efficiency is set. The output and energy generation are calculated for the alternative plan, and economic comparisons are made to determine the optimum maximum plant discharge.

Intake facilities at tributary, etc.

It might be technically possible to draw water from a adjacent gully, tributary or river. An economic study is made by comparing the additional cost incurred to draw water and the additional benefit of increased power and energy thereby to judge whether to draw water from adjacent tributaries and river. Run-of-river types have long waterways which often cross a tributary. In many cases, therefore, the facility to draw water from tributaries requires only a small cost increase.

Number of turbine unit.

During the low flow season, the available discharge of run-of-river type power plants decreases and might be less than the minimum discharge of the turbine. On some days it is not possible to generate power as shown in Figure 3.2.2. To avoid this situation, a plan to install two or more turbines is necessary to reduce the discharge for one turbine.

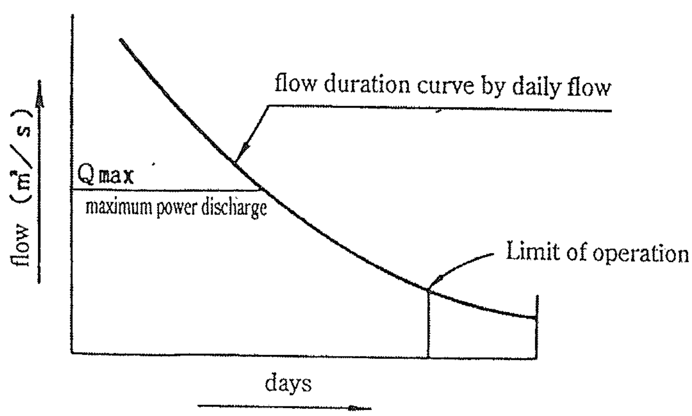


Figure 3.2.2 Flow Duration Curve and Operating Limit

Development scale and time of implementation

The effective head is obtained by fixing the dam and powerhouse sites, and the maximum plant discharge is determined, therefore the scale of development can be determined. After the scale of development is determined, the time of implementing the project is studied, and in the case staged development is expected, the sequence of development is studied.

3.2.2 Reservoir type

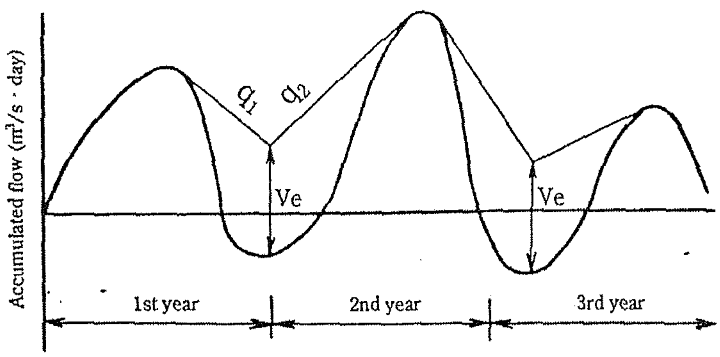
(1) Required supply capability

There are the following functional purposes of reservoir type hydroelectric projects.

Supply source for peak demand

Reservoir type power plant are generally used as a power source for peak demand in electric power systems composed mainly of thermal power. This pattern depicted on a mass curve and daily load duration curve is given in Figure 3.2.3 (a) and 3.2.3 (b). The mass curve shows an example of movement of reservoir water surface from high water level to low water level in one year, and Q_1 represents firm discharge corresponding to firm peak output. This discharge corresponds to primary energy, and discharge of q_2 is larger than q_1, the difference means secondary energy indicated in Figure 3.2.3 (b).

(a) Mass curve



(b) Daily load duration curve

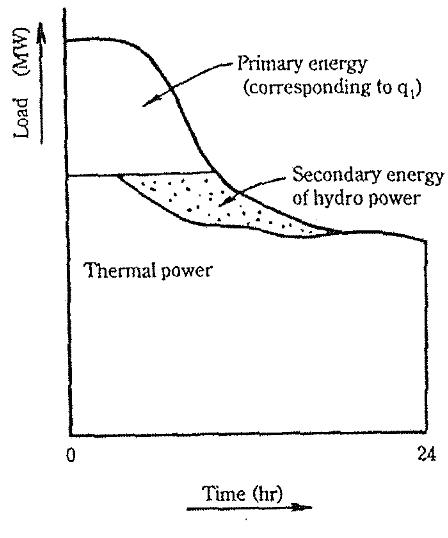


Figure 3.2.3 Mass Curve and Daily Load Duration Curve

Figure 3.2.4 shows the mass curve of a carry-over reservoir which is operated from full to empty condition once in several years. In this case, the discharge q1 indicates the firm power discharge and very little secondary energy is generated.

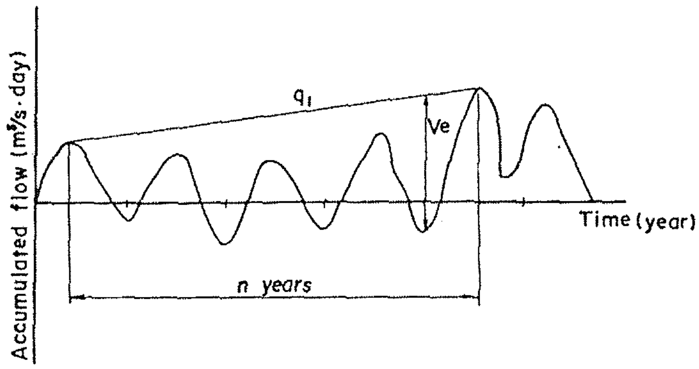


Figure 3.2.4 Mass Curve (Carry-over reservoir)

Power supply source for peak and base demand

Reservoir type power plants are mostly planned as power sources supplying for peak demand mentioned above, however the type may be rarely planned for the load as explained below.

The example shown in Figure 3.2.5 is a reservoir type power plant to supply for base demand in a system mainly composed of hydro power plants. This discharge "q_1" is more than the mean flow during the dry season. In the wet season, it is operated to supply for peak demand controlling discharge "q_2". This operation pattern is taken because in the wet season run-of-river and pondage type power plants have a small regulating capacity and therefore are operated 24 hours a day to supply for base demand, and the reservoir type plants supply the peak demand. Conversely, in the dry season, pondage type plants are operated to supply for peak load, and reservoir type plants supply for base demand using a certain volume of flow stored during the wet season.

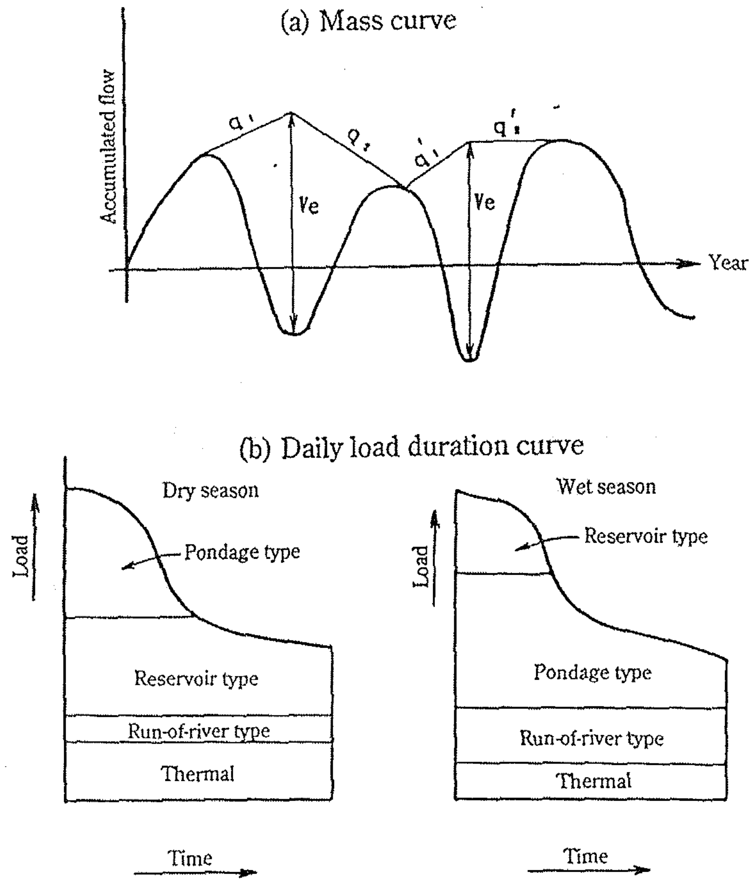


Figure 3.2.5 Mass Curve and Daily Load Duration Curve

(2) Optimization study of scale of development

Study of dam site, powerhouse site and waterway route

The dam site selected in the reconnaissance study is an approximate location based on a topographic map of scale of about 1:50,000. The topography of the dam site is, therefore, confirmed using an approximately 1:5,000 – 1:10,000 scale topographic map prepared before conducting feasibility study. The suitability of the site is confirmed from geological surveys such as geological reconnaissance and drilling, etc. Where there are multiple candidate sites for the dam, these sites are compared from technical and economical aspects and the site is then decided.

