Guideline and Manual for Hydropower Development Vol. 1

Conventional Hydropower and Pumped Storage Hydropower

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Significance of Hydroelectric Power Development

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Significance of Hydroelectric Power Development

Chapter 1 Significance of Hydroelectric Power Development

(1) Use of undeveloped energy

It is now known from available reports that developable potential hydro resources world-wide are equivalent to approximately 14 trillion kWh per year. Most of these hydro resources are located in the developing countries where sharp increases in energy demands are on-going. Development of these undeveloped hydro resources would contribute greatly in easing the global energy demand and supply balance.

(2) Global environment issues

With the increasing use of energy each year, the combustion of fossil fuel has resulted in an increasing volume of carbon dioxide (CO_2), and global warming become an urgent concern with global environmental problems. It has also resulted in acid rain problems caused by gaseous pollutants (Sox & NOx) emissions into the atmosphere. In developing countries, wood and charcoal fuels are the major energy resources, resulting in ever-advancing deforestation and desertification. Under these circumstances, demands for the development of non-fossil energy sources are growing stronger. Hydropower, especially, is a renewable energy which offers excellent merits against the negative factors of carbon dioxide and other flue gases which contaminate our environment.

(3) Economic development of developing countries

With advancing industrialization and strong moves toward better standards of living, the energy demands of the developing countries are rising significantly. The development of electricity related infrastructures is, therefore, a matter of vital importance to assure sustained growth of the economy. Since hydro power resource is an indigenous and renewable energy, its development enhances energy self-sufficiency. It also contributes toward improving the balance of payment of international trade and self-sustaining economic growth. With this, through more than 100 years of practical application, hydropower generation technology is already well established. Transfer of the appropriate technologies to engineers of the developing countries enables production of safe, reliable electric energy. The major construction works for hydropower plants can be done with domestic currency, thereby providing significant beneficial effects on domestic employment and contributing even further to a nation’s economic prosperity.

(4) Local energy source

Electricity consumption is mainly concentrated in cities and suburban areas and the imbalance with the outlying areas is quite remarkable. A relatively small hydropower development plays a significant role in not only providing local electrification, but also in enhancing local prosperity. It responds to basic human needs as the alternative energy replacing wood and charcoal fuel for heating and lighting and as the alternative energy which replaces human and animal labor for irrigation, drainage, drinking water supply, and as motive power for small processing plants. It also contributes to vitalizing local community activities, for instance, the electrification of public facilities such as hospitals and schools improves the local economy, living standards and cultural standards. The small scale hydropower supplying energy for rural area is described in Vol.2.

(5) Stabilization of electricity rate

Hydropower generation incurs no fuel costs but the large initial investment is reflected in the large proportion of capital cost in the power production cost. Though the production cost at the beginning of service life is somewhat higher than that for a thermal power plant, no fuel costs means lower unit production cost increase against inflation once the plant is completed, enabling stable, and low priced power supply for a very long period.

(6) Efficiency improvement in the entire power system

Generally, power demands fluctuate significantly depending on the time of the day. One significant feature of a hydropower plant controlled with a reservoir or pondage, and a pumped storage hydropower plant is that it is able to respond instantly to such fluctuations. Contrarily, while thermal power plants provide high efficiency through constant operation, they do not however, have a quick load following characteristic to demand fluctuations. Therefore, the combination of hydropower and thermal power provides higher efficiency in the entire power system.

Chapter 2

Objectives and Scope of Guideline and Manual

Chapter 2 Objectives and Scope of Guideline and Manual

2.1 Objectives

This guideline and manual (hereinafter referred to as "Manual") describes the hydropower projects as electric power supply sources for the electric power system. Manual includes the contents mainly project development scheme, initial study stage and feasibility study stage.

Manual is specially designed for policy makers, executives of generating authorities and private power companies, and hydro power engineers in developing countries.

The content focuses on the following;

- To provide central government officials, executives of private power companies and power authorities with basic knowledge of hydro power generation, in order to understand the process required to implement a project and to understand the development aid scheme.
- To provide engineers in developing countries with planning method in the initial stage to enable them to find new projects, formulate hydropower potential study and to understand the basic concept of the feasibility study.

2.2 Scope of Manual

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

- Hydropower 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 Manual describes generation systems of conventional and pumped storage types. The development scale for conventional type covers 5MW to 500MW, and those of pumped storage type cover 100MW to 1,000MW. The projects mentioned above are to be newly constructed and connected to the power grid system. Small scale hydropower projects for rural electrification are described in Vol.2.

The process from planning to operation of hydropower development projects is classified into investigation and planning, design, construction, and operation and maintenance stages as shown in the followings.

1) Investigation and planning : Reconnaissance study, Feasibility study
2) Design : Detailed design

3) Construction : Civil works, Hydro-mechanical and Hydro-electrical works
4) Operation & maintenance : O & M of power plant, Environment monitoring

This Manual describes the reconnaissance study and the feasibility study of hydropower projects. Reconnaissance study is defined as investigation and planning based on topographic maps to scale 1/10,000-1/50,000 as these are easily acquired in the developing countries. The basic concept of feasibility study is also explained herein.

As reference, important items related to the operation and maintenance of civil facilities and electric facilities are also described.

2.3 Composition of Manual

Vol.1 of this Manual consists of following 20 chapters in which Chapter 5, 6, 10, 14, 16 and 20 are almost same contents as “Guild Manual for Development aid Programs and Studies of Hydro Electric Power Projects” prepared by the New Energy Foundation in 1996.

Several technical methods and approaches are used such as investigations, studies to develop hydropower projects for power systems. This Manual introduces one of the typical methods in Chapter 5 to 20, however another methods could be used depending on the conditions which each project faces.

(1) Part 1 (Introduction of hydropower)

This Part consists of Chapters 1 to 4.

Significance of hydropower development, hydropower generation systems are explained as basic knowledge for those engaged in development of hydropower projects.

The following are the major content.

- Concept of power output and electric energy of hydropower station
- Power generation systems such as run-of-river type, pondage type, reservoir type, and pumped storage type
- Positioning of hydropower as a supply source in response to the power demand
- Development aid programs provided by Japan and international organizations

(2) Part 2 (Reconnaissance study)

This Part consists of Chapters 5 to 7.

It describes the concept and methodology of hydropower planning in the reconnaissance study stage, and hydropower potential study, and master plan study.

The following are the major subjects.

- 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 plant 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, and their approximate construction cost
- Simplified benefit-cost ration 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 viability of a planned project from the site reconnaissance
- Methodology to make a master plan of river basin is descried by using the method above.

(3) Part 3 (Feasibility study of hydropower project for conventional type)

This Part consists of Chapters 8 to 16.

It describes the concept of feasibility study and the following are the major subjects.

Methodology of power demand forecast

- Positioning of the planned hydropower project in the electric power system
- Investigation for feasibility study using topographic and geologic data, aerial photograph interpretation, physical prospecting, drilling, and exploratory adit
- Methodology of hydrologic and meteorological study, and hydrologic analysis
- Methodology of hydropower planning
- Design of civil structures including the dam, intake facility, water conveyance facility, and powerhouse
- Design of electric facilities including turbine and generator
- System analysis and design of transmission facility
- Construction planning, construction schedule and construction cost estimate
- Environmental assessment
- Economic analysis using border price and shadow price to benefit-cost method and internal rate of return
- Financial analysis and generation cost
- Cost allocation for multi-purpose dam

(4) Part 4 (Feasibility study of hydropower project for pumped storage type)

This Part consists of Chapters 17 to 18.

It describes the concept of feasibility study and the following are the major subjects.

- Positioning of the planned pumped storage project in the electric power system
- Methodology of pumped storage hydropower planning
- Design of civil structures
- Design of electric facilities including turbine and generator

(5) Part 5 (Operation & maintenance of hydropower plant)

This Part consists of Chapter 20, and describes operation and maintenance of hydropower plant.

Chapter 3

Outline of Hydropower Generation

Chapter 3 Outline of Hydropower Generation

3.1 Energy of Hydropower

3.1.1 Hydropower Generation

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

3.1.2 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 then 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. Water density ρ expressed in the equation below is omitted after Chapter 4.

$$P=\rho 9.8 Q H_e \eta$$

where,

P	: Power output (kW)
ρ	: Water density = 1,000kg/m^3 (at 4ºC, elevation 0m and 1atm)
9.8	: Approximate value of free fall acceleration (m/sec^2)
Q	: Power discharge (m^3/sec)
H_e	: Effective head (m)
η	: Combined efficiency of turbine and generator

The MW unit is also used to express the power output. 1,000 kilowatt (kW) is equal to 1 megawatt (MW).

Maximum output[1], rated output, firm output, and firm peak output are used to express the performance of the power plant.

3.1.3 Energy Generation

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

[1] Maximum output is the power output which power plants generate at maximum level, and the term is used as rated capacity.in a same context. Firm output is the output which plants of-run-of-river type is able to generate almost every day of the year. Firm peak output is the output which the power plant is able to produce almost every day of the year for the specified time during of peak demand.

3.2 Types of Hydropower Plant

3.2.1 Classification from Viewpoint of Power Supply Capability

(1) Conventional hydropower

1) Run-of-river type

This type takes water from the natural runoff to generate electricity, therefore it has no reservoir or pond to adjust river runoff to the generation. Waterway type mentioned in 3.2.2 (1) is the category of this type. Most of the small scale hydropower adopts run-of-river type.

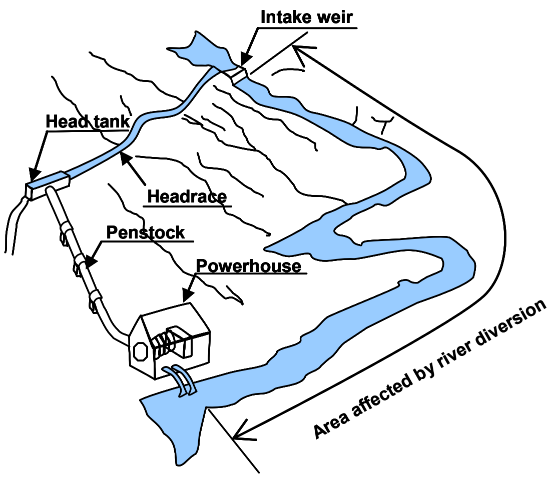


Figure 3-1 Run-of-River Type

2) Pondage type

The pondage type has a pond which can regulate the river runoff for one to several days as shown in Figure 3-2. Power demand changes in a day depending on time, the hydropower of pondage type can regulate river runoff to follow the change in power demand.

3) Reservoir type

A power plant with a reservoir which can regulate annual or seasonal river runoff is called the reservoir type as shown in Figure 3-2. Since river runoff changes depending on the season, a reservoir stores water in a rainy season and releases it in a dry season. The reservoir can release an even flow throughout the year as much as possible. This type has the same function as the pondage type to be able to follow the change in power demand. It is used for large scale hydropower plants.

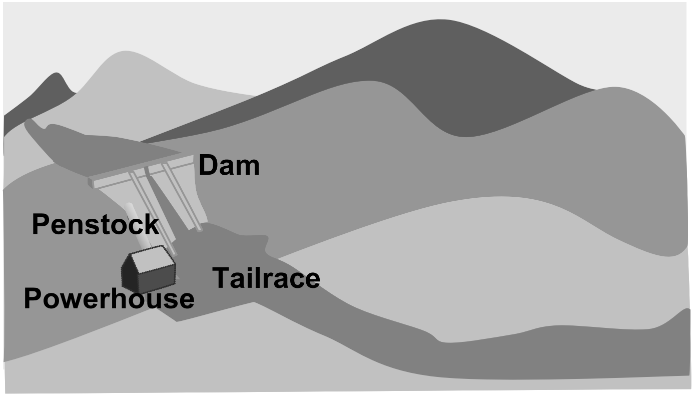


Figure 3-2 Pondage Type and Reservoir Type

(2) Pumped storage hydropower

The pumped storage power plant consists of upper pond (or upper reservoir), lower pond (or lower reservoir), waterway and powerhouse, as shown in Figure 3-3. 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 time when the power demand drops, the water is pumped up from the lower pond to the upper pond using the excess energy generated by the thermal power.

Pumped storage power generation is classified into the "pure pumped storage type” and "pumped and natural flow storage type" as shown in Figure 3-3 and below.

1) Pure pumped storage type

Electricity of the pure pumped storage type is generated by utilizing the head and circulating water stored in the lower and upper ponds. This type is not affected by river flow because the power plant does not use natural water but uses only circulating water. Therefore the output can be set freely by determining the head and maximum plant discharge.

2) Pumped and natural flow storage type

Electricity of the pumped and natural flow storage type is generated by utilizing the circulating water stored in the lower and upper ponds and natural flow into the upper pond. This type has a merit to be able to reduce pumping energy by using natural flow into the upper pond.

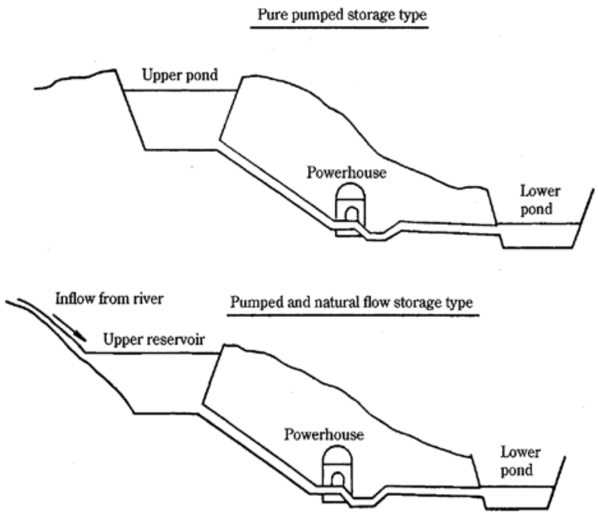


Figure 3-3 Types of Pumped Storage

3.2.2 Classification by Method of Head Acquisition

(1) Waterway type

As shown in Figure 3-1, an intake weir is constructed at the river and the river water is led to a powerhouse through waterway (headrace, penstock). The head between the intake weir and the powerhouse is utilized for power generation. This type is commonly used with run-of-river type mentioned in 3.2.1 (1). Most of the small scale hydropower adopts this type.

(2) Dam type

The head is acquired mainly by the height of a dam (intake weir) as shown in Figure 3-2. The powerhouse is installed near a dam site.

(3) Dam and waterway type

As shown in Figure 3-4, this is a combination of the two types described above to create a head by the elevation difference between a dam (intake weir) and a waterway. This type is commonly used with the reservoir type or pondage type.

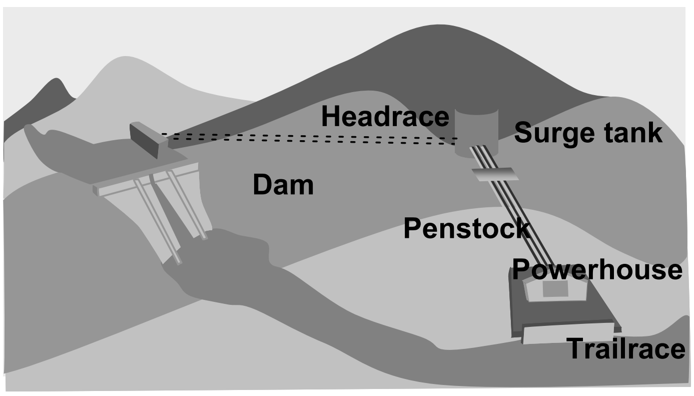


Figure 3-4 Dam and Waterway Type

3.3 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 (24hours) and is termed the daily load curve, an example is shown in Figure 3-5. 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, the load increases in the daytime due to the operation of factories and offices, or in the evening when electricity is consumed for lighting. It drops off through the night to the early morning and again during the noon-time period. In the load curve, peak load may include those areas before and after reaching its peak. The heavy load time of day is termed on-peak load times (peak time) while the light load time of day 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 3-5 described above. Figure 3-5 (a) show examples of power systems in which the major power source is thermal power. Figure 3-5 (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.

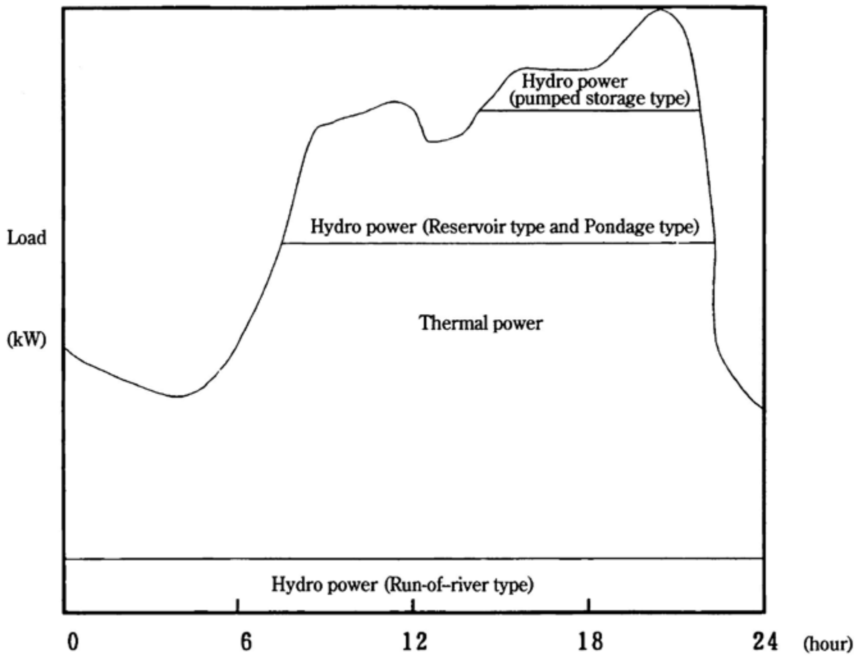


Figure 3-5 (a) Example of Daily Load Curve (System Composed Mainly of Thermal Power)

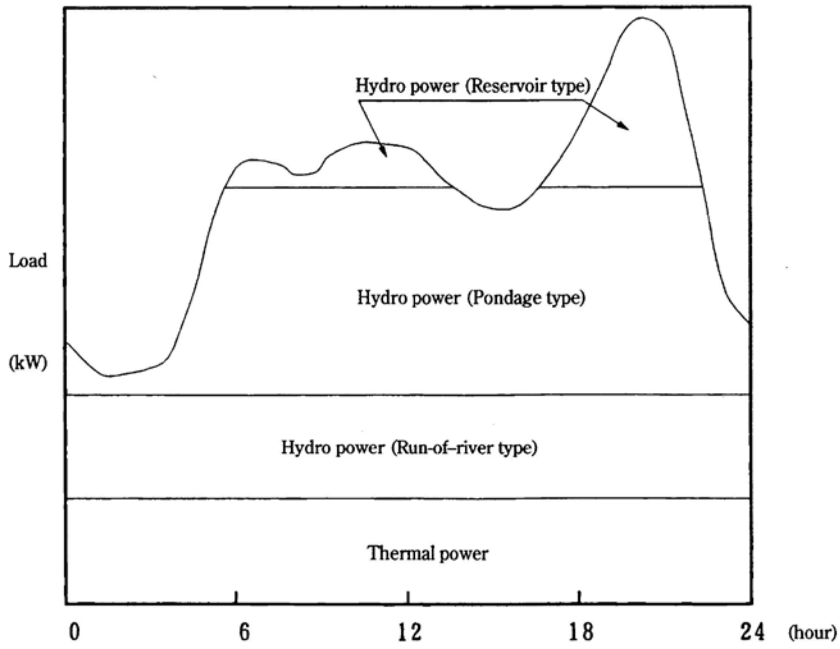


Figure 3-5 (b) Example of Daily Load Curve (System Composed Mainly of Hydropower)

3.4 Current Situation on Hydropower Development, and Climate Change and Hydropower

3.4.1 Current Situation on Hydropower Development

The following is an excerpt from a research paper[2] on water resources development

Hydropower, as one of the clean energy sources, has important roles to play to mitigate warming of the earth's atmosphere. Development of enormous volumes of untapped potential water-power resources in the world is essential to mitigate the phenomena. Furthermore, dams and reservoirs should become even more important to meet the demand for increased water consumptions required for increased food production, thereby to satisfy the need for ever-increasing world population. They are also necessary to prepare for large quantities of water consumption arising from the concentration of population in specific districts and areas, and for flood damage prevention.

Figure 3-7 shows yearly precipitations in Ethiopia and the effects on their GDP and agricultural GDP. Shaded areas above and below the centerline indicate the years and precipitations that are above or below the yearly average, respectively. The national economy is strongly dependent on rainwater, and the dependency is demonstrated by the close relationships between agricultural GDP and GDP and precipitation in the figure. In a developing country like this, the development of water resources to a certain level is imperative to prevent natural calamities like draughts and floods, and to allow economic development with water resources through hydropower and irrigation. In Figure 3-6

[2] Japan Dam Engineering Center: Engineering for Japan (No.234), Actions of the World Bank for Water resource Sector (in Japanese), S. Ueda Japan Dam Engineering Center: Engineering for Japan (No.263), Dams in era of accommodation of climate change (in Japanese), K. Takeuchi

economically feasible hydropower potential is shown horizontally, while the ratios of hydropower already developed are plotted vertically. In spite of greater potential hydropower resources in Asia, China, South America and Africa, the large percentage of them still remain untapped. In recognition of the close relationships between water resources and GDP and untapped potential hydropower, the World Bank published new water resource strategies in 2003. It cites five major policies:

(1) National level of water resources development contributes to the improvement of living standards of citizens through wider economic benefits it entails. It differs from a small-scale sanitary and tap water business targeted to the poorest segment of population.

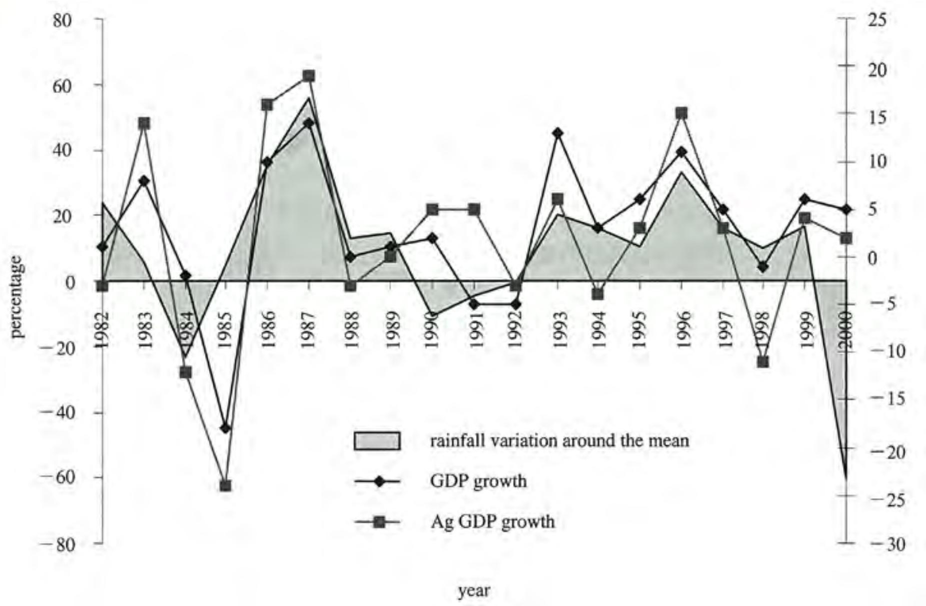
(2) Effective water resources management necessitates existence of infrastructure relating to the water resources. Lack of such provisions in developing countries warrants immediate water resources development.

(3) In dry and semi-dry regions like Africa, fluctuations of rainwater are generally large. In such cases, securing of stable supply of water is a fundamental condition for any economic development.

(4) A big project like aqueducts and water reservation involves multi-faceted expertise and nations. This essentially precludes development of such a project by a developing nation on its own. This necessitates the World Bank to support projects having greater contributions to nations' economy and to the improvement of living standards of citizens-a project of high risks and high returns-with careful attentions and considerations to socio-environmental aspects.

(5) Where the World Bank supports developing nations in water resources areas; it will evaluate their political and economic conditions, and will develop a country by country base of water resources development strategies. Deliberations in the course of strategy preparation will cover basic policy for water management, including water costs and cost recovery.

Every project financed by the World Bank has to observe ten safeguard policies on socio-environmental matters: environmental assessment, habitat environment, forests, pesticide control, resident relocation, aborigines, cultural heritages, dam safety, and business in international waters and disputed areas. The bank makes it clear that requires the funded to strictly observe the policies, and any incompliance with them by the funded constitutes a cause for immediate withdrawal of loans.



Source: World Bank

Figure 3-6 Variation of Rainfall Amount and Influence to GDP Growth and Agricultural GDP Growth

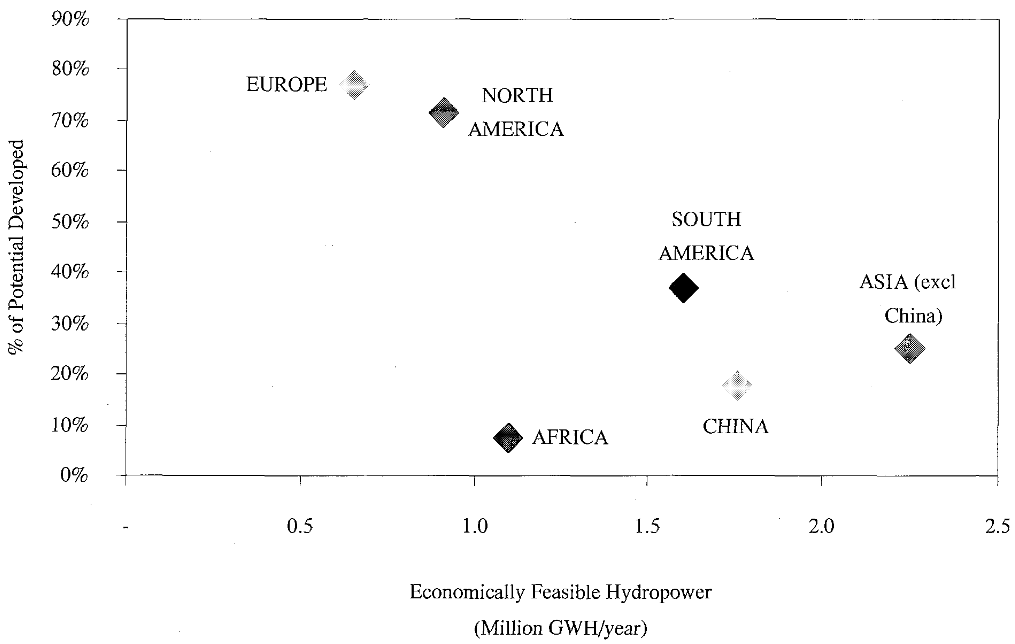


Figure 3-7 Economically Feasible Hydropower

3.4.2 Climate Change and Hydropower

(1) Changes in yearly precipitation from global warming

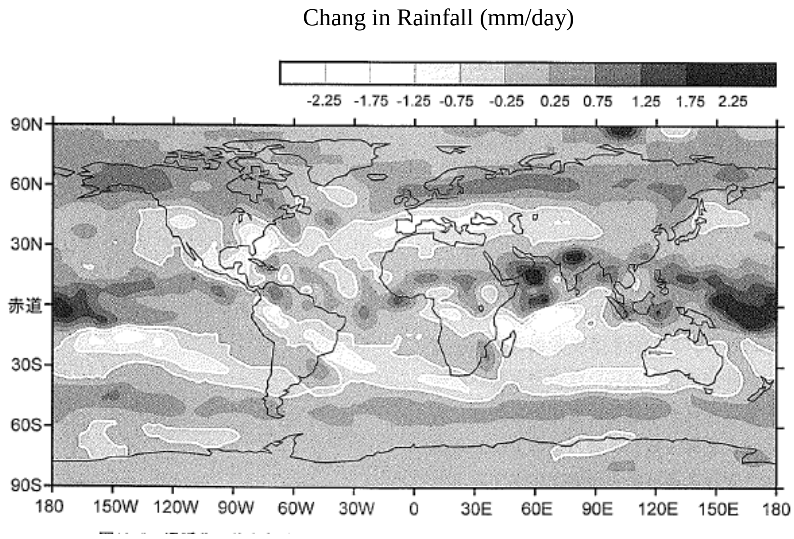
The following is an excerpt from a research paper[3] on changes of hydrology circulation from

3 Matsuoka, Sugita, Tanaka, Matuyama, Tezuka, Onda: Global Environmentology (in Japanese), p.p49-50, 2007

global warming.

Mechanisms involved with fluctuations on precipitation are fairly complex, and the degree of these fluctuations differs widely among regions. And with continuing global warming, it poses great difficulties in predicting how regional precipitations change and in what magnitudes and frequencies disasters strike different regions. These difficulties make the predictions all the more important. Past research by numerical models, which evaluate the transport and storage volumes water and energy by atmosphere, oceans and lands, conclusively predicts an increase in global precipitations, because an increase in atmospheric temperatures increases the upper limits of vapor that atmosphere can contain (saturated vapor pressure). However, subtropical semi-dry regions and Mediterranean climate provinces are very likely to see decreased precipitations from changes in atmospheric circulation patterns (Figure 3-8). Additionally, rainfall patterns are also predicted to change, with concurrent occurrences of increased frequencies both of intensified daily precipitation exceeding 50mm and continuous no-rainfall days. These are phenomena caused by an accelerated water circulation in global scale, and it would intensify their temporal and spatial mal-distribution (intensification). The mal-distribution is not an isolated event from each other: regions of increased precipitations would suffer an increased frequency of intensified rainfalls, whereas regions of decreased precipitations would face an increased frequency of severe shortage of rainfall.

Although predictions by the mathematical models need further refinement, the findings obtained so far strongly predict increased incidences of severe draughts and floods.



Source: IPCC Data Distribution Center. SRES GCM change fields

Note: Average value of 1961-80

Figure 3-8 Changes in Annual Rainfall due to Global Warming

(2) Effects on hydropower generation

Changes of precipitation patterns predicted in Figure 3-8 cause a change in river runoff. In regions where decreased precipitations are forecasted, a quantity of water usable for generation decreases which, in turn, reduces electricity generated. In addition, a growth of population in global magnitude increases water consumption. For example, an increased consumption of water drawn from the reservoir located upstream of a river for irrigation, would reduce the quantity of water available for power plants located downstream.

Even in cases where yearly precipitations remain unchanged, a short-term intensified precipitation would occur and, as a result, a possibility exists where river runoff greater than the expected values flows within a short span of time. Hydropower plants without reservoirs would be incapable of utilizing a river runoff of short duration which exceeds the maximum flows for the plants. And even for a hydropower with reservoirs, reservoir operation rules determined before global warming may become obsolete for flow patterns occurring from global warming.

Chapter 4

Development Aid Programs

Chapter 4 Development Aid Programs

4.1 Development Aid Programs of Japan

4.1.1 Types of Economic Participation Programs

Aid for the economic development of developing countries is generally called economic cooperation and is mainly classified into the following forms;

- Official development assistance (ODA): Loan, technical cooperation, grant aid cooperation, investment and contribution to international organizations, etc. by the Japanese government
- Other Official Flows (OOF): Export credit, direct investment and other funding aid by the Japanese government.
- Private Fund (PF): Export credit, direct investment, etc. by private sectors

4.1.2 Official Development Assistance (ODA)

(1) Definition of ODA

ODA, as defined by the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD), must meet the following three requirements:

- It should be undertaken by governments or government agencies.
- The main objective is the promotion of economic development and welfare in developing countries.
- It has concessional terms, having a grant element[1] of at least 25%.

(2) Bilateral aid and multilateral aid

ODA as shown in Figure 4-1 is broadly divided into bilateral aid, in which assistance is given directly to developing countries, and multilateral aid.

Donation of multilateral aid is provided for organizations of the United Nations such as UNDP[2], UNFPA[3], UNICEF[4], and investment of the multilateral aid is provided for international financial institutions such as the IBRD[5], IDA[6], and ADB[7].

Japan International Cooperation Agency (JICA[8]) provides the bilateral aid consisting of technical cooperation, ODA loans and grant aid shown in Figure 4-1.

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1 The grant element measures the concessionality or "softness" of financial terms of a loan. The lower the interest rate and the longer the maturity period, the higher the grant element, which means it is more beneficial to the borrower. The grant element for a grant is 100%.
2 United Nations Development Programme
3 United Nations Population Fund
4 United Nations Children's Fund
5 International Bank for Reconstruction and Development
6 International Development Association
7 Asian Development Bank
8 Japan International Cooperation Agency

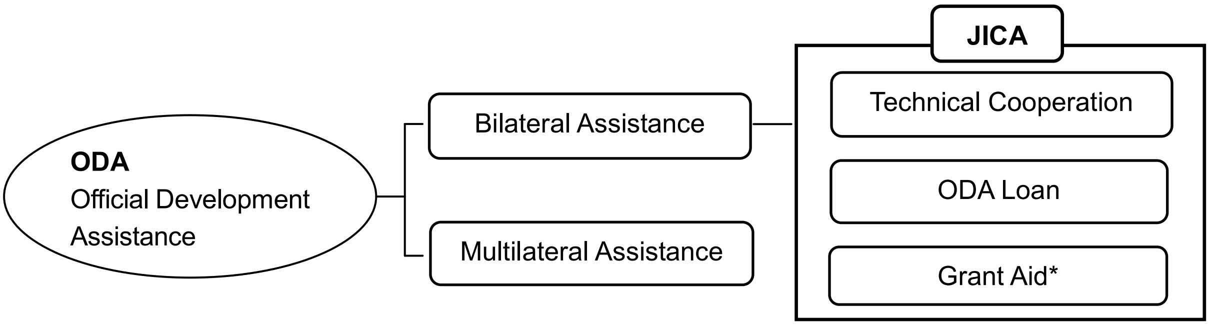

Figure 4-1 ODA Mechanism of Japan

4.2 Technical Cooperation

Technical cooperation consists of trainee acceptance, dispatch of experts, technical cooperation projects, equipment provision, Japan overseas cooperation volunteers, etc. The cooperation relating to an electric power sector is training acceptance, dispatch of experts and technical cooperation projects.

