SEMINAR ON SMALL SCALE HYDRO-ELECTRIC POWER DEVELOPMENT

MARCH 1992

SABAH ELECTRICITY BOARD

JAPAN INTERNATIONAL COOPERATION AGENCY

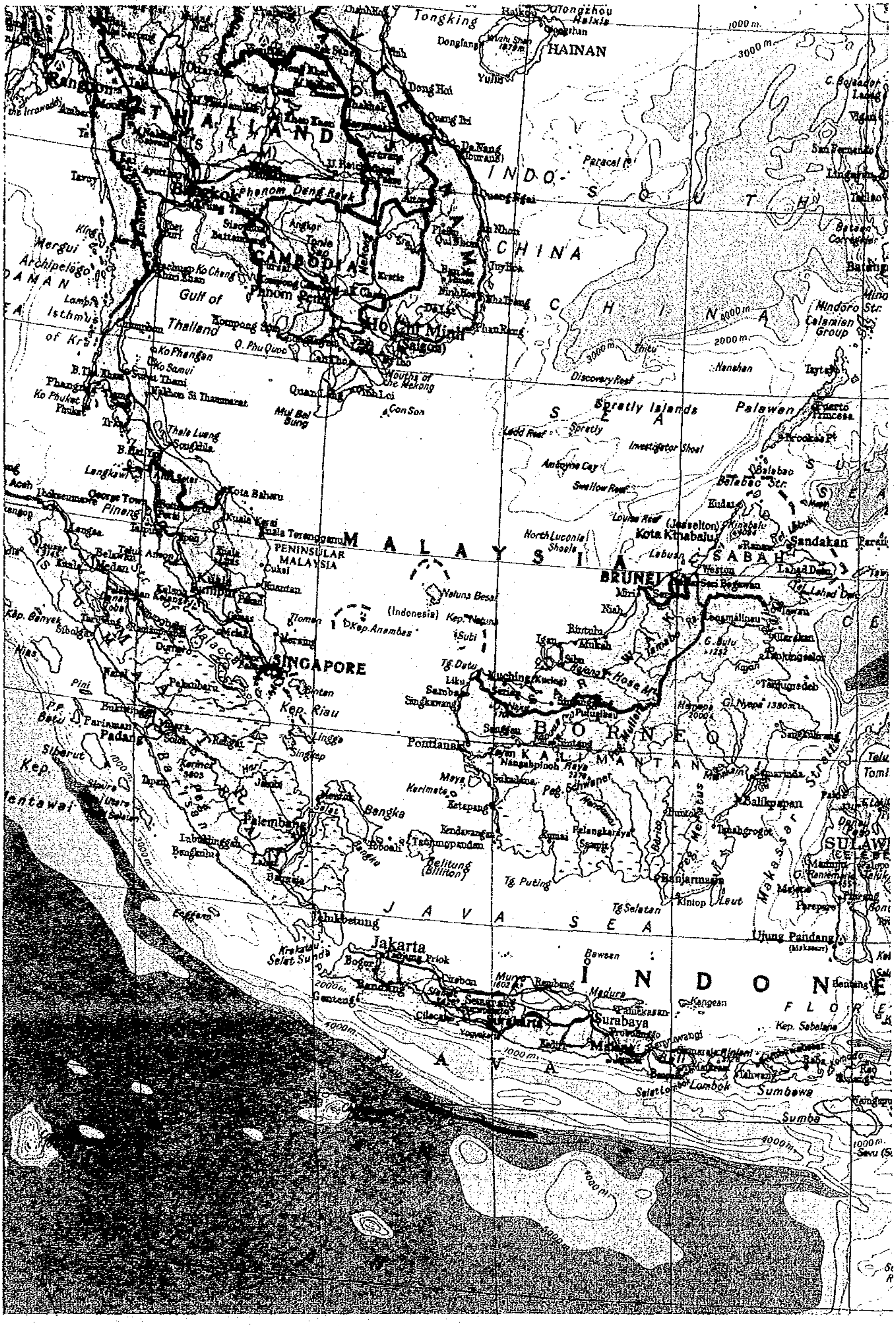
Programme of the Seminar on Small-Scale Hydro-Electric Power Development

11 Mar. 1992

9:00 - 9:15 am	-	Welcoming Speech by Deputy General Manager (Finance) Tuan Hj. Othman Abdullah
9:15 - 10:15 am	-	Main Role of Japanese Administration in Development of HP Development by Mr. MURAKAMI from MITI
10:15 - 10:30 am	-	Tea Break
10:30 - 11:30 am	-	SSHP Facilities of Japanese Local Authorities by Mr. ISHIKAWA from GUNMA
11:30 - 12:30 pm	-	SSHP Development in Japan by Mr. NAKAYAMA from NEF
12:30 - 2:00 pm	-	Lunch Break
2:00 - 3:30 pm	-	Open Discussion
3:30 - 4:00 pm	-	Tea Break

12 Mar. 1922

9:00 - 10:00 am	-	New Technology for SSHP Development in Japan By Mr. ASANO and Mr. YAMAMOTO from EPDC
10:00 - 10:30 am	-	Teak Break
10:30 - 11:30 am	-	Continue
11:30 - 12:30 pm	-	Open Discussion
12:30 - 2:00 pm	-	Lunch Break
2:00 - 3:00 pm	-	Open Discussion
3:00 - 3:30 pm	-	Closing Remark by Deputy General Manager (Engineering) Mr. PETER LAJUMIN
3:30 - 4:00 pm	-	Tea Break
7:00 - 10:00 pm (DINNER)	-	Reception at Hyatt Kinabalu International Hotel (Kimanis Ballroom II)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HAINAN
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Dong Hoi
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of Kra
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Paracel Is.
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CHINA
SEA
Spratly Islands
Palawen
Discovery Reef
Con Son
Mouths of
the Mekong
George Town
Pinang
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MALAYSIA
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MALAYSIA
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SINGAPORE
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Medan
Natuna Besar
(Indonesia)
Kep. Natuna
Kep. Anambas
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SABAH
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BRUNEI
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KALIMANTAN
Samarinda
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Banjarmasin
Padang
Palembang
Jambi
Bangka
Belitung
(Billiton)
Bengkulu
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JAVA SEA
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Lombok
Sumbawa
Sumba
INDONESIA
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Ujung Pandang
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SULAWESI
(CELEBES)
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ROLE PLAYED BY ADMINISTRATION IN HYDROELECTRIC POWER GENERATION

Summary

In Japan, electric power sources are basically developed by private sector.

***Ministry of International Trade and Industry (MITI)** (and its predecessor) has been positively supporting private sector in the development of hydroelectric power, recognizing that the economic growth is dependent on a stable supply of electric power.*

The first contribution made by MITI to hydroelectric power development was the establishment of a nationwide continual and systematic survey to clarify the feasible locations for hydroelectric power development. More recently, MITI has been executing more comprehensive measures, such as providing regional incentives to seek public acceptance from inhabitants who oppose electric power development, environment preservation measures, a variety of subsidiary measures for the improvement of the economic aspects of hydroelectric power development, technology development and technological support to hydroelectric power developers. The present situation of administrative measures for the promotion of hydroelectric power development in Japan are described below. It will be of great satisfaction to us if what is referred to below should prove to be helpful as a reference in developing hydroelectric power in your esteemed country.

ROLE PLAYED BY ADMINISTRATION IN HYDROELECTRIC POWER GENERATION

Hiroyuki MURAKAMI
Section Chief in charge of Hydroelectric Power Development Promotion
Electric Power Generation Division
Public Utilities Department
Agency of National Resources and Energy (ANRE), MITI
JAPAN

Mr. Murakami completed the post-graduate course in Electrical Engineering at Hokkaido University in 1985. After that, he entered MITI and was engaged for about two years in jobs involving working out long-term development plans and performing economic analyses in the Electric Power Development Division of the Public Utilities Department, ANRE. For the subsequent two years, he worked in the Pollution Protection Guidance Office of the Industrial Location and Environmental Protection Bureau, MITI, giving guidance relating to air pollution prevention, performing advanced high technology pollution fact-finding surveys and making studies of global environmental problems (freon control problem and global warming problem). Later, he served in the Public Utilities Department as an operations control expert officer to regulate the safety of nuclear power generation for a period of one year. Since 1990, he has been working in the Electric Power Generation Division as a section chief in charge of hydroelectric power development promotion to work out hydroelectric power development plans, map out and implement subsidiary policies, make arrangements with relevant government agencies and make an environmental review of a project. At the same time, is in charge of promoting the development of geothermal power generation. He has been performing duties performs for hydroelectric power development.

1.1 History of Hydroelectric Power Development in Japan and Water Power Resources Surveys

(1) Dawn of Hydroelectric Power Development in Japan (See Fig. 1)

The history of hydroelectric power development in Japan began approximately one hundred years ago in 1891 when a hydroelectric power plant with an output of 160 kW was developed in Kyoto city.

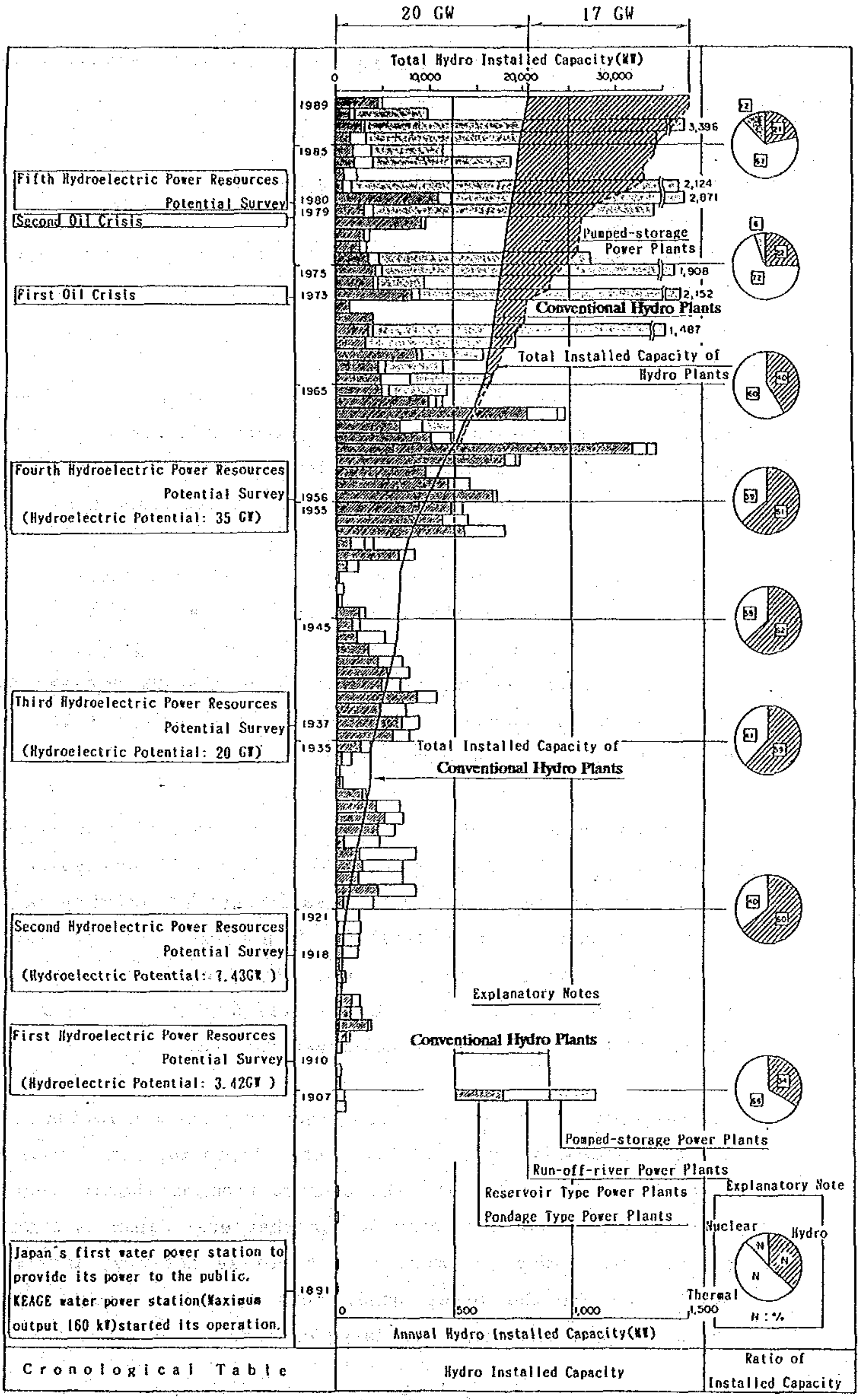
(2) Hydroelectric Power Development Feasibility Studies, which have Supported Hydroelectric Power Development in Japan

Hydroelectric power developments in Japan are closely related to the hydroelectric power development feasibility studies (water power resources surveys) conducted by the Japanese Government. So far, five surveys of this type have been performed on a nationwide basis.

In Japan, the Government first decides on a basic policy for hydroelectric power developments. With stream-gaging stations located in principal rivers all over the country, a grasp of water flow in each river is obtained. Thus, nationwide hydroelectric power development feasibility studies have been conducted in great detail. The findings in these studies and surveys have allowed uss .to uncover every location that is economically advantageous for the development of hydroelectric power. As a result, private electricity companies have been able to proceed with developments step by step, with priority given to the most economically advantageous locations.

To promote hydroelectric power development in a planned manner, it is first of all important to observe rivers flow rates and make surveys on a point by point basis continually and systematically.