Preparation of storage-capacity curve, estimation of sedimentation, and setting sedimentation level

- The storage-capacity curve is prepared using an approximately 1:5,000 – 1:10,000 scale topograplic map.
- Sedimentation volume is estimated using the study results ,and a sedimentation level is set corresponding to the sediment volume. Generally, sedimentation for 100 years is used to calculate the sediment volume. Of the sediment brought into a reservoir by riverflow, only a portion may be trapped and retained in a reservoir. The trap efficiency of a reservoir is considered in estimating the sedimentation volume. When there is an existing reservoir upstream, the effect of trap efficiency of that reservoir is also taken into consideration. The estimated sedimentation volume may be decreased when there are facilities to discharge the sediment from a reservoir such as bottom outlets.

Calculation of output and energy generation

Output and energy are calculated from the head and plant discharge determined by the reservoir operation, turbine efficiency determined from head and discharge fluctuation. A rule curve prepared using the later called Dynamic Programming (D/P) or a rule curve prepared from a mass curve is used in reservoir operation.

Study of high water level (height of dam) and active storage capacity

- Low water level is tentatively set based on the sedimentation level, intake shape and velocity of flow.
- Figure 3.2.6 is a model diagram of studies conducted with different high water levels and active storage capacities. The lower limit of the low water level is determined by the sedimentation level. The limit of the high water level is determined by topography, geology, compensation and resettlement, etc. Alternative plans with low and high water levels within this range, with different active storage capacities, are prepared. Economic comparison is made based on those plans, and the optimum high water level and active storage capacity are determined. In the case of a project that involves a huge area of inundated land and resettlement, but the unit compensation and resettlement cost are very low, the difference may not be overly remarkable in an economic comparison. In

this case, it might be important to determine the high water level politically, such as for the acquisition of alternative land etc. This issue must, therefore, be fully discussed with the authorities concerned.

- Maximum plant discharge which is used tentatively in this study is calculated from the following equation.

$$Q_{max} = \frac{Q_f \times 24}{T}$$

Where,

Q_{max} : Maximum plant discharge (m^3/s)

Q_f : Firm discharge (m^3/s)

T : Peak duration hours (hr)

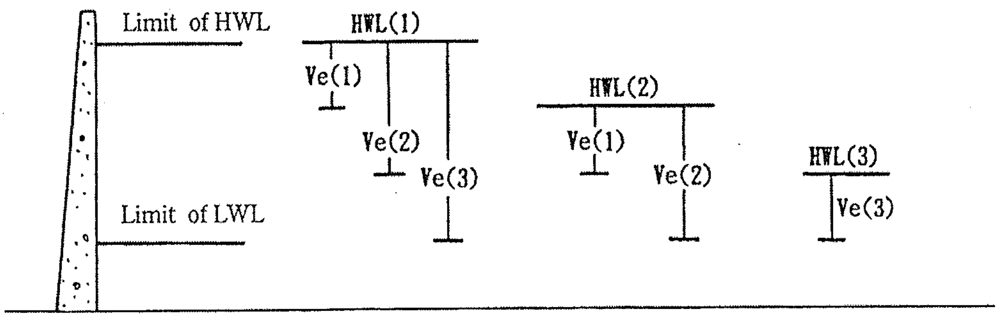


Figure 3.2.6 Study of High Water Level and Effective Storage Capacity

Study of maximum plant discharge

The maximum plant discharge is finalized in this study. Economic comparison is made by altering the maximum plant discharge against the selected high water level and active storage capacity, and the optimum maximum plant discharge is then determined.

High water level, active storage capacity and maximum plant discharge may be studied together using matrix.

Use of flow from tributaries

In some cases, it is technically possible to draw water from an adjacent gully, tributary or river. Economic comparison is made of the cost required for such intake facilities and the benefit gained from the increased output/energy. From this, analysis, judgement is made whether such an intake facility should be constructed or not.

Economic comparison considering the benefit of other sectors

When the dam is a multi-purpose project which includes irrigation, flood control, etc., those aspects are included in the study of reservoir operation. The benefits combined with power generation and other sectors are considered in the economic analysis.

Determination of scale of development

As the scale of the dam and maximum plant discharge are determined, the maximum output is determined.

Example of determining the scale of development

Examples of comparisons made with high water levels between 155 – 170m and active storage capacities between 150 x $10^6 m^3$ – 330 x $10^6 m^3$. The active storage capacity is altered for each high water level, and the optimum active storage capacity for that high water level is obtained. The shows that the values of B – C and B/C rise as the high water level rises. In this project, however, when the high water level exceeds 165m, the problem of resettlement of local residents arises. As this problem affects the project feasibility, discussions were held with the national government and 165m was subsequently selected as the high water level. In this case, the optimum active storage capacity is 240 x $10^6 m^3$. Figure 10.2.8 provides examples where the maximum plant discharge is altered. The high water level and the active storage capacity are determined by the study described above, then the maximum plant discharge is changed. From this, the plant discharge of 214 m^3/s was determined as optimum with the maximum output set at 165 MW.

4. Site reconnaissance and determination of development plan

When a Site is deemed worthy of further detailed study from study topographic map, it is extremely important to conduct a site reconnaissance along the proposed waterway route and alternative routes of a development site. Using 1:50,000 scale or 1:100,00 scale topographic maps, the differences between the topographic map and the actual topography, the geological conditions, existing facilities, and road conditions are checked in this site reconnaissance for each structure site. The results are fed back to the study to prepare a development plan. The following point should examined with care site reconnaissance.

Area surrounding dam site

(1) Topography

Topographic maps of 1:50,000 - 1:100,000 scale used in the reconnaissance study are not of reliable accuracy. The dam site Topography must be confirmed at the site as that shown in the map may differ from the actual situation.

(2) Geology

The geology of the dam site, and upstream and downstream of the site is surveyed on site. Condition of foundation rock is confirmed from the outcrop of determine the suitability as a dam site.

(3) River flow

Flow at the dam (weir) site is estimated visually or by Manning's formula and other methods. When estimating runoff using Manning's formula, the water surface width, water depth, water surface gradient, and vegetation to estimate roughness coefficient are checked at site.

(4) Riverbed deposit

Riverbed deposit is checked and the result used to estimate future sedimentation behind the dam.

Headrace

(1) Topography

Longitudinal and cross-sectional profiles of the headrace route are drawn based on the topographic maps, and the approximate route is confirmed at the site.

It is important to consider the construction adit locations when determining the headrace tunnel route.

For open channel route, hillside slope is checked at site to confirm whether an open channel is feasible.

(2) Geology

The geology of the proposed headrace route is checked from outcrops, vegetation, landslide and slope failure.

Penstock

(1) Topography

Topography and cross-sectional profiles of the penstock route are drawn based on the topographic map and an approximate location is confirmed at the site.

When there are alternative penstock routes and powerhouse locations, the topography for those alternatives are also checked.

(2) Geology

The geology of the proposed penstock route is checked from outcrops, vegetation, landslide and slope failure.

Powerhouse and its surrounding area

(1) Topography

The topography is checked at the site to confirm whether the space required for the powerhouse is available.

(2) Geology

The geology of the powerhouse site and its surrounding area is checked at the site. The suitability as a base rock of powerhouse site is determined from outcrops. When no outcrop is seen at the site and there is a large riverbed deposit, the powerhouse site should be changed to a site where bedrock can be reached easily.

(3) Conditions at opposite banks of tailrace and spillway channel end

Water discharged from the power plant may erosion of the opposite bank, therefore, the topography and geology should be investigated.

Construction related matters

(1) Road conditions to each site

As the availability of an existing road for the construction has a significant effect upon the project construction cost and construction schedule, existing trafficable roads checked at the site with a topographic map.

(2) Construction materials

For a concrete dam, the method to supply concrete and quarry site for aggregates, and for a fill dam, borrow area for core materials and quarry site for rock materials are investigated at the site.

The dam type is determined by also considering the topography and geology

(3) Transmission and distribution lines for construction use, and others

Transmission line and distribution line route(s) are confirmed to enable receiving power supply for construction use.