4.2.1 Training Acceptance

The trainee acceptance scheme accepts trainees from developing countries and they are expected to play a leading role in the development of their country. Expert knowledge and technology in many fields are transferred to these people, including administration, agriculture, forestry, fishery, mining, energy, health and medical services, and social welfare. Trainee acceptance schemes on the government base are mainly conducted through JICA as shown in Figure 4-2. Flow chart of the JICA's training acceptance is shown in Figure 4-3.

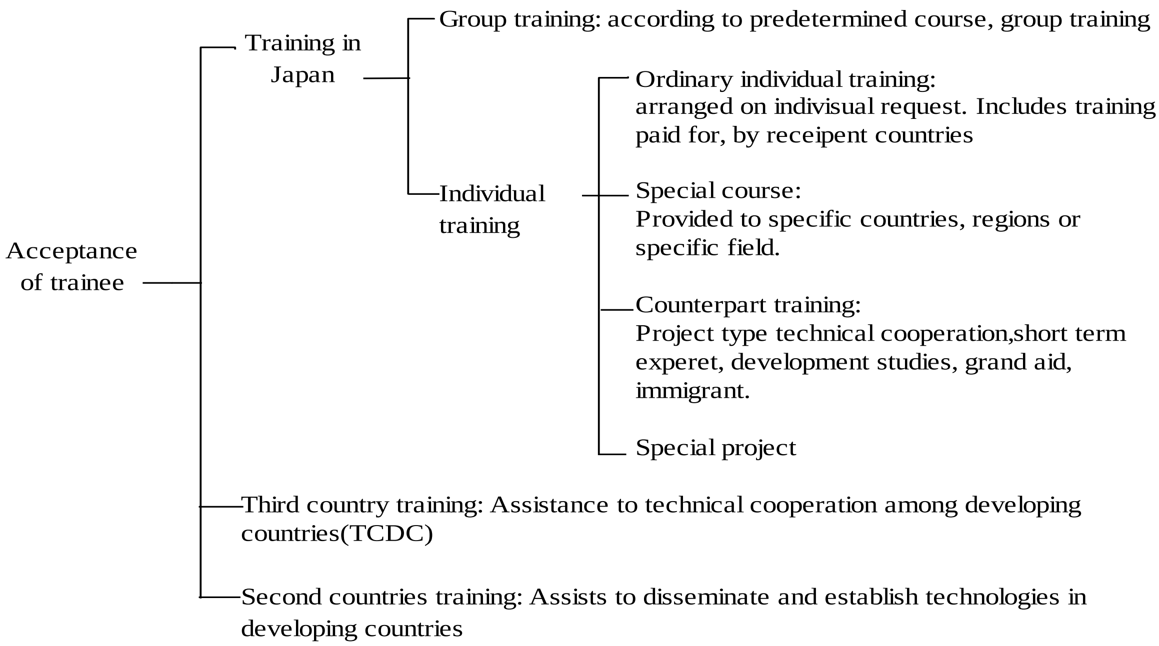

Figure 4-2 Types of Training Program

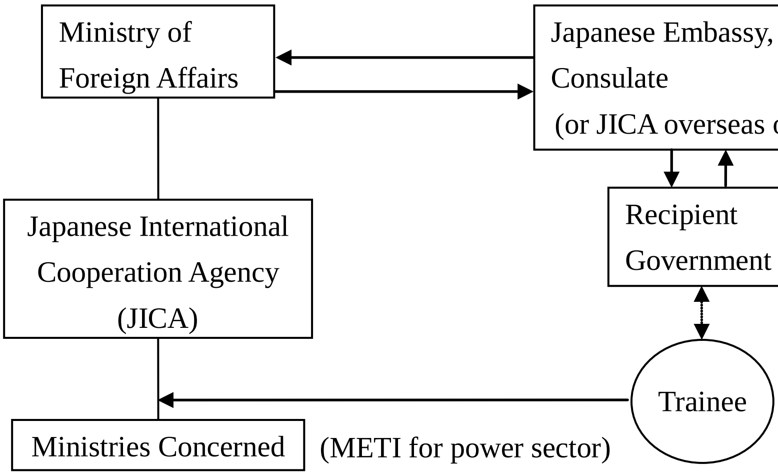

Figure 4-3 Trainee Acceptance System

Other training is conducted by the Japan Productivity Center-Social Economic Department (JPC-SED) and Association for Overseas Training Service (AOTS).

4.2.2 Dispatch of Experts

The purpose of dispatching experts is to carry out technology transfer from Japanese experts to government officers and engineers in developing countries. The technology transfer is done based on the situation in the countries. Taking into account historical background of the country etc., experts from another country other than Japan can be dispatched if it is more efficient. The flow chart for the dispatch of experts in specific fields by JICA is shown in Figure 4-4. The request form from a developing country must describe the background of the request, the detailed duty of the experts, the assignment in the organization, required years of experience and number of experts, and period of service.

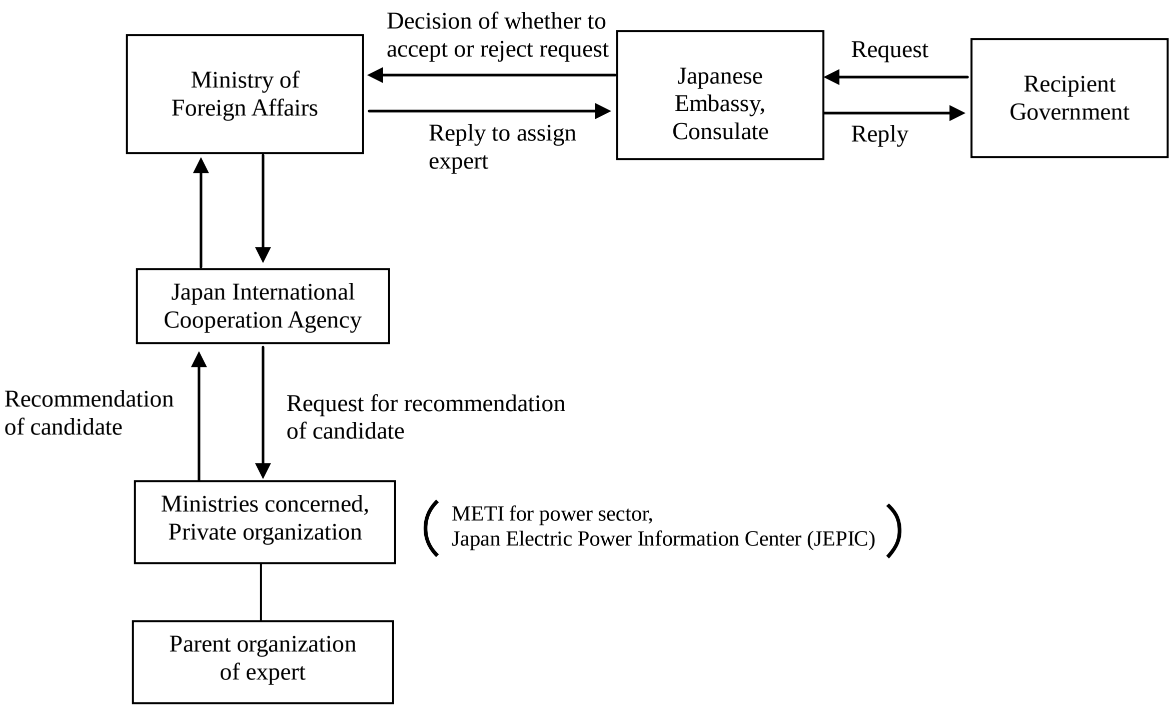

Figure 4-4 Expert Dispatch System

4.2.3 Technical Cooperation Project

Technical cooperation projects are results-oriented, with Japan and a developing country pooling their knowledge, experience, and skills to resolve specific issues within a certain timeframe. The projects may involve the dispatching of experts from Japan to provide technical support, the invitation of personnel from developing countries to Japan for training, or the provision of necessary equipment. The technical cooperation project concerning the electric power sector is about technical standards of electric power facilities.

After receiving a request from a developing country, JICA adopts various cooperation approaches (cooperation tools). In order to achieve the objective of promoting development, JICA determines how to combine these cooperation tools, how long they will be run for, and how to time them for the most effective and efficient results. These projects are run continuously for three or more year.

Project cycle of this project is as follows.

- Project findings and formation
- Request and acceptance
- Examination and ex-ante evaluation
- Project implementation, mid-term and terminal evaluations
- Ex-post evaluation and follow-up

4.2.4 Technical Cooperation for Development Planning

Technologies on investigation & analysis and planning method are transferred to counterparts in developing countries, by supporting policy planning and public work planning. This includes master plan of public works, feasibility studies, and other investigation such as mapping, etc.

After the cooperation is terminated, the developing countries conduct the followings based on the cooperation result.

- Regional and sector development plans, etc. are formulated.
- Projects are implemented by finance of international institutions and, etc.
- Organization reform and institution reform are implemented as recommended by the cooperation

4.3 ODA Loans (Yen Loan)

4.3.1 General

A government loan is to provide financing of development projects to developing countries at low interest on long, concessional terms. It is also known as a direct government loan or yen loan. Interest rate varies with market conditions, and it is lower than that of other aid organizations. The repayment period varies depending on the project's revenue.

The development of a country’s economic and social infrastructures is a vital factor for its prosperity. In many cases, however, reliance on a market mechanism to secure the required fund is not possible for a developing country. Therefore, the Japanese Government supports the necessary funding on the condition of the self-sustaining efforts of these countries for their economic independence. This is the major purpose of government loan.

4.3.2 Type of ODA Loans

Yen loans are classified into two types, project type and non project type. Projects in power sector are in the category of the project type. The project type has three kinds of loan, project loans, engineering service loans and financial intermediary loans (two-step loan).

(1) Project Loans

Project Loans, which are predominant among ODA loans, finance projects such as roads, power plants, irrigation, water supply and sewerage facilities. The loans are used for the procurement of facilities, equipment and services, or for conducting civil works and other related works.

(2) Engineering Services (E/S) Loans

This type of loan is for engineering services, which are necessary at the survey and planning stages of the projects. The services include reviews of feasibility studies, surveys on detailed data on project sites, detailed designs and preparation of bidding documents. Completion of feasibility studies or their equivalents are prerequisite for this type of loan.

(3) Financial Intermediary Loans (Two-Step Loans)

Financial intermediary loans are implemented through the financial institutions of the recipient country based on the policy-oriented financial system of that country. These loans provide funds necessary for the implementation of designated policies, such as the promotion of small-and medium-scale enterprises in manufacturing, agriculture, and other specified industries and the construction of facilities to improve the living standards of the poor. These loans are known as "two-step loans" because there are two or more steps before the end-beneficiaries receive the funds. Under this type of loan, funds can be provided to a large number of end-beneficiaries in the private sector. Since these loans are implemented through local financial institutions, they also serve to strengthen the operational capabilities of these institutions and to develop the financial sector of the recipient countries.

4.3.3 Project Cycle

ODA loans follow six steps as shown in Figure 4-5.

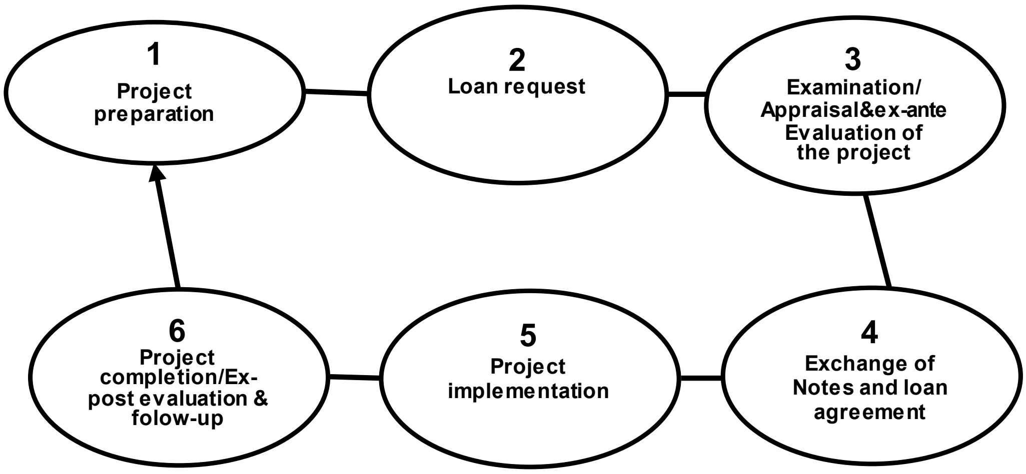

Figure 4-5 Project Cycle

4.3.4 Flow of Yen Loan

Flow chart of yen loan is shown in Figure 4-6.

(1) Project preparation

Most developing countries formulate and execute their middle and long term development plans to extend over many years. The planned project is included in this development plan. Prior to the implementation of the project, a feasibility study is conducted including technical, economical and environmental analysis as well as a study of alternative plans. The feasibility study may be carried out by the government of the recipient country, or through the technical cooperation of JICA or other international organizations. JICA may carry out an investigation which integrates project formation process for technical cooperation, ODA loans and grant.

(2) Request

The government of a recipient country requests a loan to the Japanese Government through the Japanese Embassy, together with the project implementation plan based on the feasibility study.

(3) Study and appraisal of the project

As it is necessary to justify that the project implementation will contribute to developing the economy and to improving the living standard in the recipient country, the following matters are confirmed by the Japanese Government before making a commitment for financing.

- Feasibility, viability, environmental consideration, benefits, of the projects.
- Priority and importance of the project in the economic development program of the recipient country

The contents of the feasibility study are examined to confirm that the project is technically, economically and financially feasible. In case of a yen loan, submission of a feasibility study report is required when applying for a loan. Once a feasibility study report is submitted, a government mission may be dispatched to discuss the details of the project with the government of the applicant country. If the project is deemed promising, an appraisal is conducted by the JICA.

In the JICA appraisal, discussions with the implementing organization and site survey are carried out by the mission. A comprehensive study is conducted including macro economic analysis to test the loan repayment capability together with further detailed technical, economical and environmental analysis of the project.

Based on the results of the JICA appraisal, the amount of the loan and its terms are determined by the Japanese Government through discussions with the government of the applicant country.

(4) Exchange of notes and loan agreement

The Japanese Government conveys its decision to the applicant country through the Japanese Embassy or at an international meeting. This is called a pledge. An exchange of notes (E/N) is describing the agreed detailed conditions is signed by the two governments.

The JICA then concludes a loan agreement (L/A) with the recipient country which binds the rights and obligations of the signatory of the loan. Legal and financial matters, procurement method, disbursement procedure, project purpose, project scope, and content are specified in this L/A.

(5) Project implementation (Procurement, disbursement, etc.)

The project is implemented following the signing of the L/A. A consultant is first selected by a short list method normally employed internationally when hiring consultants. The materials, equipment and services required for the project are then procured by international competitive bidding. Such procurement is carried out according to JICA guidelines.

While the loan is provided in response to the request or application of a country, in actual practice, however, disbursement from the loan is made, in principle, according to the payment terms and conditions in the agreement and/or contract with the suppliers of goods and services with the project progress after the procurement stage.

Foreign consultants carry out bidding matters of construction, construction supervision under cooperation with clients in order for construction to proceed as expected, as mentioned below.

- Whether the project progress is on schedule
- Whether the construction is carried out in accordance with the detailed design
- Whether the construction material and facility are used properly

(6) Project completion and post evaluation

When the project is completed after such process, post evaluation is carried out.

Post evaluation is conducted by the JICA or by a third party. Following its completion, the management and operation of the project is the responsibility of the recipient country. However, JICA directs its attention to inform itself of actual conditions in order to provide appropriate advice as required. The followings are evaluated for post evaluations.

- Whether the project was able to realize its purpose
- Whether the procurement procedure was appropriate
- Change in social and economical environment at project site
- Strengthening of project implementation organization
- Whether the project involved in vast cost overrun

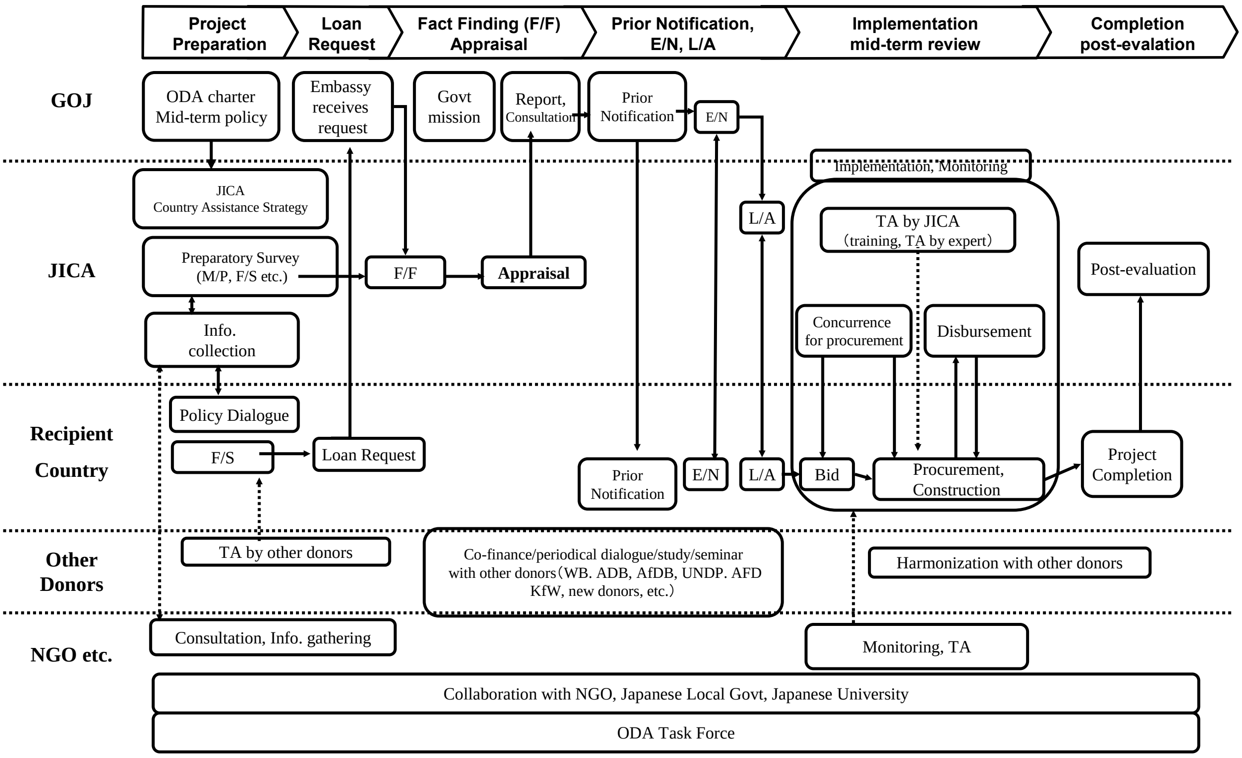

Figure 4-6 Flow of Yen Loan

4.4 Grant Aid Cooperation

Grant Aid is a form of ODA involving the provision of funds to developing countries without the obligation of repayment. The aim is to cooperate in economic and social development by helping the Government to introduce and upgrade its facilities and equipment. JICA is responsible for the preliminary surveys as well as supports for project implementation and post implementation follow up. Grant Aid is available mainly for the social development sector including education, health and medical care, agricultural development as well as upgrading of public infrastructure such as roads and bridges. Small scale hydropower plant for rural electrification, which is described in Vol.2, is included on the grant aid.

4.5 Development Scheme by IPP

4.5.1 IPP Project Scheme

(1) BOT and BOO

IPP is defined as an Independent Power Producer who wholesales electricity to public utilities. Entry into IPP markets takes two different forms: i) Construction of a new power plant, ii) Acquisition of an existing power plant. The first option does not produce revenue for the construction period, although capital infusions had already taken place, while the latter generates revenues upon acquisition. For a new power plant construction project, the first option is further divided into two different forms, BOT and BOO.

- BOT (Build, Operate and Transfer)

  The IPP owns the plant for a certain fixed period (i.e. payout time of 20 to 30 years), and after which the plant is transferred to the developing country (i.e. government, public corporation)

- BOO (Build, Own and Operate)

  The IPP continues to own and operate the plant and a transfer to the developing country does not take place.

Benefits out of BOT in developing countries include the following.

- Although infrastructure development is a pressing need in many of the developing nations, it does not proceed in ways preferable to their needs. And this causes a major slowdown in economic development in many cases. An introduction of BOT removes financial burdens and allows simultaneous development of plural projects, thereby accelerating the speed of infrastructure development.
- Other benefits of BOT include transfer of state of the art technologies from advanced nations. BOT can also be an effective vehicle to promote privatization and deregulation of the electrical power industry and to nurture domestic financial markets.

(2) IPP Project Structure

In an IPP project, each participant makes contracts with the Project Company and forms a scheme in which the participants share a proportionate amount of project risks (Figure 4-8). The Project Company, which is set up by capital investors, gets loans from financial institutions banking syndicates, and using the amounts invested and loans from the financial institutions. The Project Company takes responsibility for the project from planning and right up to operation and maintenance. The ratios of capital investments and loans to the total project costs differ from project to project, however they generally range between 30 to 70% or 40 to 60% respectively. Electric power generated is sold wholesale to public utilities or power pools.

The terms used in Figure 4-7 may be replaced as follows: Project Company by Special Purpose Company, Capital Investor by Sponsor, Financial Institutions by Lender, Power Purchaser by Offtaker and O&M Company by Operator.

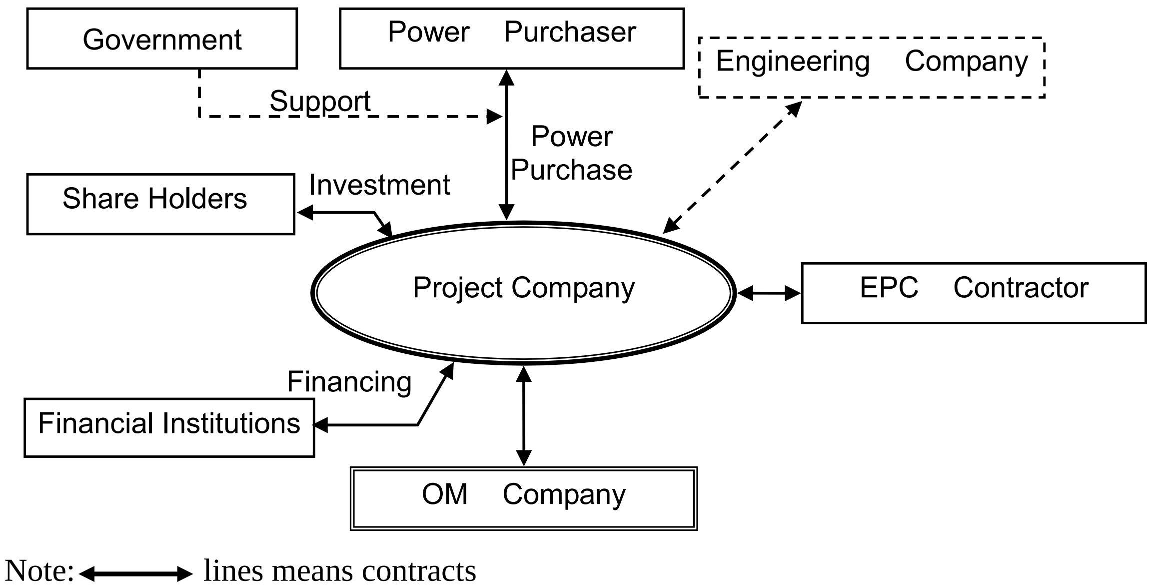

Figure 4-7 IPP Scheme

The Project Company makes equity investment contracts with share holders. They are a consortium responsible for the planning of the project and have a clear mission for the performance of the project.

The Project Company signs financing agreements with financial institutions under a project finance scheme, a most standard form of bank financing. It does not rely on the assets and creditworthiness of the investors and makes the cash flow from the project a primary source for repayment. The collateral the Project Company provides for the creditors are its assets and receivables from contracts. By formalizing the scheme, the Project Company gets loans from banks and capital markets. Under the scheme there are two financing arrangements: non-recourse finance and limited recourse finance options. In the former the sponsor is responsible only to the extent of his investments. In the latter, although sponsor's responsibility is basically limited to his investments, he is also required to share additional costs to cover contingency liability, for example, an increase in the construction costs, provided such an increase is in accordance with specified conditions.

The Project Company contracts power purchase agreements with both power transmission and power distribution companies, and agrees on electric power rates. Where a power purchaser's credit rating is low, the Project Company hedges the risk by obtaining assurance of the host government's involvement for continuance of the project, or by having buyout agreements in the contract in case of bankruptcy. The Engineering Company provides technical services according to the contracts signed with the Project Company. Where the Project Company has in-house engineers, they may replace the function of the Engineering Company.

The Project Company signs a contract with Engineering, Procurement & Construction: (EPC) contractor. The EPC contractor, under full turn-key contracts, provides services for engineering, equipment purchasing and construction of the project. The construction costs are fixed in most instances, and the project is turned over to the Project Company upon completion of the project. The EPC contractor takes the risks for potential increases in the costs of construction. An EPC contractor is a consortium consisting of construction companies, electrical equipment suppliers and steel corporations, for example, and each participant to the consortium takes risks for potential increases in construction costs and performance risks.

The Project Company may own and operate the finished facilities or outsource such management to a third party. In the latter case, the party for operation and maintenance signs contract with the Project Company.

(3) IPP Business and Risks

Risks associated with IPP businesses are categorized into commercial risks (risks of project participants), political risks (risks caused by host government and government agencies), and those from natural force majeure.

1) Commercial Risks

- Performance risk

  A failure to meet the target date or budgets, or a failure of a finished project reaching specified performance targets

- Operation and Maintenance risk

  A risk of a finished project becoming inoperable or a risk of the project not reaching target capacity factors

- Risk from electric power selling

  Risks of electric power selling not generating expected cash flows due to lower-than-expected electric power generation and electricity rates

2) Political Risks

- Exchange risk

Risks from restrictions by host government or its central bank on currency exchange transactions. An offshore escrow account is one of the methods to circumvent the risks whereby the cash flow from the project is managed in countries or their central government outside the host nation.

- Risks from amendments of applicable laws and standards

  Risks arising from amendments or repeals of laws and standards applicable to the project

- Risks from expropriation, impoundment and nationalization

  Risks of ousting of the project by the host government

- Risks from strike, civil war, insurgency, terrorism

  Direct and indirect risks in the host country from such events

- Risk of war

  Risks from host country's engagement in war with neighboring countries and regions

- Risks from failure to comply with performance obligation

  Risks arising from host country's or its agencies' failure to observe performance obligation

- Natural force majeure

  Risks caused by force majeure represented by natural events such earthquake, typhoon and cyclone, tsunami, flood and lightning

4.5.2 Development Aid Programs by Japanese Government

(1) Oversea investment loan

1) JBIC loan

JBIC provides overseas investment loans to meet long-term financing needs of Japanese firms for their international business development, including projects that will establish/expand production bases and develop natural resources overseas. As shown in Fig 4-8, direct and indirect financing is provided for the projects undertaken by the firms incorporated in developing countries and regions in which Japanese firms have equity shares.

With JBIC assuming specific risks, businesses can reduce political risk, including the risk associated with currency convertibility and transfer, which characteristically involves overseas business operations.

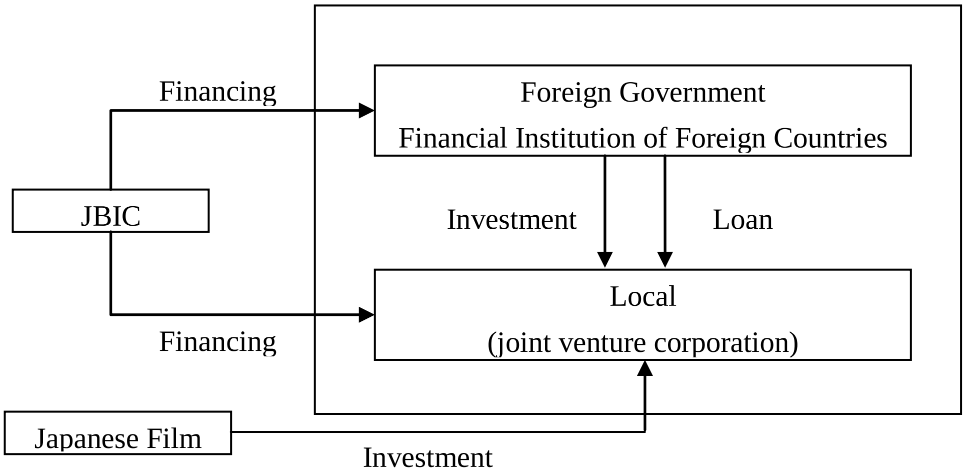

Figure 4-8 Oversea Investment Loan by JBIC

2) Loan terms

Loan terms and conditions are determined following the loan appraisal with respect to individual projects, while taking account of the following points.

(a) Loan amount, currencies and interest rates

The loan amount, which should not exceed the value of a contract associated with overseas investment, is applied to meet financial needs for undertaking a specific overseas investment project or long-term needs for investment to develop overseas business operations. Loans are disbursed when actual financing needs arise. Loans finance, in principle, up to a specified percentage of financial needs and are provided in co-financing with private financial institutions with a view to complementing their financing. Loans may be provided in currencies other than the Japanese yen (in principle, in the US dollar or euro). Loans denominated in the yen carry fixed interest rates, while loans in other currencies carry, in principle, floating interest rates.

(b) Repayment period and method

The repayment period is determined by taking account of the period required for recouping investment. Since no limit is set on the repayment period, repayment schedule can be set flexibly, including the grace period, depending on the expected rate of return on individual projects. In general, repayment periods range between one and ten years, and the repayment method is installment repayment.

(2) Export loans

1) JBIC loan

Exports to developing countries of machinery and equipment produced in Japan, such as turbine & generators and transmission facilities and provision to developing countries of Japanese technical services (including consulting services for various project-related studies, designing and project implementation monitoring and supervision) and overseas construction as well as other projects

A buyer's credit (B/C) and a bank-to-bank loan (B/L) are direct loans respectively provided to a foreign importer and a foreign financial institution for financing the import of Japanese machinery and equipment or the utilization of Japanese technical services. A direct loan to an importer is called buyer's credit and to a financial institution is called a bank-to-bank loan.

2) Loan terms

(a) Loan amount and interest rates

The loan amount is usually determined based on the OECD Arrangement. In principle, the loan amount should not exceed the value of an export contract or technical service contract and excludes down payment. While export loans, in principle, do not apply to local costs, such costs may be covered, fully or partially, provided that their amount does not exceed down payment (max.30% of the export contract value). Interest rates are determined based on the provisions of the OECD Arrangement.

(b) Repayment period and method

Loan repayment periods and methods are determined based on the OECD Arrangement. The maximum repayment period differ depending on importing countries, goods and services and contract values.

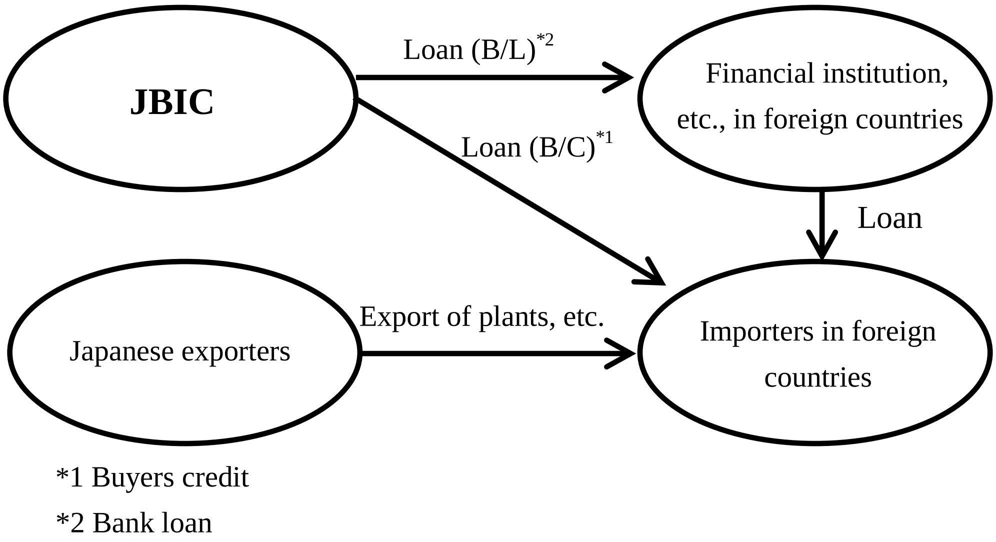

Figure 4-9 Structure of Export Loan

4.6 Development Scheme by PPP

There appears to be no universally agreed definition of Public-Private Partnership (PPP). This manual defines it as a “term to represent a form of relationship between public organizations and private sectors, which have expertise and clear objectives to make profit and are formed for the purpose of supporting movements towards opening up public facilities and services”.

In spite of vast investment opportunities for infrastructure development in developing countries, government finance alone or inputs from overseas public sectors are insufficient to meet the needs of such large investments. Specifically, a project financed by the budget of one's own government may lead to a bloated government budgets, to an unjustifiable reliance on external debts, or a lack of incentives for efficiency on the part of project owner. It is against these backgrounds that the execution of a project by PPP is becoming increasingly indispensable for infrastructure development, and for providing public services, with private and public sectors each raising adequate amount of capitals and sharing risks among them. One such example is a PPP in which the public sector takes charge of the basic part of infrastructure development and for establishment of rules and standards. Thus the private and public sectors plays collaborative roles in PPP-based development as shown in Figure 4-10.

Introduction of a PPP, in essence, is the opening up to private sectors of public facilities and services, and at the same time, encourages movements away from infrastructure -development- oriented approach to management-and-service-oriented approach. A PPP is a joint project composed of four participants, public and private sectors from both developed and developing nations, which shares risks among themselves in the execution of a collaborative project.