Fig. 1 History of Hydroelectric Power Development



(3) History of Hydroelectric Power Developments

In the 1890s, very small-sized power stations in the several hundred kW class began to be constructed in the suburbs of cities.

Around 1900, the price of coal began to rise, and it became technologically possible to transmit electricity over a distance of about 100 km. As a result, hydroelectric power stations of the 10 MW class came to be constructed one after another.

Early in 1920's, hydroelectric power production began to exceed thermalelectric power production, and an era of hydroelectric power domination was established, lasting up to around 1955. In those days, hydroelectric power stations of the 300 MW class were built one after another. Thus, this was an age of full-scale hydroelectric power in Japan.

In the beginning of 1960s, the demand for electric power showed remarkable growth, and there was possibility that reservoir-type power stations alone might be insufficient to provide enough power to supply for the peak load. As a result, MITI started to explore pumping locations. Soon, the development of pumped storage power plants began and the times changed into an era dominated by pumped storage power generation.

At that time, the scale of thermalelectric power generation began to be gradually enlarged, thereby improving its economic advantages. As a result, the construction of thermalelectric power stations was accelerated. In that era, Japan as a whole pursued efficiency and merits of scale as its most important priority. On the other hand, this tendency brought about pollution problems mainly in large cities.

At present, conventional hydroelectric power development is mainly being made gradually on a medium or small scale in upstream areas of rivers, since priority has been given to locations that are economically superior and are blessed with favorable conditions for hydroelectric power development.

1.2 Present Situation of Hydroelectric Power in Japan

In Japan, hydroelectric power had been developed as of the end of 1991 to the following levels:

(1) Conventional Hydroelectric Power: approx. 1,700 sites, 20 GW

(2) Pumped Storage Power : approx. 40 sites, 27 GW

1.3 Hydroelectric Power Development System

In Japan, the major part of the development of commercial hydroelectric power stations is being performed by nine private electric power companies and the Electric Power Development Co., Ltd., 34 public corporations owned by local public bodies and another six electricity enterprises.

Besides this, there is another type of hydroelectric power development system. It is integrated river basin development. The developers of electric power, city water, industrial process water, water for irrigation take part in dam projects for the purpose of flood control constructed by the Japanese Government.

In addition, hydroelectric power stations for private use have been developed by railway companies, mining enterprises, agricultural associations, etc.

As an organization concerned with these matters, the New Energy Foundation (NEF) has been providing some business services for executing the national hydroelectric power development policies, such as for technology developments, research and development, subsidiary measures, and so on.

2.1 Significance of Hydroelectric Power Generation

Superior Features of Hydroelectric Power Generation:

(1) Hydroelectric power is indigenous of energy. Besides this, it is a reproducible form of energy that will never be exhausted.

(2) It is a clean energy that does not generate either air pollutions or greenhouse effect gas.

(3) Hydroelectric power is a form of energy with a fully completed level of technology. It also exhibits a high level of energy conversion efficiency. In comparison with the energy required for the construction of a hydroelectric power station, a remarkable amount of energy can be generated by the station itself through its operation. It may be deemed a source of energy whoring a good energy balance.

(4) As a local energy, it is helpful for the activation of local regions.

(5) Although an immense amount of initial investments are required, a hydroelectric power station will prove to be economical in the end, with reduced power generation costs over the long term.

2.2 Roles of Hydroelectric Power in Energy Policies and Development Targets

In 1990, Advisory Committee of Energy of MITI has worked out a summary of long-term energy demand/supply outlook, as shown in Table 1.

These long-term outlook emphasize making the maximum possible effects to save energy in order to suppress the especially strong tendency towards increasing energy consumption in Japan. At the same time, emphasis has been also placed on the promotion of introducing sources of energy which generate little CO_2 (nuclear power, hydroelectric power and new energy sources such as geothermal energy, solar power generation, etc.) as a means of responding to the global warming problem (the problem of climate change).

For hydroelectric power, a goal of about 6 GW has been set for the coming twenty years.

Table 1 Long-Term Energy Supply Outlook

Item / Fiscal year	FY 1989 (actual)			FY 2000			FY 2010		
Primary Energy Supply	499 million kl			594 million kl			657 million kl		
Energy Source	Quantity	(%)		Quantity	(%)		Quantity	(%)	
New Energy Sources etc.	6.5 million kl	1.3		17.4 million kl	3.0		34.6 million kl	5.3	
Hydro (conventional)	88 billion kWh (20.5 GW)	4.6	14.9	91 billion kWh (22.7 GW)	3.7	20.2	105 billion kWh (26.2 GW)	3.7	26.8
Geothermal	0.4 million kl	0.1		1.8 million kl	0.8		6.0 million kl	0.9	
Nuclear	183 billion kWh (29.4 GW)	8.9		330 billion kWh (50.5 GW)	13.3		474 billion kWh (72.5 GW)	16.9	
Natural Gas	49.9 million kl	10.0		65.0 million kl	10.9		80.0 million kl	12.2	
Coal	113.6 million t	17.2		142.0 million t	17.5		142.0 million t	15.7	
Oil	289 million kl	57.9		305 million kl	51.3		298 million kl	45.3	
Total supply	499 million kl	100.0		594 million kl	100.0		657 million kl	100.0	

(Notes)
1. Conversion to oil equivalent is based on a thermal value of 9,250 kcal/liter.
2. "New Energy Sources, etc." includes solar energy, alcohol fuels, factory pulp waste, firewood and others.
3. "Oil" includes oil sand and oil shale.
4. Future socio-economic conditions are uncertain, while energy policy requires a realistic and flexible response, in this sense, the target figures in the estimates should be understood as being flexible rather than fixed.

3.1 Challenges of Hydroelectric Power Development in Japan

(1) Improving its Economic Attractiveness

In Japan, future hydroelectric power development will be supported by medium-scale and small-scale power plants (with a mean capacity of 4,600 kW). As a result, no merits of scale will be achieved. Hydroelectric power generation will tend to be less economical than thermalelectric power generation. It is necessary, therefore, to improve the economic attractiveness of hydroelectric power development.

(2) The Growing Movement of Environmental Protection

In Japan, a larger number of future hydroelectric power plants locates upon national parks in mountainous areas, and it is becoming more and more difficult to obtain the public acceptance of regional inhabitants and other persons for hydroelectric power development. In addition, most hydroelectric power in the future will be of the run-off-river type. Consequently, the water level will be lowered over a several kilometer long section of those rivers. Hydroelectric power development, therefore, is encountering more and more objections owing to the growing nature protection movement, which aims to protect rivers and landscapes from development.

(3) Redevelopment

In Japan, the number of old power stations has increased. From now on, therefore, it will be necessary to rebuild or redevelop them properly.

3.2 Administration of Hydroelectric Power by the Agency of Natural Resources and Energy, Ministry of International Trade and Industry

(1) Organization of ANRE, MITI, and its Hydroelectric Power Development Activities

MITI is organized as shown in **ANNEX** which is attached hereto. Concerning hydroelectric power development, the Electric Power Generation Division of the Public Utilities Department integrally conducts water power surveys, subsidiary measures, safety inspections, and environmental reviews, etc.

(2) Hydroelectric Power Development Promotion by MITI

(a) Incentive to Improve Economic Aspects

- System to Grant Subsidies covering Construction Costs of Hydroelectric Power Stations (1980 on)

Hydroelectric power generation in the future will be on a medium-scale and small-scale, thereby it is difficult to get merits of scale. Furthermore, most future hydroelectric power developments will be located in mountainous areas, making them tend to be less and less economically attractive. With these factors taken into consideration, a system has been established to have a financial assist for hydroelectric power development projects, by covering a certain percentage of their construction costs.

Subsidy Ratio:
5 to 20%, according to the scale of the development

Subsidized Parties:
Public enterprises and other electric power companies.

- System to Award Grants for Payment of a Fixed Rate of Interest on Hydroelectric Power Station Construction Costs (1985 on)

  This system can be selected instead of the subsidies for construction costs; the aim is to reduce the high cost of hydroelectric power generation immediately after startup of operations so as to promote hydroelectric power development. Under this system a fixed rate of interest is paid for a fixed period after initially putting a hydroelectric power station into operation.

- Subsidies for the Electric Power Development Co., Ltd. to Develop Hydroelectric Power (1980 and on)

  This system is similar to the construction cost subsidies. According to the scale of the hydroelectric power development to be carried out by the Electric Power Development Co., Ltd., the construction cost involved is subsidized at 5 to 20%.

(b) Technology Developments to Improve Economic Attractiveness

- Subsidies relating to Hydroelectric Power generating Technologies (1986 on)

  Subsidies are granted for demonstration tests that are conducted to confirm the successful achievements of research and for surveys for improving the economic aspects of medium-scale and small-scale hydroelectric power development.

- Development Support Subsidies, Surveys and Research

  In addition to the subsidies already referred to, a survey subsidy is available to provide guidance that is needed by medium- and small-sized hydroelectric power developers to carry out planing. New Energy Foundation (NEF) has been entrusted with performing a fundamental survey into the development of techniques to measure and collect river discharge data through the use of artificial satellites, etc., based on which hydroelectric power development plans are to be mapped out.

(c) Fiscal Grants to Local Public Bodies to Promote Establishment of Power Source Locations

- Grants to Promote Establishment to Power Source Locations

  In the case of hydroelectric power, local self-governing bodies are entitled to receive a grant to build public facilities in the local city, town or village where a hydroelectric power station with a capacity of 1 megawatt or more is located.

- Grants for areas Surrounding Hydroelectric Power Generating Facilities

  To reduce the effects owing to the presence of dam, reduced water levels, etc., a grant is paid to the city, town or village where a hydroelectric power station has been located and has been operating for a period of 15 years or more after starting operations.

(d) Surveys to Preserve the Environment

- A variety of surveys are being performed to harmonize hydroelectric power development with the preservation of the environment around the related rivers.

(3) Main Codes and Regulations relating to Electric Power Development

(a) Electric Power Development Promotion Act (Economic Planning Agency)

Every commercial power station in Japan must abide by this Act in order to position every power development plan within the National Electric Power Development Fundamental Plan after being examined ad approved by a council (the Electric Power Development Arrangement Council), whose members include men of knowledge and experience and representatives of relevent government agencies.

Before being brought to the Council, an electric power development plan is normally subjected to an environmental review by MITI, as is referred to later.

(b) Electricity Utilities Industry Act (MITI)

This Act provides for granting of approval for those who are to operate an electricity enterprise, for the notification of plans to install electric power facilities, etc., for the standards concerning related technologies and for the permission/authorization of inspections, electric power rates, etc.

A development plan which has passed through the Electric Power Development Arrangement Council is to receive a permit under the Utilities Industry Act. After that, the involved construction may be started.

(4) Other Principal Hydroelectric Power Development-Related Codes and Regulations

Hydroelectric power development in Japan is deeply related to the following codes and regulations:

(a) River Act (Ministry of Construction)

This Act is deeply related to hydroelectric power. It provides for the rights to use the water in rivers and for the technological standards relating to the safety of structures to be constructed on rivers, etc.

(b) Natural Parks Act (Environment Agency)

This Act provides for the management of natural parks, including national ones. Any hydroelectric power development that locates on the areas of a natural park must receive a permit beforehand.

Many other codes and regulations are also related to hydroelectric power development projects.

3.3 Measures for Preservation of the Environment

Environmental Assessment System

Pollution began to be a serious problem in Japan around 1960, with the rapid economic growth at that time as a background. To adopt a new approach to this problem, an Electric Power Station Environmental

Assessments System began to be entroced in 2973. The related environmental reviews have been performed by MITI.

In 1984, moreover, the Environmental Assessment System began to apply to full-scale development projects other than these involving electric power generation. The assessments have been conducted by the relevent government agencies.

In addition, every local public body has also established a similar environmental assessment system under its local ordinances.

Fig. 2 shows the environmental assessment systems relating to power generation.

A survey must be performed in advance by the related developer for a hydroelectric power development location with a capacity of 30 MW or more concerning its effects on the environment, in order to prepare an environmental impact statement.