Transmission line

Transmission line or distribution line route(s) is confirmed to transmit the electric power generated at the planned powerhouse.

Others

It is necessary to check the area for area for environmental restriction zones such as natural parks and wildlife reserves, reserves forest, cultural assets, and houses, farms and existing water utilization facilities in the area to be affected by the power plant, In the case a reservoir is to be created, fishery, dwellings and farmland to be inundated are investigated during the site reconnaissance.

Determination of development plan

The plan is reviewed based on the data acquired from the site reconnaissance, and a final in the reconnaissance study stage is produced. As a result of the review of the development plan prepared in the reconnaissance study ,it is judged that the next step of study, that is, pre feasibility study and feasibility study should be conducted an investigation schedule is prepared. When there is no runoff gaging station at the dam site or in its adjacent area, it is essential to install one as soon as possible and to start runoff recording.

5. Feasibility Study

5.1 Run-of-river Type

Principal study points are shown according to the study procedure as following.

(1) Project study

Study of waterway route

Catchment area

Preparation of Flow Duration Curve

The flow duration curve is prepared from daily runoff data at the project site as shown in Fig 5.1.

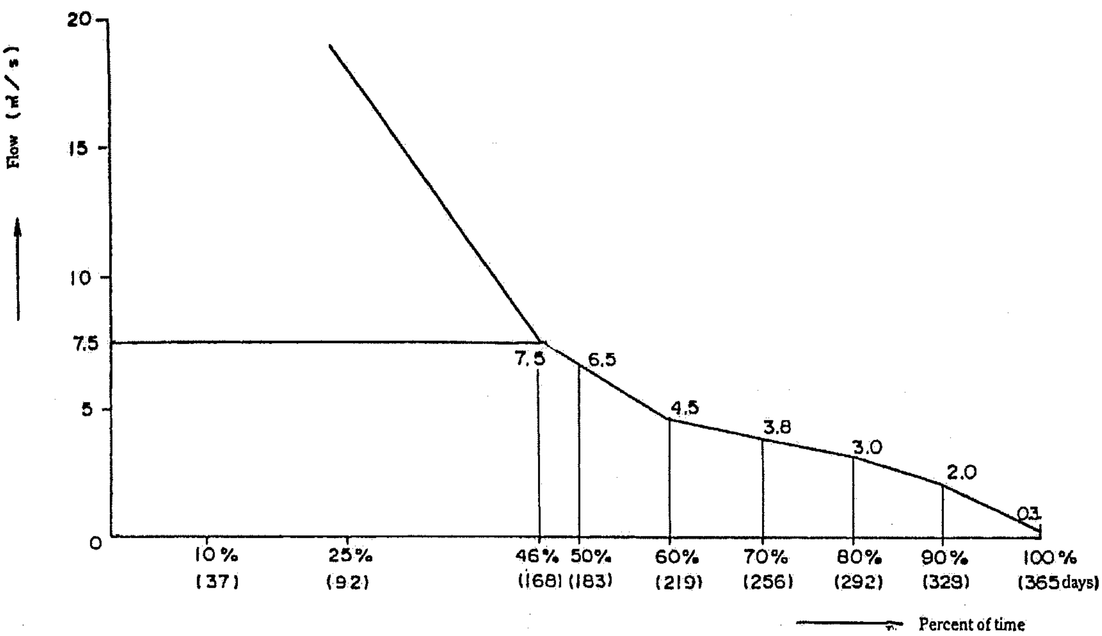


Figure 5.1 Sampled Flow Duration Curve

Firm discharge

The firm discharge considered at a specified probability of occurrence as given by Flow Duration Curve.

Maximum plant discharge (Q_{max})

Maximum plant discharge (Q_{max}) is considered at a point of significant change of the trend of Flow Duration Curve with rapidly sharp pivot.

Waterway profile

The profile of the waterway route determined above is shown in Fig 5.2.

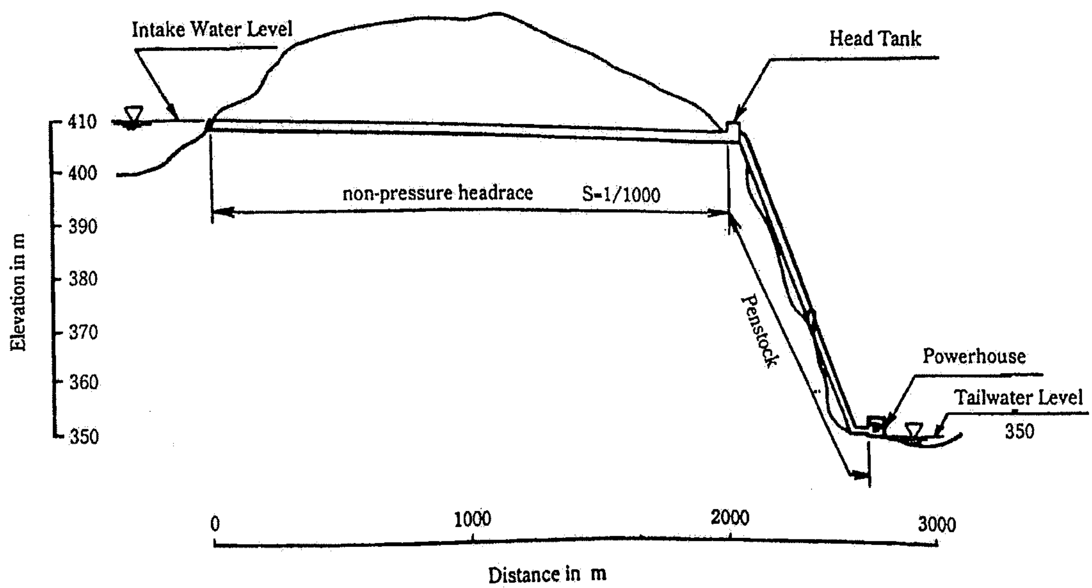


Figure 5.2 Sampled Waterway Profile

Calculation of head loss (H_e) and normal effective head (H_e)

H_g = IWL – TWL

H_l = (loss in headrace) + (loss in penstock) + (other loss)

H_e = H_g + H_l

Where

IWL : Intake water level (m)

TWL : Tailwater level (m)

Hg : Gross head (m)

Hl : Head loss (m)

He : Effective head (m)

Selection of turbine type and combined efficiency

As the maximum plant discharge and the effective head turbine type is to be selected from Fig 5.3. According to turbine and generator information, the combined efficiency is obtained.

Calculation of maximum output (P) and firm output (P_f)

Maximum output

$P = 9.8 \times Q_{max} \times H_e \times \eta$, $\eta = 0.85 \sim 0.90$

$P_f = 9.8 \times Q_f \times H_e \times \eta_f$, η_f is lower than η, depends on type and size of turbine, and turbine discharge