A concept of partnership was a rarity in the existing framework of ODA where only an implicit relationship of donor-nation versus donor-receiving-nation existed. And the roles of public sectors, both in developed and developing nations, were not explicitly recognized either. In any PPP projects it is imperative that the four participants to the partnership clearly recognize their expected collaborative and cooperative roles in the framework of PPP for the execution of PPP projects.

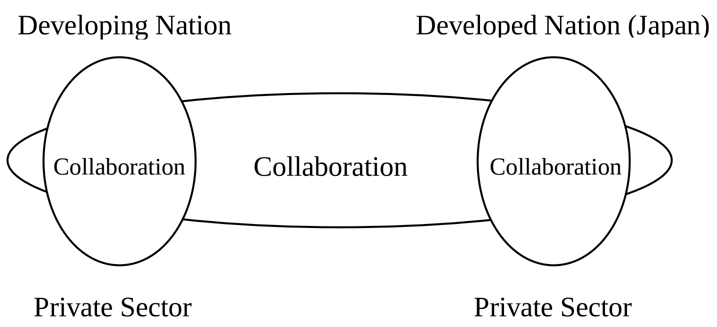

Figure 4-10 Partnership among Four Participants to PPP

Part 2

Reconnaissance Study

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Planning by Reconnaissance Study Method

Chapter 5 Planning by Reconnaissance Study Method

Chapter 5 and 6 are materials of “Guide Manual for Development Aid Programs and Studies of Hydroelectric Power Projects (New Energy Foundation, 1996).

5.1 Basics of Hydropower Planning

5.1.1 Purpose of Reconnaissance Study

A study of initial stage is called reconnaissance study or preliminary study. The term "reconnaissance study" is used in Vol.1 of this Manual.

The purpose of reconnaissance study is outlined below.

- Initial stage study of individual project
- Hydropower potential survey
- Master plan study

The flow chart of investigation and study of hydropower projects is shown in Figure 5-1. It is roughly classified into reconnaissance study and feasibility study. The reconnaissance study is the initial stage study in which 1:50,000 scale topographic maps are used. The feasibility study is the final stage study to determine the realization of the project in which 1:1,000 to 1:5,000 scale topographic maps are used. Part 2, Chapters 5 through 7, describes the method of reconnaissance study in detail. The method of feasibility study is given in Part 3, Chapters 8 through 19.

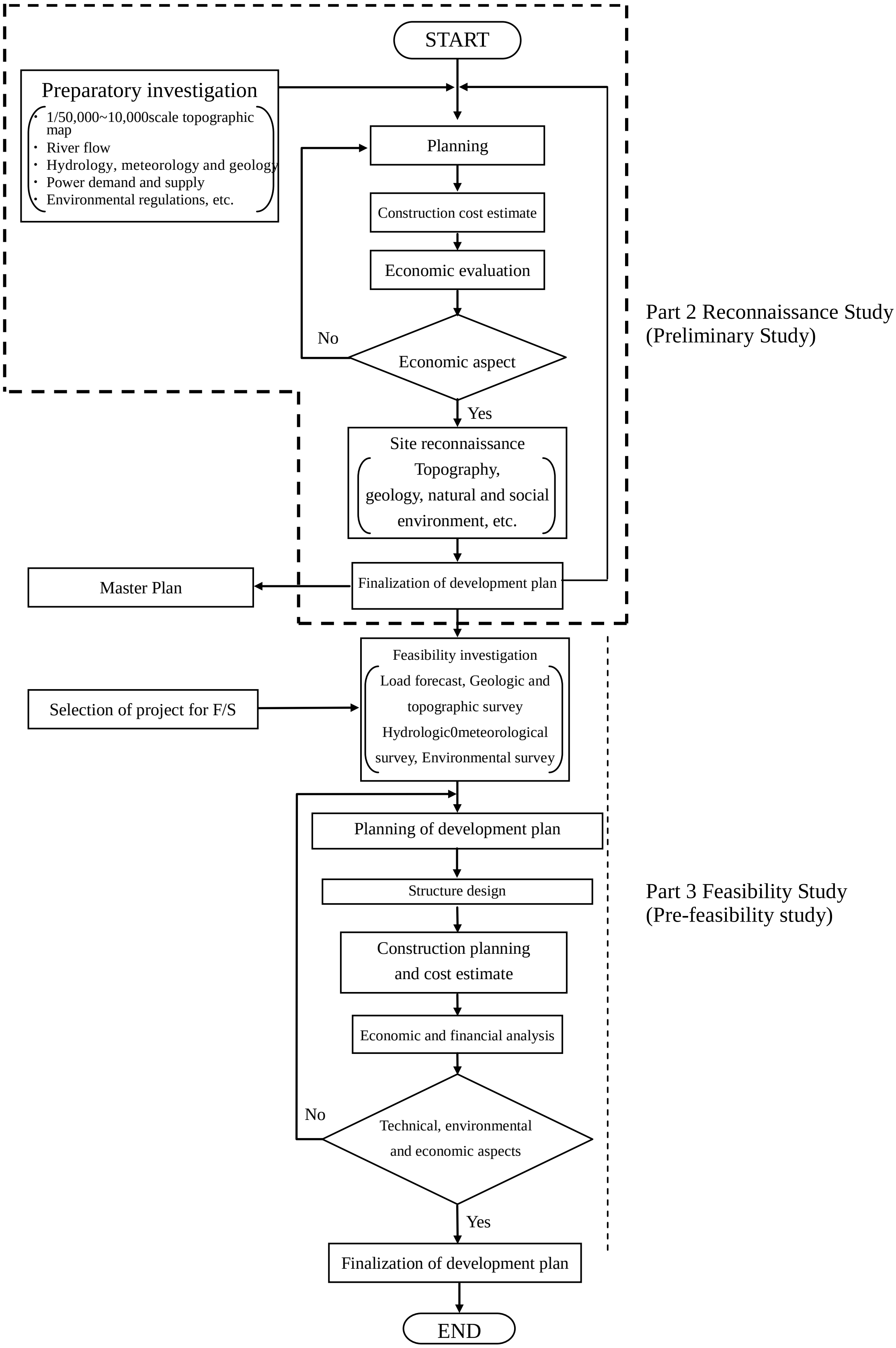


Figure 5-1 Sequence of Investigation and Study of Hydropower Project

5.1.2 Study of Hydropower Planning

Various steps are required to prepare development plans at the reconnaissance study stage. Generally, they are a series of works as described below.

- To select the dam or weir site and powerhouse site (or tailrace site) in consideration of the flow and topography of the river
- To set the maximum plant discharge on the basis of the river flow at the dam site
- To calculate the power output and energy generation from the product of the discharge multiplied by the head between the dam site and powerhouse site
- To estimate the construction cost of the dam, waterway, powerhouse and other civil works and the turbine, generator and other electric facilities, thereby obtaining the construction cost for the entire project.
- To analyze and evaluate the project from the aspects of engineering, economy and environment and to finalize the plan

Figure 5-2 and Figure 5-3 show the flow charts in the reconnaissance study stage for conventional type and pumped storage type development.

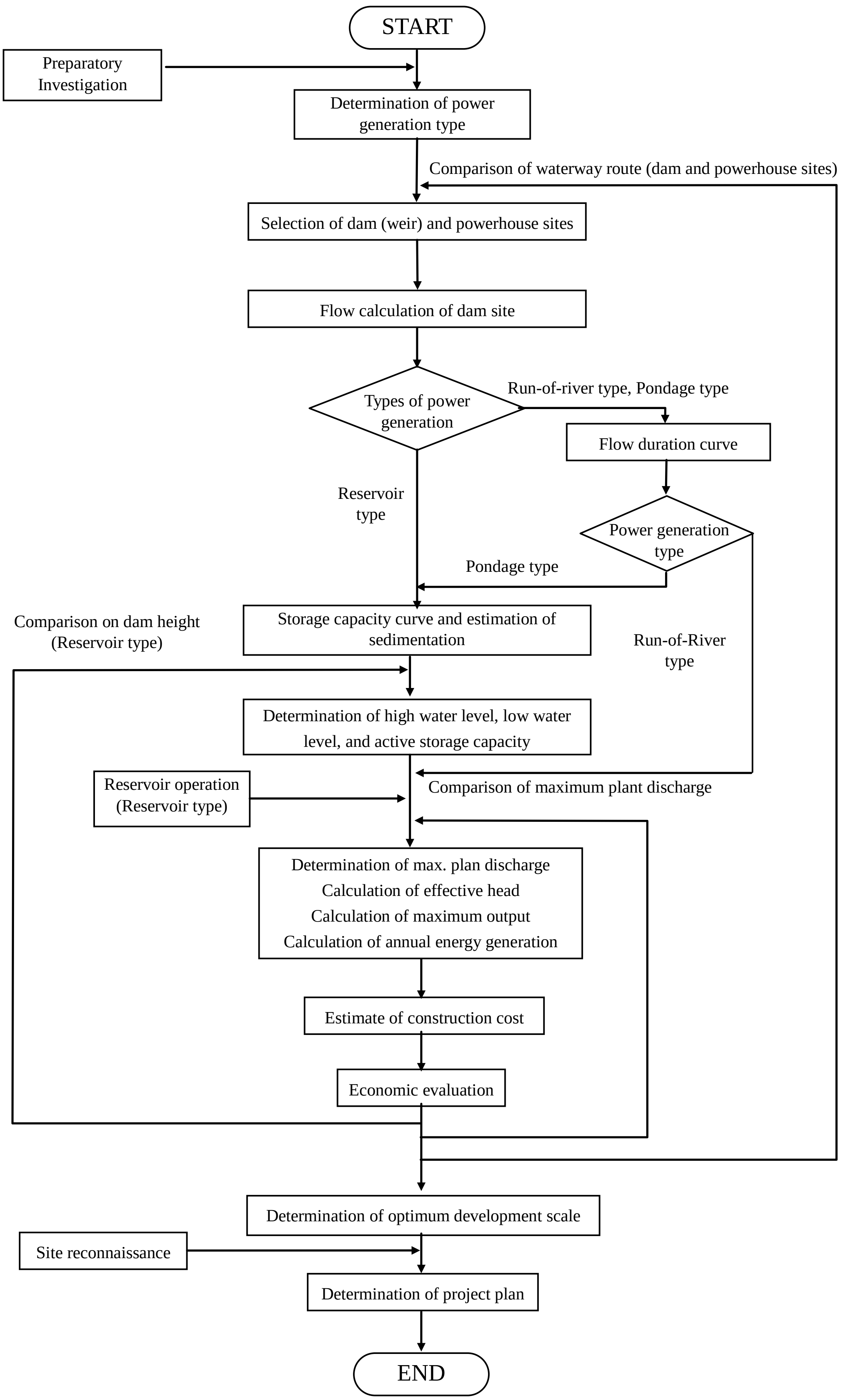


Figure 5-2 Flow Chart for Planning of Conventional Type

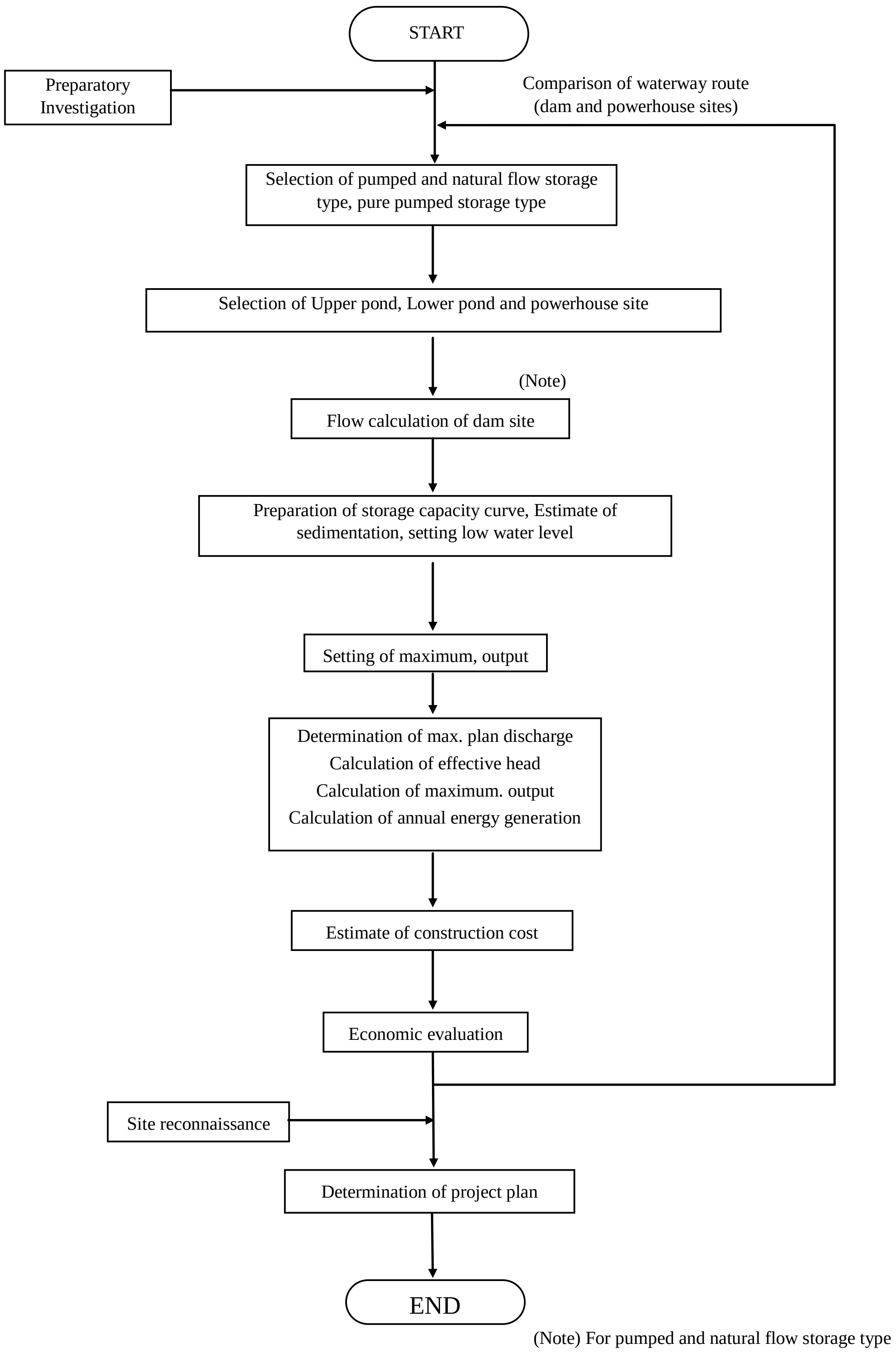


Figure 5-3 Flow Chart for Planning of Pumped Storage Type

5.1.3 Terminology of Hydropower Planning

(1) Reconnaissance study and feasibility study

The initial stage study using 1:50,000 scale maps are called the reconnaissance study. The more detailed study using 1:1,000 to 1:5,000 scale maps is called the feasibility study.

(2) Maximum output and maximum plant discharge

Maximum output is the power output which the power plant can generate. This is often used in the same context as installed capacity and rated capacity. Maximum plant discharge is the largest discharge used by the power plant. It is the basic value for the determination of installed capacity and for the design of waterway.

The maximum output corresponding to the maximum plant discharge is expressed by the following equation.

$$P_{max}=9.8\times Q_{max}\times H_e\times \eta_t\times \eta_g$$

where,

P_{max}	: Maximum output (kW)
H_e	: Effective head (at maximum output: m)
Q_{max}	: Maximum plant discharge (m^3/sec)
η_t	: Turbine efficiency (at maximum output)
η_g	: Generator efficiency (at maximum output)

The term of maximum output is used as the same meaning of rated output here. In some cases the maximum output is designed such that the output increases more than rated output without reducing the maximum plant discharge. In this condition the maximum output is defined the output by the effective head and the plant discharge.

(3) Firm output and firm discharge

The firm output is the output which the plant of-run-of-river type is able to generate almost every day of the year, for example 90 to 95% of the days of a year.

The firm discharge is the discharge which can be exclusively used for hydropower generation almost every day of the year. This Manual defines the firm discharge as “95% flow m the flow duration curve", in which the flow is the amount usable exclusively for hydropower generation, less water used for irrigation, fishery, tourism, etc.

The firm output corresponding to the firm discharge is expressed by the following equation.

$$P_f=9.8\times Q_f\times H_{ef}\times \eta_{tf}\times \eta_{gf}$$

where,

P_f : Firm output (kW)
H_{ef} : Effective head (at firm output: m)
Q_f : Firm discharge (m^3/sec)
η_{tf} : Turbine efficiency (at firm output)
η_{gf} : Generator efficiency (at firm output)

The firm output is the basic numerical value to evaluate the electric power supply capability and economy of run-of-river type project. The power supply service level (non-interruption level) is generally set at 95% depending on the importance of electric power in the supply area. The firm discharge is, therefore, set to meet the above level.

(4) Firm peak output and firm plant discharge

The firm peak output is the output which the power plant is able to produce almost every day of the year (95% of the days of a year) continuously for the specified time during the peak demand. In this Manual, the firm plant discharge is defined as the plant discharge which can be used during peak demand by regulating the firm discharge in a reservoir or pond. The firm peak output is the power output corresponding to the firm plant discharge. The firm peak output is the basic numerical value to evaluate the electric power supply capability and economy of pondage type and reservoir type projects.

(5) Gross head, head loss and effective head (rated head)

A schematic figure concerning heads is shown in Figure 5-4.

The gross head is the difference in elevation between the water level at the dam or intake weir and the river water level at the powerhouse or tailrace site. The former water level is called normal water level (NWL) and the latter water level is called tailwater level (TWL). The gross head (Hg) is calculated as follows.

$$Hg = NWL - TWL$$

In this Manual, concept of normal water level, normal tailwater level and effective head are employed and defined in order to set the maximum output as follows.

1) Normal water level (NWL)

Following definition is adapted in this manual.

(a) Run- of- river type

Water level at intake weir

(b) Reservoir type, pondage type and pumped storage type

Water level at 1/3 of available drawdown (ha) from the high water level (HWL) as shown in Figure 5-4, or the water level corresponding to the half storage volume of effective storage capacity

Basically, the NWL should be determined by the feasibility study.

$$NWL = HWL - 1/3 \times ha$$
$$Hg = NWL - TWL$$

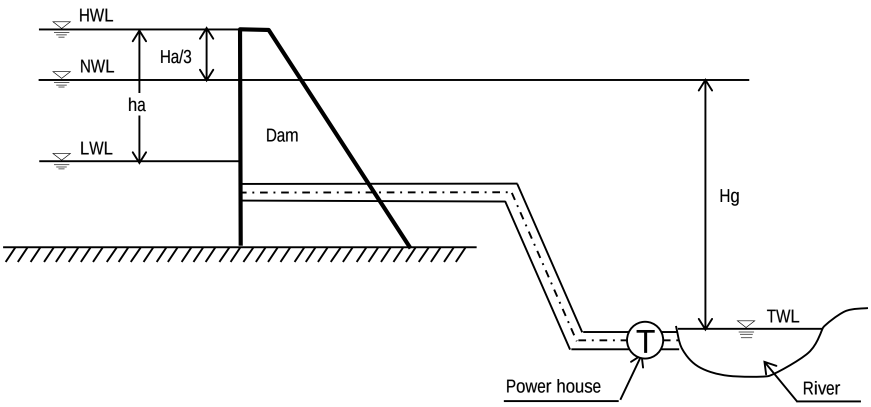


Figure 5-4 Schematic Figure on Head

2) Normal tailwater level (TWL)

(a) Conventional type

A river water level at the powerhouse or tailrace site (The water level is simply called "tailwater level" for conventional type)

(b) Pumped storage type

Water level at 1/3 of available drawdown from the high water level of lower pond

3) Effective head (Rated head)

The head loss ($H\ell$) is the loss when water flows down in a hydropower system.

Effective head (He) is the head which works effectively for the turbine, and expressed as follows.

$$He = Hg - H\ell$$

The effective head which is generally called "rated head" is the head obtained by subtracting the normal tailwater level and head loss from the normal water level.

$$He = NWL - TWL - H\ell$$

(6) Power output and Energy generation

Power output is the magnitude of electric energy generated in one second. When generated continuously, the work load is called the energy generation and is expressed in kilowatt-hours (kWh) or megawatt-hours (MWh). The energy generation in one year is called the annual energy generation. The energy is classified into primary energy, which corresponds to firm output or firm peak output, and secondary energy.

(7) Annual plant factor

The ratio of annual energy generation to electric energy produced at continuous operation for one year at maximum output is called the plant factor.

$$\text{Plant factor (\%)} = \frac{\text{Annual energy generation (kWh)}}{\text{Maximum output (kW)} \times 8{,}760\ \text{(hr)}} \times 100$$

(8) Load and load factor

Power demand is called the load at the power supply side. The ratio of the mean load to the maximum load for a specific period is called the load factor. It is also called the daily load factor and the annual load factor, according to the period taken.

$$\text{Load factor (\%)} = \frac{\text{Mean load (kW)}}{\text{Maximum load (kW)}} \times 100$$

(9) Regulating capability factor of reservoir (RCF)

The regulating capability of the river flow at a regulating pond or a reservoir is expressed by the following equation;

$$\text{Regulating capability factor (\%)} = \frac{\text{Active storage capacity}(\text{m}^3)}{\text{Annual inflow}(\text{m}^3)} \times 100$$

(10) Regulating pond

River flow fluctuates greatly with season but shows no large change in the course of one day or week. The power load does, however, change sharply in a day or week. The regulating pond regulates flow for a day or a week by storing water when the load is low at midnight or on Sunday, and then using it at peak load time. In this Manual a project having storage capacity which RCF is less than 5% is defined as “Pondage type”.

(11) Re-regulating pond

As power plants of pondage type and reservoir type are mainly operated during peak load hours in accordance with the peak load, the plant discharge is released into the river for a short duration. Consequently, the difference in river flow between the peaking hours and off-peak hours is large and may affect the living environment of the people and other water uses located downstream. A pond in order to re-regulate the peak discharge to avoid the undesirable situation above is called the re-regulating pond.

(12) Reservoir

River flow fluctuates significantly throughout the course of one year. Plant discharge can be increased by storing surplus water in the wet season and then releasing it in the dry season. Thus, a relatively equalized discharge can be obtained and stable electric power can be generated. The reservoir is, therefore, constructed to regulate seasonal fluctuation of river flow. In this Manual a project having storage capacity which RCF is more than or equal to 5% is defined as “Reservoir type”.

(13) Representative year

A representative year is the year when the features of the river flow are best expressed for an entire period for which runoff data is available. It is applied when a project is planned using runoff data of one year.

(14) Mean flow

The mean flow is obtained by dividing the total flow over a specific period of time by the number of days involved. It is called the monthly mean flow for monthly periods and the annual mean flow for yearly periods.

(15) Mass curve

A graph of the cumulative values of a hydrologic quantity such as daily flow or monthly flow plotted daily or monthly is called “mass curve”. The mass curve is used in the study of a reservoir plan. It is described in detail in 5.3.4 (11).

(16) Flow duration curve

When flows of a specific period are arranged in the order of their descending magnitude, the percent of the time for which a given magnitude is equaled or exceeded can be calculated. Plotting of the magnitude of flow on ordinate against the corresponding percent of time on abscissas is called "flow duration curve". An example of "flow duration curve" of 365 days is shown in Figure 5-5 where 100% flow, 95% flow, and 75% flow can be shown.

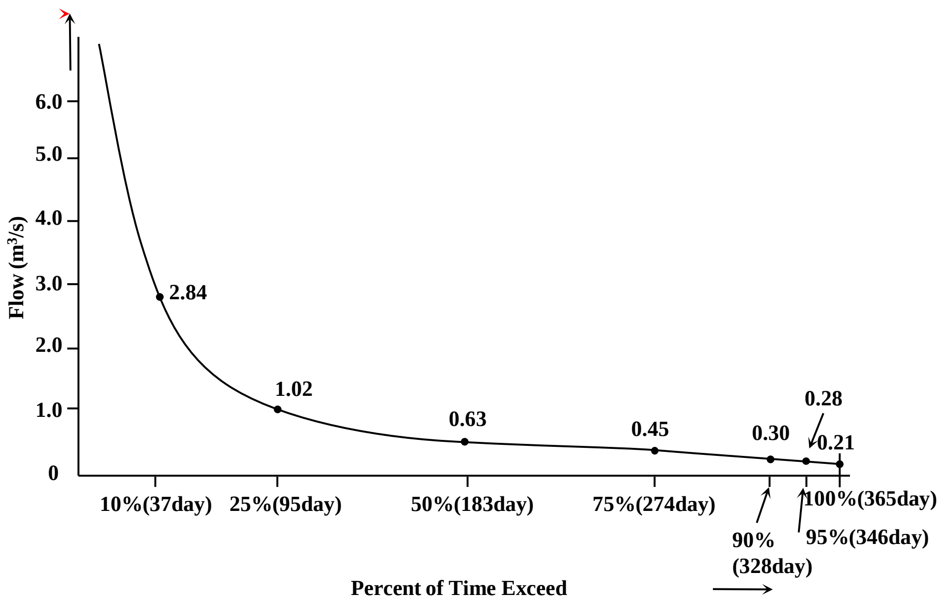


Figure 5-5 Example of Flow Duration Curve

(17) Flow utilization factor

The flow utilization factor is the ratio of the annual plant discharge to the volume of plant discharge at continuous operation of maximum output for one year. Figure 5-6 is an example of flow utilization factor using the flow duration curve.

The annual plant factor of the run-of-river type is generally 5 to 10% lower than the flow utilization factor (See (7)).

$$\text{Flow utilization factor (\%)} = \frac{\text{Annual plant discharge (m}^3\text{)}}{\text{Max. plant discharge (m}^3\text{/sec)} \times 365 \times 86{,}400\text{(sec)}} \times 100$$

$$= \frac{\text{(abcde area)}}{\text{(adcf area)}} \times 100$$

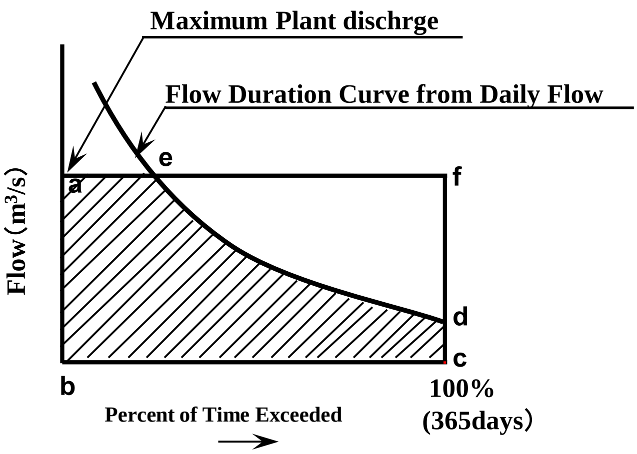


Figure 5-6 Flow Utilization Factor

(18) Peak duration hours

In this Manual, peak duration hours is defined as the minimum operating hours per day on the condition of maximum output operation or firm peak output operation required by the power system. The peak duration hours are used for planning of the reservoir type, pondage type or pumped storage type project to supply power for the peak demand. The electric energy for actual operation shown by the broken line in Figure 5-7, is equal to the electric energy for peaking hours shown in the rectangle. The peak duration hours used in planning is generally 4 to 8 hours in an area where the power system is interconnected, and 2 to 3 hours mostly in areas where the power system is not interconnected and the lighting peak accounts for the greater part of the demand.

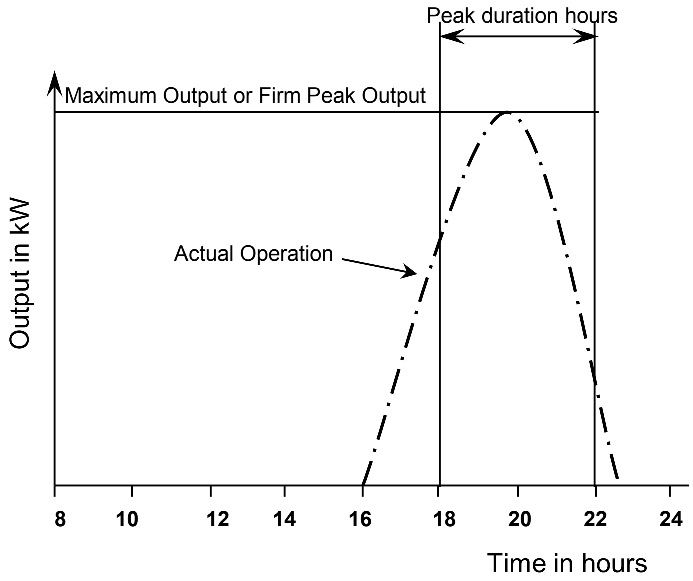


Figure 5-7 Peak Duration Hours

5.2 Preparatory Investigation

5.2.1 Data Collection

The initial stage study of hydropower is called the reconnaissance study. The minimum data required in this stage are topographic maps and runoff data. Other data on hydrology, meteorology and geology are desirable for study, if available. However the reconnaissance study can be made without such data.

(1) Topographic maps

Plant discharge of hydropower plant is determined by the river flow available at the dam site. The catchment area is necessary for calculation of the river flow. The head is determined by the difference in elevation between the intake site and tailrace site. The waterway route connecting these sites is determined from topographic maps.

Topographic maps are required to compute the catchment area and the head. Generally 1:50,000 scale topographic maps are used. If available, maps of higher accuracy than 1:50,000 will enable more reliable study.

(2) Runoff data

Together with the topographic maps described above, the most important data for drawing up a hydropower development plan is runoff data. In many cases, flow gauging and custody of data are conducted by the organization which will ultimately implement the hydropower project. If river flow is not recorded in the project site or nearby, it is necessary to prepare runoff data of the project site using data available, including runoff data of adjacent rivers.

(3) Other hydrologic and meteorological data

Normally, rainfall is observed even where runoff is not recorded. If the period of the recorded runoff data is too short and inadequate for the reconnaissance study, rainfall data is used to prepare long-term runoff data. If a flow gauging station is not installed near the project site but in other basins, runoff data can be prepared from the data of the other basins taking into consideration rainfall of both basins (Refer to 9.3.3). In the case of a plan for a large reservoir, data concerning evaporation should be collected.

(4) Geologic data

In most instances, geologic data covering the entire river basin is in the custody of public organizations of the country. River flow may infiltrate underground in limestone or volcanic ash areas. In this case, special consideration is required to estimate the flow. A hydropower plan may not be feasible in a landslide prone area. It is desirable in the planning stage to know the geologic condition of the basin and waterway route. If data concerning seismic activity in the project site is available, that data should also be collected.

(5) Data concerning power demand, power supply and transmission lines

Daily load curve of the maximum load day shown in Figure 3-4, 3.3 in the supply area and the sources of power supply are investigated. Peak duration hours required for planning of reservoir type, pondage type and pumped storage type can be assumed by the daily load curve. The type of hydropower generation required by the power system can be examined from the supply capability of the sources of power supply. In the case of a pumped storage type, the availability of pumping-up energy should also be examined. If existing hydropower plants are located near the project site, reference data for project planning is collected including maximum output, generated energy and design drawings. In many cases, the percentage of transmission line cost in the hydropower generation cost is high, data concerning transmission lines in the supply area should be collected.

(6) Other data related to the project planning

1) Existing investigation data

If a study was done in the past in the project site or in its neighborhood, available information should be collected as it is useful for project planning.

2) Master plan of river basin development

The master plan on hydropower development is prepared for development of the entire river basin in a most effective and efficient manner. If other important water utilization plans are available, the master plan must be coordinated with them.

3) Environmental regulations

Development is impossible when environmental regulations prohibit development work in the planned area. When part of the plan is located in such restricted area, the plan must be made to not infringe such an area. In many cases where development is strictly controlled in the special areas of natural parks or wildlife conservation areas, related data is necessary. If restriction or concept of such nature exists for environmental reasons, related information should be collected.

4) Vested water rights

When vested water rights have been established for a river where hydropower projects are planned, that river cannot be used on a priority basis exclusively for power generation. As this situation exerts significant influence on project planning, information on vested water rights should be collected.

(7) Data concerning construction cost

Estimate of the construction cost is necessary to evaluate the economy of a project. The unit prices of the principal work items such as concrete, excavation for a similar work in that country, interest rate, etc., are useful for the estimation of the construction cost. Data concerning these items should be collected.

5.2.2 River Investigation by Maps

(1) Study of river utilization condition

As hydropower plants use river water, the river utilization condition must be investigated for project planning. River use includes hydropower generation, drinking, irrigation and industrial water supply, fishery, and inland transport activities. Development of the hydropower projects are is accompanied by inundation of houses and farmland and decrease of river flow between the intake and tailrace sites. Therefore, the land utilization condition in the reservoir area and water utilization facility in the project area should be studied with available topographic maps.

(2) Study of river profile

Hydropower plants generate electricity by using the difference in elevation of a river. The river gradient is studied by topographic maps so that the topographic features can be used most effectively. The study includes large and small tributaries flowing into the river and their catchment area.

5.3 Planning of Conventional Hydropower Projects

The reconnaissance study method for the conventional hydropower is shown below and an example of the study is attached in Appendix A-5-1.

5.3.1 Selection of Type of Power Generation

(1) The power supply (peak power and/or base power) required in the future is studied from the present situation of power demand and supply in the power system. Then the suitable type of power generation, such as reservoir type, pondage type or run-of-river type is selected.

This Manual is dedicated to the promotion of hydropower development in developing countries where growth of power demand though of varying degree is expected. Such increased demand may result in the necessity for peak capability. Where the topography permits, in the selection of type of power generation, reservoir type and pondage type should be considered, except for supply for local independent power grid. Capacity of projects that should be studied in this Manual is about 5 to 500MW.