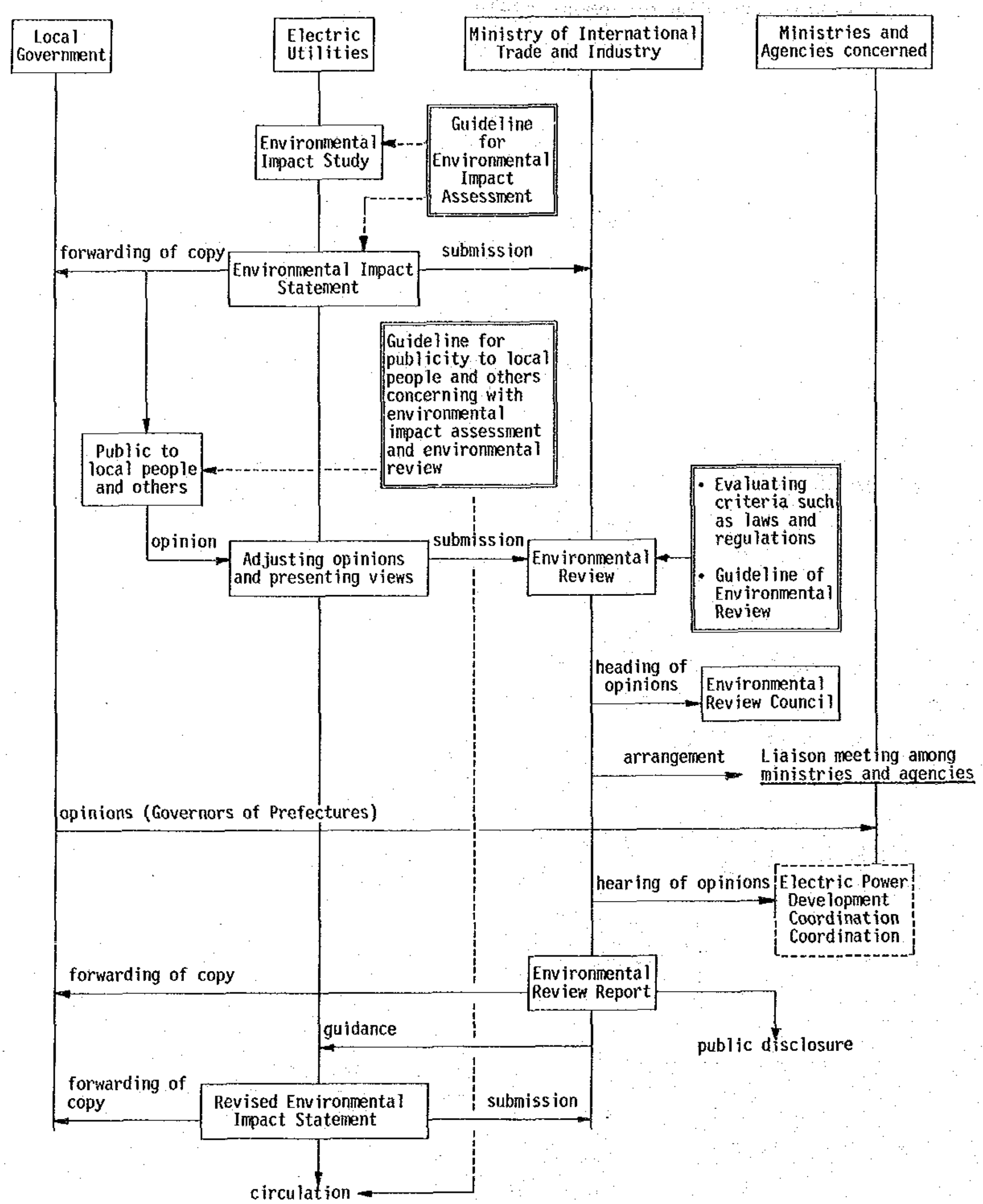
This statement must be submitted to MITI. At the same time, the developer must disclose the statement to the local public at the development location and must also hold explanatory meetings.

Concerning the environmental impact statement prepared by the developer, MITI is to perform an environmental review, based on opinions gathered from environmental review advisers in their respecture fields of specialization and from local inhabitants. After that, MITI is to prepare an environmental review report.

MITI is to then make arrangements with relevent government agencies, in concert with the Electric Power Development Arrangement Council already referred to, so as to arrange the items about which the developer needs to be guided. Thus, MITI renders guidance to have developers improve their proposed environmental protection measures.

The proceedings referred to above have allowed Japan to maintain her environment in a favorable condition thus far with regard to the electric power development field.

Fig. 2 System in MITI for Evaluation of Environmental Influence of Power Plant



- Ministry of International Trade and Industry
- Patent Office
- Small and Medium Enterprise Agency
- Agency of Industrial Science and Technology
  - General Coordination Department
    - *Sunshine Project Promotion Headquarters*
    - Moonlight Project Promotion Office
    - Other Division
  - Standards Department
- Agency of Natural Resources and Energy
  - Director-Generals Secretariat
  - Petroleum Department
  - Coal Mining Department
  - Public Utilities Department
    - Planning Division
    - Electric Power Administration Division
    - Electric Power Development Division
    - Electric Power Technology Division
    - Electricity Power Generation Division
      - • Technology Promotion Office
    - Nuclear Power Division
    - Nuclear Power Safety Examination Division
    - Nuclear Power Safety Administration Division
    - Gas Industry Division
    - Gas Safety Division

Electric Power Generation Division/Technology Promotion Office

Electric Power Generation Division

- Construction work, maintenance and operation of turbine and boiler for hydro-power generation facilities, thermal power generation facilities and nuclear power facilities.
- Coordination of rights on water and land for electric power development.
- Surveys concerning preservation of environment in the peripheral areas of hydro-power generation facilities, thermal power generation, and nuclear power facilities.
- Power generation dams.
- Presenting opinions and recommendations to governors of prefectures concerning the utilization of hydro-power generation facilities.
- Sharing of cost of common facilities used for electric power generation.
- Survey related to development of hydro-power generation.
- Surveys of flow volume of the river and weather etc. related to electric power generation.
- Flow meter coefficient test.
- Inspection for welding of machines and devices related to thermal power generation facilities and nuclear power facilities.
- Rationalization of use of fuels for power generation except nuclear power.
- Geothermal power generation.

Technology Promotion Office

- Technological survey and planning of policy related to electric power generation.
- R&D of high efficiency technology, desulfurization and denitrification technology for coal fired power generation.
- R&D of methanol gas fired power generation technology.
- R&D of hydro-power generation technology.
- R&D of power generation technology with previously unused energy sources.
- R&D of electric power storage technology.
- R&D of environment assessment technology for sitting of power plant.
- International cooperation related to above mentioned technologies.

SMALL-SCALE HYDROELECTRIC POWER GENERATING FACILITIES OWNED BY LOCAL PUBLIC ORGANIZATIONS IN JAPAN

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SMALL-SCALE HYDROELECTRIC POWER GENERATING FACILITIES OWNED BY LOCAL PUBLIC ORGANIZATIONS IN JAPAN

Summary

Japanese electrical companies may be classified into two categories; one is general electric power companies who sell electric power directly to consumers, and the other is electric power wholesalers who wholesale electric power to the general electric power companies on a blanket basis. Public electric power businesses managed by local public organizations belong to the latter category of electric power wholesalers. At present, these public electric power businesses are taking the lead in developing medium-scale and small-scale hydroelectric power stations here in Japan. The Enterprises Bureau in the Prefectural Government of Gunma manages the largest public electric power business nationwide, with a total of twenty-one power stations constructed so far.

Out of the power generator facilities owned by the Enterprises Bureau in the Prefectural Government of Gunma, three different power stations have been selected for description here as representative types from the viewpoint of small hydroelectric power generation development. These three power stations are the Tenguiwa (540 kilowatts), Kiryugawa (470 kilowatts) and Hiroike (4,200 kilowatts). An outline of the power generating facilities at each of the stations referred to above will be introduced to the reader, including a description of their new technologies and design fundamentals.

The design of the Kariyado Power Development Project (1,200 kilowatts) will also be outlined and introduced to the reader below. The situation of this project may be considered to relatively resemble that in the upstream basin of the Riwagu River in the Ranau District, Province of Sabah, and a description will be given of the principles based on which the Enterprises Bureau of Gunma Prefecture has been acting in developing small-scale hydroelectric power generation. Some of the critical problems that must be tackled to promote the development of small-scale hydroelectric power generation are cost reduction and environmental preservation.

SMALL-SCALE HYDROELECTRIC POWER GENERATING FACILITIES OWNED BY LOCAL PUBLIC ORGANIZATIONS IN JAPAN

Akira ISHIKAWA
Electricity Generation Division
Bureau of Public Utilities
Gunma Prefectural Government
JAPAN

1976 :	Graduated from Civil Engineering Course, Kanazawa University, and immediately took office in the Gunma Prefectural Government.
1976-80 :	Engaged in surveying and supervising works involving housing and industrial development.
1981-83 :	Engaged in design and work supervision in the hydroelectric power station construction field.
1984 :	Engaged in planning a new power station project.
1985-87 :	Engaged in surveying the multipurpose dam construction.
1988-89 :	Took the office in charge of public enterprise management planning, in addition to water resource surveys.
1990 on :	Is once again engaged in hydroelectric power generation survey and construction services. At present, holds office in the capacity of Survey Section Chief, Electric Power Generation Section, Enterprises Bureau, Gunma Prefectural Government, and is in charge of planning and designing hydroelectric power stations and of making arrangements with related government organs while promoting the development of medium-scale and small-scale hydroelectric power.

SMALL-SCALE HYDROELECTRIC POWER GENERATING FACILITIES OWNED BY LOCAL PUBLIC ORGANIZATIONS IN JAPAN

Section 1 : Role to be Played by Public Electricity Enterprises in Small-Scale Hydroelectric Power Development

1.1 Public Electricity Enterprises in Japan

Electric power enterprises in Japan can be classified into two categories; general electric power companies and electric power wholesalers. General electric power companies sell electric power which they generate themselves or purchase from electric power wholesalers directly to the users who require electricity. The electric power wholesalers, on the other hand, do not sell any electrical energy directly to the user, but wholesale it entirely to the general electric power companies. All general electric power companies are privately owned, and as a whole they conduct operations all over the nation, divided into ten sales territories. The electric power wholesalers include some private companies such as the Electric Power Development Co., which is partially owned by the Japanese Government, and others owned by local public organizations such as public corporations. Electric power companies managed by local public organizations are called "public electricity enterprises."

From a historical point of view, the first public electricity enterprise was established in 1909. In those days, such enterprise supplied power generally on a regional basis. Later, in 1938, the national government began to control electric power while public electricity enterprises were merged into a nationally controlled company. After the end of World War II, however, demand for electric power rapidly increased, coupled with the reconstruction of the nation and its industries. To meet requests for regional promotion, etc., moreover, an overall river development project was promoted on a full scale, and public electricity enterprises consequently came to actively participate in the project. In 1951, moreover, electric power companies were reorganized and converted to the existing scheme whereby electric power companies supply power on a region by region basis. Coupled with this, public electricity enterprises adopted their current form of business, whereby the electricity they produce is not supplied ot the general public but is wholesaled to electric power companies on a blanket basis.

From the second half of the 1960s, the Japanese economy entered into a growth period. In those days, electric power companies constructed full-scale thermoelectric power stations, based on the supply of low-priced oil. As a result, hydroelectric power development by public electricity enterprises slowed down temporarily. With the oil price hikes that erupted from 1973 on, however, it became a major national priority to secure energy sources to substitute for oil. Consequently, public electricity enterprises, which are the leaders in medium-scale and small-scale hydroelectric power development, are now positively tackling the development of hydroelectric power as a clean energy source.

At present, there are public electricity enterprises managed by thirty-four local public organizations throughout the nation. They now have 243 hydroelectric power stations in operation, with a maximum output of 2.37 million kilowatts and an annual available power supply of 9.5 billion kilowatt-hours. Besides this, 32 power stations are now under construction, with a maximum output of 160 thousand kilowatts and with an annual available power supply of 0.62 billion kilowatt-hours (as of April, 1991).

The power stations now in operation have a mean output of 10 thousand kilowatts per station, while those under construction will attain a mean output of 5 thousand kilowatts. A decrease in the number of locations blessed with a situation favorable for building a power station has halved the development size per station. Thus the power station locations to be planned from now will become smaller in size, accordingly. Consequently, many such locations will be high in cost, bringing about low merits of scale, so subsidies and technological developments will be essential requirements to reduce the costs. To achieve an overall decrease in costs, including those for maintenance and management, moreover, it will be necessary to come up with creative contrivances using drastically new concepts.

1.2 Role to be Played by Public Electricity Enterprises

At present, medium-scale and small-scale hydroelectric power development in Japan is being led by the public electricity enterprises. This is mainly because the points at which medium-scale and small-scale hydroelectric power will be developed in the future will be mostly located under unfavorable conditions. Under these circumstances, public electricity enterprises will be able to easily work out a development plan in harmony with regional development and readily establish a system of cooperation with related administrative organizations. In addition, these enterprises have been advantage in that they are able to make effective use of benefit systems in which funds may be raised at a low interest rates and in which fiscal subsidies may be granted on a preferred basis.

Public electricity enterprises wholesale their product electricity to private electric power companies. Compared to other public corporations that render services directly to regional inhabitants, therefore, these enterprise may give the impression of being only loosely connected with the region. Nevertheless, public electricity enterprises have been contributing to the improvement of public welfare through hydroelectric power development in the following ways:

- By contributing to the stable supply of national and regional electricity, with hydroelectric power as a clean energy that is wholly produced domestically,

- By helping to build up the public interest and welfare of regional inhabitants in cooperation with flood control and water-utilization activities by participating in overall river exploitation projects as a co-developer,

- By striving to promote the regional employment and regional industries by executing works to construct power-generating facilities.

- By furthering the stabilization of the financial situation of municipal authorities and the buildup of public facilities under the subsidy system whereby subsidies are granted to the municipal authorities where such power stations are located, and

- By contributing to the inhabitants' welfare by spending electricity enterprise operating profits on measures to aid the region.

1.3 Enterprise Bureau of Gunma Prefecture

Japan in divided into 47 prefectures. Gunma Prefecture is located nearly at the center of Japan, having an area of 6,363 square kilometers, extending 96 kilometers in the east-west direction and 199 kilometers in the north-south direction. It has a population of approximately 1.96 million. Out of the 47 prefectures, Gunma is ranked 21st in area, 19th in population and 17th in gross prefectural product. Thus, it may be deemed to be a prefecture that ranks nearly at the average level. Approximately two thirds of the land in the prefecture is covered with hills and mountains. From the west to the north of the Prefecture, there are imposing mountains of the 2,000 meter high class. The source of the Tonegawa River, which has the largest drainage basin area in Japan (extending over a total of 152 kilometers), starts in the mountainous zone to the north of the Prefecture. This river pierces the Kanto plains while absorbing the discharge from medium- and small-sized rivers from various regions, and finally flows into the Pacific Ocean. Gunma Prefecture has an annual rainfall of approximately 1,700 millimeters, which is also the mean numerical value for nationwide rainfall in Japan. The mountainous zone to the north of the Prefecture, however, is an area with heavy snowfall in the winter season. This ample water flow has been used for many years to construct hydroelectric power stations.