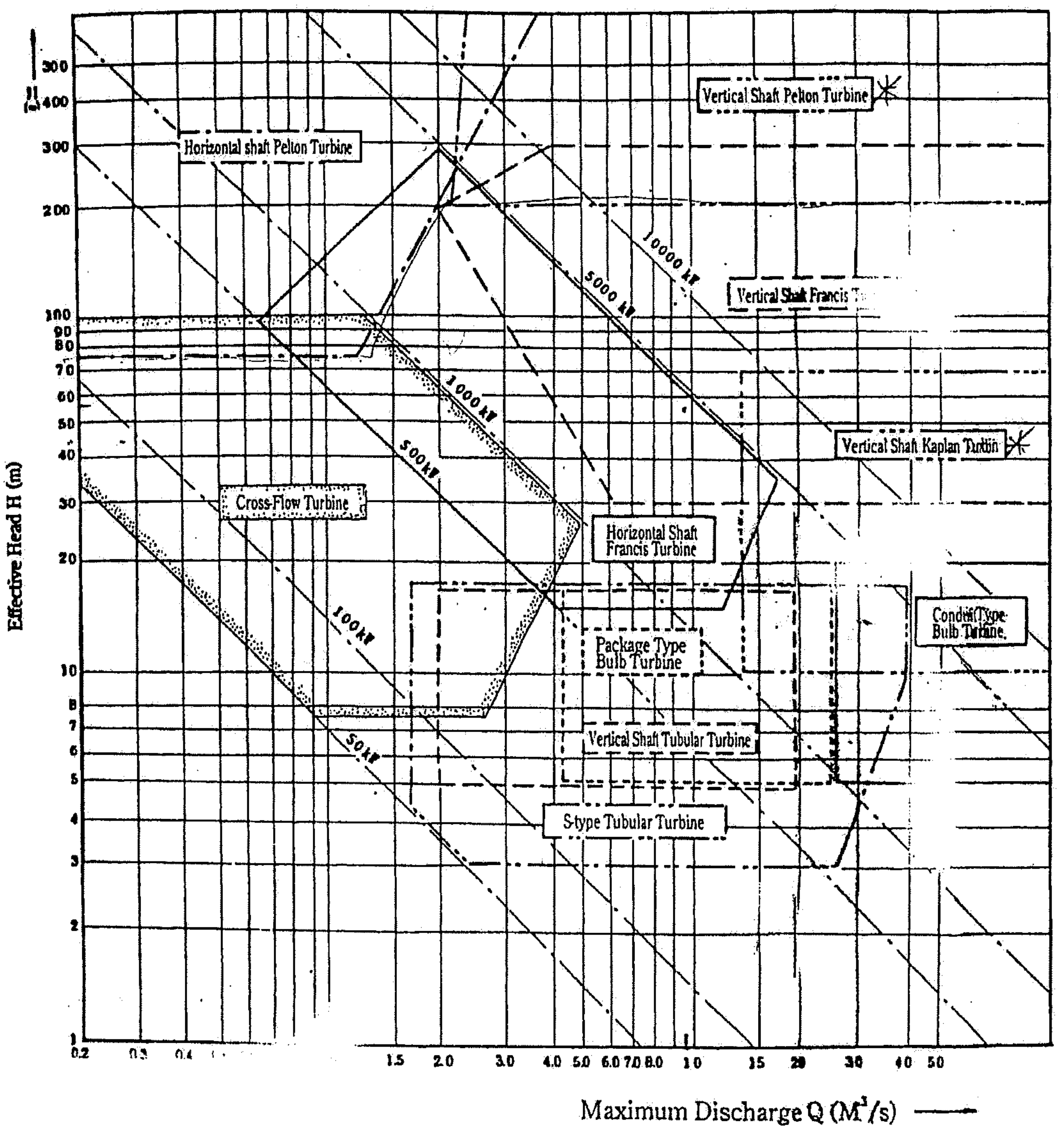


Figure 5.3 Turbine Selection Criteria

Annual energy generation (E and E_f)

Total Energy,	E	= P x H	for Project Evaluation
Primary Energy,	E_f	= P_f x H	for Power Supply Guarantee
	H : Generating Hours		

Plant factor

PF = (Annual energy production)/ (Max. output x 8,760) x 100

(2) Construction cost estimation

(2.1) Sampled Calculation of quantities of work

Intake dam

- Height (Hd) = 10 m

  Crest length = 30 m

- Quantities

  $Ve = 8.69x(HdxL)^{1.14} = 5,800\ m^3$

  $Vc = 16.1x(Hd^2xL)^{0.695} = 4,2\ 00\ m^3$

  $Wr = 0.0274xVc^{0.830} = 28$ tons

  $Wg = 0.145xQf^{0.692} = 10$ tons

  Annual rainfall 1,100 mm gives H district runoff coefficient "a" = 170

  $A = 55\ km^2$ $g = 8.2\ m^3/s/km^2$ $Af = 8.2x55 = 45\ m^3/s$

Intake

- Hon–pressure type
- $Q = 7.5\ m^3/s$

  Tunnel inner diameter D = 2.2 m and radius R = 1.1 m

- Quantities

  $Ve = 171x(RxQ)^{0.666} = 700\ m^3$

  $Vc = 147x(RxQ)^{0.470} = 400\ m^3$

  $Wr = 0.0145xVc^{1.15} = 14$ tons

  $Wg = 1.27x(RxQ)^{0.533} = 4$ tons

  $Ws = 0.701x(RxQ)^{0.582} = 2$ tons

Setting basin

- $Q = 7.5\ m^3/s$
- Quantities

  $Ve = 515xQ^{1.07} = 4,400\ m^3$

  $Vc = 169xQ^{0.936} = 1,100\ m^3$

  $Wr = 0.120xVc^{0.847} = 45$ tons

$Wg = 0.910 x Q^{0.613} = 3$ tons

$Ws = 0.879 x Q^{0.785} = 4$ tons

Headrace

- Non–pressure tunnel
- $I = 1/1{,}000$, $Q_{max} = 7.5\ m^3/s$, $L = 2{,}000$ m, $D = 2.2$ m
- Quantities

$Ve = (0.893xD^2+1.07xD+0.321)xL = 14{,}000\ m^3$

$Vc = (1.07xD+0.321)xL = 5{,}400\ m^3$

$Wr = (0.00911xD+0.00273)xL = 46$ tons

Head tank

- $Q = 7.5\ m^3/s$
- Quantities

$Ve = 808xQ^{0.697} = 3{,}300\ m^3$

$Vc = 197xQ^{0.716} = 830\ m^3$

$Wr = 0.051xVc = 42$ tons

Penstock and spillway channel

<u>Penstock</u>

- $Q = 7.5\ m^3/s$, $He = 56.8$ m

Inner diameter of steel pipe	Dm	=	1.8 m
Length of steel penstock	L	=	100 m (From waterway profile)
Design head	H	=	60 m

- Quantities

$Ve_1 = 10.9xDm^{1.33}xL = 2{,}400\ m^3$

$Vc_1 = 2.14xDm^{1.68}xL = 570\ m^3$

$Wr_1 = 0.018xVc = 10$ tons

$tm = 0.0362xHxDm+2 = 6$ mm

$Wp_1 = 7.85x\pi xDmxtmx10^{-3}x1.15xL = 31$ tons

Spillway channel

- Q_{max} = 7.5 m^3/s, mean gradient 1/1

  D = 0.8 m, L = 100 m (Installed parallel with penstock)

- Quantities

  $Ve_2 = 9.87xD^{1.69}xL = 680\ m^3$

  $Vc_2 = 2.78xD^{1.70}xL = 190\ m^3$

  $Wr_2 = 0.029xVc_2 = 6$ tons

  $Wp_2 = 1.165xD^{1.25}xL = 12$ tons

Total quantities

$Ve = Ve_1+Ve_2 = 3{,}100\ m^3$

$Vc = Vc_1+Vc_2 = 760\ m^3$

$Wr = Wr_1+Wr_2 = 16$ tons

$Wp = Wp_1+Wp_2 = 43$ tons

Powerhouse

- Q_{max} = 7.5 m^3/s, He = 56.9 m, Number of unit n = 1
- Quantities

  $Ve = 97.8x(QxHe^{2/3}xn^{1/2})^{0.727} = 3{,}000\ m^3$

  $Vc = 28.1x(QxHe^{2/3}xn^{1/2})^{0.795} = 1{,}200\ m^3$

  $Wr = 0.046xVc^{1.05} = 79$ tons

Tailrace

- Non-pressure type
- Q = 7.5 m^3/s, R = 1.1 m
- Quantities

  $Ve = 395x(R\ xQ)^{0.479} = 1{,}100\ m^3$

  $Vc = 40.4x(RxQ)^{0.684} = 170\ m^3$

  $W_R = 0.278xVc^{0.61} = 6$ tons

(2.2) Total cost

The unit prices of "A" country are applied to the above quantities of works to arrive at the estimated total construction cost of 138 million monetary unit. Given below are the basis for calculation, and Table 5.1 and 5.2 gives the details of calculation example.

- The mean interest rate of local and foreign currencies is used.
- Unit prices for items of work are based on past examples.
- The construction period is assumed to be 3 years.