(2) Topographically, where the river is narrow and its immediately upper course is a wide valley, the reservoir type of development is selected as a reservoir having large storage capacity can be created with a relatively small dam. The pondage type of development is selected where the topography will not permit a large storage reservoir but a regulating pond to regulate daily or weekly runoff can be constructed.

In this Manual, reservoir type and pondage type are defined by using "Regulating capability factor (RCF) ". A plan providing a storage capacity of 5% or higher RCF is defined as the reservoir type and a plan providing less than 5% is defined as a pondage type. By experience, if the RCF is 5% or higher, it is judged that the reservoir operation will enable to store the wet season runoff and release it in the dry season. This Manual applies a slightly different planning method for reservoir type and pondage type development.

(3) Where topographic features will not permit the development of either a reservoir type or pondage type and the river gradient is steep and where a high head can be obtained by the waterway, a run-of-river type development described in 5.3.3 should be studied.

The run-of-river type is mainly small scale hydropower. This type has the characteristics of less impact on the environment than the reservoir type and pondage type of development. Even though the project site has the topographic feature which is suitable for reservoir and pondage types, run-of-river type should be adopted in case environmental problems are foreseen. This Manual treats run-of-river type development of about 5 to 50 MW.

5.3.2 Calculation of Flow at Dam Site and Preparation of Flow-Duration Curve

(1) Runoff data

It is necessary to use runoff data of the longest possible period for hydropower planning.

Generally monthly runoff data is used for the reservoir type and daily runoff data is used for the run-of-river type and the pondage type. For the purpose of training to acquire knowledge in hydropower planning procedure, a representative year is selected from the entire period of available runoff data.

(2) Calculation of river flow at the dam site

The flow at the dam site is obtained by catchment area ratio by applying the runoff data of the recorded runoff data or representative year obtained in (1) above. Runoff calculation is made by the following equation. Figure 5-8 shows catchment area of dam site and gauging station. Daily flow is used for the run-of-river type and pondage type, and monthly flow is used for the reservoir type.

$$Q(d) = Q(g) \times \frac{CA(d)}{CA(g)}$$

where,

Q (d) : Daily or monthly flow at dam site (m^3/sec)
Q (g) : Daily or monthly flow at gauging station (m^3/sec)
CA (d) : Catchment area at dam site (km^2)
CA (g) : Catchment area at gauging station (km^2)

In the application of the above equation, the runoff conditions such as the meteorology (rainfall), soil, vegetation, land utilization, topography, at the gauging station and proposed dam site must be similar. It is desirable that the gauging station is located near the dam site. The runoff analysis method under various conditions is described in 9.4.

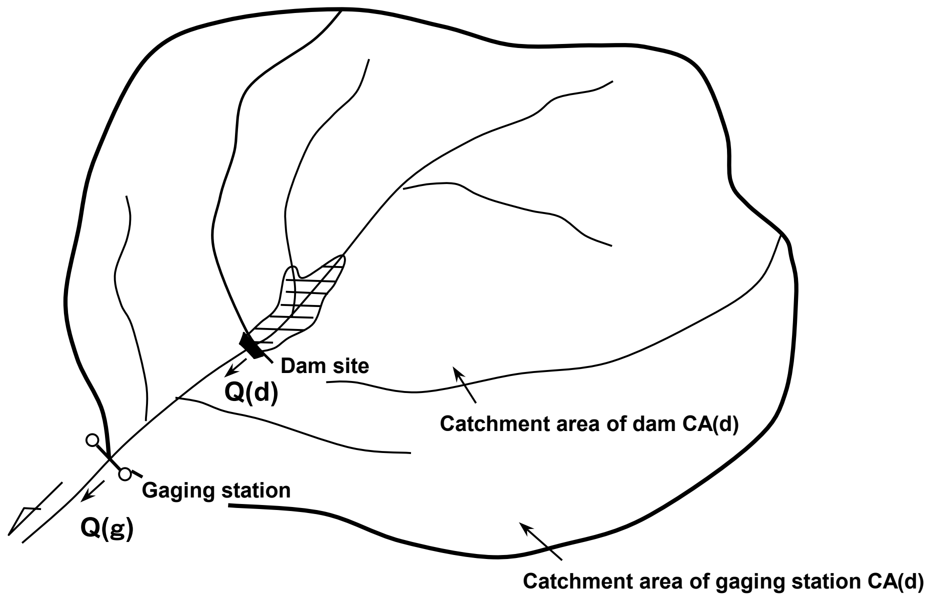


Figure 5-8 Calculation of Flow at Dam Site

(3) Preparation of flow duration curve

The flow duration curve is used in the planning of run-of-river type and pondage type development and is prepared by using the daily runoff data in the entire period of recorded runoff. The flow duration curve is prepared by condensing the entire period of runoff record into one year and is used for planning in this Manual for easy understanding of the study process. For example, when the recorded period is 10 years the flow of the flow duration curve is condensed by ten to prepare a flow duration curve for 365 days.

5.3.3 Study on Run-of-River Type

(1) Layout and sequence of study of run-of-river type

An example of the run-of-river type layout is shown in Figure 5-9 and sequence of study is shown in Figure 5-2.

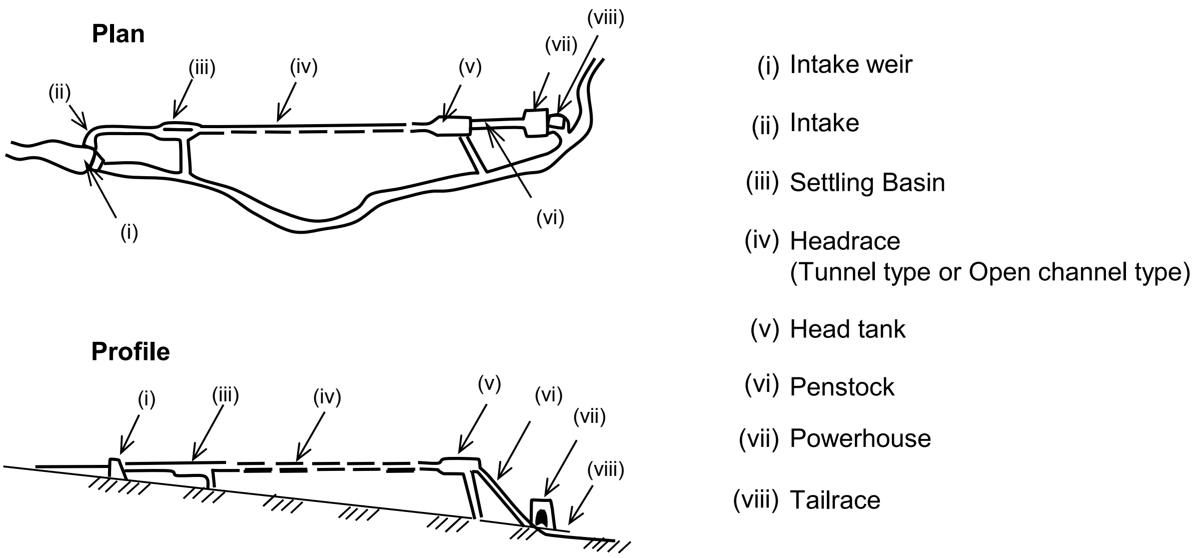


Figure 5-9 Layout Example of Run-of-River Type

(2) Decision of waterway route and its type

1) Waterway route

The waterway route is a general term given for the route of headrace, penstock and tailrace. Hydropower projects are advantageous when a large head is obtained with a short waterway. An intake weir is generally constructed in the upper reaches of river where the river changes from a gentle to a steep gradient and the powerhouse is constructed where the river changes from a steep to a gentle gradient. If the waterway is a tunnel, a work adit is constructed at intervals of about 3 to 4 km in many cases to curtail the construction period. Generally, the tunnel is aligned at least 30 m below the ground surface (rock cover) for the safety of the tunneling work.

Power output and energy generation are determined by the product of the available river flow and head. The construction cost is mainly determined by the length of waterway and the number and size of dams. The river flow is determined by the catchment area at the dam site.

The comparative study in Figure 5-10 shows routes A, B and C with the site of the power house unchanged and with only the intake weir site changed. The features are shown in Table 5-1. The optimum route is determined by conducting economic comparison. The sites of the intake weir, powerhouse and other facilities, are decided in full consideration of the access road, and other factors to enable easy maintenance and administration both during construction and after completion.

Table 5-1 Features of Waterway Route

Route	Catchment area	River flow	Head	Waterway length
A	Small	Small	Large	Large
B	Medium	Medium	Medium	Medium
C	Large	Large	Small	Small

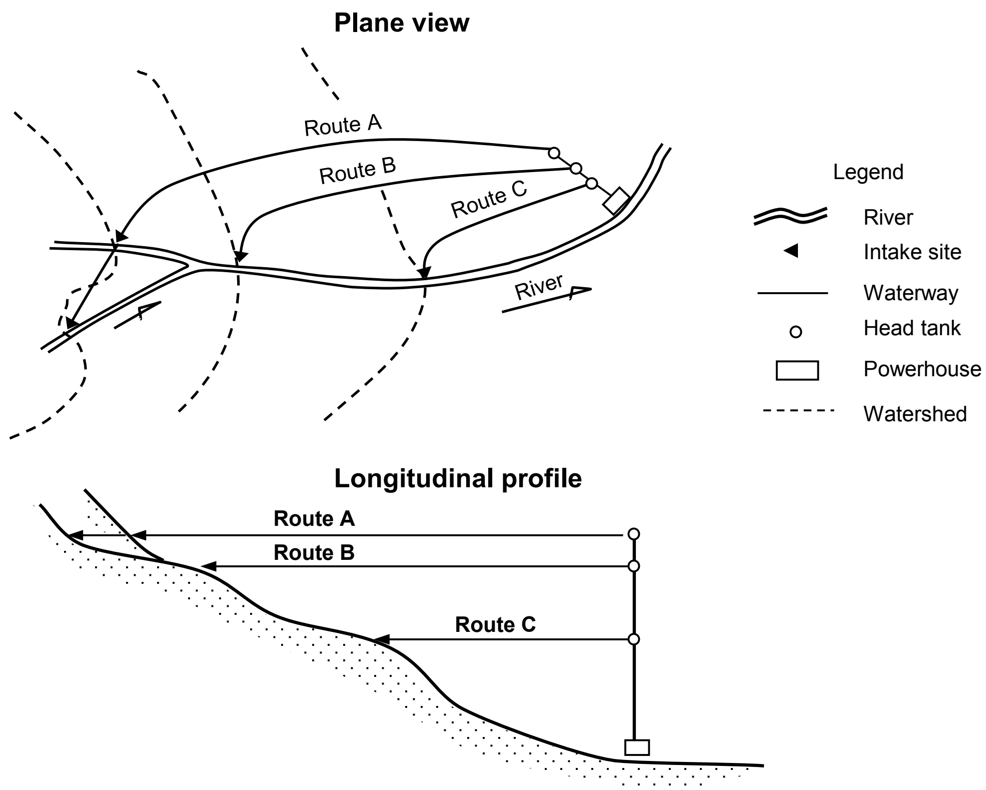


Figure 5-10 Comparison of Waterway Routes

2) Structure of waterway

The structure of waterway is classified into a non-pressure tunnel and an open channel (or canal). As shown in Figure 5-11, the waterway route is aligned on the same contour line as the normal water level when the open channel type is selected. Either the open channel or the tunnel is selected in consideration of the topography, geology and construction cost.

Construction cost of open channel is significantly less than tunnel of the same length. However, an open channel is unsuitable in locations where the topography is steep and the geology is unfavorable. A minimum cross section of approximately 1.8m high and wide is required for tunnel excavation and the discharge capacity is 3 to 4 m^3/s at a gradient of 1:1,000. If the maximum plant discharge is less than this value, a tunnel would be overly expensive and an open channel would be more economical.

3) Determination of waterway route

(a) In the case the headrace is a non-pressure tunnel

- Intake should be located immediately upstream of the intake weir.
- Align the waterway route from the intake to the powerhouse (or tailrace) that will minimize the length of the headrace tunnel, and penstock.
- The site of the head tank should be determined so as to shorten the length of penstock. The elevation of the head tank should be the same elevation of the intake in consideration of the accuracy of the reconnaissance study.
- The penstock route should be along the ridge
- Prepare a waterway profile. An example is given in Figure 5-15.

(b) In the case the headrace is an open channel.

- Intake site should be the same as (a) above.
- The open channel route should be aligned along the natural contour.
- The site of the head tank and penstock route should be the same as (a) above.

(3) Measurement of catchment area

After the intake weir site is determined, confirm the watershed on the topographic map, and measure the catchment area. The catchment area is also called drainage area and is expressed in units of km^2. In case water is to be drawn from tributaries, this should be included in the catchment area.

(4) Calculation of flow at the intake site and preparation of flow duration curve

Flow at the intake site is calculated in accordance with 5.3.2 and the flow duration curve is prepared.

(5) Determination of firm discharge

The firm discharge is obtained from the flow duration curve as shown in Figure 5-12. Here, 95% flow which corresponds to 347 day of a year is used as the firm discharge.

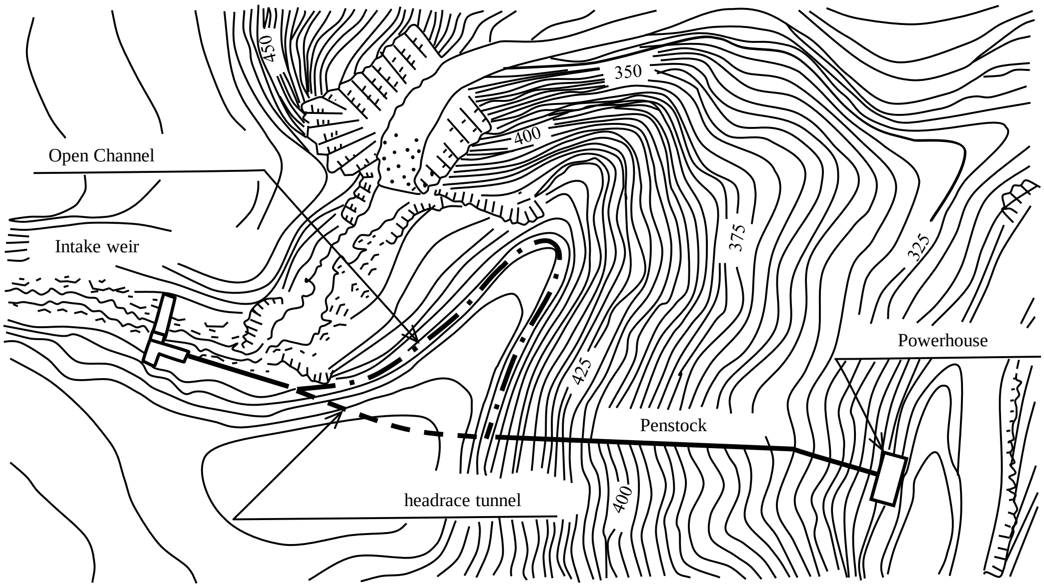


Figure 5-11　Waterway Route

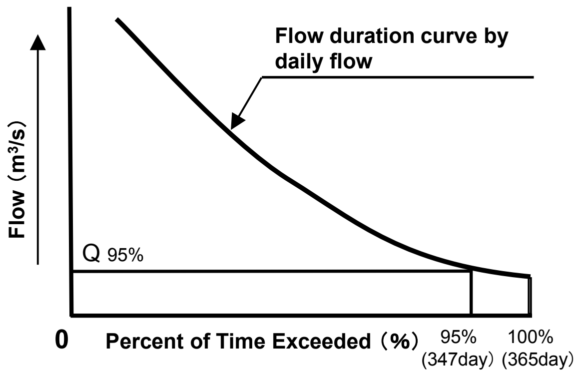


Figure 5-12　95% Flow by Flow Duration Curve

(6)　Temporary setting of maximum plant discharge

The maximum plant discharge is set so that the flow utilization factor (FUF) at the planned site is approximately 70% as shown in Figure 5-13. The FUF of 70% is adopted in this Manual taking into account the fact that it is difficult for power systems in developing countries to consume all the secondary energy and its energy value is much lower than the primary energy. In case the project is planned to supply its power to an isolated power system of rural area, please refer to Vol.2.

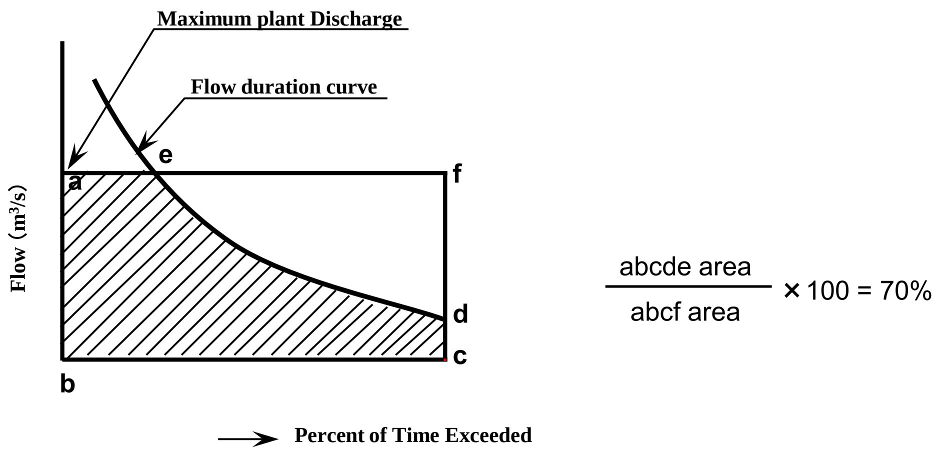


Figure 5-13 Temporary Setting of Maximum Plant Discharge (Run-of-River Type)

(7) Setting of water level of intake weir (Normal water level)

The intake weir diverts river flow into the waterway and does not regulate the flow. Therefore, the lowest possible height of weir is desirable to minimize construction cost. In this Manual, as shown in Figure 5-14, the intake water level of intake weir is 10m above the river bed as measured from topographic map, and this water level is called normal water level.

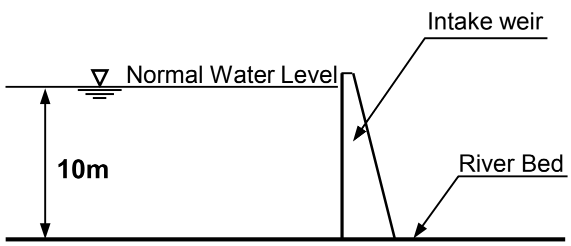


Figure 5-14 Water Level of Intake Weir

(8) Setting of tailwater level

The riverbed elevation at the powerhouse or tailrace site is taken from a topographic map to set the tailwater level. In case a tailrace channel is constructed, the tailwater level is set taking into consideration the tailrace channel gradient.

(9) Waterway profile

The waterway profile from the intake to the powerhouse is drawn to obtain the length of the headrace and penstock. An example is shown in Figure 5-15.

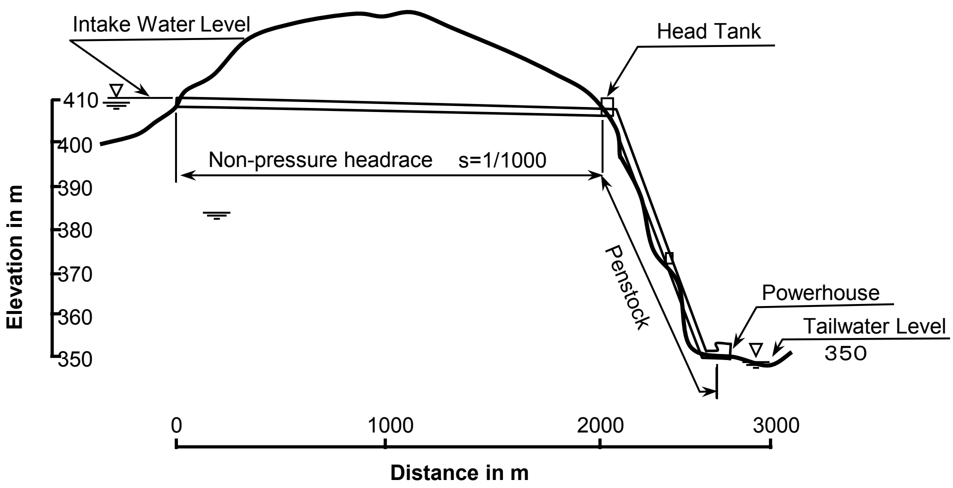


Figure 5-15 Waterway Profile

(10) Calculation of head loss and effective head

The effective head is calculated on the basis of the following equation;

$$Hg = NWL - TWL$$
$$H\ell = a \times L_1 + b \times L_2 + c \times L_3 + \Delta h$$
$$He = Hg - H\ell$$

where,

NWL	: Normal water level (m)
TWL	: Tailwater level (m)
Hg	: Gross head (m)
$H\ell$	: Head loss (m)
He	: Effective head (m)
L_1	: Length of headrace (m)
L_2	: Length of penstock (m)
L_3	: Length of tailrace channel (m)
Δh	: Other head loss (m)
a, b and c	: Factors to obtain head loss

Values in the following table are applied to factors a, b and c for the reconnaissance study.

a	Non-pressure headrace	1/1,000 for tunnel、1/1,000 - 1/5,000 for open channel
b	Penstock	1/200
c	Non-pressure tailrace	1/1,000 for tunnel、1/1,000 - 1/5,000 for open channel

(11) Selection of turbine type, combined efficiency of turbine and generator and number of unit

The turbine type is selected on the basis of Figure 12-16, 12-17, Chapter 12. The combined efficiency for the turbine is obtained from Figure 5-10. Power generation is not possible for many days due to the effect that the efficiency declines when the discharge is small in the flow duration curve. In this case, two or more units of turbine may be installed.

(12) Calculation of maximum output and firm output

$$P = 9.8 \times Q_{max} \times H_e \times \eta$$

$$P_f = 9.8 \times Q_f \times H_e \times \eta_f$$

where,

P	: Maximum output (kW)
P_f	: Firm output (kW)
Q_{max}	: Maximum plant discharge (m^3/sec)
Q_f	: Firm discharge (m^3/sec)
H_e	: Normal effective head (m)
η	: Combined efficiency at maximum output (Table 5-2)
η_f	: Combined efficiency at firm output (See Table 5-2 and Figure 5-10)

Table 5-2 Standard Efficiency of Turbine and Generator (Francis Turbine of 100% load)

Output	Turbine efficiency ηt	Generator efficiency ηg	Combined efficiency of turbine and generator $\eta = \eta t \times \eta g$
5 MW	88	96	84
10 MW	89	96.5	86
50 MW	90	97.5	88
100MW	90.5	98	89
200MW	91	98	89

Table 5-2 shows the standard efficiency of 5 to 200MW Francis turbine and generator at 100% output. Figure 5-16 shows the combined efficiency of generator and each type of turbine for maximum output of 50MW. Rough calculation of maximum output is made by applying efficiency at 100% output. In the case of the Francis turbine with 5MW output, for example, the combined efficiency at 100% output is 84% from Table 5-2. Since the combined efficiency is 88% for 50MW Francis turbine at 100% load, the efficiency curve for 5MW is made by shifting 4% down from that for 50MW shown in Figure 5-16. Rough calculation of energy generation is made by applying the efficiency corresponding to Q/Qmax in the modified efficiency curve. Small discharge may not generate power and the lower limit of Q/Qmax is about 35% for the Francis turbine, about 25% for the Bulb turbine and Kaplan turbine and about 20% for the Pelton turbine. The lower limit of Q/Qmax is taken to be 20% for all turbines for the reconnaissance study of this Manual.

(13) Calculation of annual energy generation

Daily energy generation is calculated by the following equation, and the annual energy generation is obtained.

$$E=\sum(9.8\times qi\times H_e\times \eta_i\times 24)$$

where,

E	:	Annual energy generation (kWh)
qi	:	Daily plant discharge (m^3/sec)
H_e	:	Effective head (m)
η_i	:	Combined efficiency per one unit of turbine and generator for qi. This is obtained from Q/Qmax in Table 5-2 and Figure 5-16.

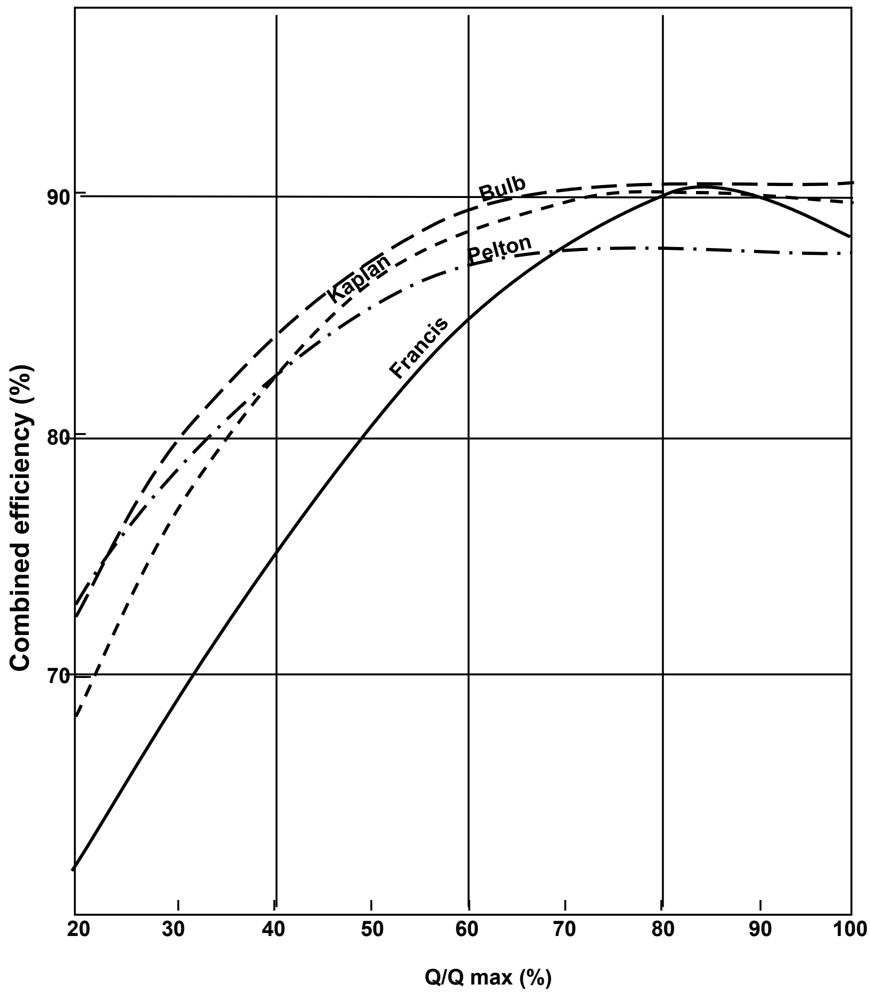


Figure 5-16 Combined Efficiency of Turbine and Generator (50 MW)

(14) Preparation of comparative plans

From the above study the project features such as maximum output, and energy generation are determined for one scheme. Based on these project features, project cost is estimated as described in Chapter 6, and an economic evaluation is conducted. For a promising site, alternative sites of the intake weir and powerhouse are selected, and alternative plans are prepared for flow utilization factor of 50 to 90%. Then these alternative plans are studied by economic evaluation to select the most optimum plan. However, detailed studies should be made in the feasibility study.

5.3.4 Reservoir Type

This Manual classifies projects with a reservoir having 5% or higher regulating capability factor (RCF: see 5.1.3(9)) as the reservoir type and projects with a reservoir of less than 5% as the pondage type. The procedure of study for a reservoir type project is described below. Paragraphs (1) through (10) are applicable for study of both the reservoir type and pondage type, and the scheme of development is decided. When hydropower is a part of multi-purpose dam project, reservoir operation is mainly decided by other uses and hydropower operation becomes secondary. The project study in this case is described in paragraph (22).

(1) Layout and sequence of study of reservoir type

Examples of layouts of reservoir type are shown in Figure 5-17. Sequence of study is shown in Figure 5-2. Layout 1 is "dam type" in which the dam is constructed across the main river course. Layout 2 is "dam waterway type (See 3.2.2)". Layout 3 is "dam waterway type" constructing a dam across a tributary and diverting water from the main river course. This type of development is adopted where the topography of the main course is unsuitable for a reservoir or pondage type. This layout is also useful when the main river course faces heavily sediment. The following description is focused on Layouts 1 and 2.

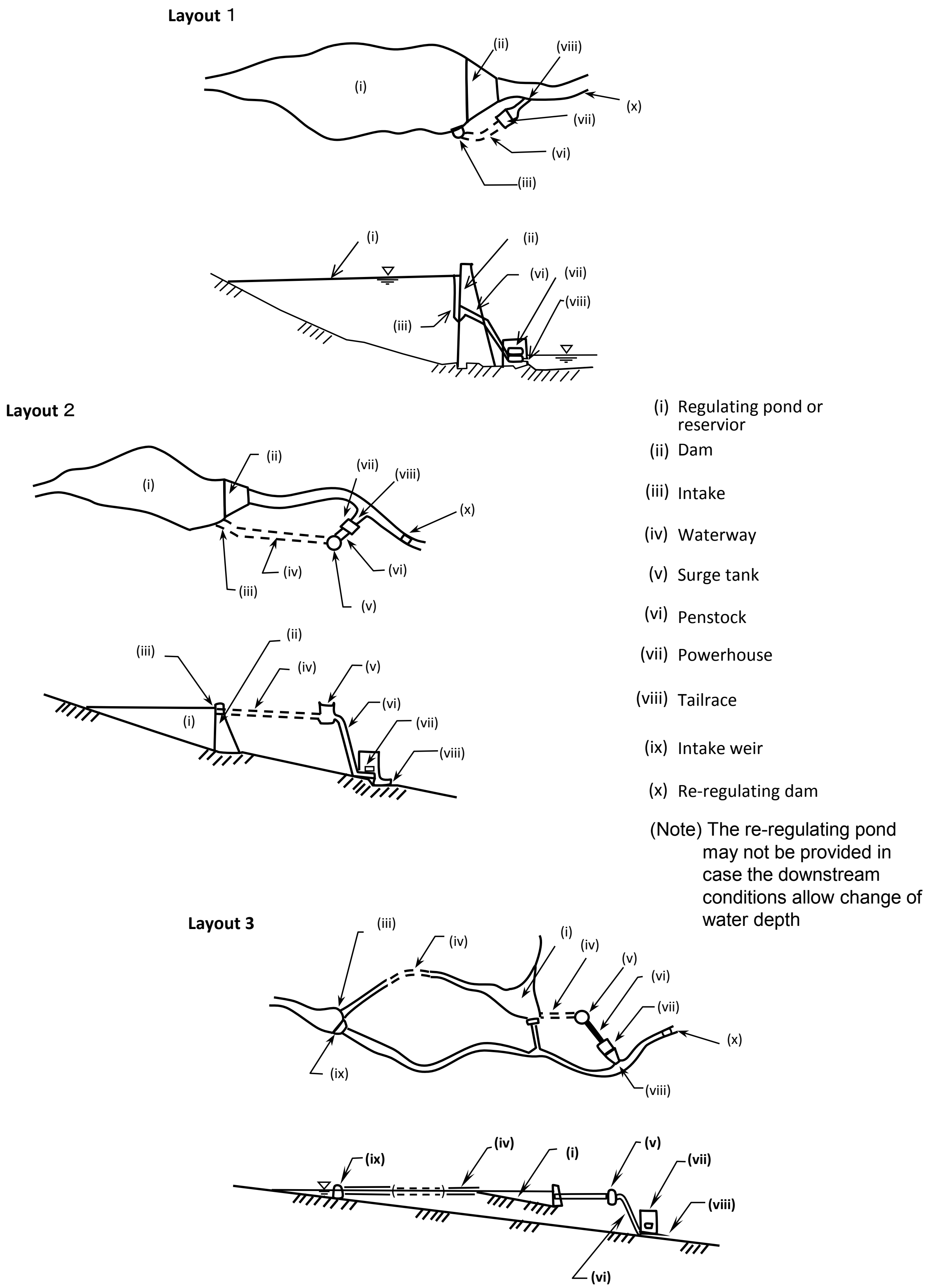
(2) Selection of dam and powerhouse sites and waterway route

Figure 5-18 is an example of site selection.

1) Selection of dam site

The dam site is selected from the following point of view by using a topographic map.

- A large storage capacity can be obtained with a dam of relatively small volume. That is a site where the river is narrow and its upper reaches is a wide valley. In case the river gradient is gentle, the head must be obtained by the dam height. The dam is constructed in a narrow part of the river to reduce the construction cost as much as possible.
- As water leakage from a reservoir or pondage presents a problem in calcareous rock zone, such possibility should be investigated in detail.
- When a large head is obtained by the waterway, the suitable dam site is just upstream of the river where a gentle gradient changes to a steep gradient.
- No serious compensation and/or resettlement problems are foreseen.
- Roads exist nearby, and access to the site is easy.



Note: Plan (upper figure), Profile (lower figure)

Figure 5-17 Layout Examples of Reservoir Type and Pondage Type

2) Selection of powerhouse site

The powerhouse site is selected by considering the following factors;

- In case a large head is attained by the waterway, the desirable site of the powerhouse is immediately downstream where the river changes from a steep gradient to a gentle gradient.
- Space is available for the powerhouse.
- Roads exist nearby to allow easy access.
- Sudden change of river flow due to the peak generation does not adversely influence downstream area. A re-regulating pond is required where such influence is expected.
- The location is safe from flooding.

3) Waterway route

The waterway route is the general term for the route of headrace, penstock and tailrace channel. Hydropower projects are advantageous when a large head is gained with a short waterway. The dam and powerhouse sites are generally selected by considering the river gradient described above. For a reservoir type or pondage type development, the type of headrace is a pressure tunnel in many cases. Work adits are provided along waterway tunnel route at intervals of about 3 to 4 km to ensure timely completion of the work. In general, the minimum distance from the tunnel to the ground surface (rock cover) is about 30m to assure safe tunnel work.