The Enterprises Bureau of Gunma Prefecture was established in 1958 and thereafter started to operate an electric power business. Later, however, it began to develop new businesses one by one in response to the needs of the times. At present, it conductors such businesses as housing and industrial development, water-supply for industry, tool road management, tourism facilities and general water-supply in addition to its electricity provision business. At present, the electric power generation business continues to be the mainstay of the Bureau.

The Bureau's electric business began with Aimata Power Station (7,300 kilowatts) and the Momono Power Station (6,200 kilowatts), both constructed as part of a overall river development project with which the Japanese government had been promoting in 1958. At present, 21 power stations have been completed, outputting a total of 211,910 kilowatts to supply electricity of 0.8 through 0.9 billion kilowatt-hours. We are proud that this is the largest business scale among the public electricity enterprises all over the nation. Table 1.1 shows a list of the power stations owned by the Bureau.

At present, the Kumakura Power Station, with a maximum output of 2,900 kilowatts, is under construction. Nevertheless, the development of medium-scale and small-scale hydroelectric power plants is scheduled to be positively promoted continually from now on. The Bureau has been proceeding with studies and research concerning the utilization of wind force, solar and geothermal energy not limited itself to hydroelectric power only. Thus, the Bureau has adopted the policy of performing its role as a public electricity enterprise while giving due consideration to environmental pollution problems as well.

Table 1.1 Hydraulic Power Station of Gunma

Power station name	Maximum discharge (m^3/sec)	Effective head (m)	Maximum output (kW)	Completed Year
AIMATA	10.00	91.00	7,300	1958
MOMONO	11.50	66.34	6,200	1958
NAKANOJO	12.57	106.30	11,000	1960
SHIMA	4.80	130.65	5,000	1961
SHIRASAWA	20.00	151.70	26,000	1964
TONAMI	14.00	46.10	5,300	1964
YUKAWA	4.50	213.00	8,200	1965
TAGUCHI	58.20	12.40	6,000	1966
SEKINE	99.00	9.50	7,800	1967
KOIDE	78.10	12.90	8,400	1967
YANAGIHARA	90.10	10.00	7,500	1967
SHIMOKUBO	12.00	148.62	15,000	1968
TAKATSUDO	30.00	21.30	5,300	1973
ODAIRA	24.29	171.79	36,200	1976
AZUMA	24.00	100.48	20,300	1976
SOHRI	15.30	85.00	11,000	1981
TENGUIWA*	10.40	7.36	540	1982
YAGURA	7.00	137.75	7,800	1983
KIRYUGAWA*	1.80	39.00	470	1984
HIROIKE*	6.50	80.30	4,200	1986
NARAMATA	11.00	133.30	12,400	1989
TOTAL			211,910	

* : The detailed are described in Section 2.

Out of the power generating facilities owned by the Bureau, three power stations, i.e. Tenguiwa (540 kilowatts), Kiryugawa (470 kilowatts) and Hiroike (4,200 kilowatts) with different sizes, will be introduced to the reader by giving their outlines from the viewpoint of small hydroelectric power generation.

2.1 Tenguiwa Power Station

Maximum discharge	:	10.4 cubic meters per second
Effective head	:	7.36 meters
Maximum output	:	540 kilowatts
Type of hydraulic turbine	:	horizontal axis fixed vane propeller hydraulic turbine 457 million yen (9.140 million M$)

(1) Backgrounds of the Construction

Twenty and several years ago, this location began to be studied for a plan to construct a power station. On those days, however, it was unfeasible owing to the poor economical justiciability. Later or in 1973, small hydroelectric power generation began to be reviewed due to a hike of oil prices. With the lead taken by the National Government, a trend toward the development of medium-scale and small-scale hydroelectric power uprose and a variety of technologies started being studied to reduce the development cost. On that occasion, the "study and research into small hydroelectric power generating systems with low falls" was commenced. A man from the Bureau took part in the research as one of its researchers. As a result of this research, a conclusion was reached to the effect that a hydroelectric power generation even with a low fall could be economically justifiably developed, with new technologies introduced.

In response to that conclusion, the National Government (Ministry of International Trade and Industry) founded a national subsidy grant system for the development of medium-scale and small-scale hydroelectric power in 1980. To promote the energy development and continually proceed with the research and development on new technologies, moreover, the Ministry established the New Energy Foundation. This foundation made a nationwide survey on the locations to develop, together with the research into new power station models suitable for a low flow with a low fall. As a results, Tenguiwa was selected as a candidate location. This point was found suitable for a new power station model, i.e. a built-in type hydraulic turbine generator (horizontal axis fixed vane propeller hydraulic turbine).

The built-in type hydraulic turbine power generator literally has a hydraulic turbine unified with a generator and it is suitable for a low flow rate of water (about 0.5 through 4.0 cubic meters per second). If a few units of an identical built-in type hydraulic turbine power generator are installed according to an actual flow rate, moreover, it will be possible to design and construct the power station at a lower cost. Thus, this power generator may be considered matching with the objective of developing small hydroelectric power.

(2) Power Generating Plan

Coupled with the development of the built-in type hydraulic turbine power generator, a "reliability demonstration test" thereon was decided to carry out at the Tenguiwa location. Since 1981, therefore, the Enterprises Bureau of Gunma Prefecture has been striving to promote the power generating plan.

The special conditions for locating the Tenguiwa Power Station lay in the power generating plan with a farming water channel utilized. An idle head of 7.36 meters existing in a farming water channel was utilized to generate a maximum output power of 540 kilowatts. And structures involved were installed along the water channel. This farming water channel is mainly used to replenish water to rice fields and has its water flow vary significantly from season to season. So, it was planned to install four identical hydraulic turbine power generators, whose operating number should be changed according to a decrease or increase in water flow. The power station was subject to the following specifications divided into irrigation and non-irrigation seasons:

- Irrigation season (June 1 through September 25)

Maximum discharge	:	10.4 cubic meters per second
Effective head	:	7.36 meters
Maximum output	:	540 kilowatts (with four generators put into operation)

- Non-irrigation season (September 26 through May 31)

Maximum discharge	:	2.66 cubic meters per second
Effective head	:	8.12 meters
Maximum output	:	150 kilowatts (with one generators put into operation)

(3) Design and Execution of Work

The work was planned to be completed entirely within the season at a low flow rate of water and the hydraulic turbine power generators were scheduled to start being installed simultaneously with the completion of the civil engineering work. As planned, the work was commenced in February, 1982 and the power station started to operate in June, same year. Its main facilities were designed while the work was executed with features as follows:

- Existing farming water channel

The existing farming water channel was constructed in 1952. Typhoons and other weather conditions thereafter, however, brought a deposition of soil and sand into the channel. The soil accumulated was carried out and those portions superannuated were repaired to maintain its functions as a water channel.

- Head tank

The farming water channel had its bank raised intermediately. It was decided, therefore, to raise the bank over an upstream section of about 200 meters from the water tank. A water control gate was provided in the head tank and screens were installed at intervals of 4 centimeters in the upstream to effectively collect dust. An excess water channel, moreover, was constructed as a deservoir with an extension of 30 meters diagonally across the existing water channel. From this deservoir, the water was made to overflow into the existing farming water channel.

- Penstock, power station and afterbay

The power station was so constructed as to be equipped with four hydraulic turbine power generators outdoors so that it would be operated while controlling the number of generators in operation as the feature of a built-in type hydraulic turbine power generator. As tailored to this construction, a steel pipe structure was required and an Etcherwiss type branch pipe was employed. The afterbay, moreover, was arranged as displaced approximately every three meters to avid mutual interference after studying the area and depth at which the hydraulic jump discharged out of the hydraulic turbine should be stabilized.

(4) Power Station Equipment

For main equipment, the power station employed the built-in type hydraulic turbine power generator, a new model selected by the National Government for the research and development of new technologies. To secure an efficient operation according to a change in flow rate of farming water, four generators of an identical model were installed, with consideration given to a decrease in cost through standardization.

The built-in type hydraulic turbine type generator employed a fixed vane type propeller hydraulic turbine and a cage-type inductor motor in the generator unit. With the hydraulic turbine runner vane incorporated inside the rotor, the generator was of outdoor type monoblock construction.

(5) Funds

The power station required a total project cost of 457 million year at a unit construction price of 850 thousand yen per kilowatt in power generated. For funds, a fiscal subsidy was granted to cover 50% of the portions required for the built-in type power generator, a subject of the demonstration test, and 15% of any portions other than that, considering that it was the first experimental case of new equipment recommended by the National Government. The funds could be broken down into a fiscal subsidy of 119 million yen, a borrowing of 264 million yen and a self-owned fund of 75 million yen.