Table 5.1 Total Construction Cost (Run-of-river type)

(10^3 monetary unit)

	Estimated Cost	Note
1. Preparatory Work		
(1) Access Road		
(2) Camp & Facilities	2,800	(3. Civil work) × 0.05
Sub total	2,800	
2. Environmental Mitigation Cost	550	(3. Civil work) × 0.01
3. Civil Works		
(1) Intake Weir	11,960	
(2) Intake	1,330	
(3) Settling Balin	3,840	
(4) Headrace	23,330	
(5) Head tank	3,510	
(6) Penstock	2,440	
(7) powerhouse	5,380	
(8) Tailrace channel		
(9) Tailrace	640	
(10) Miscellaneous Work	2,670	[(1) ~ (9)] × 0.05
Sub total	55,100	
4. Hydraulic Equipment		
(1) Gate & Screen	1,900	
(2) Penstock	2,600	
Sub total	4,560	
5. Electro-mechanical Equipment	38,000	
Direct Cost	100,950	1 + 2 + 3 + 4 + 5
6. Administration & Engineering Fee	15,100	(Direct Cost) × 0.15
7. Contingency	10,150	(Direct Cost) × 0.1
Total	126,200	
8. Interest during Construction	11,800	(Total) × 0.4 × i × T i = 8%, T = 3 years
Total Cost	138,000	

Table 5.2(1) Civil Works Cost (Run-of-river type)

(10^3 Monetary Unit)

Work Items	Unit	Unit Price		Quantity		Total Amount
1. Intake Weir						11,960
Excavation	m^3	80		5,800		464
Concrete	m^3	2,000		4,200		8,400
Reinforcement bar	ton	12,000		28		336
Others	L.S.	-		30%		2,760
2. Intake						1,330
Excavation	m^3	80		700		56
Concrete	m^3	2,100		400		840
Reinforcement bar	ton	12,000		14		168
Others	L.S.	-		25%		266
3. Settling Basin						3,840
Excavation	m^3	80		4,400		352
Concrete	m^3	2,100		1,100		2,310
Reinforcement bar	ton	12,000		45		540
Others	L.S.	-		20%		638
4. Headrace						23,330
Excavation	m^3	600	-	14,000	-	8,400
Concrete	m^3	2,100	-	5,400	-	11,340
Reinforcement bar	ton	12,000	-	46	-	552
Others	L.S.			15%	30%	3,038
5. Head Tank						3,510
Excavation	m^3	80		3,300		264
Concrete	m^3	2,100		830		1,743
Reinforcement bar	ton	12,000		42		504
Others	L.S.	-		40%		999
6. Penstock & Spillway						2,440
Excavation	m^3	80		3,100		248
Concrete	m^3	2,100		760		1,596
Reinforcement bar	ton	12,000		16		192
Others	L.S.	-		20%		404
7. Powerhouse						5,380
Excavation	m^3	80		3,000		240
Concrete	m^3	2,000		1,200		2,400
Reinforcement bar	ton	12,000		79		948
Others	L.S.	-		50%		1,792
8. Headrace						-
Excavation	m^3	-	-	-	-	-
Concrete	m^3	-	-	-	-	-
Others	L.S.	-	-	15%	30%	-
9. Tailrace						640
Excavation	m^3	80		1,100		88
Concrete	m^3	2,100		170		357
Reinforcement bar	ton	12,000		6		72
Others	L.S.	-		25%		123
10. Miscellaneous Works	L.S.	-		5%		2,670
Sub total	-	-		-		55,100

Table 5.2 (2) Hydraulic Equipment Cost (Run-of-river type)

(10^3 Monetary Unit)

Work Items	Unit	Unit Price	Quantity	Total Amount
1. Weir				240
Gate	ton	80,000	3	240
2. Intake				400
Gate	ton	80,000	4	320
Screen	ton	40,000	2	80
3. Settling Basin				400
Gate	ton	80,000	3	240
Screen	ton	40,000	4	160
4. Penstock and Spillway	ton	50,000	43	2,150
5. Outlet Gate	ton	----	-	----
6. Others	L.S.	----	20%	610
Sub total				3,800

5.2 Reservoir Type

The main study points are shown below in accordance with the feasibility study procedure.

(1) Project study

Study of dam site, waterway route and power generation type

Catchment area at the dam site

Mean flow and inflow at the dam site

The runoff data at nearby gauging station are converted to those at the dam site and annual mean flow (Q_{ave}) and annual total inflow ($\sum Q$) at the dam site are calculated.

Reservoir area and storage capacity curve

The storage area is measured on topographic maps for many elevations and the storage capacity curve shown in Figure 5.4 is prepared.

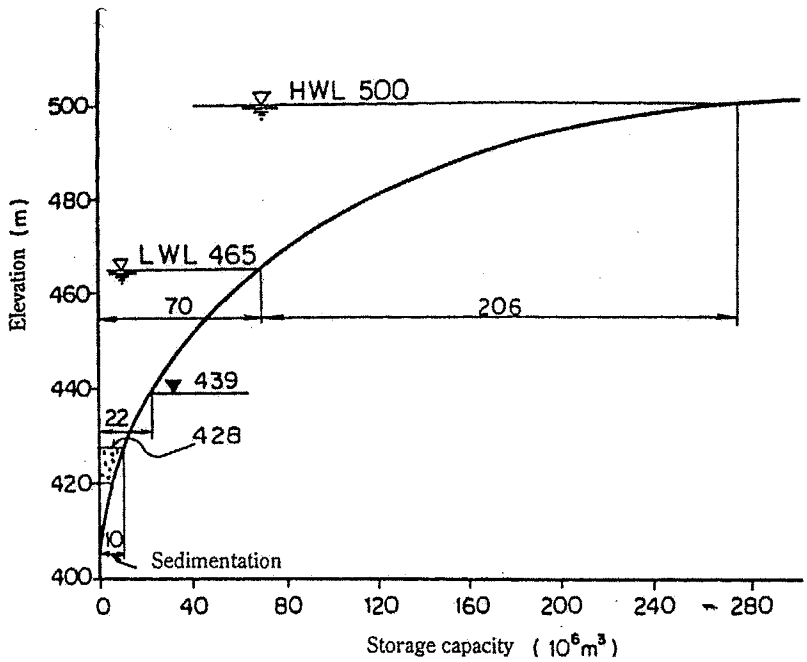


Figure 5.4 Reservoir Storage Capacity Curve

Sediment volume and sedimentation level

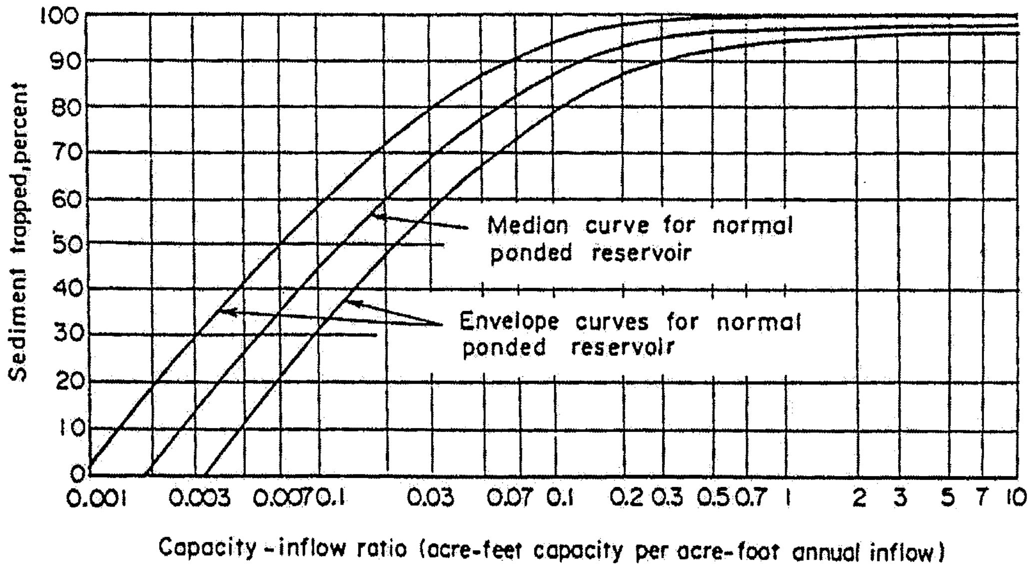
The specific sediment yield of this catchment area is assumed. According to Brune Curve in Figure 5.5, sediment trap efficiency is estimated based on the gross storage capacity (V_g) and calculated annual inflow ($\sum Q$). Sediment volume (V_s) in this reservoir for T years is obtained from the following equation.

$$Vs = q_s \times C_A \times \alpha \times T$$

Where,

- q_s : Specific sediment yield ($m^3/km^2/year$)
- C_A : Catchment area (km^2)
- α : Sediment trap efficiency as a function of storage capacity and sediment yield, $\alpha = f(V_g/q_s)$
- T : Project life time (year)

The sedimentation level read from the storage capacity curve (Figure 5.4)



(After G.M.Brune)

Figure 5.5 Sediment Trap Efficiency

Tentative setting of low water level (LWL)

Low water level is tentatively set based on the sedimentation level (El_s) and the inner diameter of tunnel (D, tentative). The basis for setting this value is as follow.