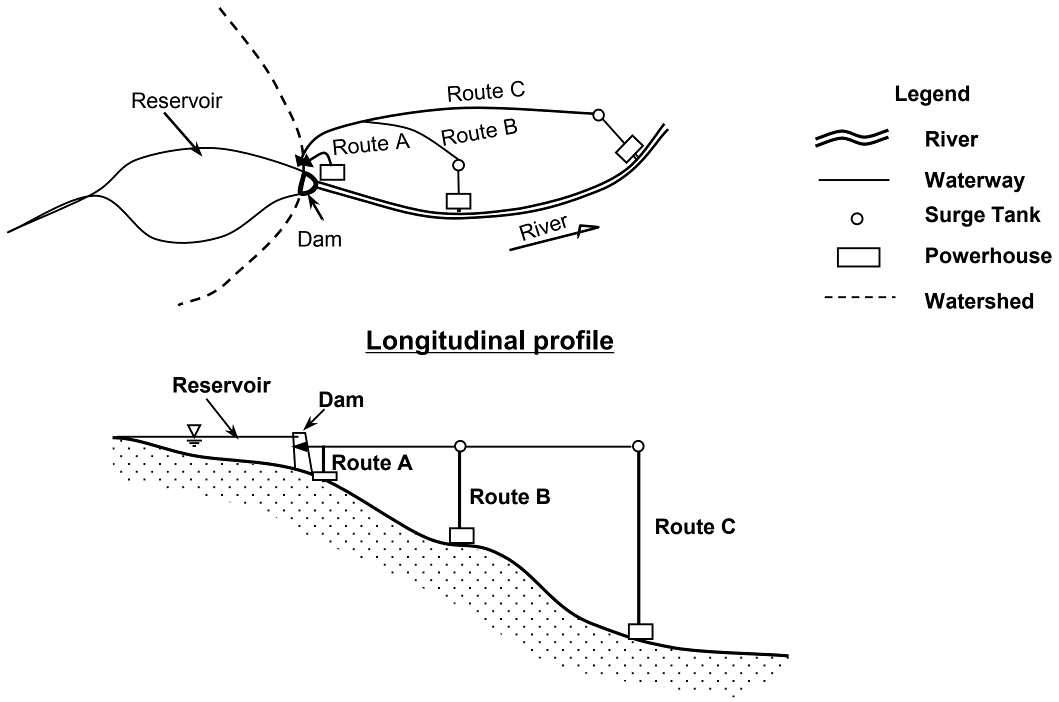


Figure 5-18 Example of Dam and Powerhouse Sites

(3) Calculation of catchment area

When the dam site is selected, the watershed is checked using the topographic map. The catchment area is measured, and the unit is expressed in km^2.

(4) Calculation of flow at dam site

The flow at the dam site is calculated in accordance with 5.3.2. The flow is calculated from the runoff data of the flow gauging station either at or near the dam site by catchment area ratio.

(5) Preparation of storage capacity curve

The reservoir area at each elevation is measured on a topographic map, and the water storage capacity curve shown in Figure 5-19 is prepared. The interval between the contour lines on a 1:50,000 topographic maps are generally 20 m and the storage capacity may not be measured for a reservoir or pond created by a low dam. In this case, the storage capacity curve is estimated by the river gradient and neighboring topographic features.

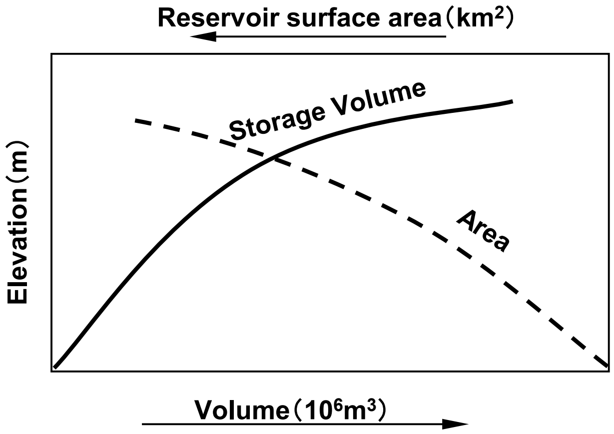


Figure 5-19 Reservoir Area and Storage Capacity Curve

(6) Estimation of sediment volume and setting of sedimentation level

1) Estimation of Sediment Volume

The sedimentation level is determined by estimating sedimentation for a certain period. Generally 100 years period is used. If there is an existing dam nearby and data on annual sediment yield are available, that data is used. Specific sediment yield is expressed as the annual amount of sediment per km^2 of catchment area. The sediment volume is estimated as follows.

$$Vs = qs \times CA\,(d) \times 100$$

where,

Vs	: Sediment volume for n years (m^3)
Qs	: Specific sediment yield (m^3/km^2/year)
CA(d)	: Catchment area at dam site (km^2)
n	: Calculation period of sediment volume (years)

In case data on specific sediment yield is unavailable, estimate method is described in 9.3.3.

2) Setting of Sedimentation level

The sedimentation level is obtained for the estimated sediment volume from the reservoir area and storage capacity curve as shown in Figure 5-20.

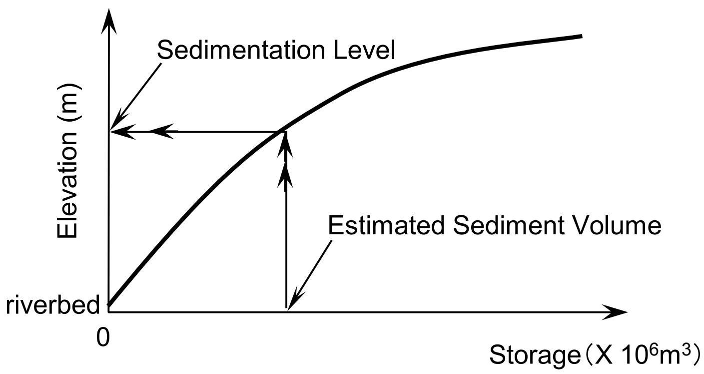


Figure 5-20 Setting of Sedimentation Level

(7) Temporary setting of low water level

The low water level (LWL) is set at a position of about twice the inner diameter (D) of the headrace tunnel above the sedimentation level, to prevent intrusion of air into the tunnel. (See Figure 5-21).

The inner diameter of the pressure tunnel is obtained from Figure 5-22 by using the design discharge. When the maximum plant discharge is carried by one waterway or two waterways, the design discharge for each case is the same as the maximum plant discharge or 1/2 of the maximum plant discharge respectively. The maximum plant discharge is determined by (13). Here, a temporary value is obtained by the following equation;

The value 0.25 is the annual plant factor of about 25%.

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

where,

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

Q_{ave} : Annual mean flow (m^3/sec)

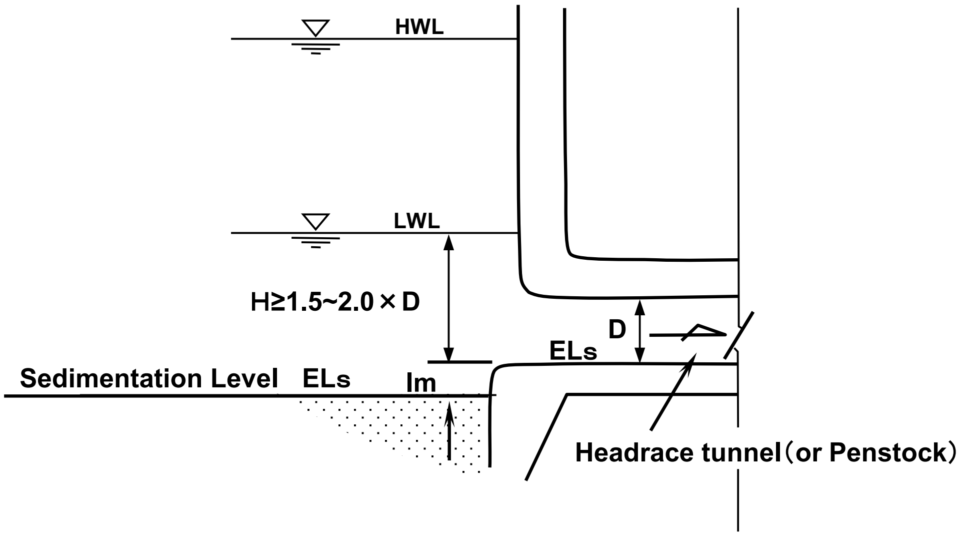


Figure 5-21 Relation Between Intake and LWL

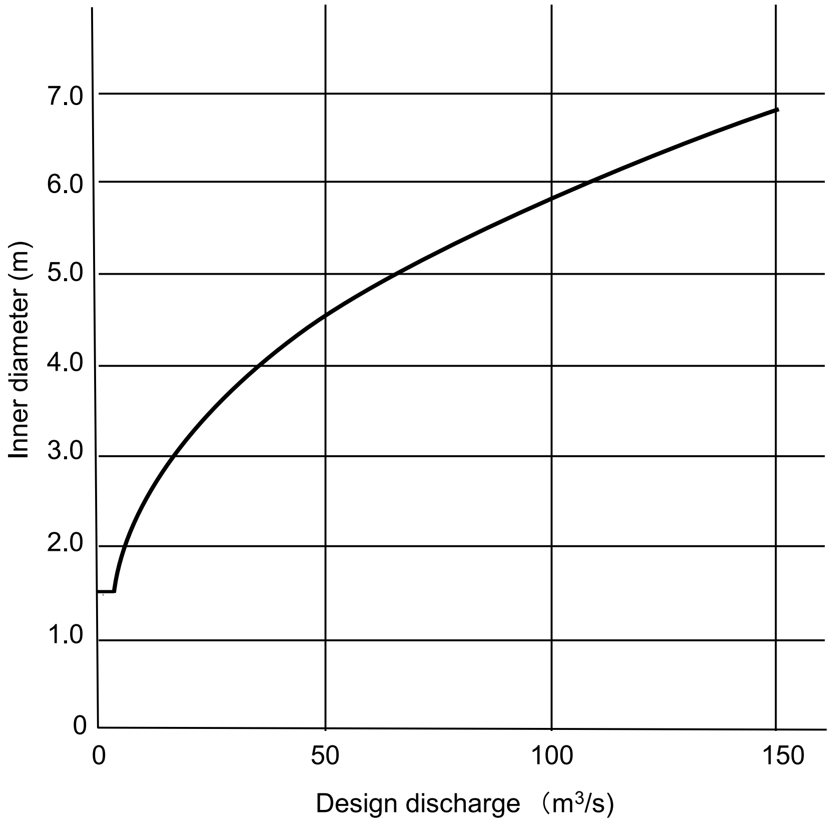


Figure 5-22 Discharge and Tunnel Inner Diameter

(8) Temporary setting of high water level

1) Topographical constraint

The high water level (HWL) is set temporarily taking into consideration the following.

- A water level that will provide a large storage capacity with no sharp increase in dam construction cost.

- Reservoir water level shall not exceed water divide elevation to avoid spillage into an adjacent basin. In case spillage is foreseen, HWL must be lowered or saddle dam must be constructed. (See Figure 5-23)

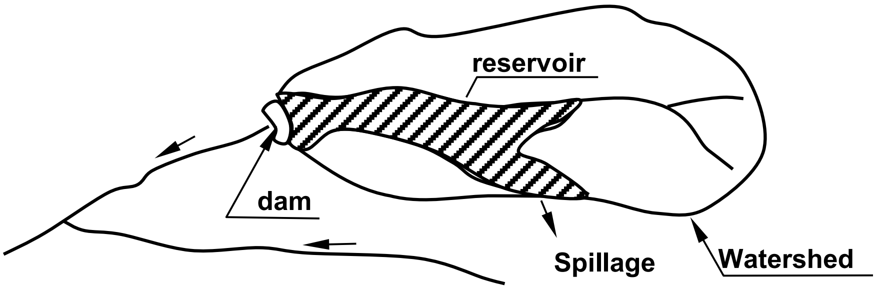


Figure 5-23 Spillage to Adjacent River Basin

- When the geology of the reservoir is limestone or other rock susceptible to leakage, its distribution may determine the HWL.
- In the case the reservoir area is topographically broad and flat, the setting of HWL should be carefully determined because many people might live in the area.

2) Constrain on economic view point

The effective storage capacity becomes excessive in relation o the inflow and no increase of firm plant discharge can be expected. If the height of the dam is raised to increase the effective storage capacity it may adversely affect the economy of the project. Consideration to lower the HWL is, therefore, necessary.

(9) Determination of LWL, HWL and effective storage capacity

1) Lower limit of low water level considering turbine characteristics

Turbine operation may be interrupted by the relation between the turbine efficiency and head fluctuation, depending on the available drawdown which is the water depth between HWL and LWL of the reservoir.

The limit of head fluctuation of the Francis turbine is about 0.7 and that of the Kaplan turbine about 0.55. For the Francis turbine, attempt is made to set the HWL and LWL in the range of the following equation. When the head fluctuation rate cannot be controlled to a value under 0.7, check if it is in the region of the Kaplan turbine and set the HWL and LWL so that the head fluctuation rate is more than 0.55.

$$\text{Head fluctuation rate} = \frac{\text{LWL} - \text{TWL}}{\text{HWL} - \text{TWL}} \geq 0.7$$

where,

HWL : High water level (m)
LWL : Low water level (m)

LWL : Tailwater level (m)

The lower limit of LWL is determined from the higher water level between the water level obtained in (7) and (9) 1) above.

2) Determination of effective storage capacity

The effective storage capacity is determined from the HWL and LWL determined above and using the storage capacity curve.

(10) Preparation of mass curve

The mass curve as shown in Figure 5-24 (a) is the curve accumulating daily or monthly inflow to the reservoir. The tangent of its tangential line shows the flow and the ordinate of a specific period shows the total inflow in that period.

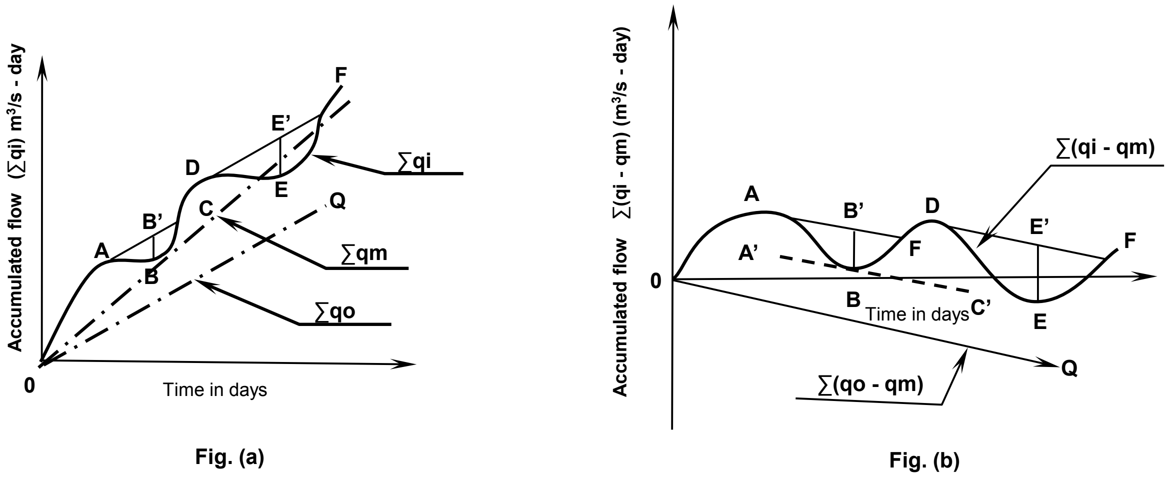


Figure 5-24 Concept of Mass Curve

The mass curve is expressed in two ways. In Figure 5-24 (b), the abscissa represents the day or month and the ordinate represents the accumulated flow obtained by adding the difference between the inflow volume and mean flow for one year or a fixed period. This curve is called the differential mass curve. While it is troublesome to make the curve, the accuracy of the flow obtained from the figure is high and it is, therefore, convenient to use it.

The mass curve of natural flow (Σqi) becomes OABCDEF and the mass curve of design discharge (Σq_0) becomes OQ in Figure 5-24 (a) where qi is the natural flow into the reservoir, q_m is mean flow in the study period and q_0 is design discharge. In Figure 5-24 (b), the mass curve of the difference between the natural flow and mean flow { Σ (qi $-$ q_m) } becomes OABCDEF, and the mass curve of the difference between the design discharge and mean flow { Σ ($q_0 - q_m$) } becomes OQ. When the straight line AC is drawn from the contact point A in parallel to OQ, and A' BC' is drawn in the same way, the ordinate of B and B’ where the perpendicular line of point B intersects line AC is the required capacity of the reservoir for the period. If EE' obtained in the same way is greater than BB’, EE' becomes the necessary storage for the period O to F.

In a project where the storage volume is predetermined, the ideal rule curve of reservoir operation can be set for each year having different runoff conditions. The storage condition can be obtained from the ordinate and plant discharge from the gradient of the operation line. As the unit of the ordinate of the mass curve, "m^3/s-day" is used. The storage capacity can be obtained in unit of m^3 by multiplying EE' by the seconds in a day, i.e. 1m^3/s-day =1 (m^3/sec) × 24 (hr) × 60 (min) × 60 (sec) = 86,400m^3.

(11) Calculation of firm discharge

Using the mass curve produced for one year, the concept of calculation of firm discharge is explained by referring to Figure 5-25.

A tangential line AB' is drawn from point B' corresponding to the effective storage capacity (Ve) and the firm discharge is calculated by the following equation;

$$Q_f = \frac{S_2 + V_e - S_1}{n \times 86400} + Q_{ave}$$

where,

S_1 : Accumulated flow at T_1 (m^3)
S_2 : Accumulated flow at T_2 (m^3)
Q_{ave} : Annual mean flow (m^3/sec)
Q_f : Firm discharge (m^3/s)
V_e : Effective storage capacity (m^3)
N : Number of days from full reservoir to empty condition

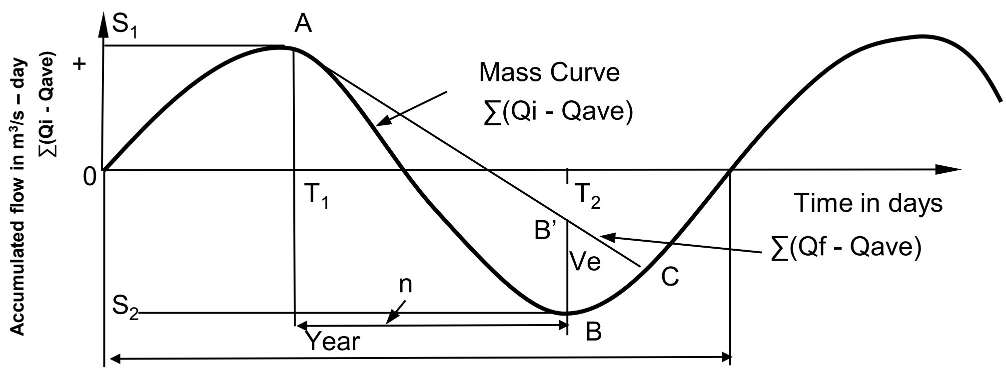


Figure 5-25 Firm Discharge by Mass Curve

(12) Setting of maximum plant discharge

Firm discharge is peaked into T hours required from the power system to determine the maximum plant discharge.

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

where,

Q_{max} : Maximum plant discharge (m^3/sec)
Q_f : Firm discharge (m^3/sec)
T : Peak duration hours (horr)

(13) Normal water level and tailwater level

The normal water level is defined as the water level which is at 1/3 of the available drawdown below the HWL. The riverbed elevation at the powerhouse or tailrace site is taken from a topographic map to set the tailwater level. In case tailrace channel is constructed, the tailwater level is set taking into consideration the tailrace channel gradient.

(14) Drawing of waterway profile

After the dam site, HWL and powerhouse site are determined, the waterway profile shown in Figure 5-26 is drawn to measure the length of the headrace and penstock. The procedure for a dam waterway type of development is shown below.

- The intake sill level (ELc) in Figure 5-21 is used as the intake elevation. The inner diameter of the headrace is checked with the maximum plant discharge obtained in (13) and Figure 5-22.
- The headrace route is laid to the vicinity of the powerhouse with a horizontal line.
- The surge tank site is set such that the ground surface level is HWL and penstock length is minimized. A surge tank is not required when the headrace length is less than 500m.
- The penstock is laid between the surge tank and powerhouse along the ridge.

When the headrace cannot be constructed due to topographic condition, an underground powerhouse may be selected and a tailrace tunnel is constructed.

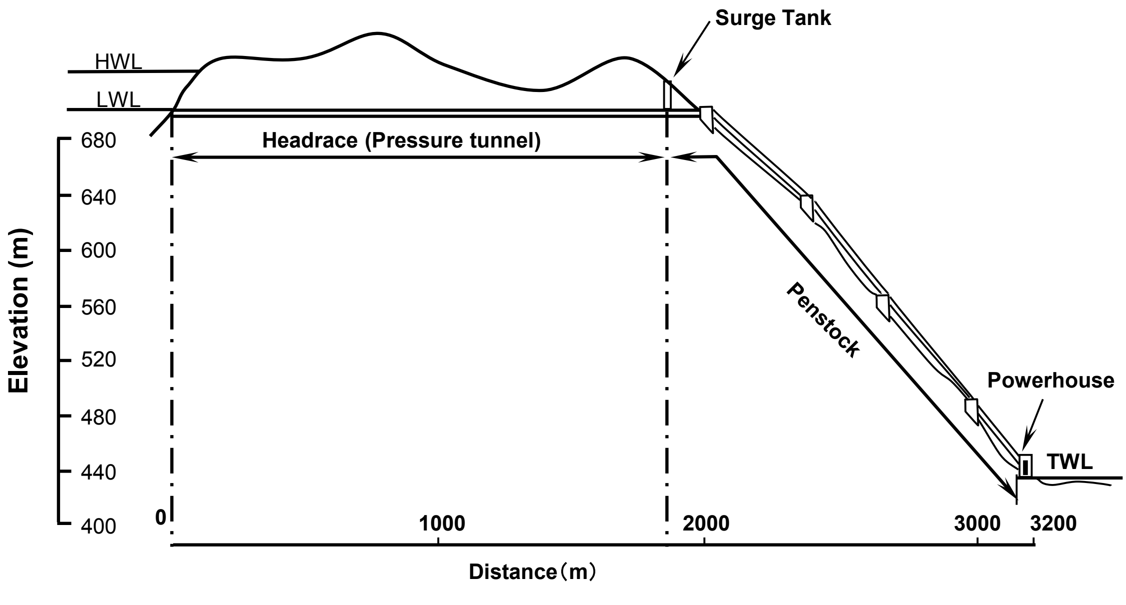


Figure 5-26 Profile of Waterway

(15) Calculation of head loss and effective head

The effective head is calculated on the basis of the following equation;

$Hg = MWL – TWL = HWL – h_a/3 – TWL$

$H\ell$ -= $a \times L_1 + b \times L_2 + c \times L_3 + \Delta h$

$He = Hg – H\ell$

where,

NWL	: Normal water level (m)
TWL	: Tailwater level (m)
h_a	: Available drawdown (m)
Hg	: Gross head (m)
$H\ell$	: Head loss (m)
He	: Effective head (m)
L_1	: Length of headrace (m)
L_2	: Length of penstock (m)
L_3	: Length of tailrace (m)
Δh	: Other head losses (m)
a, b and c	: Coefficients to obtain losses

a	Pressure headrace tunnel	1/700
b	Penstock	1/200
c	Pressure tailrace tunnel	1/700
	Non-pressure tailrace tunnel	1/1,000

(16) Selection of turbine type, combined efficiency of turbine and generator and number of unit

The turbine type is selected by using Figure 12-16 and 12-17, Chapter 12. Two or more units of turbine and generator may be used when the discharge fluctuation is large or when required by power system demand.

(17) Calculation of maximum output and firm peak output

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

$P_{fp} = 9.8 \times Q_{fp} \times H_{es} \times \eta_f$

where,

P	: Maximum output (kW)
P_{fp}	: Firm peak output (kW)
Q_{max}	: Maximum plant discharge (m^3/sec)
Q_{fp}	: Firm plant discharge (m^3/sec)
H_{es}	: Normal effective head (m)
η	: Combined efficiency of turbine and generator at maximum output
η_f	: Combined efficiency of turbine and generator at firm peak output

When the maximum plant discharge is set on the basis of (12), P and P_{fp} have the same value.

(18) Calculation of annual energy generation by mass curve

The plant discharge and water level of reservoir for each month are obtained from the mass curve and reservoir storage capacity curve. The effective head is obtained from the water level, and then the energy generation of each month is calculated. The concept of calculation by using the mass curve is explained below and an example of energy calculation is given in Appendix A-5-1.

1) The mass curve (B) is prepared by drawing a line parallel to the mass curve (A). To arrive at the effective storage (Ve) which is the vertical distance between A and B curves. The mass curve (A) in Figure 5-27 is the same as the mass curve shown in Figure 5-25.

   - The operation line (1) of firm discharge (See (11).) in relation to water storage period (dry season) , and operation line (2) of maximum plant discharge in relation to supply period are drawn on the mass curve from which the plant discharge of each month is calculated.
   - When the line (Qmax) drawn from B' intersects the mass curve (A), it shows that the reservoir is full and water is spilled.

2) The vertical distance between the operation line and the mass curve (B) shows the volume of water stored in the reservoir, and vertical distance between the operation line and the mass curve (A) shows the vacant volume. The water level corresponding to this storage volume is obtained from the storage capacity curve at the beginning of each month.

3) Table 5-3 shows the calculation sheet of energy generation.

   - The water level at the beginning of the month and that at the beginning of the next month are averaged to obtain the mean water level of the month. (See column (6)).
   - Using the tailwater level explained in (14) and the head loss in (16), effective head of the month is calculated from the mean water level of the reservoir (See Column (7)).
   - Variable head efficiency is obtained from Figure 5-28 to Figure 5-30 by using the ratio of effective head of the month to effective head of maximum output (See Column (8) (9)).
   - Being a reservoir type, the combined efficiency of the turbine and generator at the effective head (at maximum output) is obtained by the maximum plant discharge on the condition that peak power generation is performed.
   - The combined efficiency for the water level of each month is obtained by multiplying the variable head efficiency by the combined efficiency at the effective head (at maximum output) (See Column (10)).
   - The energy generation of each month is calculated by the following equation; (See Column (11)).

     $$E = 9.8 \times (\sum Q_i) \times H_{ei} \times \eta t_h \times 24$$

     where,

E : Energy generation (10^6 kWh)

$\sum Q_i$: Plant discharge in i month (m^3/sec-day) Column (2)

H_{ei} : Effective head in i month (m) Column (7)

η_{th} : (Combined efficiency at maximum output) × (Variable head efficiency) Column (10)

4) The energy generation is classified into primary energy and secondary energy which are dealt in the same way as in 5.3.3 (13).

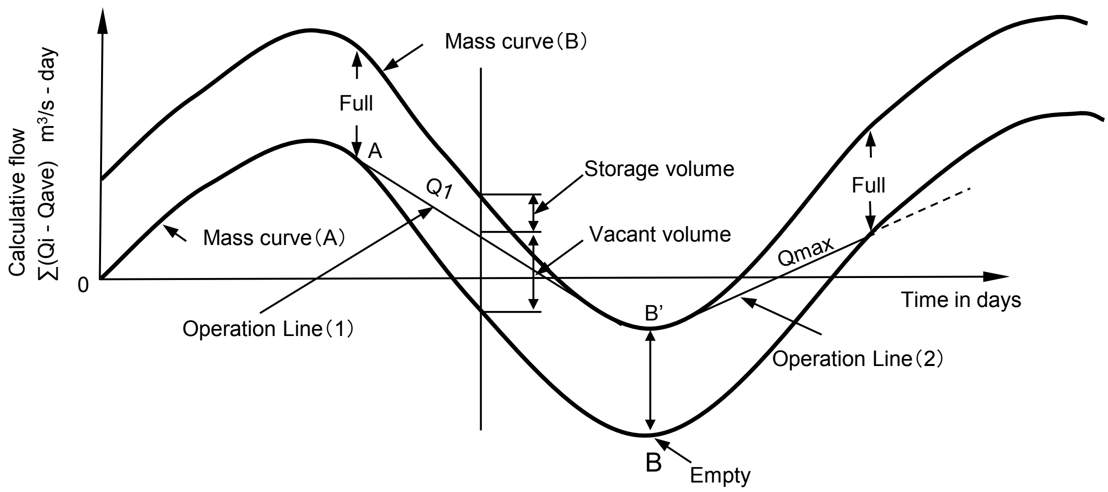


Figure 5-27 Reservoir Operation by Mass Curve

Table 5-3 Energy Calculation by Mass Curve

Month	Number of days	(1) Inflow (m^3/s-day)	(2) Plant discharge (m^3/s-day)	(3) Overflow (m^3/s-day)	(4) Storage (m^3/s-day)	(5) Water level (m)	(6) Averaege of (5) (m)	(7) Effective head (m)	(8) Head variation	(9) Variable head efficiency	(10) Combined efficiency	(11) Energy generation (10^6kWh)
(7)												
8												
9												
10												
11												
12												
1												
2												
3												
4												
5												
6												
7												
Total												

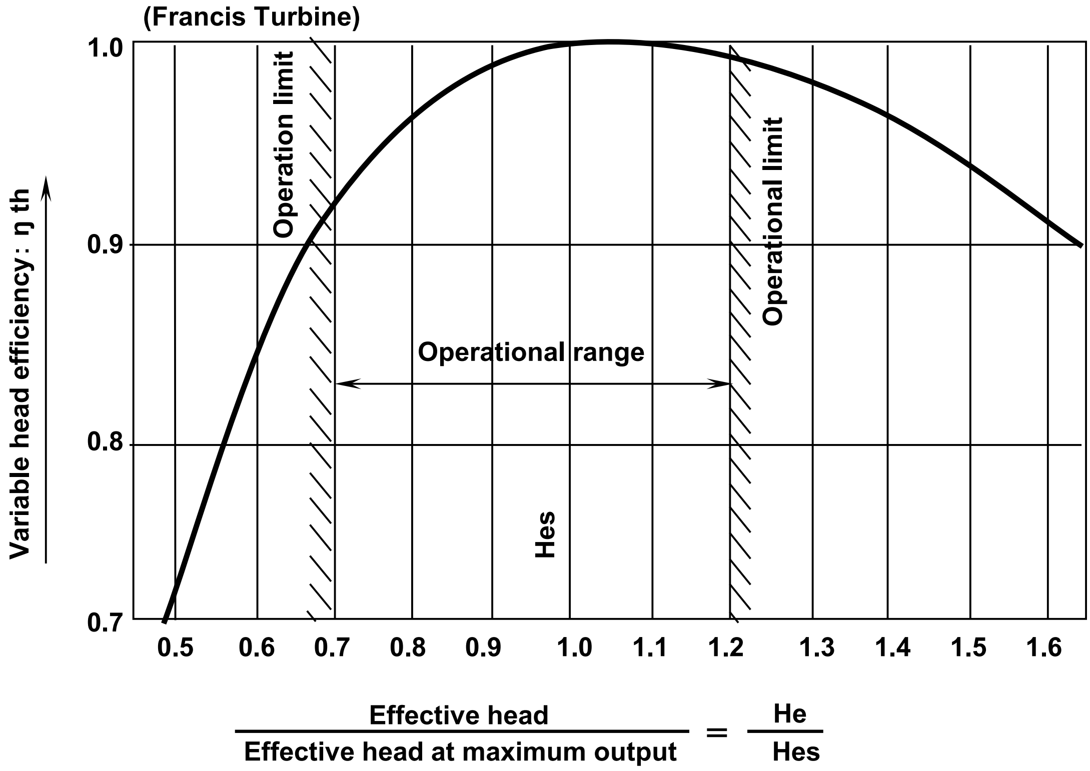


Figure 5-28 Variable Head Efficiency (Francis Turbine)

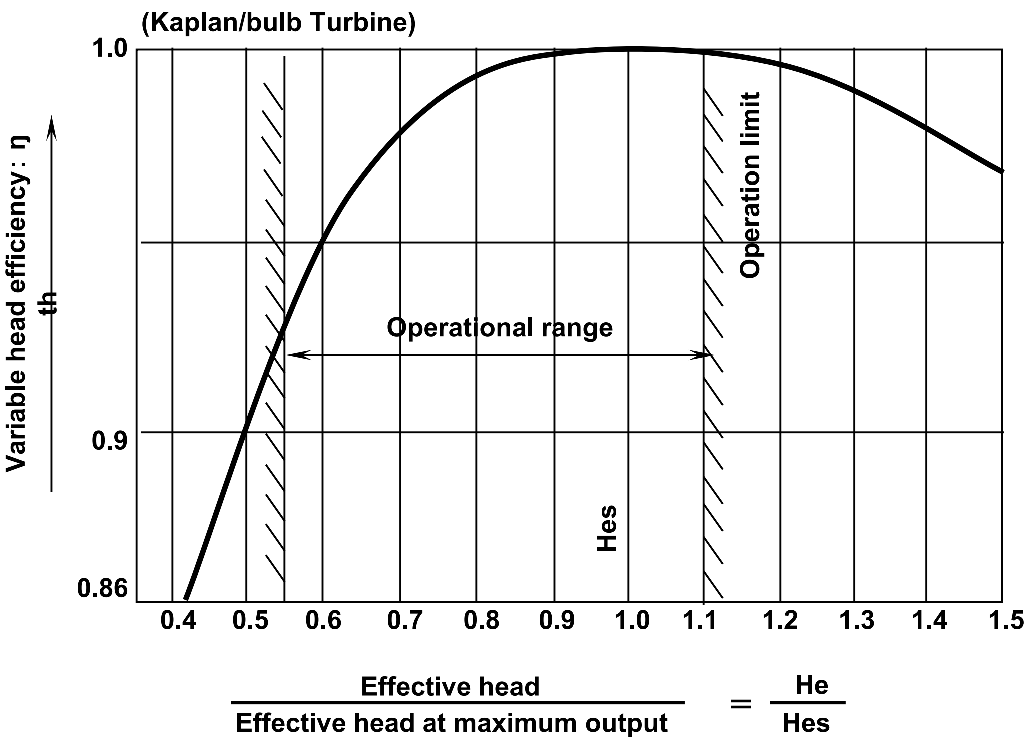


Figure 5-29 Variable Head Efficiency (Kaplan Turbine and Bulb Turbine)

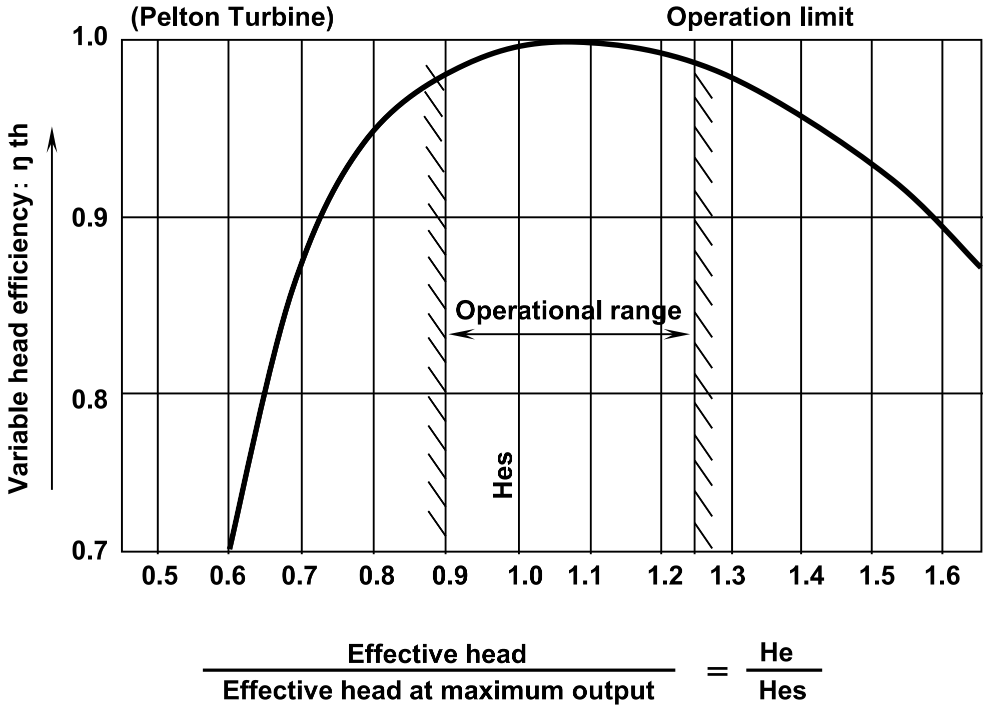


Figure 5-30 Variable Head Efficiency (Pelton Turbine)

(19) Storage capacity of re-regulating pond

Since reservoir type and regulating pondage type are operated to generate peaking power, released water from the power plant causes fluctuation of downstream river flow and water level. A re-regulating pond is constructed when water utilization facilities exist on the downstream and there operation is adversely influenced. The storage capacity of the re-regulating pond is obtained by the following equation to regulate daily peak flow.

$$V_e = (Q_{max} - Q_f) \times T \times 3{,}600$$

where,

V_e	: Storage capacity of re-regulating pond (m^3)
Q_{max}	: Maximum plant discharge (m^3/sec)
Q_f	: Firm discharge (m^3/sec)
T	: Peak duration hours (hour)

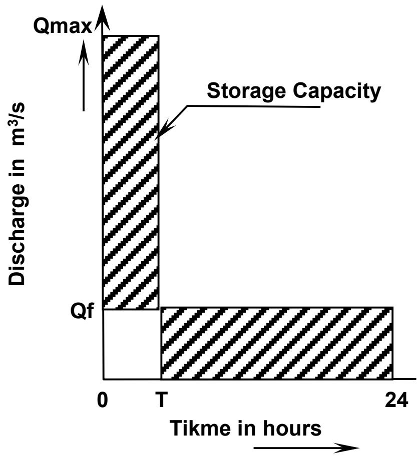


Figure 5-31 Capacity of Re-regulating Pond

(20) Preparation of comparative plans

From above study maximum output and energy generation are calculated, and the project features are determined for one scheme of development. Then the construction cost is estimated and economic evaluation is done as described in Chapter 6. Alternative plans changing the location of powerhouse site and the maximum plant discharge are to be compared for the promising site, and then the optimum development scale can be determined. However, detailed studies should be conducted in the feasibility study.