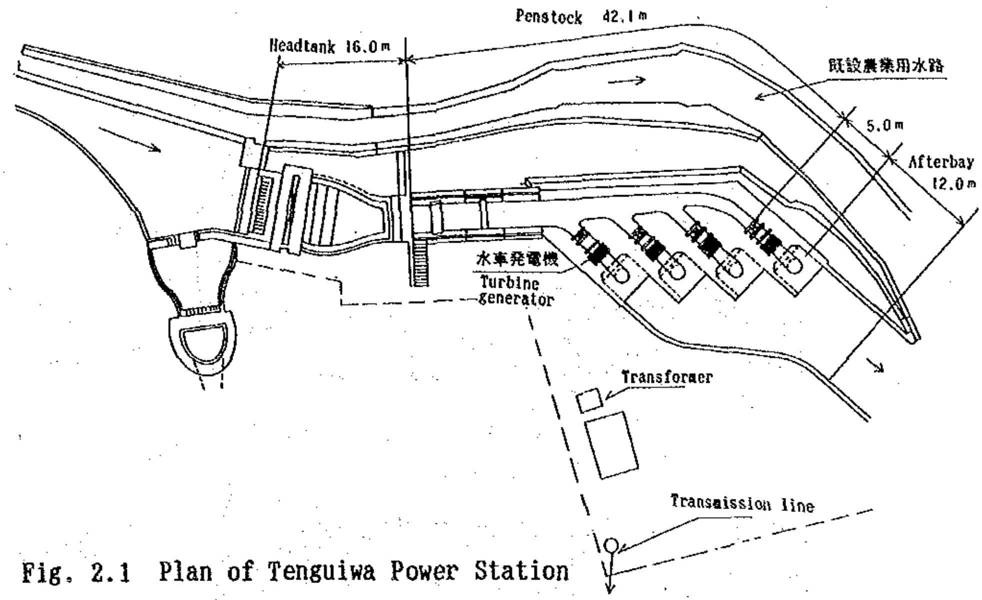

Fig. 2.1 Plan of Tenguiwa Power Station

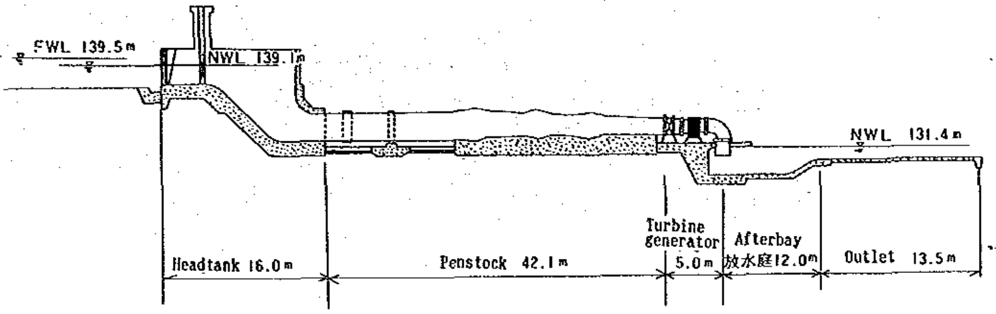

Fig. 2.2 Section of Tenguiwa Power Station

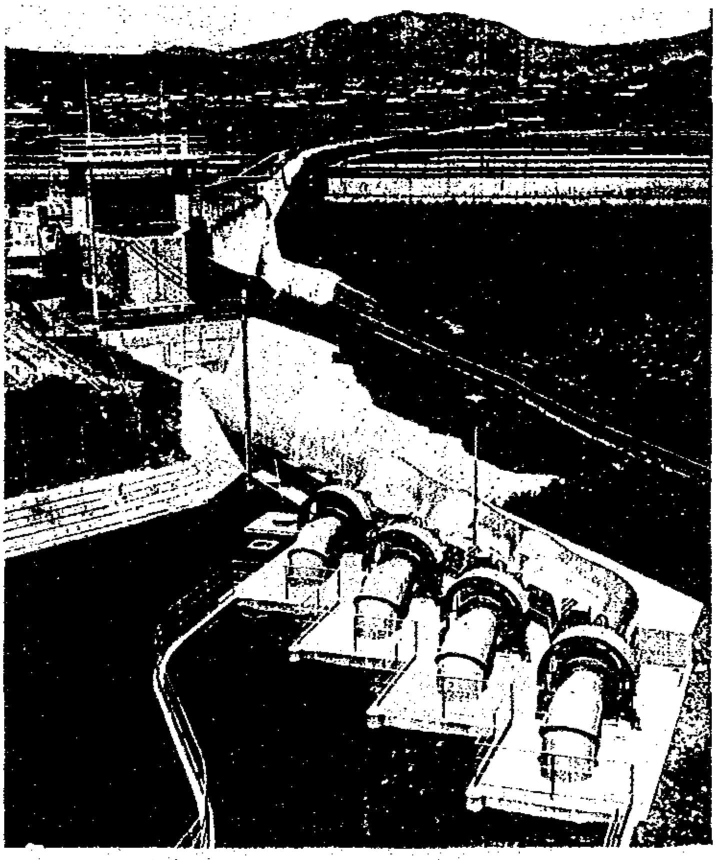

Fig. 2.3 General view of Tenguiwa Power Station

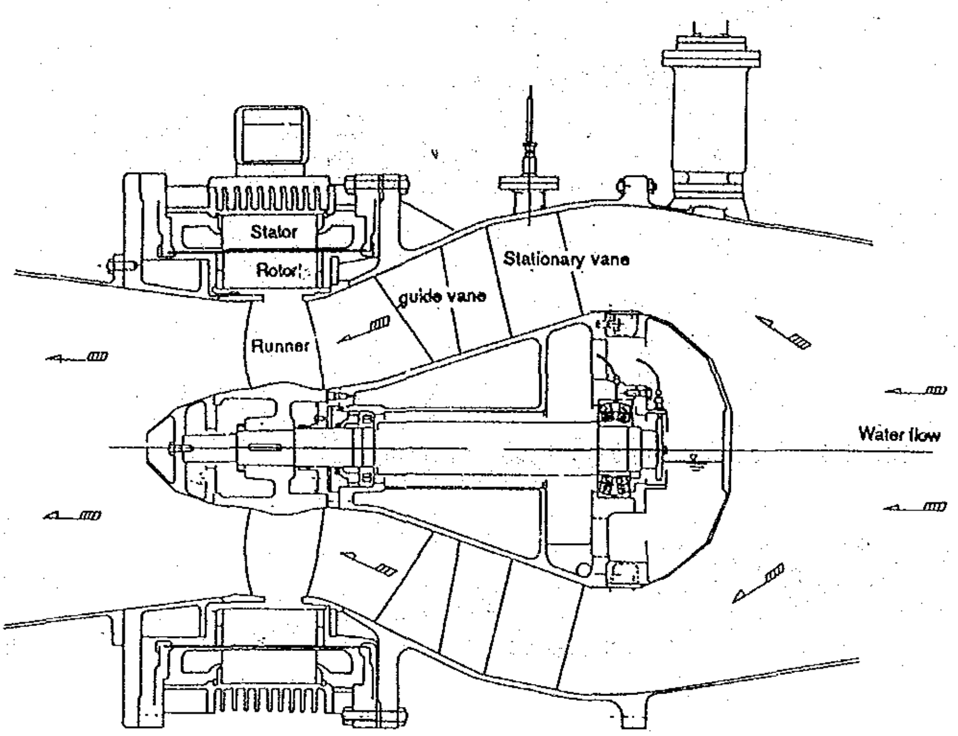

Fig. 2.4 Section of built-in type hydraulic turbine generator

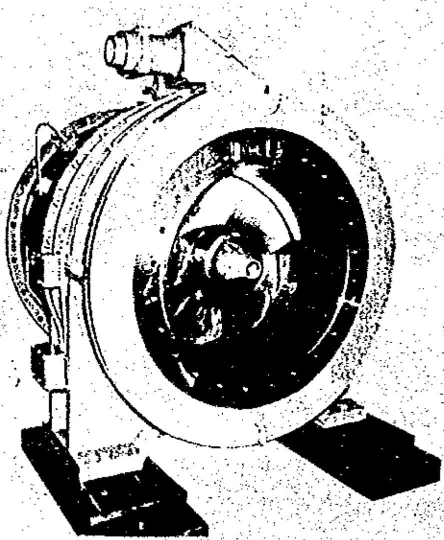

Fig. 2.5 View of built-in type hydraulic turbine generator

2.2 Kiryugawa Power Station

Maximum discharge	:	1.8 cubic meters per second
Effective head	:	39.00 meters
Maximum output	:	470 kilowatts
Type of hydraulic turbine	:	horizontal axis cross-flow hydraulic turbine
Total project cost	:	287 million yen (approximately 5.7 million M$)

(1) Kiryugawa Dam Construction Plan

The Kiryugawa Dam was of multi-purpose type owned by the Prefectural Government of Gunma, whose construction was commenced for the purpose of regulating floods, maintaining the normal functions of flowing water and supplying city water. It was a gravity type concrete dam 60.5 meters high, with a bank top level of 264 meters and with a total water storage capacity of 12 million cubic meters.

- At 410 m^3/sec of the design high water flow or 560 m^3/sec in the dam location, floods were be regulated to eliminate a possible flood disaster in the downstream of the dam.

- The formal functions of flowing water were be maintained by replenishing the water already consumed along the Kiryugawa River in the downstream of the dam.

- It was made possible to take city water newly at a rate of 34,500 cubic meters per day (0.4 m^3/sec.)

For the dam construction plan, a substantial survey was started in 1972 and the construction work was commenced in 1974.

(2) Power Generation Plan

When the dam construction project was started, the Enterprises Bureau could not take part in the plan to generate power by use of the Kiryugawa dam because the costs for the dam had been allocated ambiguously and the project itself could not be deemed economically justifiable. The oil crisis which took place twice in 1970s, however, changed the oil-substitute energy development over to one of national projects. as a results, the hydroelectric power generation was recognized again in the needs for diversification of electric power sources. In 1980, moreover, the "Medium-scale and Small-scale Hydroelectric Power Development Subsidy Grant System" began to operate so that the power generation plan turned out feasible in the long run. As a result, the project took such an irregular form that the power generation plan was made to take part in the project in 1982 when the dam body had been constructed almost completely. The power generation plan was allowed to take part under the fundamental conditions as follows:

- The water reservoir operation plan was not to be changed at all.

- No dedicated power generation capacity is provided.

- The poser station was to be managed by the power generating enterprise.

- For the power generation plan to take part in the project, the costs involved were to be allocated on a dual basis; one was to bear a portion of the total dam project costs (primary allocation) and the other to bear the cost for selective water intake equipment (secondary allocation).

The primary allocation was broken down into 85.9% for flood control, 13.8% for city water and 0.3% (69 million yen) for power generation. For the secondary allocation, the Bureau was to bear 16.8% (35 million yen) as calculated from the maximum working water flow ratio of river management to power generation.

In the power generation plant, water was to be taken through a river management discharge pipe from the surface intake equipment located on the body of the Kiryugawa River dam (at the maximum intake water flow of 8.9 cubic meters per second). And the water so taken in was to be branched at a distance of approximately 40 meters from the starting point at the maximum flow rate of 1.8 cubic meters per second. From this branching point, an approximately 28 meters long power generating pipe was provided to guide the water to the power station located just below the dam. An effective head of 39 meters was used to generate a maximum power of 470 kilowatts. After generating the power, the water was discharged into the stilling basin for the existing water-utilization/outlet works.

(3) Design and Execution of Work

The power generation plan was made to take part in the dam project near its completion. In the stages when the power station work was executed, the dam body work had been already completed mostly while test bonding had started. In August, 1983, therefore, the power station work was commenced in accordance with the test bonding plan. And the power station started to operate in June, 1984 subject to the start of discharge in the dam.

The water intake port for the dam surface water intake equipment was jointly used. Since the front screen had so rough a bar pitch as 10 centimeters, however, the power station work was provided with a trash boom at a bar pitch of 5 centimeters in front of the screen, with a possible adverse effect of water chips, etc. on the hydraulic turbine taken into consideration.

(4) Power Station Equipment

To select a hydraulic turbine, a study started concerning two types; i.e. Francis hydraulic turbine and cross flow hydraulic turbine, considering that the effective head varied from a maximum of 39 meters to a minimum of 13.2 meters and that the working water flow changed from a maximum of 1.8 cubic meters per second to a minimum of 0.5 cubic meters per second. As a result of this study, it was decided to employ the cross-flow hydraulic turbine, which was probably adaptable with both changing falls and flows, had a simple construction and could be delivered within a short term. Besides, the guide vane of 2:1 split type was adopted to increase the efficiency as lightly loaded.

This hydraulic turbine was the largest cross-flow type available in Japan on those days when the Kiryugawa Power Station was constructed. With the field-proven production increased later, however, the hydraulic turbine came to be employed in a 1,000 kilowatt power station, too.

(5) Funds

The Kiryugawa Power Station required a total project cost of 287 million yen at a construction unit price of 610 thousand yen per kilowatt in power generated. The funds raised could be broken down into a fiscal subsidy of 37 million yen, a borrowing of 165 million yen and a self-owned funds of 85 million yen.

A fiscal subsidy for medium-scale and small-scale hydroelectric power development, meanwhile, was mandatorily limited to a subsidy ration of 5 through 15% by output size. A power station with a capacity of 5,000 kilowatts and below was entitled to a fiscal subsidy of 15%. This subsidy ratio applied to the Kiryugawa Power Station. Nevertheless, it did not apply to the total project cost since the project included those portions which could not be deemed applicable to the subsidy.