- Maximum plant discharge is set (tentative) based on the assumption that average flow is regulated at 25% of the maximum discharge

$$Q_{max} = Q_{ave}/0.25$$

- The maximum discharge is used in designing headrace tunnel or penstock diameter (D)

Therefore, low water level, $LWL = El_s + 1.0 + D \times 1.5$

Tentative setting of high water level (HWL) and gross storage capacity (V_g)

Judging from the topographical and geological features, compensation, etc. Figure 5.6 shows the schematic of reservoir capacity.

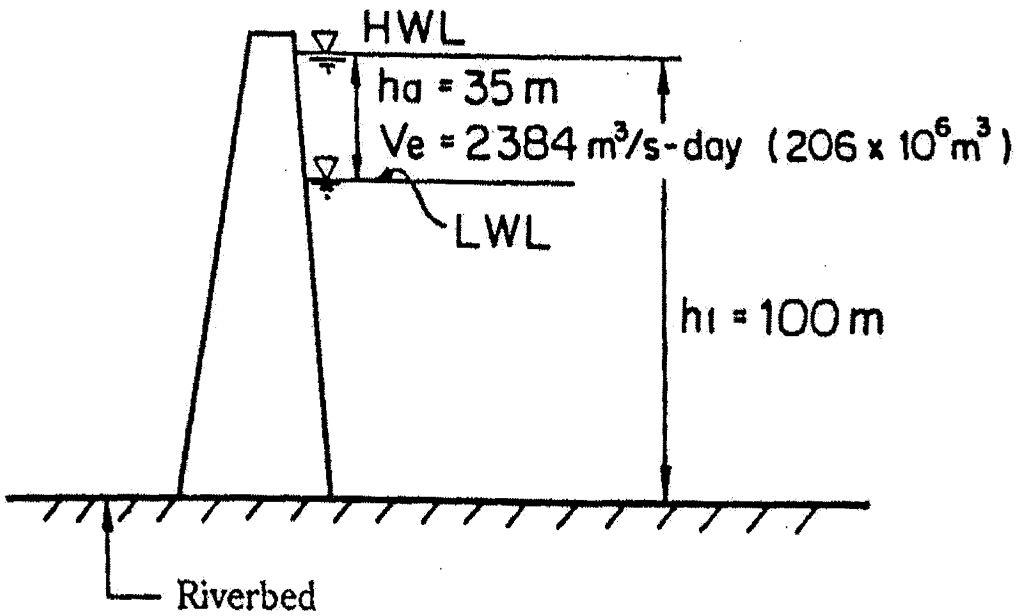


Figure 5.6 Schematic of Reservoir Capacity

Determination of high water level (HWL), low water level (LWL) and effective storage capacity (V_e)

Jusification of low water level is checked.

Available drawdown, h_a = HWL – LWL

Effective storage capacity, $V_e = V_g - V_s$

Regulating Capability Factor, $RCF = V_e / \sum Qi \times 100$

RCF = 100% ~ 200% indicates excessive reservoir storage for hydropower generation. If reservoir storage is not excessive, estimate head fluctuation ratio

Head fluctuation ratio, (LWL – TWL)/(HWL – TWL)

If head fluctuation ratio > lower limit of turbine – O.K.

If head fluctuation ratio < lower limit of turbine, the head fluctuation is too large for turbine and the available drawdown should be decreased by increasing LWL

Effective storage capacity corresponding to the high water level and low water level

$$V_e = V(HWL) - V(LWL)$$

Determination of power generation type

$$RCF = V_e / \Sigma Q_i \times 100 \quad > 5\% \text{ for reservoir type hydropower}$$

Preparation of mass curve

Figure 5.7 is an example of mass curve calculation.

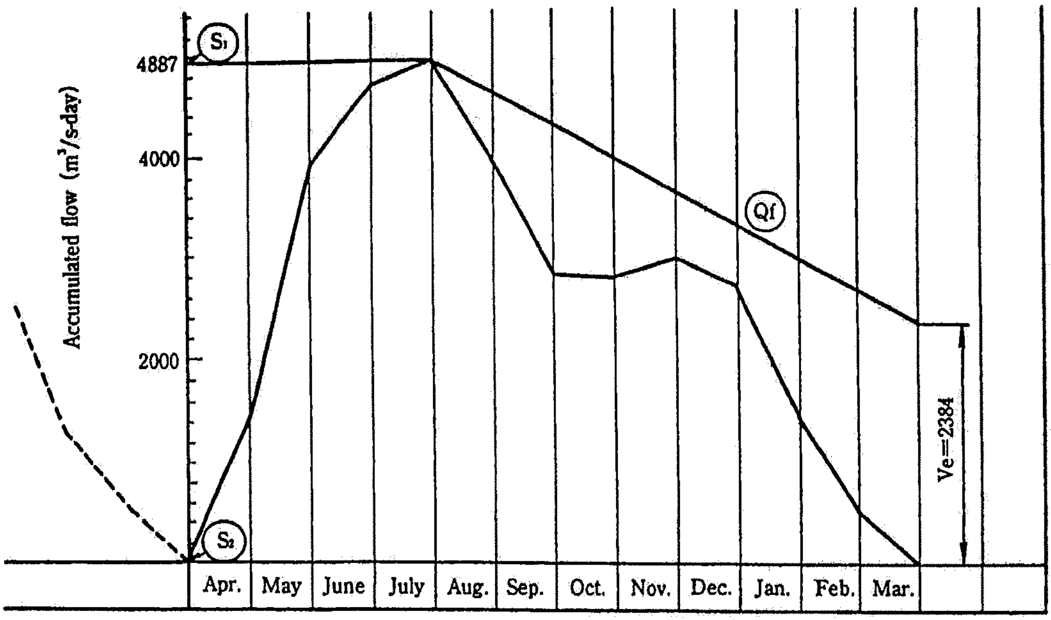


Figure 5.7 Mass Curve

Calculation of firm discharge (Q_f)

Firm discharge is the least discharge from the reservoir when it is ideally operated. Firm discharge is calculated by using Figure 5.7.

S_1 = Max accumulated flow in Mass Curve

S_2 = Min accumulated flow in Mass Curve = 0

V_e = Reservoir Effective Storage

n = Number of days Mass Curve declining from Max to end of cycle

$Q_f = (S_2 + V_e - S_1)/n + Q_{ave}$

A firm discharge for one year is easily calculated as mentioned above. In actual studies, however, long-term runoff data is used and "the least discharge" is obtained for every year of every period of years. The firm discharge for actual project is obtained with probability analysis of every year's least discharge.

Determination of maximum plant discharge (Q_{max})

Peak duration hour (t_p) is assumed, then the maximum plant discharge is calculated as follows.

$$Q_{max} = Q_f \times 24\ (hr)/t_p\ (hr)$$

Normal intake water level (NIWL) and tailwater level (TWL)

The normal intake water level is set at one third of available drawdown from HWL and the tailwater level is set at the riverbed elevation at the powerhouse site.

Waterway profile

Refer to Figure 5.8.

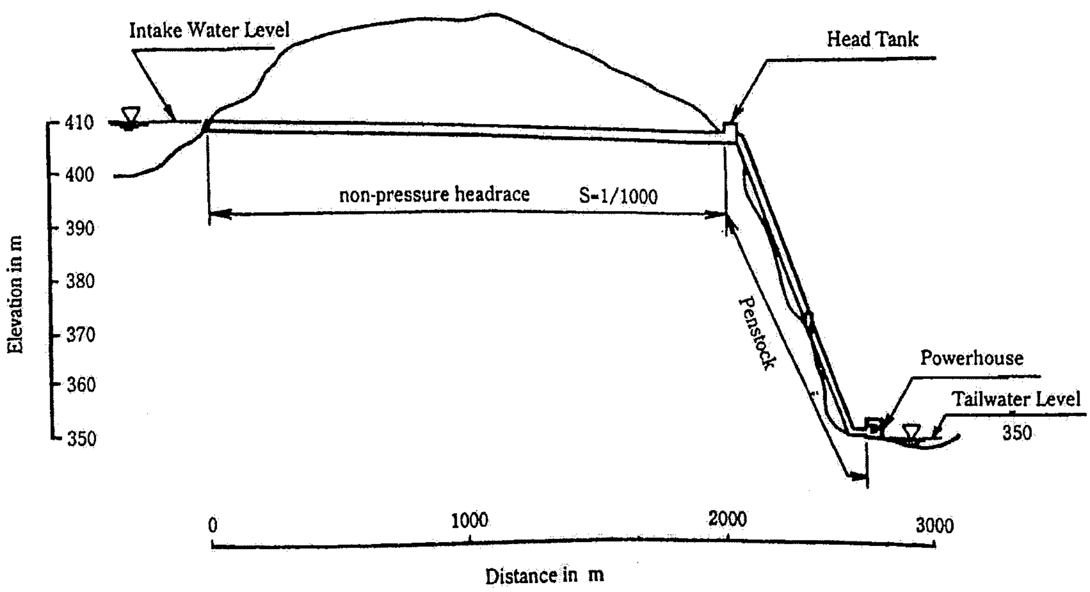


Figure 5.8 Waterway Profile

Calculation of head loss (H_l) and normal effective head (H_e)

$$H_g = HWL - (HWL - LWL) / 3 - TWL$$

Head loss (H_l) is calculated

$$H_l = a \times L_1 + b \times L_2 + h$$
$$= 850 / 700 + 155 / 200 + 0.6 = 2.6 \text{ m}$$

where,

L_1 and L_2	: Length of headrace and penstock (m)
H	: Other head loss (m)
a and b	: Head loss coefficient