(21) Planning of hydropower in multi-purpose dam

Hydropower plant, in a multi-purpose dam for purposes of irrigation, other water uses, flood control etc. is studied as shown below.

1) To obtain the firm discharge from flow duration curve prepared according to water releases from reservoir operation for other purposes. (See 5.3.3 (5))

2) The maximum plant discharge is determined. When peak operation is impossible, see 5.3.3 (6). When peak operation is possible, see 5.3.4 (12).

3) Normal water level and tailwater level: See 5.3.4 (13).

4) Calculation of head loss and effective head: See 5.3.4 (15).

5) Selection of turbine type and combined efficiency of turbine and generator: See 5.3.4 (16).

6) Calculation of maximum output and firm output: See 5.3.4 (17)

7) Calculation of annual energy generation

The calculation procedure of output and energy generation of each month is shown in Table 5-4. In the case of hydropower in a multi-purpose dam, the efficiency of turbine varies significantly by flow and head fluctuation, and this should be taken into consideration.

Table 5-4 Energy Calculation Table

	Month		J	F	M	A	M	J	J	A	S	O	N	D	Total
(a)	Number of days	day													
(b)	Average monthly plant discharge	m^3/sec													
(c)	Water level at the beginning of the month	EL. m													
(d)	Monthly mean water level	EL. m													
(e)	Tailwater level	EL. m													
(f)	Gross head	m													
(g)	Head loss	m													
(h)	Effective head	m													
(i)	Turbine input	kW													
(j)	Standard combined efficiency	-													
(k)	Variable head efficiency	-													
(l)	Power output	kW													
(m)	Energy production	kWh													

(b) Monthly mean plant discharge is obtained from the water released from dam.

(c) The water level at the beginning of the month is obtained from the reservoir operation, and then monthly mean water level (d) is calculated.

(e) The tailwater level is set at the river bed elevation of the powerhouse site (or tailrace).

(f), (g), (h) Gross head, head loss and effective head at the beginning of the month are obtained.

(i) Turbine input is obtained by the following equation;

When peak operation is not possible : (i) = 9.8 × (b) × (h)
When peak operation is possible : (i) = 9.8 × (b) × 24/T × (h)
where, (b) × 24/T ≤ Qmax.

(j) Combined efficiency of the turbine and generator is obtained from Figure 5-16 in 5.3.3 in relation to (b)/Qmax. When peak power generation is possible, combined efficiency is obtained from the ratio of peak discharge (b) × 24/T to Qmax.

(k) Variable head efficiency is obtained from He/Hes. The variable head efficiency of Francis turbine, Kaplan turbine (bulb turbine) and Pelton turbine is shown respectively in Figure 5-28, Figure 5-29 and Figure 5-30.

(l), (m) Output and energy generation.

(l) = (i) × (j) × (k)

When peak operation is not possible : (m) ＝ (l) × (a) × 24

When peak operation is possible : (m) ＝ (l) × (a) × T

＝ 9.8 × (a) × (b) × (h) × (j) × (k) × 24

8) After the scheme of development is determined, the construction cost is estimated and economic analysis is made as described in Chapter 6.

5.3.5 Pondage Type

(1) Layout and sequence of study of pondage type

The power generation method which has a pond capable of regulating river flow for one or several days is called the pondage type. In this Manual, a pond with regulating capability factor (RCF) of less than 5% is defined as a regulating pond. Layout examples of the pondage type are shown in Figure 5-17. The sequence of study chart is shown in Figure 5-2.

(2) Calculation of flow at dam site and preparation of flow duration curve

Flow duration curve shown in Figure 5-32 is prepared on the basis of 5.3.2 (3).

(3) Calculation of firm discharge

Firm discharge is obtained from the flow duration curve as shown in Figure 5-32 corresponding to 347 day flow of a year is used as the firm discharge.

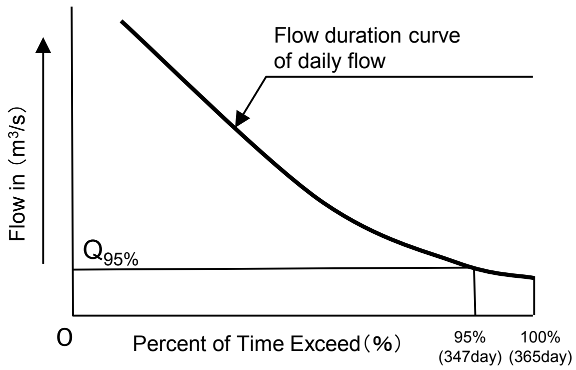


Figure 5-32 95% Flow by Flow Duration Curve

(4) Determination of maximum plant discharge

As shown in Figure 5-33, and the maximum plant discharge is obtained by the equation.

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

where,

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

Q_f : Firm discharge (m^3/sec)

T : Peak duration hours (hour)

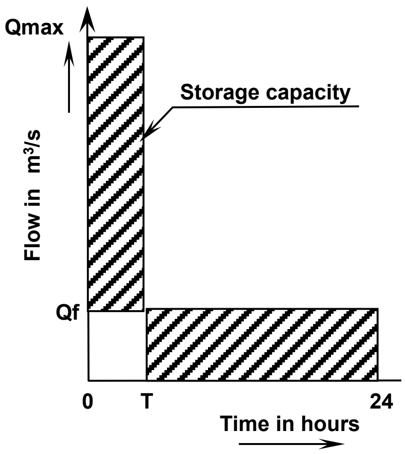


Figure 5-33 Maximum Plant Discharge and Pondage Capacity

(5) Determination of low water level

The low water level is set in relation to the tunnel diameter determined from the maximum plant discharge obtained above and the sedimentation level obtained in 5.3.4 (6).

(6) Determination of effective storage capacity and high water level

1) The effective storage capacity expressed by the following equation is determined as the pondage capacity necessary for daily flow regulation. (See Figure 5-33)

$$V_e = (Q_{max} - Q_f) \times T \times 3,600$$

where,

Ve : Effective storage capacity (m^3)
T : Peak duration hours (hour)

2) The water level which gives this effective storage capacity above the low water level is the high water level. The high water level may be raised to secure head when no sharp increase of construction cost is expected even if the high water level is raised.

(7) Normal water level and tailwater level

Refer to 5.3.4 (13).

(8) Preparation of waterway profile

Refer to 5.3.4 (14).

(9) Calculation of head loss and effective head

Refer to 5.3.4 (15).

(10) Selection of turbine type, combined efficiency of turbine and generator and number of unit

Refer to 5.3.4 (16).

(11) Calculation of maximum output and firm peak output

Refer to 5.3.4 (17).

(12) Calculation of annual energy generation

Daily energy generation is calculated by the following equation to arrive at the annual energy generation.

$$E = \sum(9.8 \times \eta \times q_1 \times H_e \times 24)$$

where,

E	: Annual energy generation (kWh)
q_1	: Daily plant discharge (m^3/sec)
H_e	: Effective head (m)
η	: Combined efficiency at maximum output

(13) Storage capacity of re-regulating pond

A re-regulating pond is constructed when the peak flow must be flattened before discharging water to the downstream of the power plant. Refer to 5.3.4 (19).

(14) Preparation of comparative plans

From the above study, maximum output and energy generation are calculated for one scheme and the project features are determined. By using the project features, construction cost is estimated and economic evaluation is done as described in Chapter 6. For promising sites, alternative plans changing the powerhouse site and maximum plant discharge to arrive at utilization factor of 30 to 70% are prepared. However, detailed studies should be conducted in the feasibility study.

5.4 Planning of Pumped Storage Type

The reconnaissance study for the pumped storage hydropower is shown below and an example pf the study is attached in Appendix A-5-1.

(1) Classification, layout and sequence of study of pumped storage type

Layout examples of pumped storage type are shown in Figure 5-34, and sequence of study is shown in Figure 5-3. Pumped storage power generation is classified into the "pure pumped storage type” and "pumped and natural flow storage type", depending on natural inflow into the upper pond. The former type does not utilize natural river flow into the upper pond for generation or does not have the natural flow, and electricity is generated by circulating water stored in the lower and upper ponds. The latter type uses pumped water as well as natural flow into the upper pond to generate electricity. Therefore, the latter type is a conventional reservoir type or pondage type with pumping facility added.

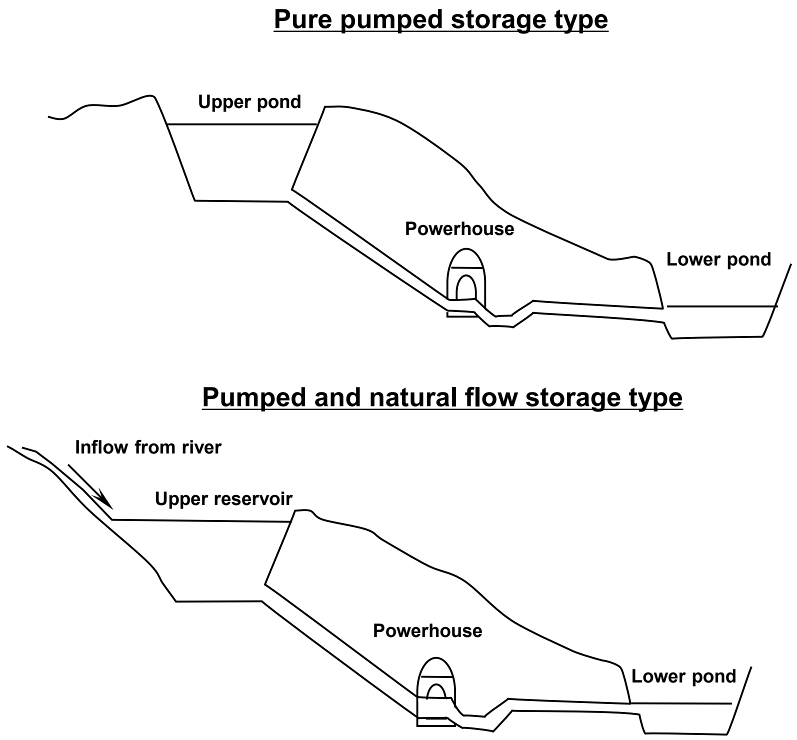


Figure 5-34 Types of Pumped Storage Power Generation

(2) Determination of installed capacity and peak duration hours

For a pumped storage type, maximum output can be set as desired without regard to river flow if the topographic features of the site are good, therefore, the project site can be selected after fixing the maximum output and peak duration hours. In the reconnaissance study, maximum output is set at 10% or less of the total capacity of power system and the peak duration hours is set at about 6 to 8 hours. If the system capacity is 10,000MW and 5,000MW, for example, the development scale of pumped storage is studied respectively at less than 1,000MW and 500MW. The number of 10% mentioned before is the example of Japan, the value might change depending on developing countries' power systems.

(3) Selection of project site

A pure pumped storage type can be constructed where the topographic features allow construction of upper and lower ponds and where desirable head is available. The degree of freedom for site selection is wide and a high head site can be easily found. The site selection condition of the pumped and natural flow storage type is almost the same as conventional hydroelectric site and does not have a high degree of freedom for site selection as in the case of pure pumped storage type.

Since energy for pumping in a pumped storage power plant is supplied from thermal power plant, etc., integrated operation with these electric power facilities is important in project planning.

From the aspect of economic efficiency, it is desirable that the pumped storage power plant is situated close to the load center as well being near to transmission lines with the capacity needed for sending and receiving power. Location near the load center saves construction cost of transmission line and decreases transmission line loss.

The pumped storage power plant site is selected on a topographic map by taking the above into consideration. Attention should be given to the following factors in the study of topographic features.

1) An indicator of L/H is used as reference index for site selection.

where,

L : Horizontal length of waterway from intake to tailrace (m)
H : Difference of riverbed elevation between both dam sites (m)

From experience, a promising site is where the L/H is 4 to 6 times or less and H is 400 m or over. These values may be used as a target in the study if local conditions enable to construct tunnel at low cost.

2) When an existing and proposed reservoir or pond for other sector can be used as the pond for the pumped storage power plant, a plan utilizing these storage dams should be studied.

3) Necessary storage capacity of the pond can be obtained with a small scale dam. Geologic conditions indicate that there is no likelihood of water leakage from the pond to exert adverse influence on power generation. There is a road nearby allowing easy access. Compensation and resettlement problems are minimal.

(4) Calculation of catchment area

Refer to 5.3.4 (3).

(5) Calculation of flow at the upper dam site

Refer to 5.3.4 (4) for the pumped and natural flow storage type. River flow flowing into the upper pond is calculated.

(6) Preparation of storage capacity curve

The storage capacity curve of the upper and lower ponds is prepared by referring to 5.3.4 (5).

(7) Temporary fixing of maximum plant discharge

The maximum plant discharge is obtained by the following equation;

$$Q_{max} = \frac{P_{max}}{9.8 \times H \times \eta}$$

where,

Q_{max} : Maximum plant discharge (m^3/sec)
P_{max} : Maximum output (kW)
H : Head (Difference in riverbed elevation between upper and lower dams)

η : Combined efficiency at maximum output

The value of 9.8×η＝8.5 should be used in the study.

(8) Determination of storage capacity of pond

The peak duration hour is set to obtain the effective storage capacity. Peak duration hours is set at about 6 to 8 hours.

$$V_e = Q_{max} \times T \times 3{,}600$$

where,

V_e : Effective storage capacity (m^3)

T : Peak duration hours (hour)

(9) Estimation of sediment volume and determination of sedimentation level

Refer to 5.3.4 (6).

(10) Determination of low water level (Upper and lower ponds)

Refer to 5.3.4 (7) to determine the low water level from the intake sill level and sedimentation level. The tunnel inner diameter is obtained by setting the flow velocity at about 6 m/sec. In the case of the pumped storage type, the optimum inner diameter of tunnel generally becomes smaller than that of conventional hydropower plant.

(11) Determination of high water level

Refer to 5.3.4 (8) to determine the high water level (HWL) of the upper and lower ponds from the low water level (LWL) determined in (10) and effective storage capacity obtained in (8) by using the storage capacity curve.

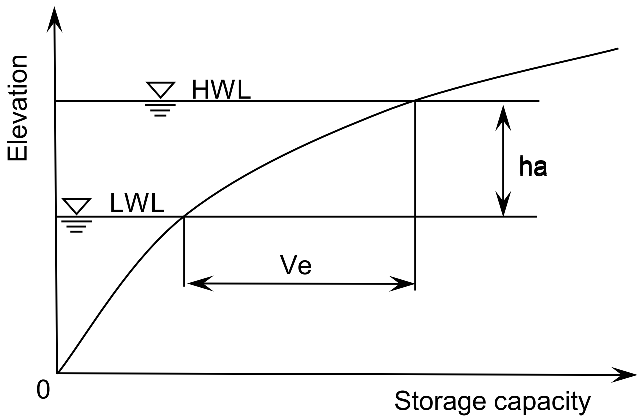


Figure 5-35 Setting of High Water Level

(12) Determination of normal water level and tailwater level

The normal water level and tailwater level are each mean water level corresponding to pond operation of the upper pond and lower pond.

(13) Preparation of waterway profile

1) Setting the elevation of turbine center

The turbine center is set at the elevation corresponding to the draft head below the low water level of the lower pond. The relation between the maximum pumping head and draft head is shown in Figure 5-36.

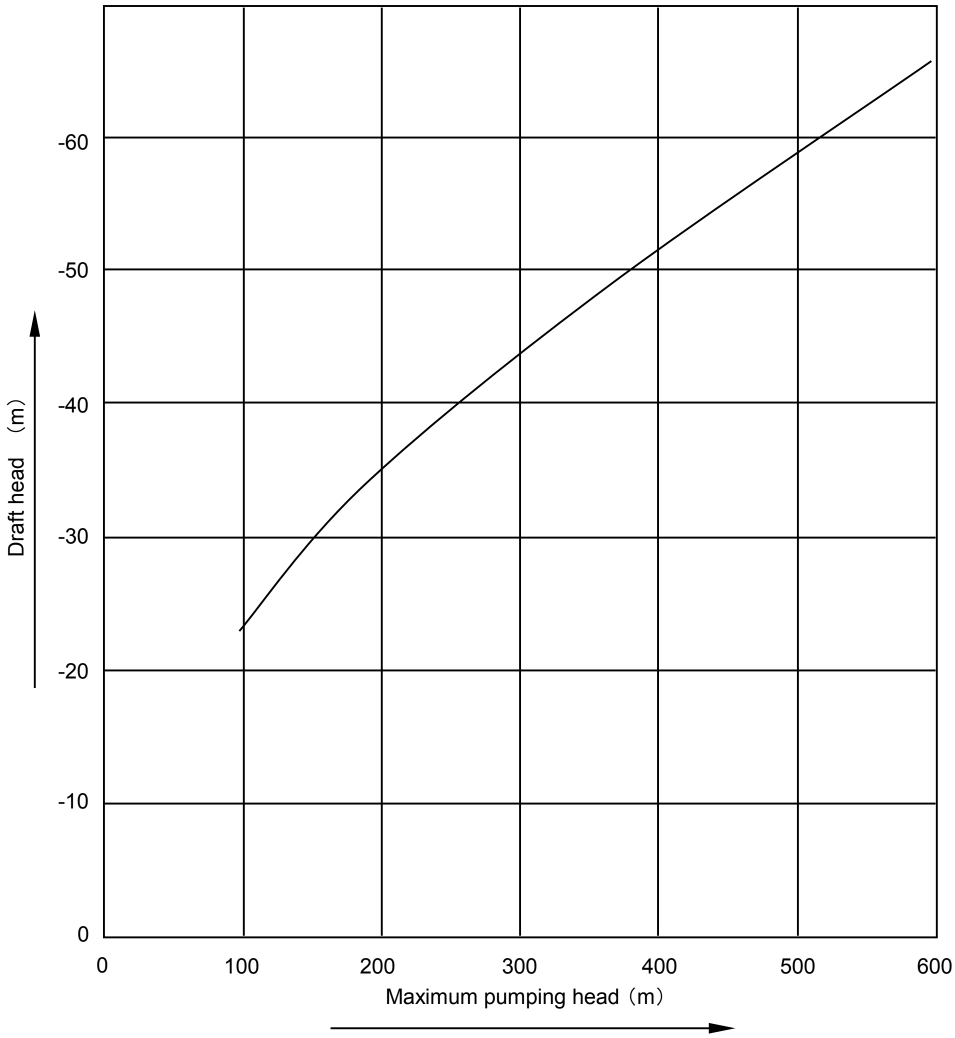


Figure 5-36 Draft Head

2) Dam specification and turbine center

Dam specifications (HWL and LWL) and the elevation of turbine center of the power plant are determined and the waterway profile shown in Figure 5-37 is then prepared.

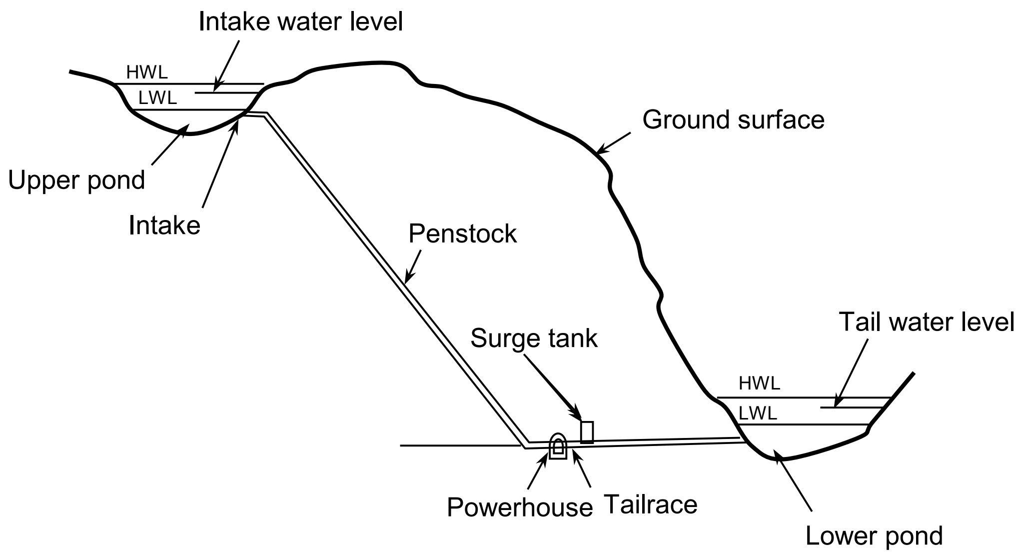


Figure 5-37 Waterway Profile

(14) Calculation of head loss and effective head

Refer to 5.3.4 (16). Coefficients a, b and c to obtain head loss are shown below.

a= 1/300, b = 1/ 100, c = 1/300

(15) Re-calculation of maximum plant discharge

The normal effective head (Hes) is determined in (14) and the maximum plant discharge is then determined from the following equation;

$$Q_{max} = \frac{P_{max}}{8.5 \times Hes}$$

(16) Calculation of annual energy generation

The energy generation is obtained by the following equation.

$$E = P \times T$$

where,

E	: Annual energy generation (kWh)
T	: Annual generating hours (hour)

When there is natural inflow into the upper pond and this natural water can be used for power generation, the electric energy (E') is calculated by the following equation;

$$E' = 9.8 \times \eta \times \sum Qi \times Hes \times 24/3600$$

where,

$\sum Qi$	: Annual inflow available for power generation (m^3)

(17) Calculation of annual pumping energy by pumped storage

$$Ep = (E - E')/\alpha$$

where

α : Gross efficiency of pumped storage power plant (around 0.7, which is the ratio of the generated energy to pumping-up energy of pumped storage power plant)

(18) Determination of project features

The above study determines the project features including output and other factors. The construction cost is then estimated by the method described in Chapter 6 and an economic evaluation is conducted.

Reference of Chapter 5

[1] Guide Manual for Hydropower Development, New Energy Foundation, 1996

Chapter 6

Preliminary Estimate of Construction Cost and Project Optimization

Chapter 6 Preliminary Estimate of Construction Cost and Project Optimization

6.1 Construction Cost Estimate

The condition of construction cost estimate for the reconnaissance study is shown below and an example of the study is attached in Appendix A-5-1.

(1) Construction cost of reconnaissance study is calculated using Tables 6-1 to 6-3 without distinguishing local and foreign currencies.

(2) Access roads cost of the preparatory works is calculated based on quantity of work and unit cost, while the cost of the office and camp facilities is the amount of 5% of the total cost of civil works for run-of-river type and 2% for pondage type, reservoir type and pumped storage type. Since the run-of-river type is a relatively small scale hydropower project, compensation and resettlement costs are ignored.

(3) Environmental mitigation cost is l% of the total cost of the civil works for the run-of-river type, and 3% for the pondage type, reservoir type and pumped-storage type.

(4) The cost of civil works and hydraulic equipment are calculated by multiplying the quantity of main work items by unit cost (See Table 6-4 through Table 6-6). The work quantity is obtained from tables, diagrams and numerical formula.

1) In this Manual, the main work items of civil structures are excavation, concrete, embankment, and reinforcement bars, and those of hydraulic equipment are gate, screen, and steel pipe.

2) The costs of other work items, other than the main items, are calculated as "Others" in a lump-sum at a certain ratio against the total cost of the main work items.

3) Unit costs are used by referring to the latest data of similar works in the relevant country.

4) In case it is difficult to collect such data in the relevant country, it is recommendable to collect data on prices on the international market for hydraulic equipment from specialists, consultants, and/or manufacturers.

(5) The construction cost of electro-mechanical equipment such as turbines, generators, control devices and main transformers, etc. are estimated in a lump-sum in "Electro-mechanical equipment". Follow the same procedures as unit prices explained above when it is difficult to obtain data of the electro-mechanical equipment. There is a relationship that is almost as a straight line on logarithmic paper between electro-mechanical equipment cost according to each turbine type and $P/He^{1/2}$ (P: maximum output in kW, He: effective head in meters), as shown in the example in Figure 6-1. Therefore, actual cases of recent projects should be used as reference by plotting the data on logarithmic paper.

(6) In this Manual, the construction cost of transmission lines is treated in the following manner. Transmission line cost is only calculated in case the project appears promising, and is not calculated in other cases or in hydropower potential survey. Transmission line cost is calculated

by multiplying the length by the unit price per km which is determined by the line capacity and number of circuits. Follow the same procedures in (4) in case it is difficult to obtain unit price data.

(7) The following are included in the costs of “administration”, “engineering service”, “contingencies”, which are calculated by multiplying the direct construction cost by an appropriate ratio.

1) The administration cost includes personnel expense and expenses to maintain the construction office. The engineering service cost includes expenses related to technical services such as design work and construction supervision of consultants. In this Manual, 15% of the direct construction cost is assumed to be as the cost of administration and engineering service.

2) The contingency includes physical contingency which is the increase of quantities of work, and 10% of the direct construction cost is assumed for the contingencies.

(8) Interest during construction is calculated based on the following conditions.

Interest rate (i) is calculated taking into account the ratio of local currency and foreign currency. For example, if the local and foreign currency portions are 40% and 60% respectively, the calculation is as follow.

$i = i_1 \times 0.4 + i_2 \times 0.6$

i_1 : Interest rate for local currency

i_2 : Interest rate for foreign currency

Interest during construction = (cost of preparatory works + cost of environmental mitigation + cost of civil works + cost of hydraulic equipment + cost of electro mechanical equipment + cost of administration and engineering service + contingency)×0.4×i×T

where,

T : Construction period (years)

The value of 0.4 is a cash flow coefficient which is an empirical value of existing projects

(9) Preliminary construction cost is calculated according to the following tables.