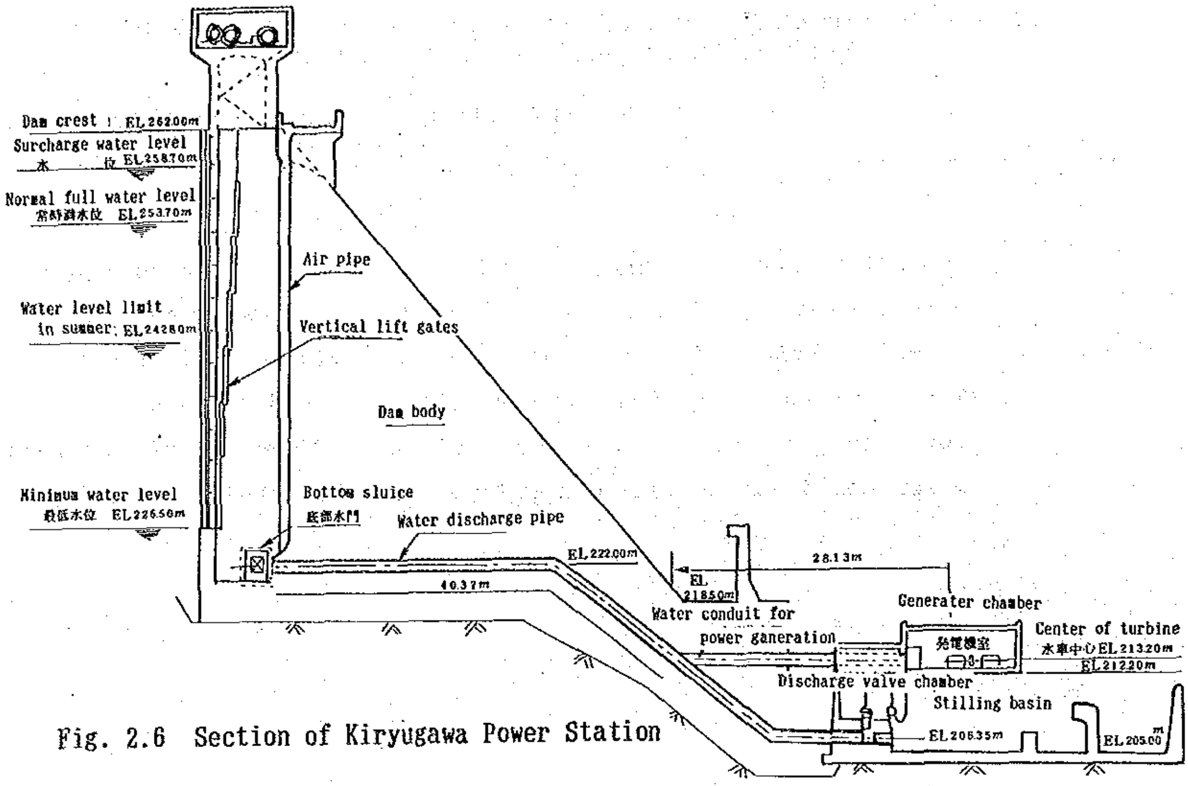

Fig. 2.6 Section of Kiryugawa Power Station

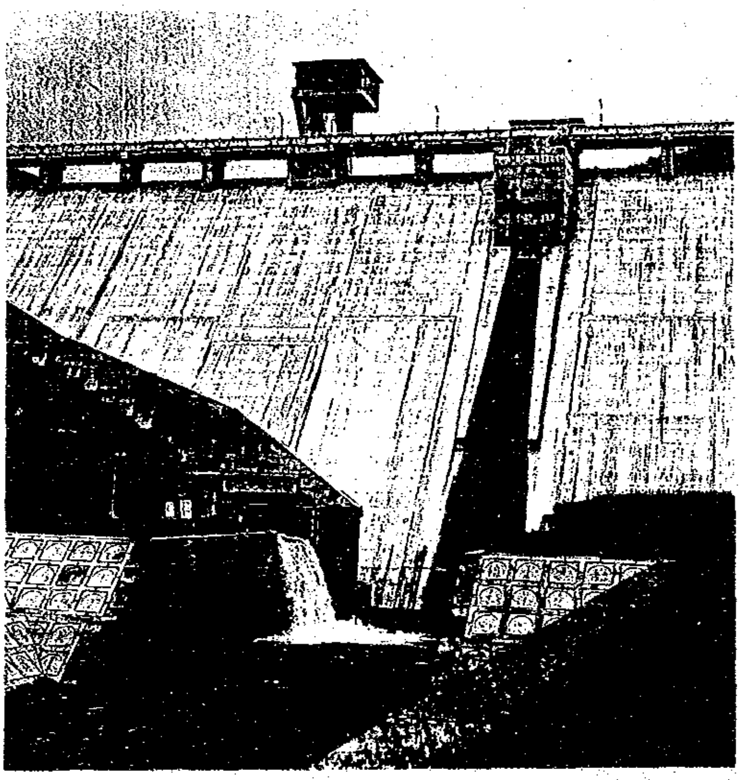

Fig. 2.7 General view of Kiryugawa Power Station

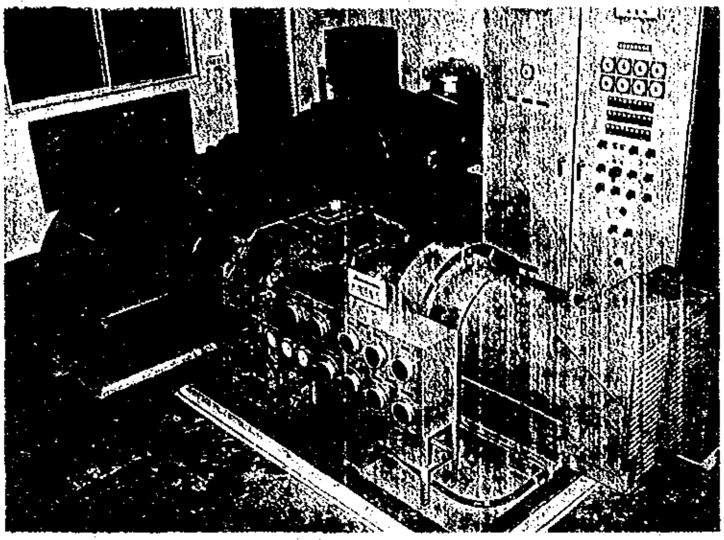

Fig. 2.8 View of cross-flow hydraulic turbine generator

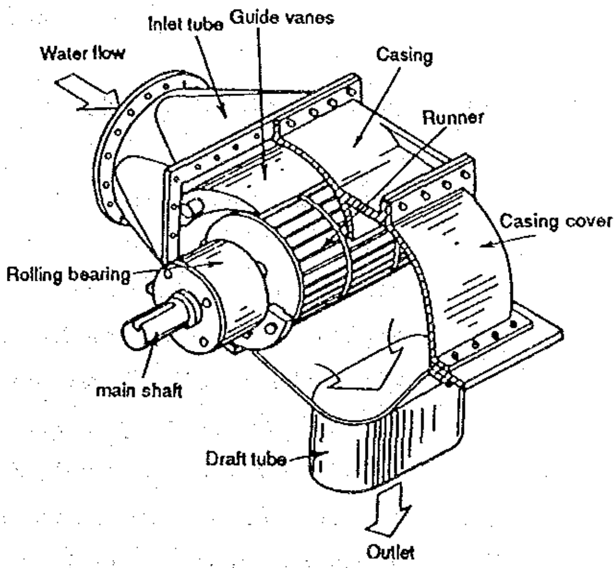

Fig. 2.9 Structure of cross-flow hydraulic turbine

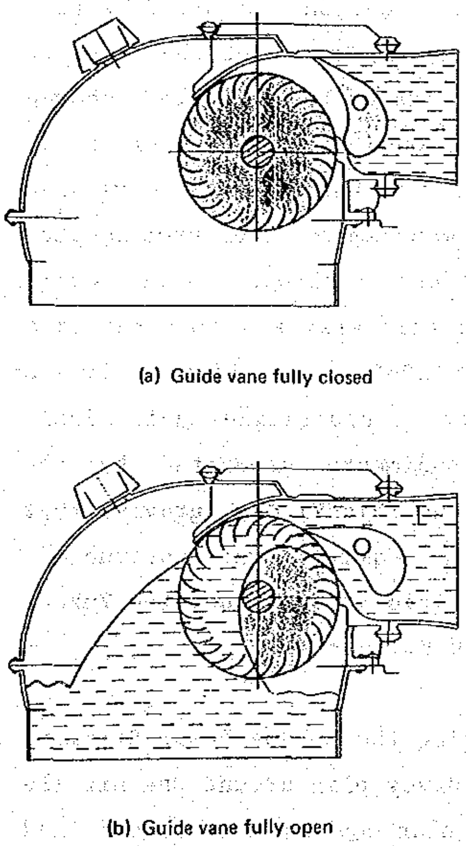

Fig. 2.10 Section of cross-flow hydraulic turbine

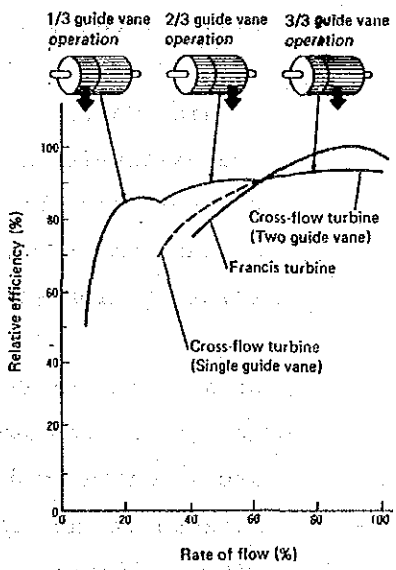

Fig. 2.11 Efficiency curves

2.3 Hiroike Power Station

Maximum discharge	:	6.5 cubic meters per second
Effective head	:	80.3 meters
Maximum output	:	4,200 kilowatts
Type of hydraulic turbine	:	vertical axis Francis hydraulic turbine
Total project cost	:	4,256 million yen (approximately 85.1 million M$)

(1) Backgrounds of the Construction

Since the upstream mountainous area had the soil denatured by hot springs, the rivers in this area had the water of high acidity started to flow from such soil. Many locations had acidic water. Especially the Yukawa River, an upstream branch of the river on which the Hiroike Power Station was planned to be located, showed so high an acidity level of pH = around 2 or 3. This highly acidic water was not only inapplicable to the irrigation but also brought serious damage to the river management structures located along the coast. The Bureau, therefore, took part in an overall river development project covering this area and constructed a neutralizing plant in 1961 through 1966 to continually dose a lime emulsion into the rivers so as to neutralize their highly acidic water. To store the sediments generated by the neutralization in the downstream, the Shinaki dam (gravity type concrete dam with a bank height of 43.5 meters) was constructed. At the same time, this dam was utilized to construct the Yukawa Power Station (maximum output 8,200 kilowatts).

As a series of developments following the Yukawa Power Station, the Bureau was proceeding with a survey plan around the Hiroike area. On those days, however, the plan could not be concertized because it was not profitable enough from an economic point of view. Similarly to the Tenguiwa and Kiryugawa Power Station cases introduced to you in the preceding sections, however, the Hiroike Power Station came to be really constructed as an independent electric power development point owing to a change in environments surrounding hydroelectric power generation and to the establishment of a fiscal subsidy system.

(2) Power Generation Plan

In the Hiroike Power Generation Plan, a 7.3 meters high intake weir was located on the Shirasunagawa River just below the meeting point of a branch in the downstream of an outlet for the existing Yukawa Power Station owned by the Bureau. And the water was taken in at a maximum flow of 5.77 cubic meters per second from that intake weir and led into a settling basin through a headrace channel with a total extension of 580 meters. After settling down sand there, the water was led into a head tank through a 3,640 meters long headrace channel at a maximum flow rate of 6.5 cubic meters per second together with an intermediate intake from streams on the way. From this head tank, the water was further led to the power station by way of a 151 meters long penstock to generate electric power at a maximum output of 4,200 kilowatts, using an effective head of 80.3 meters. The flowing water after generating the power was discharged in the upstream of the intake weir for the existing power station owned by an electric power company through a 595 meters long tailrace tunnel across the Sirasunagawa River.

(3) design and Execution of Work

The Hiroike Power Station had a total tunnel extension of 4.8 kilometers with headrace plus tailrace. And these tunnels, work governed the term required to complete the power station. In June, 1984, the work was commenced and the power station was put into operation in two years and one month or in July 1986 as originally planned.

■ Intake weir

To determine a design flood flow rate at each intake weir, a centurial probability rainfall of 257 millimeters per day was obtained, based on the data collected at rainfall observatories in the vicinity. And this probability rainfall was used as the basis to calculate a design flood water flow rate at each location for the purpose of arithmetically obtaining a safety factor of each structure.

The intake weir on the Shirasunagawa River, main river for the power station, was made of concrete and provided with a sediment discharge gate, having a bank height of 7.3 meters, a crest length of 53 meters and a bank volume of 3,200 cubic meters.

The three torrent intake facilities were of Tirol type, with consideration given to the simplification of maintenance and management, including the riverbed situations at the site. For structural features, these facilities had their shapes and dimensions determined by the use of 1/5 prototypes so that sand and soil might not enter readily into the headrace and that the river could take in water effectively. The crest, moreover, was lined with pebbles to prevent the bank from being worn out.

■ Settling basin

The setting basin was designed into a 17 meters long and 7 meters wide single tank subject to a design flow rate of 5.77 cubic meters per second, an internal mean flow rate of 0.3

meters per second and a minimum sediment particle size of 1 millimeter. Besides, the settling basin was provided with horizontal overflow type excess water discharge and a sand-flash gate at a bed gradient of 1/20, with sand flash taken into consideration.

- Headrace and tailrace tunnels

The tunnels had a total extension of approximately 4.8 kilometers, which occupied a high percentage of the construction cost. In terms of work execution process, moreover, they governed the progress of the entire work execution. As a result, importance was not attached to how less costly they could be dug but how promptly they could be completed. For excavation, the headrace and tailrace tunnels were made through a simple repetition of drilling, explosive-charging, blasting, mucking and timbering. The machinery employed was selected in an appropriate combination after making a comprehensive examination of tunnel lengths and geological conditions on a section by section basis.

- Penstock and spillway

Both penstock and spillway comprised the upper tunnel portion across under a road, the middle exposure portion and an embedded shaft lower than the reclaimed level of the power station, with anchor blocks located in their boundaries.

The spillway was located below the penstock at a road-crossing portion, with the section stability taken into consideration. With these conditions taken into account, the spillway had plane and cross-section designed into a complex linear box culvert with vertical and horizontal curves made at several locations. And structures involved were determined, therefore, while making certain of safety by conducting a hydraulic phototype test, including the stilling work.

- Power station

The power station was designed into a semi-underground reinforced concrete construction with a square section, based on the geographical and geological conditions. With each floor designed to have a minimum possible area, the structures supporting the main equipment were of dual-floor construction while an overhead crane (with a lifting capacity of 15 tons) was installed to place the equipment in position.

(4) Power Station Equipment

Judging from both effective fall and working water flow, a hydraulic turbine of either vertical or horizontal shaft was applicable within a range of Francis hydraulic turbine applications. As a result of making a comprehensive comparison study, however, it was decided to employ the vertical shaft Francis hydraulic turbine, which generates a large quantity of electricity and has an economic advantage, accordingly.

To operate the hydraulic turbine guide vane, an electric servo motor system was employed, which allows us to dispense with a hydraulic unit and other ancillaries and is easy to operate in comparison with the conventional hydraulic system. This was aimed at reducing the building area while striving to economize and simplify the power station equipment by making the entire power station free from oiling, with inlet valves and other auxiliaries electrified as well. To control the power station, a remote control system was employed to conduct monitoring as required and it was provided with the equipment which permits us to remotely monitor and control at a control station located at a distance of 19 kilometers.

(5) Funds

The Hiroike Power Station required a total project cost of 4,256 million yen at a construction unit price of 1.01 million yen per kilowatt in power generated. The funds raised could be broken down into a fiscal subsidy of 769 million yen, a borrowing of 2,044 million yen and a self-owned fund of 1,443 million yen.

As already referred to concerning the Kiryugawa Power Station, a fiscal subsidy ration of 5 through 15% applied to a medium-scale and small-scale hydroelectric power development. This subsidy, however, was never sufficient for the full promotion of medium-scale and small-scale hydroelectric power developments. As a results, a system to exceptionally provide the subsidy with an extra of 5% was established in 1982 for those locations which might be economically disadvantageous and difficult to start a development but deemed appropriate to develop in earlier stages. And this system was adopted for the Hiroike Power Station so that a fiscal subsidy ratio of 20% applied.