Normal Effective head (H_{es}) is obtained with the following equation.

$$H_{es} = H_g - H_l$$

Selection of turbine type and combined efficiency of turbine and generator

Turbine is selected from Figure 5.9 and the combined efficiency (η) for the maximum output is approximated

Calculation of maximum output and firm peak output

$$P_{max} = 9.8 \times \eta \times Q_{max} \times H_{es}$$

Annual energy generation

Rough estimate of annual energy production from annual plant discharge for generation

As it is judged that no overflow occurs in Figure 5.7, all the inflow can be used for power generation.

$$E = 9.8 \times \eta \times \sum Q_i \text{ (m}^3\text{/sec-day)} \times H_{es} \times 24 \text{ (hr/day)}$$

Calculation of monthly energy generation by mass curve

As shown in Figure 5.10, the reservoir is full at the beginning of August. The reservoir supplies the firm discharge of 48.18 m^3/s from August through March and reaches LWL at the end of March. In the rainy season, from April through June, the reservoir is operated along the line Q.

$$Q = (V_{Jun} - V_{Mar})/n' + Q_{ave}$$

where, n' = Number of days Mass Curve rising from beginning of cycle to Max

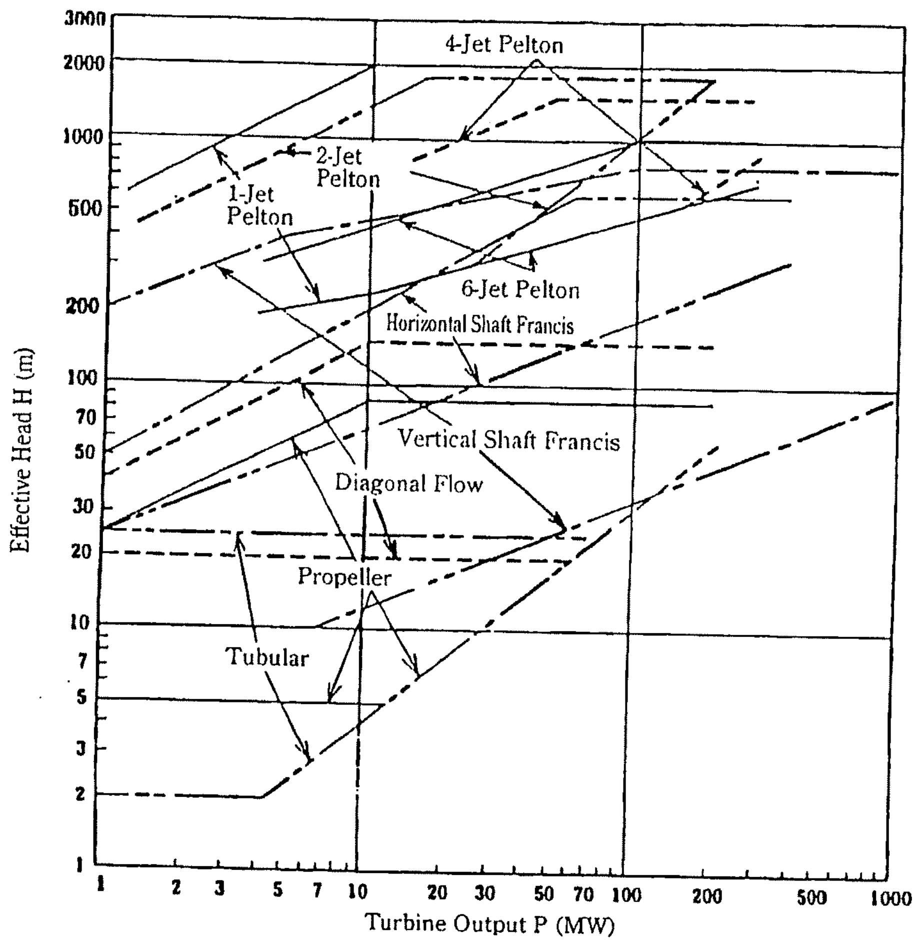


Figure 5.9 Turbine Selection Diagram

When Q exceeds the maximum plant discharge that means overflow occurs. The maximum value of Q is, therefore, the maximum plant discharge. In July, the water level is at HWL and reservoir is operated so that the outflow is equal to the inflow.

The efficiency of the turbine and generator (η) of the month is varied by the head fluctuation

Combined Efficiency = Combined Efficiency at Max Output x Variable Head Efficiency

The energy production is obtained by the following equation.

$$E = 9.8 \times Q_i \times H_{es} \times \eta \times 24 \text{ (kWh)}$$

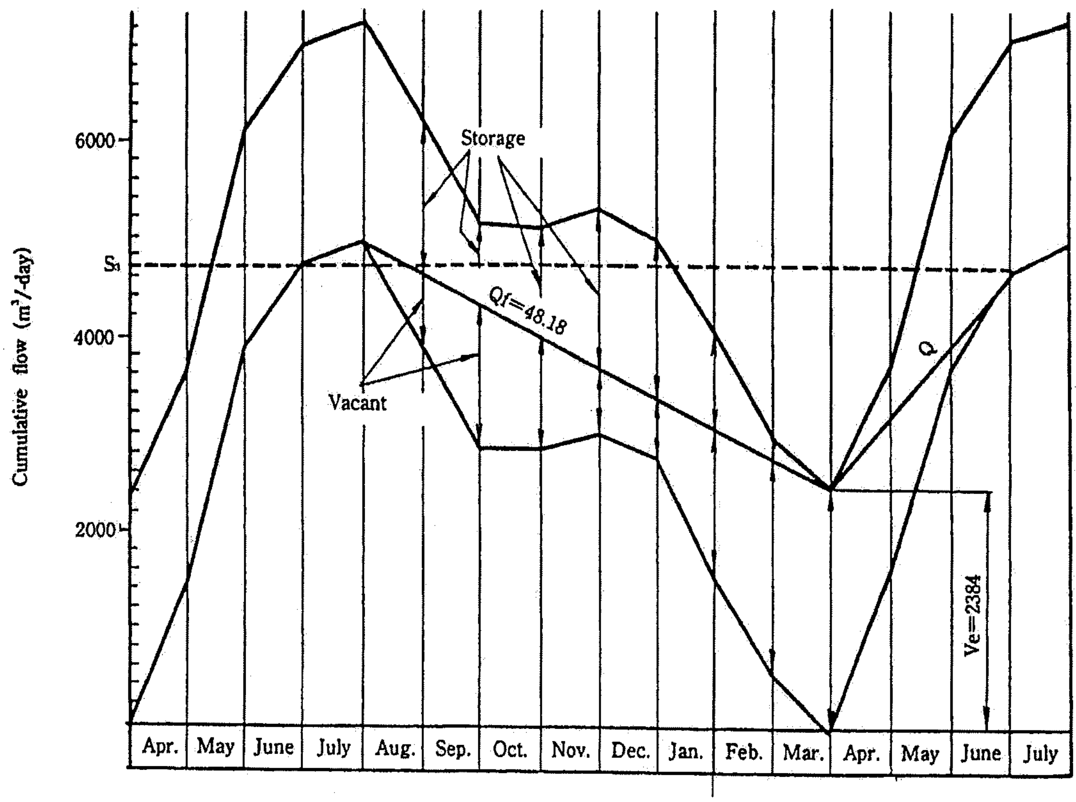


Figure 5.10 Reservoir Operation based on Mass Curve

(2) Estimation of construction cost

(2-1) Calculation of quantities of work

Dam

Concrete gravity dam is selected.

- Dam height (Hd) = 100 m
  Crest length (L) = 350 m
  Riverbed width (b) = 70 m
  Design flood discharge (Qf) = 4,600 m^3/s

The design flood discharge is calculated by using the simplified equation. From the annual rainfall of 1,350 mm of this area, the regional coefficient of T district is (a) = 34.