Run-of-river type: Table 6-1 and Table 6-4 (1) (2)

Pondage and Reservoir types: Table 6-2 and Table 6-5 (1) (2)

Pumped storage type: Table 6-3 and Table 6-6 (1) (2)

Table 6-1 Construction Cost Summary (Run-of-River Type)

Item	Cost	Note
1. Preparation work (1) Access Road (2) Camp & Facilities		(3 Civil work)×0.05
2. Environmental mitigation cost		(3 Civil work)×0.01
3. Civil works (1) Intake weir (2) Intake (3) Settling basin (4) Headrace (5) Head tank (6) Penstock and spillway channel (7) Powerhouse (8) Tailrace channel (9) Tailrace (10) Miscellaneous		((1)～(9))×0.05
4. Hydraulic equipment (1) Gate and screen (2) Penstock		
5. Electro-mechanical equipment		Turbine and Generator,Transformer,etc
6. Transmission line		
Direct cost		1+2+3+4+5+6
7. Administration and engineering service		Direct cost×0.15
8. Contingency		Direct cost×0.1
9. Interest during construction		(1+2+3+4+5+6+7+8)×0.4×i×T
Total cost		1+2+3+4+5+6+7+8+9

Table 6-2 Construction Cost Summary (Pondage and Reservoir Types)

Item	Cost	Note
1. Preparation and Land acquisition (1) Access road (2) Compensation & Resettlement (3) Camp & Facilities		 (3 Civil work)×0.02
2. Environmental mitigation cost		(3 Civil work)×0.03
3. Civil work (1) Care of river (2) Dam (3) Spillway (4) Intake (5) Headrace (6) Surge tank (7) Penstock (8) Powerhouse (9) Trailrace channel (10) Tailrace (11) Miscellaneous		 ((1)～(10))×0.05
4. Hydraulic equipment (1) Gate and screen (2) Penstock		
5. Electro-mechanical equipment		Turbine and Generator,Transformer,etc
6. Transmission line		
Direct cost		1+2+3+4+5+6
7. Administration and Engineering service		(Direct cost)×0.15
8. Contingency 8'. Cost allocation of dam		(Direct cost)×0.1 Multipurpose development
9. Interest during construction		(1+2+3+4+5+6+7+8+8')×0.4×i×T
Total cost		1+2+3+4+5+6+7+8+8'+9

Table 6-3 Construction Cost Summary (Pumped Storage Type)

Item	Cost	Note
1. Preparation and Land acquisition (1) Access road (2) Compensation & Resettlement (3) Camp & Facilites		 (2 Civil work)×0.02
2. Environmental mitigation cost		(3 Civil work)×0.03
3. Civil work (1) Upper dam (2) Lower dam (3) Intake (4) Headrace (5) Headrace surge tank (6) Penstock (7) Trailrace surge tank (8) Tailrace channel (9) Powerhouse (10) Trailrace (11) Access road to powerhouse (12) Miscellaneous		 ((1)～(11))×0.05
4. Hydraulic equipment (1) Gate and screen (2) Penstock		
5. Electro-mechanical equipment		Turbine and Generator,Transformer,etc
6. Transmission line		
Direct cost		1+2+3+4+5+6
7. Administration and Engineering service		(Direct cost)×0.15
8. Contingency 8'. Cost allocation of dam		(Direct cost)×0.1 Multipurpose development
9. Interest during construction		(1+2+3+4+5+6+7+8+8')×0.4×i×T
Total cost		1+2+3+4+5+6+7+8+8'+9

Table 6-4 (1) Civil Engineering Work Cost (Run-of-River Type)

Item	Unit	Unit Cost		Quantity		Cost		Calculation method of construction cost
1. Weir								(1) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③)×0.3
2. Intake								(2) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③)×0.25
3. Settlement Basin								(3) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③)×0.2
4. Headrace		tunnel	canal	tunnel	canal	tunnel	canal	(4) =①+②+③
① Excavation	m³							①
② Concrete	m³							②
③ Others	L. S.							③=(①+②)×0.15～0.30
5. Head Tank								(5) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③+④)×0.40
6. Penstock and Spillway								(6) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③)×0.2
7. Powerhouse								(7) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③)×0.5
8. Tailrace channel		tunnel	canal	tunnel	canal	tunnel	canal	(8) =①+②+③
① Excavation	m³							①
② Concrete	m³							②
③ Others	L. S.							③=(①+②)×0.15～0.30
9. Tailrace outlet								(9) =①+②+③+④
① Excavation	m³							①
② Concrete	m³							②
③ Reinforcement bar	ton							③
④ Others	L. S.							④=(①+②+③)×0.25
10. Miscellaneous	L. S.							(10) ={Σ(1～9)}×0.05
Subtotal								

Table 6-4 (2) Hydraulic Equipment Cost (Run-of-River Type)

Item	Unit	Unit Cost	Quantity	Cost
1. Intake weir				
Sand flush gate	ton			
2. Intake				
Gate	ton			
Screen	ton			
3. Settling basin				
Gate	ton			
Screen	ton			
4. Penstock and spillway conduit	ton			
5. Tailrace gate	ton			
6. Others	L. S.			(1+2+3+4+5) ×0.2
Subtotal				

Table 6-5 (1) Civil Engineering Work Cost (Pondage and ReservoirTypes)

Item	Unit	Unit Cost	Quantity	Cost	Calculation method of construction cost
1. Rockfill Dam					(1)＝(1.1)＋(1.2)＋(1.3)
1.1 Care of River	L. S.				(1.1)＝(1.2)×0.25
1.2 Dam					(1.2)＝①＋②＋③
① Excavation	m³				①
② Embankment	m³				②
③ Others	L. S.				③＝(①＋②)×0.2
1.3 Spillway					(1.3)＝④＋⑤＋⑥＋⑦
④ Excavation	m³				④
⑤ Concrete	m³				⑤
⑥ Reinforcement bar	ton				⑥
⑦ Others	L. S.				⑦＝(④＋⑤＋⑥)×0.1
2. Concrete Gravity Dam					(2)＝(2.1)＋(2.2)
2.1 Care of River	L. S.				(2.1)＝(2.2)×0.02
2.2 Concrete Dam	m³				(2.2)＝①＋②＋③
① Excavation	m³				①
② Concrete	m³				②
③ Others	L. S.				③＝(①＋②)×0.2
3. Intake					(3)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.25
4. Headrace					(4)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.15
5. Surge Tank					(5)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.55
6. Penstock					(6)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.2
7. Powerhouse					(7)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.5
8. Tailrace channel		tunnel / canal	tunnel / canal	tunnel / canal	(8)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.15～0.30
9. Tailrace outlet					(9)＝①＋②＋③＋④
① Excavation	m³				①
② Concrete	m³				②
③ Reinforcement bar	ton				③
④ Others	L. S.				④＝(①＋②＋③)×0.25
10. Miscellaneous	L. S.				(10)＝Σ{1～9}×0.05
Subtotal					

Table 6-5 (2) Hydraulic Equipment Cost (Pondage and Reservoir Types)

Item	Unit	Unit Cost	Quantity	Cost
1. Dam and spillway				
Gate	ton			
2. Intake				
Gate	ton			
Screen	ton			
3. Penstock (steel pipe)	ton			
4. Tailrace gate	ton			
5. Others	L. S.			(1+2+3+4) ×0.2
Subtotal				

Table 6-6 (1) Civil Engineering Work Cost (Pumped Storage Type)

Item	Unit	Unit Cost	Quantity	Cost	Calculation method of construction cost
(1) Upper dam					
(1).1 Rockfill dam					(1).1=(1).1.1+(1).1.2+(1).1.3
(1).1.1 Care of river	L. S.				(1).1.1=(1).1.2×0.25
(1).1.2 Dam					(1).1.2=①+②+③
①Excavation	m^3				①
②Embankment	m^3				②
③Others	L. S.				③=(①+②)×0.2
(1).1.3 Spillway					(1).1.3=④+⑤+⑥+⑦
④Excavation	m^3				④
⑤Concrete	m^3				⑤
⑥Reinforcement bar	ton				⑥
⑦Others	L. S.				⑦=(④+⑤+⑥)×0.1
(1).2 Concrete dam					(1).2=(1).2.1+(1).2.2
(1).2.1 Care of river	L. S.				(1).2.1=(1).2.2×0.02
(1).2.2 Concrete dam	m^3				(1).2.2=①+②+③
①Excavation	m^3				①
②Concrete	m^3				②
③Others	L. S.				③=(①+②)×0.2
(2) Lower dam					
(2).1 Rockfill dam					(2).1=(2).1.1+(2).1.2+(2).1.3
(2).1.1 Care of river	L. S.				(2).1.1=(2).1.2×0.25
(2).1.2 Dam					(2).1.2=①+②+③
①Excavation	m^3				①
②Embankment	m^3				②
③Others	L. S.				③=(①+②)×0.2
(2).1.3 Spillway					(2).1.2=④+⑤+⑥+⑦
④Excavation	m^3				④
⑤Concrete	m^3				⑤
⑥Reinforcement bar	ton				⑥
⑦Others	L. S.				⑦=(④+⑤+⑥)×0.1
(2).2 Concrete dam					(2).2=(2).2.1+(2).2.2
(2).2.1 Care of river	L. S.				(2).2.1=(2).2.2×0.02
(2).2.2 Concrete dam					(2).2.2=①+②+③
①Excavation	m^3				①
②Concrete	m^3				②
③Others	L. S.				③=(①+②)×0.2
(3) Intake					(5) =①+②+③+④
①Excavation	m^3				①
②Concrete	m^3				②
③Reinforcement bar	ton				③
④Others	L. S.				④=(①+②+③)×0.25
(4) Headrace					(6) =①+②+③+④
①Excavation	m^3				①
②Concrete	m^3				②
③Reinforcement bar	ton				③
④Others	L. S.				④=(①+②+③)×0.15

(5) Surge tank (Headrace)								(5)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							②
③Reinforcement bar	ton							③
④Others	L. S.							④＝(①＋②＋③)×0.55
(6) Penstock								(6)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							②
③Reinforcement bar	ton							③
④Others	L. S.							④＝(①＋②＋③)×0.2
(7) Powerhouse								(7)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							②
③Reinforcement bar	ton							③
④Others	L. S.							④＝(①＋②＋③)×0.5
(8) Tailrace channel		tunnel	canal	tunnel	canal	tunnel	canal	(8)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							②
③Reinforcement bar	ton							③
④Others	L. S.							④＝(①＋②＋③)×0.15～0.30
(9) Surge tank (Tailrace)								(9)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							②
③Reinforcement bar	ton							③
④Others	L. S.							④＝(①＋②＋③)×0.2
(10) Tailrace outlet								(10)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							②
③Reinforcement bar	ton							③
④Others	L. S.							④＝(①＋②＋③)×0.25
(11) Access road to powerhouse								(11)＝①＋②＋③＋④
①Excavation	m^3							①
②Concrete	m^3							③
③Reinforcement bar	ton							②
④Others	L. S.							④＝(①＋②＋③)×0.15
(12) Miscellaneous	L. S.							(12)＝Σ{(1～13)}×0.05
Subtotal								

Table 6-6 (2) Hydraulic Equipment Cost (Pumped Storage Type)

Item	Unit	Unit Cost	Quantity	Cost
1. Dam and spillway				
Gate	ton			
2. Intake				
Gate	ton			
Screen	ton			
3. Penstock (steel pipe)	ton			
4. Tailrace outlet				
Gate	ton			
Screen	ton			
5. Others	L. S.			(1+2+3+4) ×0.2
Subtotal				

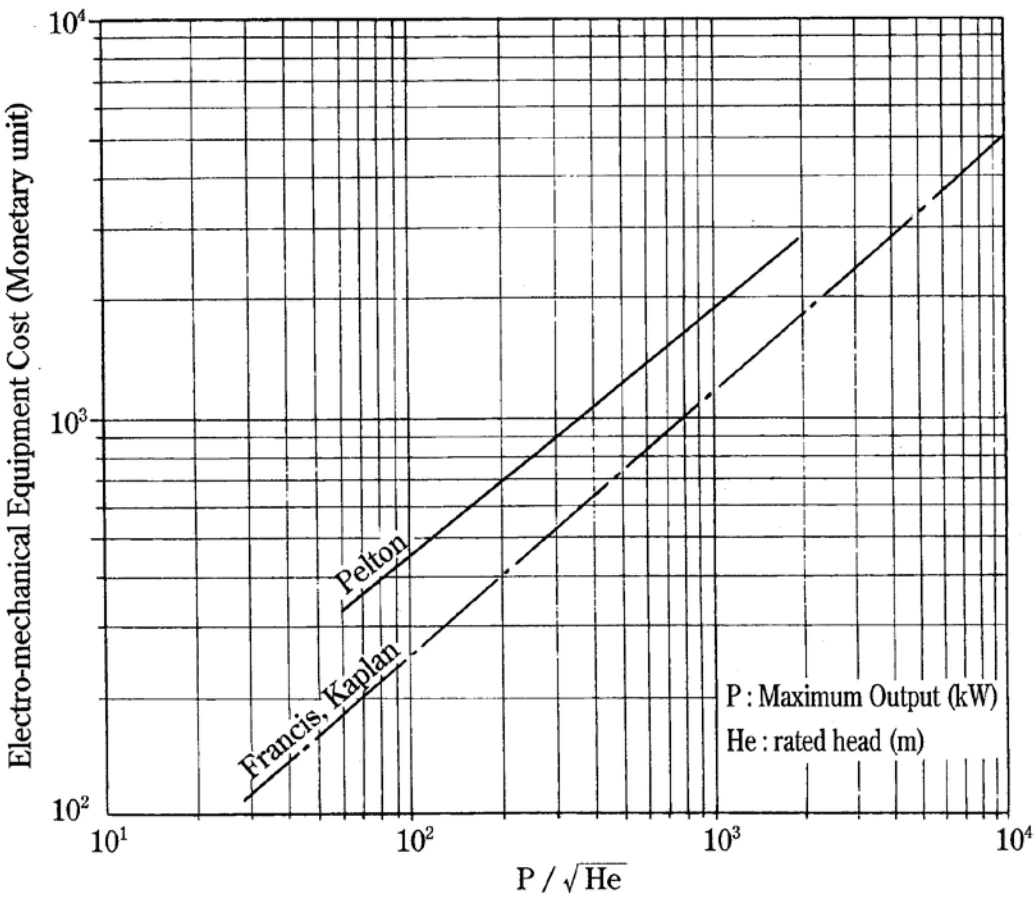


Figure 6-1 Example of Electro-mechanical Equipment Cost

6.2 Calculation of Quantity of Work

6.2.1 Calculation Method

As 1:50,000 scale topographical maps do not provide the accuracy required to enable the design and cost estimate of structures, the quantities of civil works and hydraulic equipment, are, calculated by formulae based on the quantities of existing facilities. The formulae used were developed in Japan for the purpose of the hydropower potential study. When adequate data regarding quantity of work are available in the relevant country, these data are used to revise the above formulae and may be used for practical application.

These formulas are prepared for each facility such as intake weir, intake, and headrace etc. The quantities of work are calculated for main work items such as excavation, concrete, embankment, reinforcement bars, gates, screens, and steel conduits.

Following symbols and units are used in the calculation.

Ve	: Excavation volume (m^3)
Vc	: Concrete volume (m^3)
Vf	: Dam embankment volume (for fill dam) (m^3)
Wr	: Weight of reinforcement bars (ton)
Wg	: Weight of gate (ton)
Wp	: Weight of steel conduit (ton)
Ws	: Weight of screen (ton)

Quantities of work items other than main work items are not calculated. However, their cost are calculated as "others" in a lump-sum at a certain ratio against the total cost of main work items

Quantities of work of headrace tunnels and penstock are calculated based on their inner diameters. The inner diameter adopted in this Manual indicates the economic cross section based on the prices of commodities in Japan. Although there may be differences due to the price levels in the relevant developing countries, such differences are neglected in this Manual.

6.2.2 Quantities of Construction Work for Run-of-River Type Power Plant

Quantities of construction work are calculated according to Table 6-4 (1) and (2).

(1) Intake weir

The height of weir is assumed at 10m, and its crest length is obtained from the contour lines of topographic maps. The excavation volume, concrete volume, weight of reinforcement bars, and weight of gates are calculated by the following equations.

$$Ve = 8.69 \times (Hd \times L)^{1.14}$$
$$Vc = 16.1 \times (Hd^2 \times L)^{0.695}$$
$$Wr = 0.0274 \times Vc^{0.830}$$
$$Wg = 0.145 \times Qf^{0.692}$$

where,

Hd	: Weir height (m)
L	: Crest length of weir (m)
Qf	: Design flood discharge (m^3/sec)

Design flood discharge is calculated by Creager equation as follows.

$$Qf = q \times A$$

$$q = 46CA^{(0.894A^{-0.048}-1)}$$

where,

Qf	: Design flood discharge ($feet^3$/sec)
q	: Maximum specific discharge ($feet^3/sec/mile^2$)
C	: Region coefficient
A	: Catchment area ($mile^2$)

The following simplified equation referring to Creager equation is applied in Japan.

$$Qf = q \times A$$

$$q = a \times A^{\left(A^{-0.05}-1\right)}$$

where,

Qf	: Design flood discharge (m^3/sec)
q	: Specific discharge ($m^3/sec/km^2$)
a	: Region coefficient
A	: Catchment area (km^2)

Region	Region H	Region T	Region Ka	Region Ki	Region S
Region Coefficient (a)	17	34	48	41	84
Annual Rainfall (mm)	1,080	1,360	1,710	1,440	2,280

Note: Values of annual rainfall are obtained from Chronological Tables of Science in Japan.

Cost of other items of civil works such as grouting and coffering except the main items stated above is estimated as "Others" at 30% of the costs of the main items.

(2) Intake

Non-pressure type is adopted. And the inner diameter of the waterway is obtained from Figure 6-2 based on the maximum plant discharge. The excavation volume, concrete volume, weight of reinforcement bars, weight of gates, and weight of intake screen are obtained by the following equations.

$$Ve = 171 \times (R \times Q)^{0.666}$$
$$Vc = 147 \times (R \times Q)^{0.470}$$
$$Wr = 0.0145 \times Vc^{1.15}$$

$$Wg = 1.27\times(R\times Q)^{0.533}$$
$$Ws = 0.701\times(R\times Q)^{0.582}$$

where,

D	: Inner diameter of waterway (m)
R	: Radius of waterway (=D/2, unit: m)
Q	: Maximum plant discharge (m^3/sec)

In this Manual the waterway gradient is 1:1,000 and the inner diameter of the headrace is the value obtained in (4), for tunnel. Even when an open channel (canal) is adopted in (4), calculation is made using the inner diameter of tunnel.

Cost of other items of civil works such as coffering and trash rack, rake except the main items stated above is estimated at 25% of the cost based on the main items.

(3) Settling basin

The excavation volume, concrete volume, weight of reinforcement bars, weight of gates, and weight of screen are obtained by following equations.

$$Ve = 515\times Q^{1.07}$$
$$Vc = 169\times Q^{0.936}$$
$$Wr = 0.120\times Vc^{0.847}$$
$$Wg = 0.910\times Q^{0.613}$$
$$Ws = 0.879\times Q^{0.785}$$

where,

Q	: Maximum plant discharge (m^3/sec)

Cost of other items of civil works such as slope protection, etc. not included in the main items stated above is estimated at 20% of the cost of the main items.

(4) Headrace

1) In the case of tunnel

Concrete lined non-pressure tunnel of horseshoe shape is adopted.

The excavation volume, concrete volume, and weight of reinforcement bars are calculated by the following equations.

$$Ve = (0.893\times D^2+1.07\times D+0.321)\times L$$
$$Vc = (1.07\times D+0.321)\times L$$
$$Wr = (0.00911\times D+0.00273)\times L$$

where,

L	: Total length of tunnel (m)
D	: Inner diameter of tunnel (m), obtained from Figure 6-2

2) In the case of open channel

The excavation volume, concrete volume, and weight of reinforcement bars are calculated by the following equations.

$$\sqrt{BH} = 1.09 \times Q^{0.379}$$

$$Ve = 6.22 \times \left(\sqrt{BH}\right)^{1.04} \times L$$

$$Vc = H \times t \times 2 + (B + 2t) \times t$$

$$Wf = 0.577 \times (Vc/L)^{0.888} \times L$$

where,

Q : Maximum plant discharge (m^3/sec)
L : Total length of open channel (m)
B : Width of open channel (m)
H : Height of open channel (m)
t : Concrete thickness (m)

3) Others

In the case of a tunnel, cost of other items of civil works such as grouting and excavation of adit, which are not included in the main items stated above, is estimated at 15% of the cost of the main items. In the case of an open channel, it is estimated at 30% of the cost of main items for items such as slope protection and fencing.

(5) Head tank

The excavation volume, concrete volume, and weight of reinforcement bars are obtained by the following equations.

$$Ve = 808 \times Q^{0.697}$$

$$Vc = 197 \times Q^{0.716}$$

$$Wr = 0.051 \times Vc$$

where,

Q : Maximum plant discharge (m^3/sec)

Cost of other items of civil works not included in the main items stated above is estimated at 40% of the cost of the main items. This 40% includes the cost of gate, screen, etc.

(6) Penstock and spillway channel

1) Penstock

The exposed type is adopted and a spillway channel is built. The average inner diameter is obtained from Figure 6-3.using the maximum plant discharge. The excavation volume, concrete volume, and weight of reinforcement bars for penstock are calculated by the following equations.

$$Ve_1 = 10.9 \times D_m^{1.33} \times L \text{ (for } D_m > 2.0\text{m, see reservoir and pondage types)}$$

$$Vc_1 = 2.14 \times D_m^{1.68} \times L$$

$Wr_1 = 0.018 \times Vc$

where,

D_m : Average inner diameter of steel conduit (m)
Lc : Total length of penstock (m)

The weight of the steel conduit is obtained by the following equation. An allowable tensile stress of $115 N/mm^2$ is adopted for steel pipes.

$Wp_1 = 7.85 \times \pi \times D_m \times t_m \times 10^{-3} \times 1.15 \times L$
$t_m = 0.0362 \times H \times D_m + 2$

where,

Wp_1 : Weight of steel conduit (ton)
t_m : thickness of steel conduit (mm)
D_m : Average inner diameter of steel conduit (m)
H : Design head (intake water level - tailwater level, in meters)
L : Total length of penstock (m)

2) Spillway channel

The inner diameter (D) of the spillway channel is obtained from Figure 6-4. The excavation volume, concrete volume, weight of reinforcement bars, and weight of steel conduit are calculated by the following equations. It is unnecessary to consider the spillway channel when excess water can be discharged into a small valley.

$Ve_2 = 9.87 \times D^{1.69}$
$Vc_2 = 2.78 \times D^{1.70}$
$Wr_2 = 0.029 \times Vc$
$Wp_2 = 0.165 \times D^{1.25} \times L$

3) Total quantity of penstock and spillway channel

$Ve = Ve_1 + Ve_2$
$Vc = Vc_1 + Vc_2$
$Wr = Wr_1 + Wr_2$
$Wp = Wp_1 + Wp_2$

Cost of other items of civil works such as grouting and slope protection not included in the main items stated above is estimated at 20% of the cost of main items.

(7) Powerhouse

An above-ground powerhouse is adopted. The number of unit of turbine and generator is determined. The excavation volume, concrete volume, and weight of reinforcement bars are calculated by the following formula.

$Ve = 97.8 \times (Q \times He^{2/3} \times n^{1/2})^{0.727}$
$Vc = 28.1 \times (Q \times He^{2/3} \times n^{1/2})^{0.795}$

$$Wr = 0.046 \times Vc^{1.05}$$

where,

Q	: Maximum plant discharge (m^3/sec)
He	: Effective head (m)
n:	Number of unit

Cost of other items of civil works such as drainage works, foundation of outdoor steel structure, etc. not included in the main items stated above is estimated at 20% of the cost of main items. In addition to this cost, another cost of 30% of the cost of main items is added for the powerhouse building.

(8) Tailrace channel

Calculation of quantity of channel work is made in accordance with the calculation method of the quantity of work for the headrace.

(9) Tailrace

A non-pressure type is adopted. In case that the tailrace is constructed in a regulating pond or a reservoir, a pressure type should be adopted, however this case is not described in this Manual.

The inner diameter of the waterway is obtained from Figure 6-2 using the maximum plant discharge.

The excavation volume of the tailrace (without gate), concrete volume, and weight of reinforcement bars are calculated by the following equations.

$$Ve = 395 \times (R \times Q)^{0.479}$$
$$Vc = 40.4 \times (R \times Q)^{0.684}$$
$$Wr = 0.278 \times Vc^{0.610}$$

where,

Q	: Maximum plant discharge (m^3/sec)
R	: Waterway radius (m)

Cost of other items of civil works such as coffering, slope protection, etc. not included in the main items, is estimated at 25% of the cost of the main items.

(10) Miscellaneous works

Cost of miscellaneous works such as the disposal area and landscaping work is estimated at 5% of the total cost of the civil works.

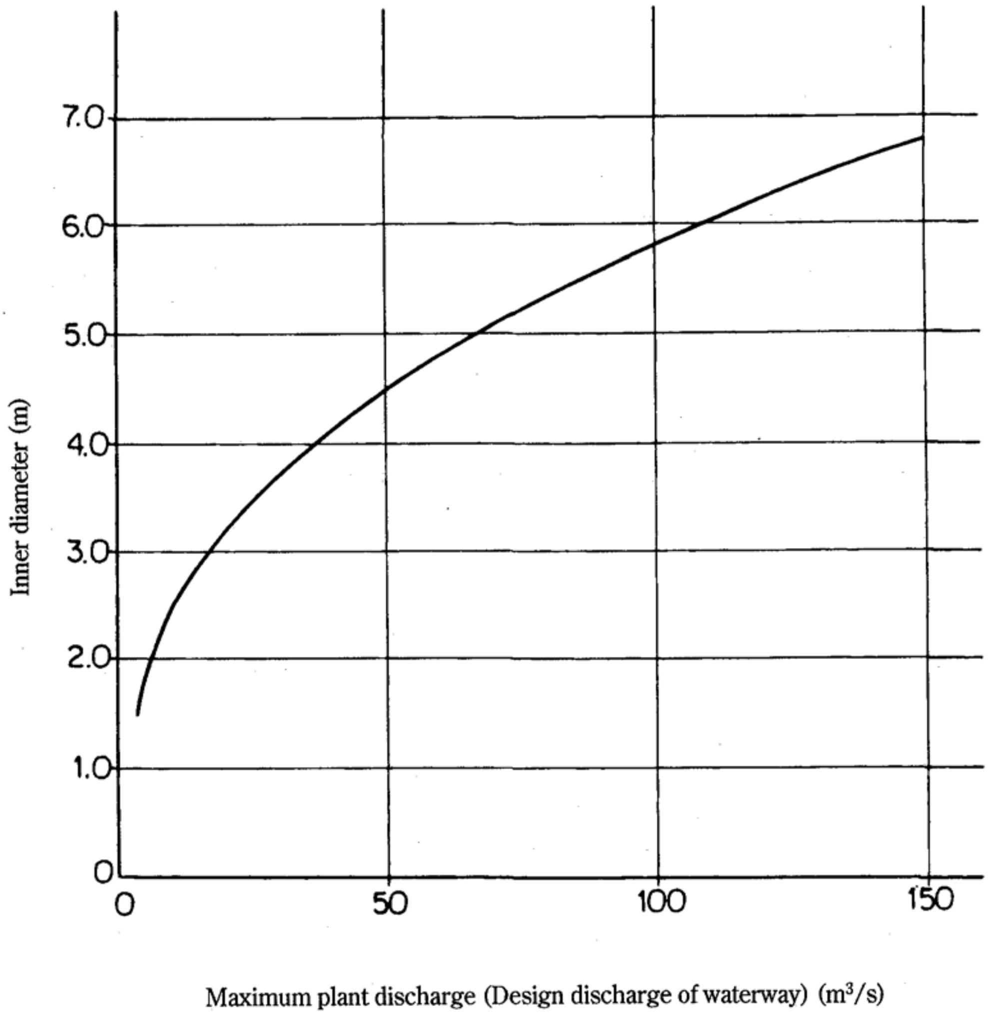


Figure 6-2 Inner Diameter of Waterway

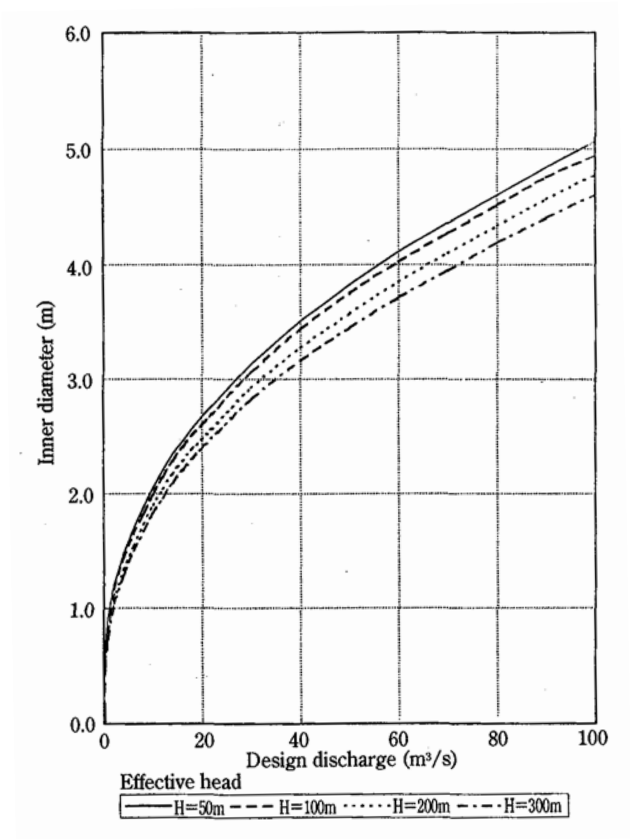


Figure 6-3 (1) Inner Diameter of Penstock

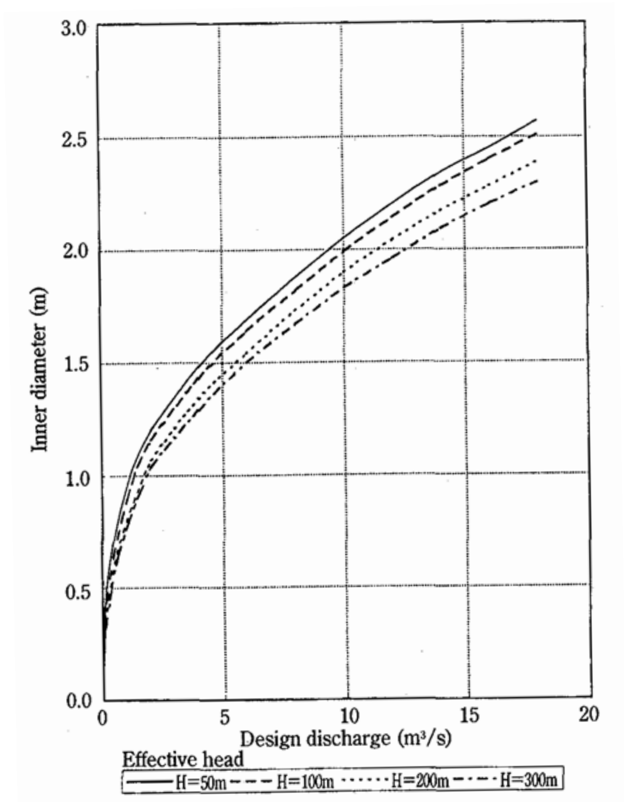


Figure 6-3 (2) Inner Diameter of Penstock (Design Discharge<20m^3/sec)

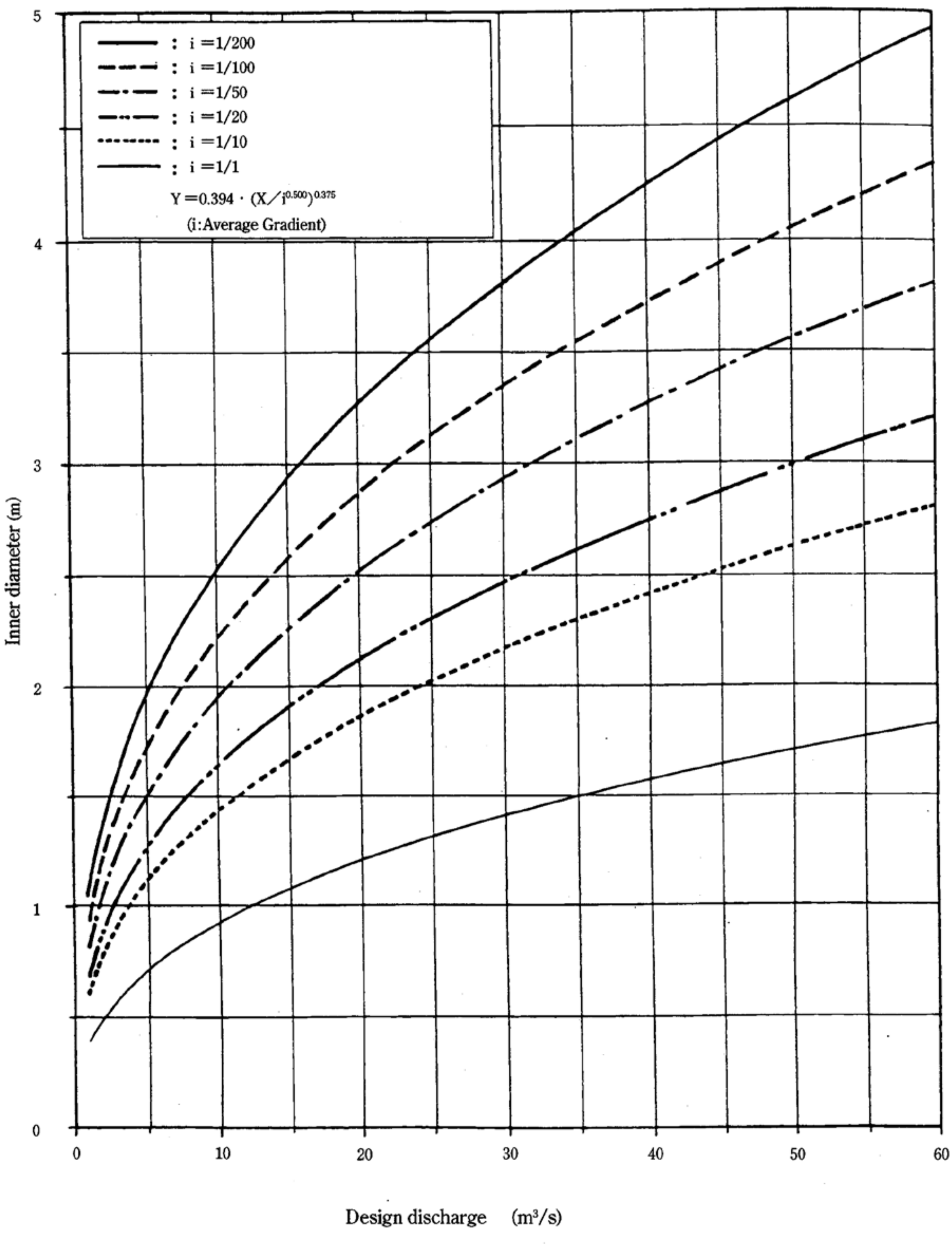


Figure 6-4 Inner Diameter of Spillway Channel

6.2.3 Quantities of Work for Pondage Type and Reservoir Type Power Plant

Quantities of work are calculated according to Table 6-5(1) (2).

(1) Dam

- Determination of type of dam
- In the case of a fill dam, as the spillway construction cost is large, type of dam should be studied including the spillway.
- Crest length (L) is calculated in relation to the dam height (Hd) from the contour lines in the map.
- Design flood data such as Creager's curve should be used to calculate the design flood discharge. In case such data are not available in the relevant country, calculation is made in accordance with 6.2.2 (1).
- Excavation volume and dam volume is obtained by the following equations.

1) Rockfill dam

$$Ve = 10.0 \times Hd \times L$$

$$Vf = 1/6 \times (m+n) \times Hd^2 \times (L+2 \times B) + \frac{W}{2} \times Hd \times (L+B)$$

where,

Hd	: Dam height (m)
L	: Dam crest length (m)
B	: River bed width (m)
W	: Crest width
m	: Upstream slope of dam (m=2.0 in this Manual)
n	: Downstream slope of dam (n=1.8 in this Manual)

2) Concrete gravity dam

In the case : $Hd^2 \times L \leq 100 \times 10^3$

$$Ve = 10.0 \times Hd \times L$$
$$Vc = 38.0 \times (Hd^2 \times L)^{0.59} \ (B/L=0.5)$$
$$Vc = 35.5 \times (Hd^2 \times L)^{0.59} \ (B/L=0.4)$$
$$Vc = 32.4 \times (Hd^2 \times L)^{0.59} \ (B/L=0.3)$$
$$Vc = 27.5 \times (Hd^2 \times L)^{0.59} \ (B/L=0.2)$$
$$Vc = 22.4 \times (Hd^2 \times L)^{0.59} \ (B/L=0.1)$$
$$Wg = 0.13 \times Qf$$

In the case : $Hd^2 \times L > 100 \times 10^3$ (Ve is same as above)

$$Vc = 0.34 \times (Hd^2 \times L) \ (B/L=0.5)$$
$$Vc = 0.30 \times (Hd^2 \times L) \ (B/L=0.4)$$

$$Vc = 0.27\times(Hd^2\times L) \quad (B/L=0.3)$$
$$Vc = 0.21\times(Hd^2\times L) \quad (B/L=0.2)$$
$$Vc = 0.16\times(Hd^2\times L) \quad (B/L=0.1)$$

where,

B : River bed width (m)

L : Crest length (m)

Qf : Design flood discharge: See 6.2.2 (1) (m^3/sec)

Where the dam height is approximately 10 m, refer to the calculation method for the weir of run-of-river type described in 6.2.2.

Cost of other items of civil works such as grouting and coffering not included in the main items above, is estimated at 10% of the cost of the main items.