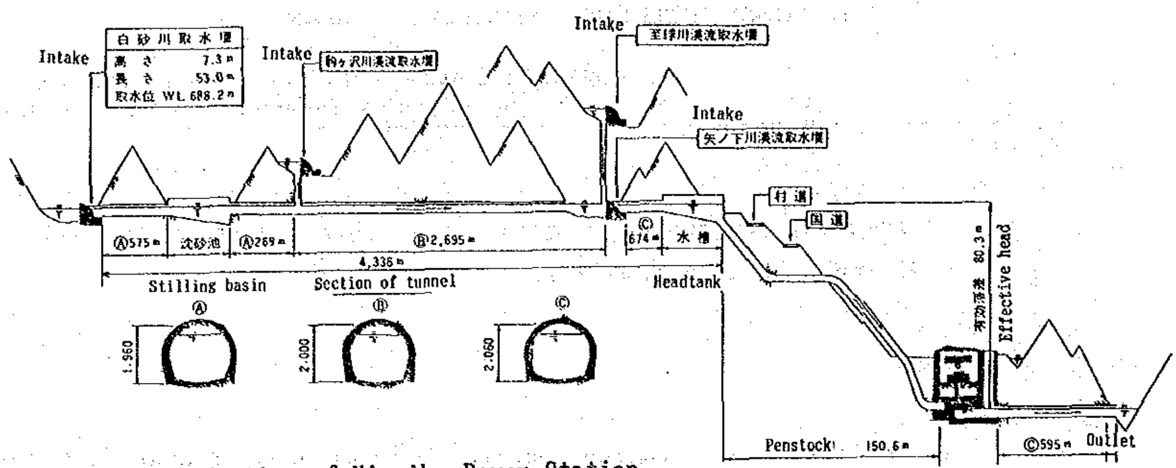

Fig. 2.12 Section of Hiroike Power Station

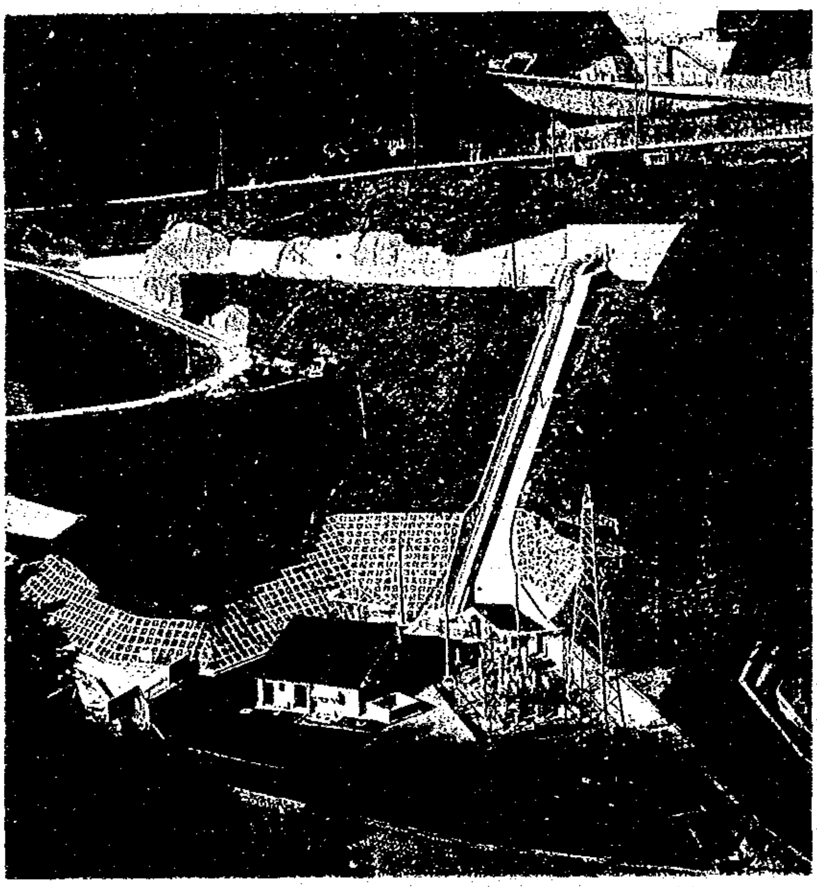

Fig. 2.13 General view of Hiroike Power Station

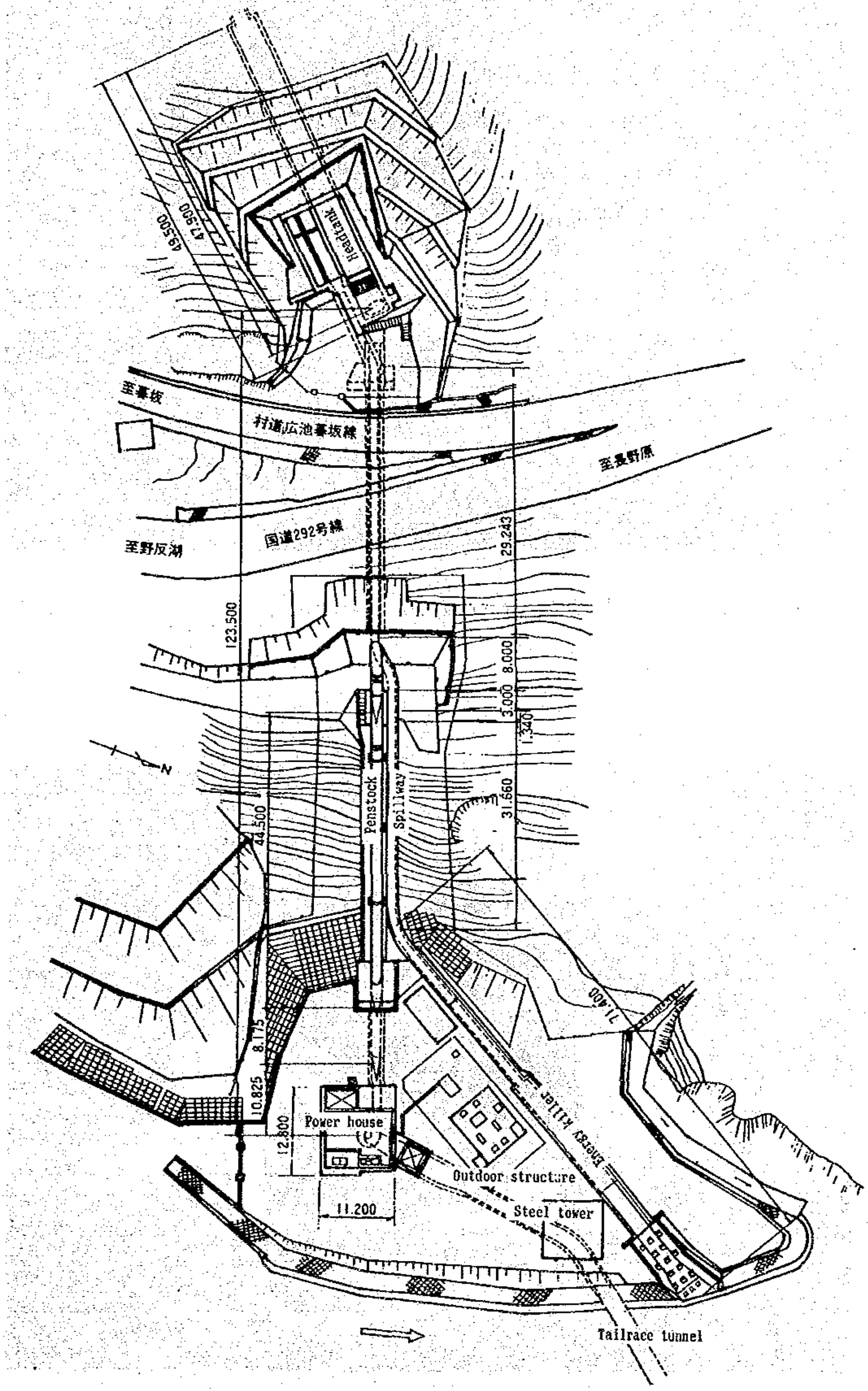

Fig. 2.14 Plan of Hiroike Power Station

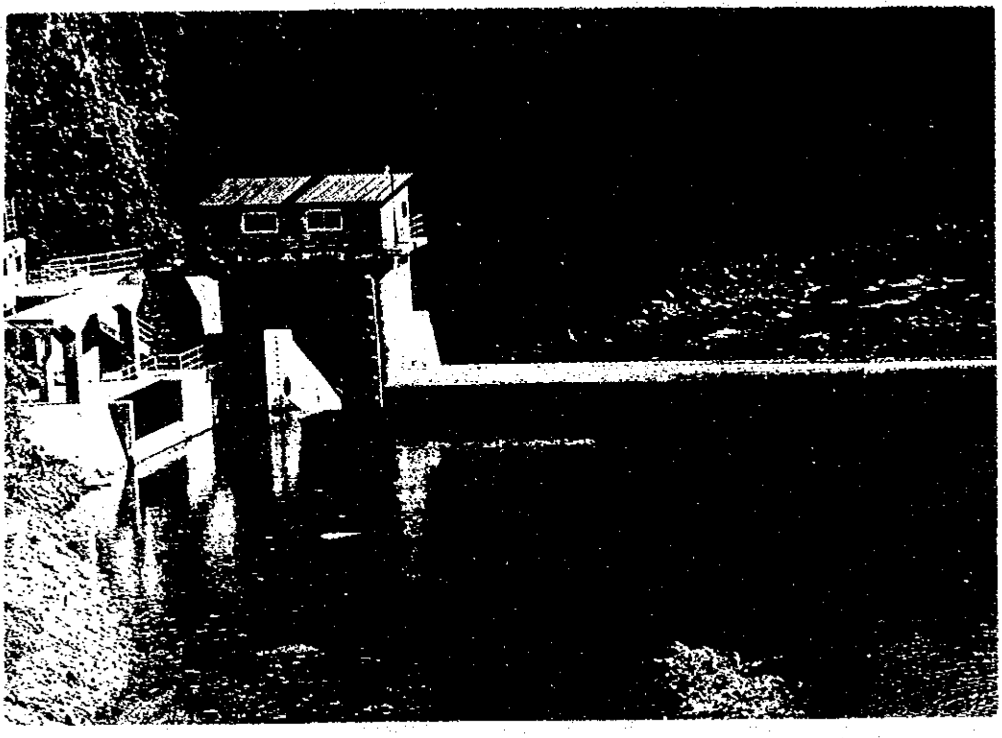

Fig. 2.15 Shirasunagawa intake dam

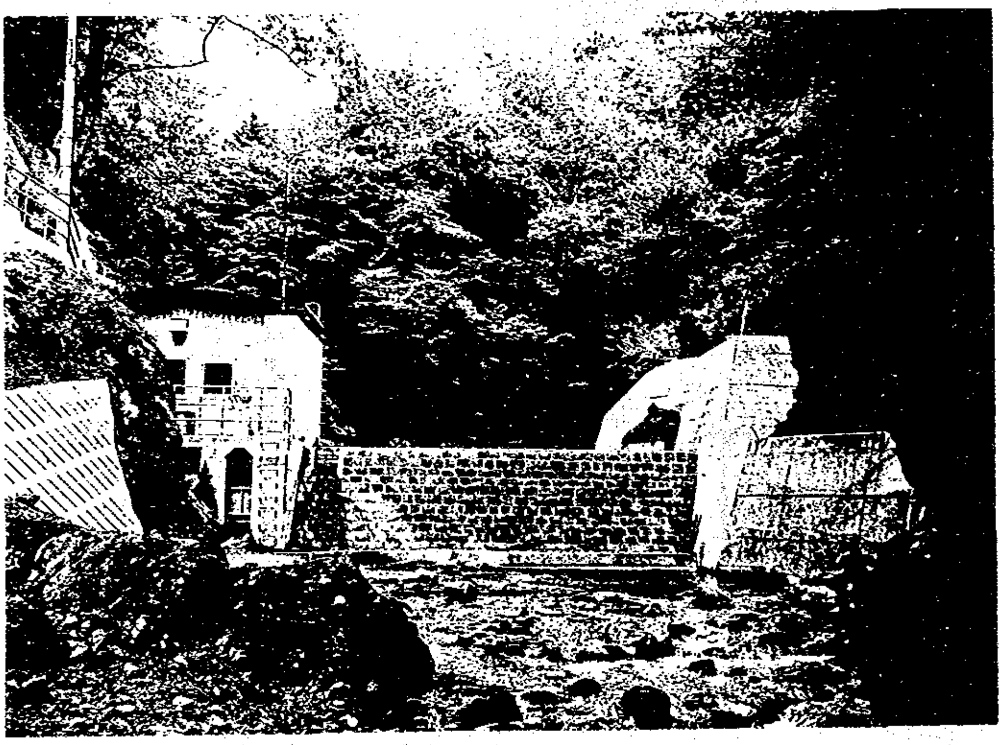

Fig. 2.16 Komagazawa intake dam

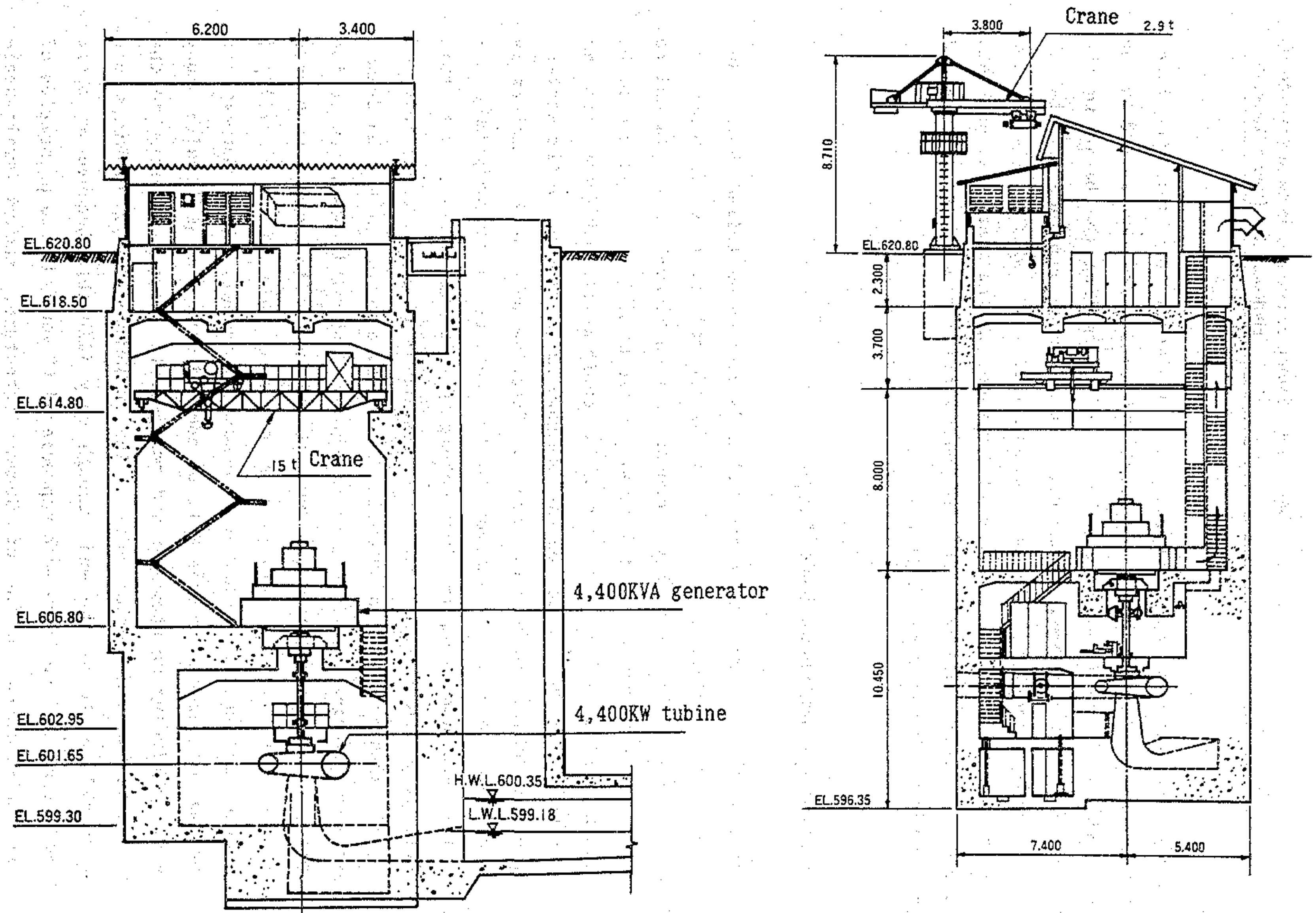

Fig. 2.17 Hiroike Power Station

An outline has been so far introduced to you already concerning the three existing power stations. Out of the locations being currently planned by the Bureau, the Kariyado location may be deemed resembling the basin in the upstream of the Riwagu River in the district of Ranau, Province of Sabah in terms of their situations. An explanation, therefore, will be given below concerning the design, as an example, at Kariyado. At the same time, problems involved in a small-scale hydroelectric power station would like to be grasped from the view point of a developer.

3.1 Example of Kariyado Power Station Design

This Kariyado Power Generation Plan is now being boiled down. And there are possibilities that it may be altered partially from now on. If things go ahead smoothly, however, the work involved is planned to commence next year. In this power generation plan, water is to be taken in at a maximum flow rate of 2.1 cubic meters per second from an intake weir to be located on the Kumagawa River flowing in the western part of Gubnma Prefecture. And an effective head of 72.9 meters is available to a power station to be constructed approximately 2.2 kilometers downstream (maximum output of 1,200 kilowatts). With this effective head utilized, the power station is to obtain electricity of 6,210 megawatt-hours in potential generated a year. It may be deemed as a run-of-river type power station plan. Under this power generation plan, the first emphasis has been placed on a reduction of both work period and cost by employing a concrete hume pipe (centrifugal reinforced concrete pipe) as a headrace channel. Nevertheless, an optimum engineering method will be adopted with a comprehensive study made, including maintenance and management, without adhering to the construction unit price only. The principal design drawings are attached hereto at the end, though very illegible because of their small sizes. It will be much appreciated if you fell the principles of the Enterprises Bureau of Gunma Prefecture, toward small-scale hydroelectric power developments.

The plan is to be subject to the following specifications:

Intake area	:	45.2 square kilometers
Maximum discharge	:	2.1 cubic meters per second
Effective head	:	72.3 meters
Maximum output	:	1,200 kilowatts
Power generated a year	:	6,210 megawatt-hours
		inflatable rubber weir, 2.0 meters high with crest length of 13.0 meters
Penstock	:	FRP pipe (fiber glass reinforced plastic pipe) and steel pipe
Hydraulic turbine	:	horizontal axis Francis hydraulic turbine
Generator	:	horizontal axis 3-phase alternating current synchronous motor generator

3.2 Outline of Works

Some of the special conditions given to a plan of the works around the Kariyado Power Station will be introduced to you.

- Intake weir

This area has a geological feature based on the Neocene pyroxenic andesite, which is covered with Pleistocene lake-produced deposits in the Quaternary period, mud flow deposits, volcanic crush flow deposits and loam layers. Mud flow and volcanic crush flow deposits, among others, have a relatively low specific gravity. The bed gravel in the river contains many pumice pieces and the riverbed has a sharp gradient of approximately 1/30 through 1/40, resulting in a larger volume of drift sand.

If a stationary concrete weir were constructed on the river course, therefore, an advance of sand deposition would impede the normal intake of water. And it would be necessary to discharge the sand and soil deposited. In reality, an existing power station located in the downstream of the planned location has had a significant problem of sand deposited since it could not be effectively discharged through the soil/sand discharge gate. With the cost taken into account for a future continuous discharge of sand, the inflatable rubber weir has been decided to be employed through a comprehensive examination, including the maintenance and control costs, though requiring a significant amount of initial investments. The rubber weir is planned to be 2.0 meters high and so constructed as to inflate pneumatically. Once the river has had a flow increased to reach an overflow depth of 0.5 meters from the rubber weir, it is automatically deflated to prevent sand from depositing in the upstream of the weir according to the plan.