$A = 1050\ km^2$, $q = 4.4\ m^3/s/km^2$, $Q_f = 4.4x1050 = 4600\ m^3/s$

- Quantities
  Ve = 10.0xHdxL = 350,000 m^3
  Vc = $22.4Hd^2xL$ = 735,000 m^3 (B/L=0.2)
  Wg = $0.13xQ_f$ = 600 tons

Intake

- Pressure type
- Q = 230 m^3/s

When two tunnels are constructed, the design discharge per tunnel is 115 m^3/s. Therefore, the inner diameter of the tunnel is D = 6.2

- n = 2, Q = 230 m^3/s, D = 6.2 m, ha = 35 m
- Quantities
  Ve = $130x[\{(ha+D)xQ\}^{1/2}xn^{1/3}]^{1.27}$ = 58,400 m^3
  Vc = $56.5x[\{(ha+D)xQ\}^{1/2}xn^{1/3}]^{1.23}$ = 20,900 m^3
  Wr = 0.04xVc = 840 tons
  Wg = $0.9x(ha+D)^{1/9}xQ$ = 310 tons

$Ws = 0.5x(ha+D)^{1/9}xQ$ = 170 tons

Headrace

- Circular pressure tunnel

  D = 6.2 m so R = 3.1 m, L = 850 m, n =2

- Quantities

  to = 0.55 m

  $Ve = 3.2x(R+t_0)^2xLxn = 72{,}000\ m^3$

  $Vc = \{3.2x(R+t_0)2- \frac{\pi}{2} R2\}xLxn = 21{,}200\ m^3$

  Wr = 0.04xVc = 850 tons

Surge tank

- $Q = 230\ m^3/s$, $q=Q/n =115\ m^3/s$, ha = 35 m, L = 850 m, n = 2

- Quantities

  $Ve = 38xqx(ha+L)^{1/4}xn = 47{,}600\ m^3$

  $Vc = 11xqx(ha+L)^{1/4}xn =13{,}800\ m^3$

  Wr = 0.05xVc = 690 tons

Penstock

- Exposed type is selected.
- $q = 115\ m^3/s$, n=2, H=500-350 = 150 m
- Steel pipe inner diameter Dm=5.1m (when $q=115\ m^3/s$)
- Steel pipe length L =115m
- Design head H=500-350 = 150m
- Quantities

  $Ve = (20.3xDm^2-49.5xDm+41.3)xn^{1/3}xL = 61{,}900\ m^3$

  $Vc = (0.5xDm^2+2.5xDm)xn^{1/3}xL = 5{,}000\ m^3$

  Wr = 0.018xVc = 90 tons

  Tp = 0.0313xHxDm+2 = 26

$Wp = 7.85x \pi x5.1x26x150x1.15x2 = 1,130$ tons

Powerhouse

$Q = 230\ m^3/s$, $He=135.4$, $n=4$

- Quantities

$Ve = 97.8x(QxHe^{2/3}xn^{1/2})^{0.727} = 91,100\ m^3$

$Vc = 28.1x(QxHe^{2/3}xn^{1/2})^{0.795} = 49,600\ m^3$

$Wr = 0.05xVc = 2,480$ tons

Tailrace

- Non-pressure type

$Q = 230\ m^3/s$, $D=8.0m$ ($R=4.0$ m extrapolated from Figure 6.2.1)

- Quantities

$Ve = 395x(RxQ)^{0.479} = 10,400\ m^3$

$Vc = 40.4x(RxQ)^{0.684} = 4,300\ m^3$

$W_R = 0.278xVc^{0.61} = 46$ tons

(2-2) Total construction cost (Project cost)

Total construction cost is calculated on the above quantities and unit prices. It is estimated to be $4529x10^6$ monetary unit. Calculation conditions are described below, and detailed examples of the calculation are shown in Table 5.3 and Table 5.4

- Cost of preparatory works is calculated at 2% of the civil works cost.
- The mean interest rate of local and foreign currencies is used.
- Unit prices were taken from past experience.
- The construction period is 4 years.

As this example is a hydropower potential study, transmission line cost is not included. As a result of the study, if the project is recognized as promising, site reconnaissance is conducted and the transmission line or distribution line cost is calculated. In this example, the installed capacity is 270 MW and the distance from the powerhouse to the substation (or existing transmission line) is assumed to be 100 km, two circuits of 140 kV is selected. The transmission line cost is estimated by multiplying the unit price to the line length.

Table 5.3 Total Construction Cost (Reservoir type)

(10^3 monetary unit)

Description	Estimated Cost	Note
1. Preparation works & Land acquisition Cost		
(1) Access Road	45,700	
(2) Compensation & Resettlement		
(3) Camp and Facilities		(3 Civil work)×0.02
Sub total	45,700	
2. Environmental Mitigation Cost	68,500	(3 Civil work)×0.03
3. Civil Works		
(1) Care of River	33,000	
(2) Dam	1,647,800	
(3) Spillway	-	
(4) Intake	73,300	
(5) Headrace	113,000	
(6) Surge Tank	63,700	
(7) Penstock	19,900	
(8) Powerhouse	211,800	
(9) Tailrace channel	-	
(10) Tailrace	13,100	
(11) Miscellaneous Works	108,800	[(1)~(10)] × 0.05
Sub total	2,284,400	
4. Hydraulic Equipment	95,500	
(1) Gate & Screen	67,800	
(2) Penstock		((1)~(2))×0.05
Sub total	163,300	
5. Electro-mechanical Equipment	650,000	
Direct Cost	3,211,900	1+2+3+4+5
6. Administration & Engineering fee	481,800	(Direct Cost) × 0.15
7. Contingency	321,200	(Direct Cost) × 0.1
7'. Cost allocation of dam	------	
Total	4,014900	
8. Interest during Construction	514,100	(Total)×0.4×i×T i=8%, T=4 years
Total Cost	4,529,000	

Table 5.4 (1) Civil Works Cost (Reservoir type)

(10^3 Monetary Unit)

Work Items	Unit	Unit Price	Quantity	Total Amount
1. Concrete gravity dam				1,680,800
(1) 1 Care of river	L. S.	-	1	33,000
(1) 2 Concrete dam				1,647,800
1) Excavation	m^3	80	35,000	28,000
2) Concrete	m^3	2,000	735,000	1,470,000
3) Others	L.S.	-	1	149,800
2. ntake				73,300
1) Excavation	m^3	80	58,400	4,672
2) Concrete	m^3	2,100	20,900	43,890
3) Reinforcement bar	ton	12,000	840	10,080
4) Others	L.S.	-	1	14,658
3. Headrace				113,000
1) Excavation	m^3	600	72,500	43,500
2) Concrete	m^3	2,100	21,000	44,520
3) Reinforcement bar	ton	12,000	850	10,200
4) Others	L.S.	-	1	14,780
4. Surge tank				63,700
1) Excavation	m^3	80	47,600	3,808
2)Concrete	m^3	2,100	13,800	28,980
3) Reinforcement bar	ton	12,000	690	8,280
4) Others	L.S.	-	1	22,630
5. Penstock				19,900
1) Excavation	m^3	80	61,900	4,952
2) Concrete	m^3	2,100	5,000	10,500
3) Reinforcement bar	ton	12,000	90	1,080
4) Others	L.S.	-	1	3,368
6. Powerhouse				211,800
1) Excavation	m^3	80	91,100	7,288
2) Concrete	m^3	2,100	49,600	104,160
3) Reinforcement bar	ton	12,000	2,480	29,760
4) Others	L.S.	-	1	70,592
7. Tailrace				13,100
1) Excavation	m^3	80	10,400	832
2) Concrete	m^3	2,100	4,300	9,030
3) Reinforcement bar	ton	12,000	46	552
4) Others	L.S.	-	1	2,686
8. Miscellaneous work	L.S.	-	1	108,800
Sub total				2,284,400

Table 5.4 (2) Hydraulic Equipment Cost Cost (Reservoir type)

(10^3 Monetary Unit)

Work Items	Unit	Unit Price	Quantity	Total Amount
1. Dam and Spillway				48,000
Gate	ton	80,000	600	48,000
2. Intake				31,600
Gate	ton	80,000	310	24,800
Screen	ton	40,000	170	6,800
3. Penstock	ton	50,000	1,130	56,500
4. Tailrace	ton	----	-	----
5. Others	L.S.	----	20%	27,220
Sub total				163,300