(2) Spillway

In the case of a fill type dam, the quantity of work of the spillway is calculated by the design flood discharge described in (1).

The excavation volume, concrete volume, weight of reinforcement bars, and weight of gates are calculated according to the following equations

$$Ve = 84\times\sqrt{Qf}\times Hd$$

$$Ve = 13\times\sqrt{Qf}\times Hd$$

$$Wr = 0.020\times Vc$$
$$Wg = 0.22\times Qf$$

where,

Qf : Design flood discharge (m^3/sec)

Hd : Dam height (m)

Cost of other items of works such as grouting not included in the main items described above is estimated at 10% of the cost of the main items.

(3) Intake

A pressure type is adopted in this Manual, and the inner diameter of waterway is obtained from Figure 6-2 by using the maximum plant discharge. The excavation volume, concrete volume, weights of reinforcement bars, gate and screen are calculated by the following equations.

$$Ve = 130\times[\{(ha+D)\times Q\}^{1/2}\times n^{1/3}]^{l.27}$$
$$Vc = 56.5\times[\{(ha+D)\times Q\}1/2\times n^{1/3}]^{1.23}$$
$$Wr = 0.04\times Vc$$
$$Wg = 0.9\times(ha\times D)^{1/9}\times Q$$
$$Ws = 0.5\times(ha\times D)^{1/9}\times Q$$

where,

ha	Available drawdown (m)
Q	Maximum plant discharge (m^3/sec)
D	Inner diameter of waterway
n	Number of headrace tunnel

Cost of other items of works such as coffering and trashrack, rake, etc. not included in the main items obtained above is estimated at 20% of the cost of the main items.

(4) Headrace

A circular fully lined pressure tunnel is adopted. The excavation volume of the pressure tunnel, concrete volume, and weight of reinforcement bars are calculated by the following equations.

$$Ve = 3.2\times(R+t_0)^2\times L\times n$$

$$Vc = \{3.2\times(R+t_0)^2 - \pi R^2\}\times L\times n$$

$$Wr = 0.04\times Vc$$

where,

R	: Tunnel radius (m) obtained from Figure 6-2 (design discharge = maximum plant discharge/ for one headrace tunnel)
t_0	: Lining concrete thickness (m) calculated from Figure 6-5 (Upper line is used when the geology is unknown.)
L	: Total length of headrace tunnel (m)
n	: Number of headrace tunnel

Cost of other items of works such as grouting, adit, etc. not included in the main items stated above is estimated at 15% of the cost of the main items.

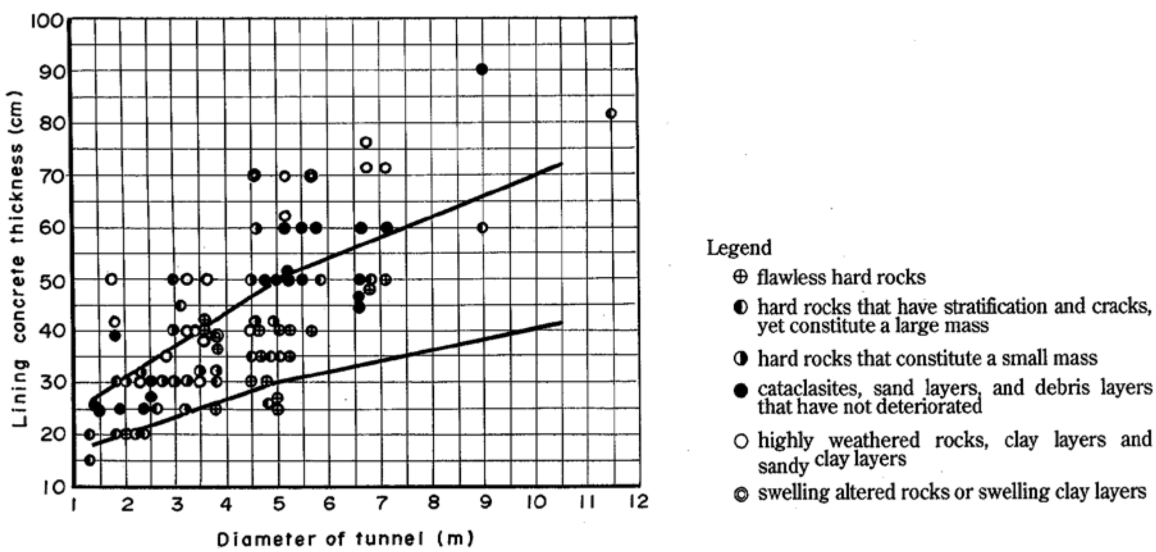


Figure 6-5 Relationship Between Inner Diameter of Tunnel and Lining Concrete Thickness

(5) Surge tank

The excavation volume, concrete volume, and weight of reinforcement bars are calculated in accordance with the following equations.

$$Ve = 38 \times q \times (ha+L)^{1/4} \times n$$
$$Vc = 11 \times q \times (ha+L)^{1/4} \times n$$
$$Wr = 0.05 \times Vc$$

where,

- q : Design discharge (m^3/sec), equivalent to the maximum plant discharge when the waterway has only one headrace tunnel.
- L : Total length of waterway (m)
- ha : Available drawdown of regulating pond or reservoir (m)
- n : Number of headrace tunnel

A surge tank is not provided when the length of waterway is less than 500m.

Cost of other items of works such as steel lining not included in the main items stated above is estimated at 55% of the cost of the main items.

(6) Penstock

The average inner diameter (D_m) is obtained from Figure 6-3.

For exposed type of penstock, the excavation volume, concrete volume and weight of reinforcement bars are calculated by the following equations.

In case D_m is less than 2.0m, refer to 6.2.2, run-of-river type

$$Ve = (10.5 \times D_m^2 - 10.5 \times D_m + 12) \times n^{1/3} \times L \qquad (2.0 < D_m \leq 3.0)$$
$$Ve = (20.3 \times D_m^2 - 49.5 \times D_m + 41.3) \times n^{1/3} \times L \qquad (D_m > 3.0)$$
$$Vc = (0.25 \times D_m^2 + 3.25 \times D_m) \times n^{1/3} \times L \qquad (2.0 < D_m \leq 3.0)$$
$$Vc = (0.5 \times D_m^2 + 2.5 \times D_m) \times n^{1/3} \times L \qquad (D_m > 3.0)$$
$$Wr = 0.018Vc$$

For embedded type of penstock, excavation volume and concrete volume are obtained by the following equation, assuming constant thickness of backfill concrete of 60cm.

$$Ve = \frac{\pi}{4}(D_m+2t)^2 \times L$$
$$Vc = \frac{\pi}{4}\{(D_m+2t)^2 - D_m^2\} \times L$$
$$Wr = 0.012 \times Vc$$

where,

- D_m : Average inner diameter of steel pipe (m)
- t : Thickness of backfill concrete (m)
- L : Total length of penstock (m)

Weight of steel conduit for exposed type is calculated by the following equations, provided, however, incremental weight of steel conduit of exposed type is 1.15 and 1.1 for embedded type.

$$Wp = 7.85\times\pi\times D_m\times t_m\times 1.15\times L\times n\times 10^{-3}$$

$$t_m = 0.0313\times H\times D_m+2$$

where,

Wp	: Weight of steel conduit (ton)
t_m	: Thickness of steel conduit (mm)
H	: Design head (m) (= high water level - tailwater level)

An allowable tensile stress of 160N/mm^2 is used for steel conduits.

Cost of other items of works not included in the main items stated above is estimated at 20% of the cost of the main items.

(7) Powerhouse

1) Above-ground type

The number of units of the turbine and generator is first determined. The excavation volume, concrete volume, and weight of reinforcement bars are then calculated by the following equations.

$$Ve = 97\ 8\times(Q\times He^{2/3}\times n^{1/2})^{0.727}$$

$$Vc = 28.1\times(Q\times He^{2/3}\times n^{1/2})^{0.795}$$

$$Wr = 0.05\times Vc$$

where,

Q	: Maximum plant discharge (m^3/sec)
He	: Effective head (m)
n	: Number of unit

2) Underground type

Calculation method for the pumped storage type described in 6.2.4 (7) is applied.

(8) Tailrace channel

Calculation method of quantity of work for the headrace is applied.

(9) Tailrace

Calculation method for the run-of-river type described in (9) is applied.

When two or more tailrace tunnels are adopted, tunnel diameter of one tunnel to handle the maximum discharge is calculated using Figure 6-2, and then quantities of work are calculated. If a tailrace gate is to be installed, use the same weight of the intake gate.

(10) Miscellaneous works

Cost of miscellaneous works such as the disposal area and landscaping work, is estimated at 5%

of the total cost of civil works (from (1) through (9)).

6.2.4 Quantities of Work for Pumped Storage Type Power Plant

Quantities of work are calculated according to Table 6-6 (1) and (2).

(1) Dam

Quantities of work are calculated according to 6.2.3 (1), pondage type and reservoir type. However, upper and lower dams are required.

(2) Spillway

Quantities of work are calculated according to 6.2.3 (2), pondage type and reservoir type. However, spillways are required for both the upper and lower dams.

(3) Intake

Quantities of work are calculated according to 6.2.3 (3), pondage type and reservoir type.

(4) Headrace

A circular fully lined pressure tunnel is adopted.

The excavation volume, concrete volume, and weight of reinforcement bars are obtained in accordance with the formula described in 6.2.3 (4) for a flow velocity of 6.0 m/sec in the tunnel.

(5) Surge tank

Quantities of work are calculated according to Section 6.2.3 (5), pondage type and reservoir type.

(6) Penstock

1) Exposed type

Quantities of work are calculated according to Section 6.2.3 (6), pondage type and reservoir type.

2) Embedded type

Quantities of work are calculated according to Section 6.2.3 (6), pondage type and reservoir type. The inner diameter of the steel conduit is obtained for a design discharge based on a velocity of flow in the conduit of constant value of 10 m/sec.

The weight of the steel conduit is obtained by the following equations for embedded type in tunnel.

$$Wp = 7.85 \times \pi \times D_m \times t_m \times 1.1 \times L$$

$$t_m = 0.0270H \times D_m + 2$$

where,

Wp : Weight of steel conduit (ton)

t_m : Thickness of steel conduit (mm)

H : Design head (m) (high water level - tailwater level)

An allowable tensile stress of 185N/mm^2 is used for the steel conduit.

(7) Powerhouse

1) Above-ground type

Quantities of work are calculated according to Section 6.2.3 (7), pondage type and reservoir type.

2) Underground type

The excavation volume, concrete volume, and weight of reinforcement bars are obtained by the following equations.

$$Ve=27\times A+1.3\times A\times d$$
$$Vc=15\times A$$
$$Wr=0.6\times A$$

Provided that,

$$A=20\times Q^{1/2}\times He^{1/3}$$

where,

Q : Maximum plant discharge (m^3/sec)
He : Effective head (m)
A : Area of powerhouse (m^2)
d : Height of powerhouse (m)

The cost of powerhouse building and transformer chamber is included in 50% of "Others" in Table 6-6 (1).

(8) Tailrace tunnel

Quantities of work are calculated according to the calculation method of headrace.

(9) Tailrace outlet

During pumping operation, the tailrace is an intake; therefore, calculation method of quantity of work for intake is adopted.

(10) Access tunnel to powerhouse

Excavation volume, concrete volume, and weight of reinforcement bars of the access tunnel are obtained by the following equations. The maximum gradient of the access tunnel is 1:10.

$$Ve = 45\times L \text{ (m}^3\text{)}$$
$$Vc = 10\times L \text{ (m}^3\text{)}$$
$$Wr = 0.3\times Vc \text{ (ton)}$$

(11) Miscellaneous Works

Cost of miscellaneous works such as the disposal area and landscaping work is estimated at 5% of the total civil work cost.

6.2.5 Transmission Lines

The total length of transmission line is calculated on a straight line between the powerhouse site and the nearest existing transmission line. The capacity of transmission line is determined by the transmission distance and the output of the power plant shown in Figure 6-6. Figure-A is an example of single circuit (S/C) and double circuit (D/C). Figure-B is an example of double circuit, and for a single circuit, 1/2 of the vertical value shown on the figure is used.

Figure-A

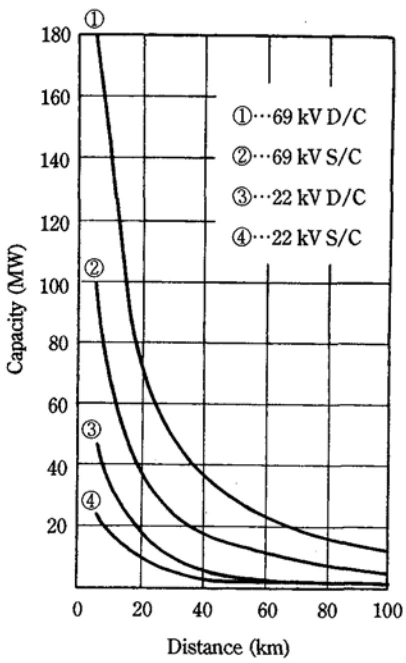


Figure-B

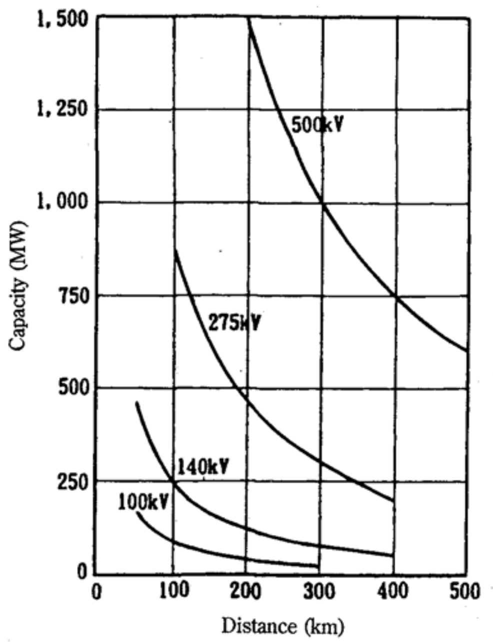


Figure 6-6 Capacity of Transmission Line

6.3 Optimization of the Scale

6.3.1 Economic Analysis (Simplified Method)

The economics of the project is analyzed on the basis of maximum output and energy generation determined in Chapter 5, and the construction cost obtained in Section 6.1 and 6.2.

(1) Methodology of analysis

An economic analysis of a hydropower project is made by a method to compare its benefit (B) and cost (C). The benefit (B) of a hydropower project is the cost of an alternative thermal power that supplies electric power equivalent to the hydropower project and the cost (C) is derived from the construction cost of the hydropower project. In the case B/C≥1.0 (or B−C≥0), the hydropower is economically better than the alternative thermal power while in the case B/C<1.0 (or B−C<0), the hydropower is economically less attractive than the alternative thermal power. It is also possible to judge that a certain hydropower project is economically attractive if the B/C value is outstanding among a number of hydropower projects that are compared. One method to calculate B and C is to calculate the annual costs of thermal power and hydropower (i.e. method by annual expense). Another method to arrive at B and C is to calculate the present values of annual costs of hydropower and thermal power throughout the period of analysis. Yet another method is to use the latter method and calculate the Internal Rate of Return (IRR) applying a discount rate which will give equal present values for both B and C. In this section, the former method, i.e. "Method by Annual Cost" is introduced in a simple manner.

When the latter method is adopted to conduct detailed analysis of individual sites in the reconnaissance study refer to Chapter 16.

(2) Selection of alternative thermal power

The alternative thermal power plants are gas turbine, coal fired, oil fired, liquefied natural gas fired, combined cycle, and diesel power plants. The power source most commonly used in the electric power system is selected as the alternative thermal power.

(3) Benefit and cost of conventional hydropower projects

1) Benefit

Annual benefit (B) of a hydropower project is obtained in accordance with the following formula, based on the fixed cost (mainly the equipment cost) and variable cost (mainly the fuel cost) of the alternative thermal power selected.

$$B = B_1 + B_2$$
$$B_1 = P_H \times b_1$$
$$B_2 = E \times b_2$$

where,

B : Annual benefit of hydropower plant (monetary unit)

B_1 : kW benefit (monetary unit/kW)

B_2 : kWh benefit (monetary unit/kWh)

P_H : Effective output (kW), firm peak output (kW) for reservoir type and pondage type, and firm output for run-of-river type.

E : Annual energy generation of conventional hydro power (kWh)

b_1 : kW value (also called capacity value), which is the fixed cost per kW for alternative thermal power (monetary unit/kW)

b_2 : kWh value (also called energy value), which is mainly the fuel cost and is the variable cost per kWh of alternative thermal power (monetary unit/kWh)

Correction for the difference in reliability (station use, forced outage, scheduled outage, transmission loss) between hydropower and thermal power is ignored. The detail is explained in Chapter 16 if necessary.

2) Calculation of kW value (b_1) and kWh value (b_2)

The kW value and kWh value are calculated from the following equations for the selected power source.

b_1 = $Ct \times \alpha_t$

b_2 = Heat consumption (kcal/kWh)/Heat value (kcal/l or kg) ×fuel price (monetary unit/kcal)

Heat consumption=860 (kcal/kWh)/Thermal efficiency

where,

Ct : Unit construction cost of thermal power (monetary unit/kW)

α_t : Annual cost factor of thermal power

The annual cost factor is calculated as follows.

Annual cost factor (α_t) = capital recovery factor (CRF) +operation and maintenance cost (O&M for 3% of construction cost, fuel cost is excluded)

where,

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i : Discount rate

n : Service life (years)

The thermal efficiency and service life for gas turbine, coal fired, diesel, and combined cycle plants are shown below.

	Gas Turbine	Coal Fired	Combined Cycle	Diesel
Thermal efficiency	approx. 30%	approx. 40%	approx. 43%	approx. 35%
Service life	approx. 20 years	approx. 25 to 30 years	approx. 25 to 30 years	Approx 15 years

3) Calculation of cost

Annual cost of hydro power is derived from the following equation.

$$C = Ch \times \alpha_h$$

where,

C	: Annual cost (monetary unit)
Ch	: Construction cost (monetary unit)
α_h	: Annual cost factor (ratio of annual cost to construction cost)

Annual cost factor of hydropower is calculated in the same way as the thermal power. It varies depending on service life of hydropower, O&M cost and discount rate. In the case of 10% of discount rate and 0.1% of O&M cost, the annual cost factor of hydropower is approximately 0.10 to 0.12 in general.

Annual cost factor = capital recovery factor + ratio of O&M cost.

$$\text{Capital recovery factor} = \frac{i(1+i)^{50}}{(i+1)^{50} - 1}$$

In case that (i) = 10% and ration of O & M cost is 1%, α_h=0.1009 + 0.01=0.11.

(4) Benefit and Cost of Pumped Storage Type

1) Benefit

The same methods used for conventional hydropower are applied, however the energy is estimated as follow.

P_H	: Effective output (kW)
E	: Annual energy generation (kWh), here it is assumed to be 800 hours

2) Cost

The same concepts used for conventional hydro power apply, but the cost of pumping-up energy is additional.

$$C = Ch \times \alpha_p + E \times b_3 / \gamma$$

where,

b_3	: Pumping energy cost (monetary unit/kWh)
α_p	: Annual cost factor of pumped storage
γ	: Gross efficiency (= generated energy/pumping-up energy)

Energy losses arise at the waterway and turbine during pumping and generation of pumped storage power plants. Ratio of generated energy (output) to pumping energy (input) is defined as "Gross efficiency of pumped storage power plant", and the ratio is generally about 70%. Since pumped storage power plants use the excess energy of thermal power plants such as coal fired, etc for base and/or middle load supply for pumping. Pumping energy cost is calculated based on fuel cost of such thermal power plants.

6.3.2 Unit Construction Cost Method

More easy methods are described as follows.

(1) Conventional type

In the case of run-of–river type, kWh benefit is much larger than kW benefit, therefore only kWh is weighed heavily and "construction cost per kWh" can be used for economic evaluation.

$$\text{Construction cost per kWh (monetary unit/kWh)} = \frac{\text{Construction cost (monetary unit)}}{\text{Annual energy generation (kWh)}}$$

(2) Pumped storage type

In the case of pumped storage type, kW benefit is much larger than kWh benefit, therefore only kW is weighed heavily and "construction cost per kW" can be used for economic evaluation.

$$\text{Construction cost per kW (monetary unit/kW)} = \frac{\text{Construction cost (monetary unit)}}{\text{Maxmum output (kW)}}$$

6.4 Optimization Study

(1) Optimization study

Scale of development is determined from maximum plant discharge and the effective head, therefore, comparative studies should be conducted by applying different parameters. The following are often examined for prospective projects in a reconnaissance study.

1) Run-of-river type

- Alternative plans with different locations of intake weir and powerhouse (study of waterway route)
- Alternative plans with different values of maximum plant discharge
- There are cases where diversion of water from neighboring river or tributary is studied.

2) Reservoir type and pondage type

- Alternative plans with different dam and powerhouse sites (study of waterway route)
- Alternative plans with different dam heights (reservoir type only)

- ➢ Alternative plans with different maximum plant discharge values

3) Pumped storage type

- ➢ Alternative plans with different dam and powerhouse sites (study of waterway route)

(3) Optimization method

The optimum scale of development is a plan that gives the maximum value of B/C or B−C. A plan of development that gives the maximum B/C value is deemed the optimum plan when the emphasis is efficiency of capital investment. The plan of development that gives the maximum B−C value is deemed the optimum plan when emphasis is effective use of resources. Figure 6-7 and Figure 6-8 are examples to adopt the former criteria.

Since the kW benefit is small in the case of a run-of-river type, in many cases a plan with the maximum B/C value and a plan with a minimum construction cost per kW are identical. For convenience' sake, therefore, the plan with the minimum construction cost per kWh is deemed the optimum plan.

Figure 6-7 shows an example of optimization study of run-of-river type power development. In the study 3.0m^3/sec is concluded as being optimum.

In the study of the reservoir type, as shown in Figure 6-8, comparison of three waterway routes, i.e. Route A, B and C is made with Route B being selected as the optimum as it provides the maximum B/C value. The alternative with Maximum plant discharge of Q_2 and dam height of option 1 is selected for Route B.

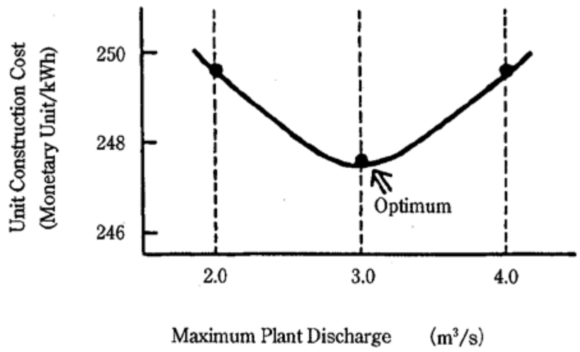


Figure 6-7 Determination of Optimum Scale of Development (Run-of-River Type)

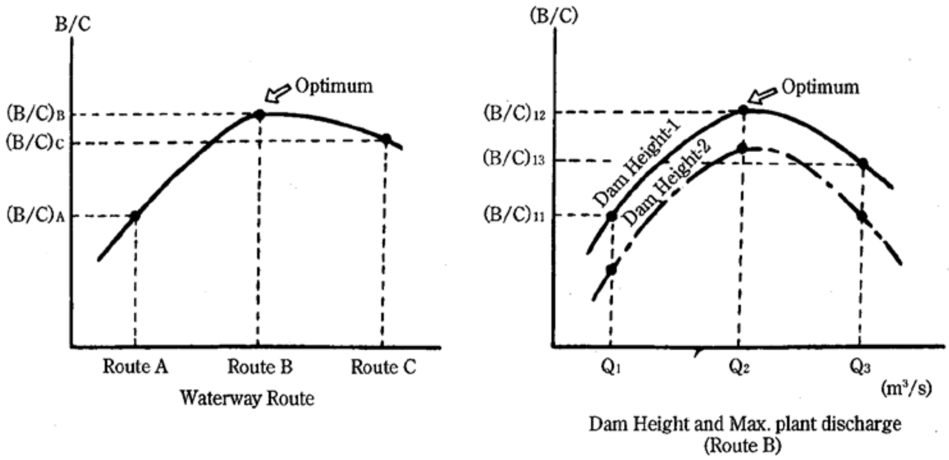


Figure 6-8 Determination of Optimum Scale of Development (Reservoir Type)

Reference of Chapter 6

[1] Guide Manual for Development Aid Programs and Studies of Hydroelectric Power Projects, New Energy Foundation, 1996

Chapter 7

Application of Reconnaissance Study Method

Chapter 7 Application of Reconnaissance Study Method

7.1 Application for Study of Individual Projects

In advancing the investigation and study of hydropower projects, the general method is to upgrade the quality of the work gradually considering the work and cost efficiency. The reconnaissance study method mentioned in Chapter 5 and 6 is useful for an initial study of projects because existing information such as 1/50,000 maps and runoff records can be utilized without sizable budget.

Project characteristics can be grasped roughly from the reconnaissance study by comparing alternatives changing the sites of dam and powerhouse, dam height, waterway route and maximum plant discharge, etc.

The study results of the individual projects can be reflected to the feasibility study of the individual project, hydropower potential study and development master plan.

7.2 Application for Hydropower Potential Study

Hydropower potential is defined as the amount of potential energy existing in a river or a certain area. A hydropower potential survey is carried out from the following view points.

- To utilize the water head existing in a river as much as possible in consideration of the present technical and economic level of hydropower.
- To determine generation types (reservoir type, runoff- river-type and pondage type) judging from topography and river flow conditions.
- To select the appropriate dam site where river flow is stored and utilized as much as possible.

The reconnaissance study method is used to carry out planning and investigation of many projects. The result is tabulated with project name, maximum output, generated energy, economic factor, environmental and other important matters. Development priority is put for all projects, and prospective project is selected for pre-feasibility and/or feasibility study.

7.3 Application for Master Plan Study

7.3.1 Conventional Hydropower

(1) Identification of core projects of the basin development

A master plan study is carried out for the river basin development of relatively large drainage area having many hydropower projects. It has the following main purposes.

- To plan possible projects and grasp the overall feature of basin development
- To find core projects which play the most important role for the entire basin development

- To figure out the development priority of projects in order to develop the hydropower resources most efficiently

Core projects are determined by judging from a view points of project scale (output), economic viability, natural and social environment, access road, transmission lines etc. In case core projects are developed in an early stage, they should bear a large portion of the costs of transmission line and access road. Consequently the other projects with low development priority have chance to be developed because they can reduce bearing the ~~s~~costs.

Although 1/50,000 scale map is used for the master plan study, more detailed map such as 1/5,000 or 1/10,000 scale can be used for prosperous projects.

In case there are very few projects in the basin, a study on individual project mentioned in 7.1 is carried out without conducting the master plan study.

(2) Development of mainstream and tributaries

Figure7-1 shows a schematic of a basin development. “Main river development (MD)” means that a large dam is constructed for hydropower plants along the main river. “Tributary development (TD)” means that several dams are constructed mainly in the tributaries and a large dam is not constructed at a main river. Figure7-1 shows the figure focusing on tributaries at left bank of the main river, and those at right bank are left out from the figure.

Compared with the MD plan and the TD plan which has almost same runoff regulating effect and water head as the MD has, the MD plan might be more economical than the TD plan in case a high dam of MD can be constructed with low construction cost, because river runoff gathers to the main river. However MD plan might have defects of vast inundated reservoir area, resettlement of villagers, change in ecosystem, sedimentation, etc.

A comparison study among the MD plan, TD plan and their mixed plan should be considered for the master plan study.

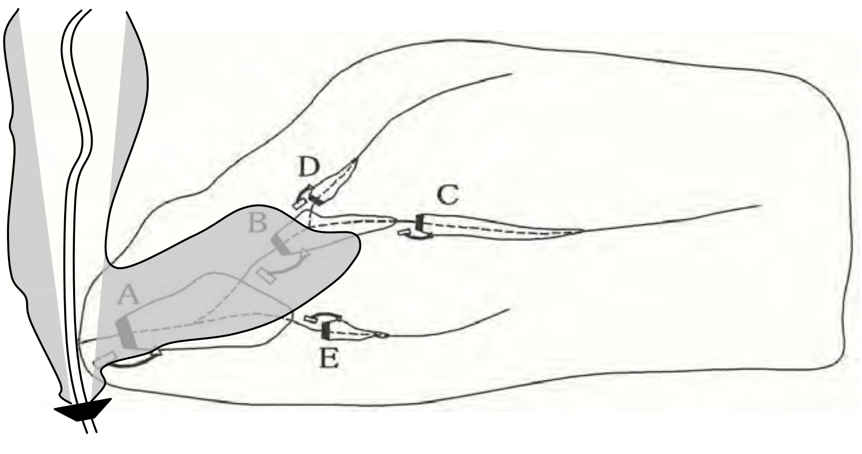
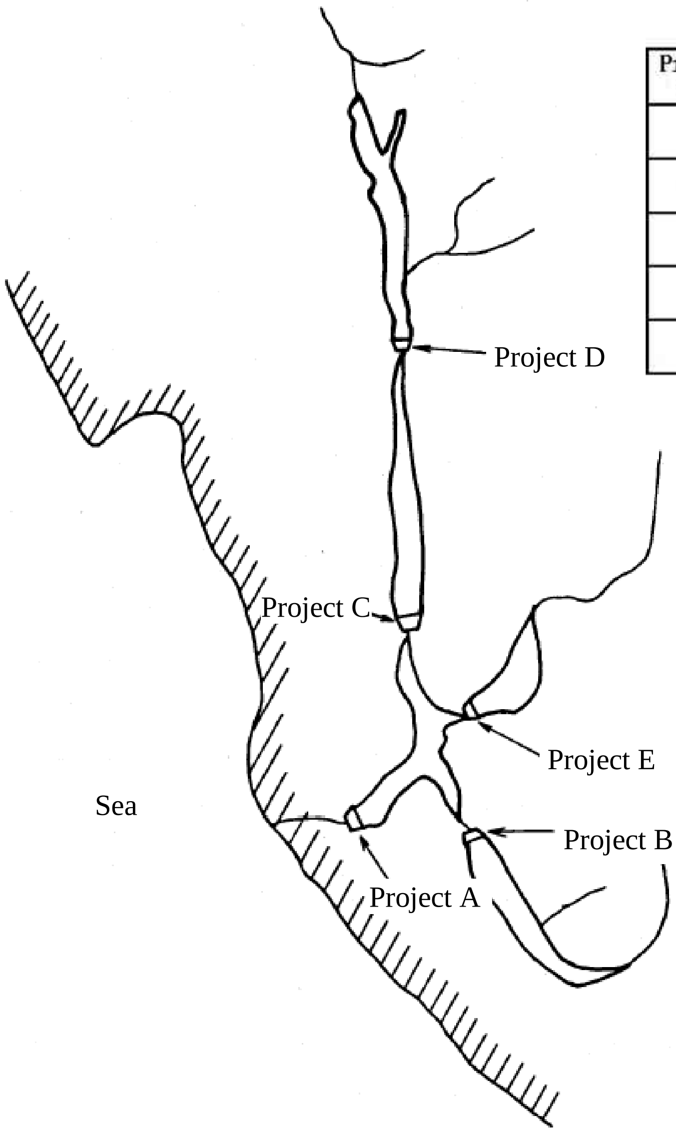


Figure 7-1 Schematic Figure of Mainstream’s Developments and Tributary’s Development

(3) Example of basin development master plan

An example of the master plan is shown in Figure 7-2 where five projects are selected as development potential. The most promising project "A" is found and identified as a core project for basin development.



Project Plan

Project Name	Output (MW)	B／C
A	162	1.52
B	117	0.98
C	24	0.69
D	58	0.95
E	40	0.74

Figure 7-2 Example of Master Plan of Basin Development

7.3.2 Master Plan Study on Pumped Storage Hydropower

A master plan study of pumped storage projects is different from that of conventional hydropower projects. Power supply area and thermal & nuclear power plants are roughly specified firstly, and then possible candidate project sites are found by map and be listed as shown in Figure 7-3.

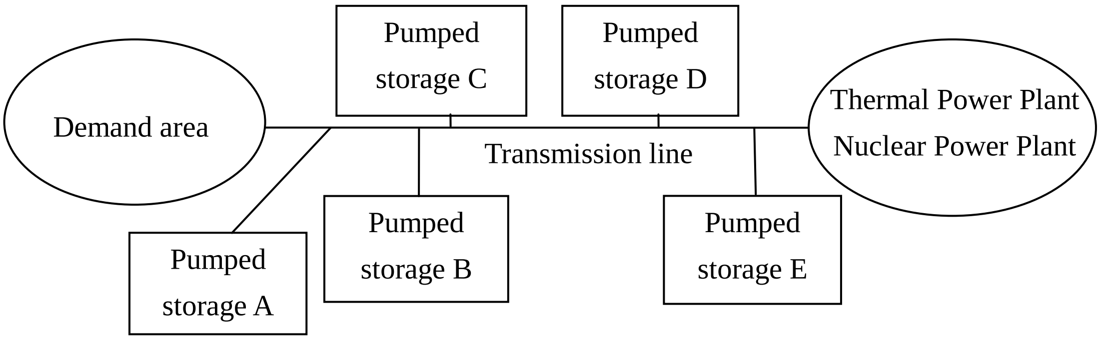


Figure 7-3 Candidate Projects for Pumped Storage Projects

Investigation is carried out from following points.

- Head of more the 400m is available and serious geological problems for civil structures cannot be observed
- It is located relatively close to the area of demand
- It is located close to the existing or planned transmission line connecting between the power demand areas and sites of large scale thermal power plants.
- The transmission line has enough capacity to send generated power by the project and to receive pumping energy for the proposed projects
- Environmental problem is less, and access condition is good

The project site is selected by using 1:50,000 scale map and "L/H value" explained below. In the case a site has head of more than 400m and L/H of less than about 6, the site might be worth to study.

L/H

where,

H : horizontal distance between upper dam site and lower dam site

L : Height difference between upper dam site and lower dam site

Project finding is conducted by the above mentioned procedure.