Besides, the weir is planed to be provided with a fishway, through which water is made to flow at a constant flow rate normally so as to protect fish and to preserve the landscapes and environments in the downstream basin of the river. To discharge water through the fishway at a constant flow rate, a water level gage is provided in front of the intake port to regulate the aperture of the intake port gate. Thus, the upstream of the intake weir is planned to be kept level normally at a flow rate less than the maximum working water flow.

■ Settling basin

As already referred to, the riverbed gravel contains many pumice pieces so that the river has a lot of drift sand. As a result, a larger volume of sand than normal is expected to deposit in the settling basin. Under the Kariyado Power Station Project, the settling basin is divided into two so that the power can continue being generated wile discharging soil and sand. In other words, it is so constructed that either side of the two so divided will permit sand to be discharged normally. The settling basin, moreover, has had its capacity so determined that one side only will allow fine sand to settle down satisfactorily.

- Headrace channel

A route of the headrace channel has been so determined that the water channel will have a total extension minimized, with geographical conditions taken into consideration. Basically, the headrace channel is made of a hume pipe culvert, with consideration given to both economical and workability. Over the section where the geographic features prevent the hume pipe from being buried, a box culvert or pressure-free tunnel is to be employed. Besides, the route has two crossings; one is across a stream and the other across a road. These crossings are constructed of FRP (fiberglass reinforced plastics) and steel pipes in an inverted siphon form. Except some portions including the stream crossing, etc., moreover, the headrace channel is entirely buried under the ground.

- Penstock

The penstock pipeline is to be of exposure type, with the linearity near a straight line while there are a small number of portions bent and curved. Since the design water pressure reached a maximum of approximately 10 kg/cm^2, the FRP pipe has been selected after making a study in comparison with steel pipe.

- Spillway

FRP pipe is to be employed as the spillway, too. And it is planned to be located in parallel with the penstock. The spillway, moreover, is to have a baffle type stilling work located at the end to discharge water safely in the downstream.

- Power station

The power station is to be of ground type. With its building divided into two ridges, i.e. equipment room and control room, a wrecker truck or the like is to be used to assemble and install the hydraulic turbine and generator. And the machine room is to have the overhead crane omitted.

3.3 Problems Involved in Small Hydroelectric Power Developments

Needless to say, hydroelectric power generation has excellent power supply characteristics. Even a small-scale hydroelectric power station should be developed positively. As far as small hydroelectric power generation is concerned, however, it may be often blessed poorly with an optimum location and a favorable scale merit. And it involves many problems mainly from an economic point of view.

From the standpoint of a public electricity enterprise who has been so far promoting the medium-scale and small-scale hydroelectric power generation, two significant subjects may be considered lying in developing small hydroelectric power; one is a decrease in cost and the other is an environment preservation problem.

First of all, the hydroelectric power is characterized by a stable cost for a long term but requires an immense amount of investments in initial stages. So, hydroelectric power has a higher initial prime cost than thermoelectric power. A small-scale hydroelectric power station has many economic disadvantages and its development carries every unfavorable factor for the management of an enterprise. It is necessary, therefore, to secure a fiscal subsidy and a low-interest loan for raising the fund required. In addition, it is necessary to introduce new technologies and study the feasibility of executing such small power station construction work jointly with another project.

Besides, a lot of creative contrivances should be made, with consideration given to maintenance and management on an overall basis. And exertions should be used to reduce the cost involved.

Second, even a small hydroelectric power generation should take into due consideration the preservation of environments at portions with water levels lowered in a river and at every work-executing site. And endeavors should be made to make the hydroelectric power generation compatible with the preservation of environments while pursuing for an effective use of hydraulic energy.

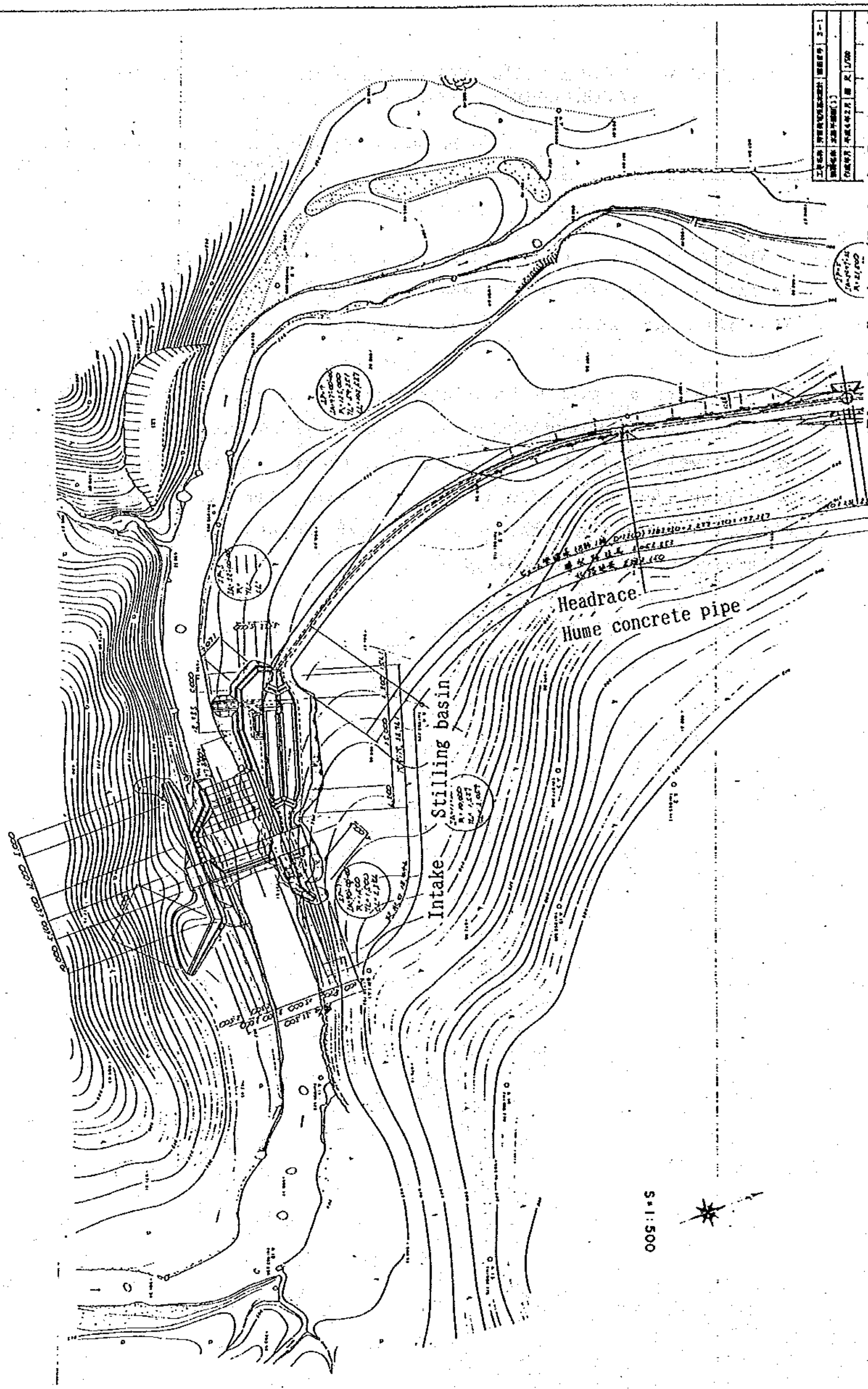

Fig. 3.1 Intakes (Kariyado Power Station)

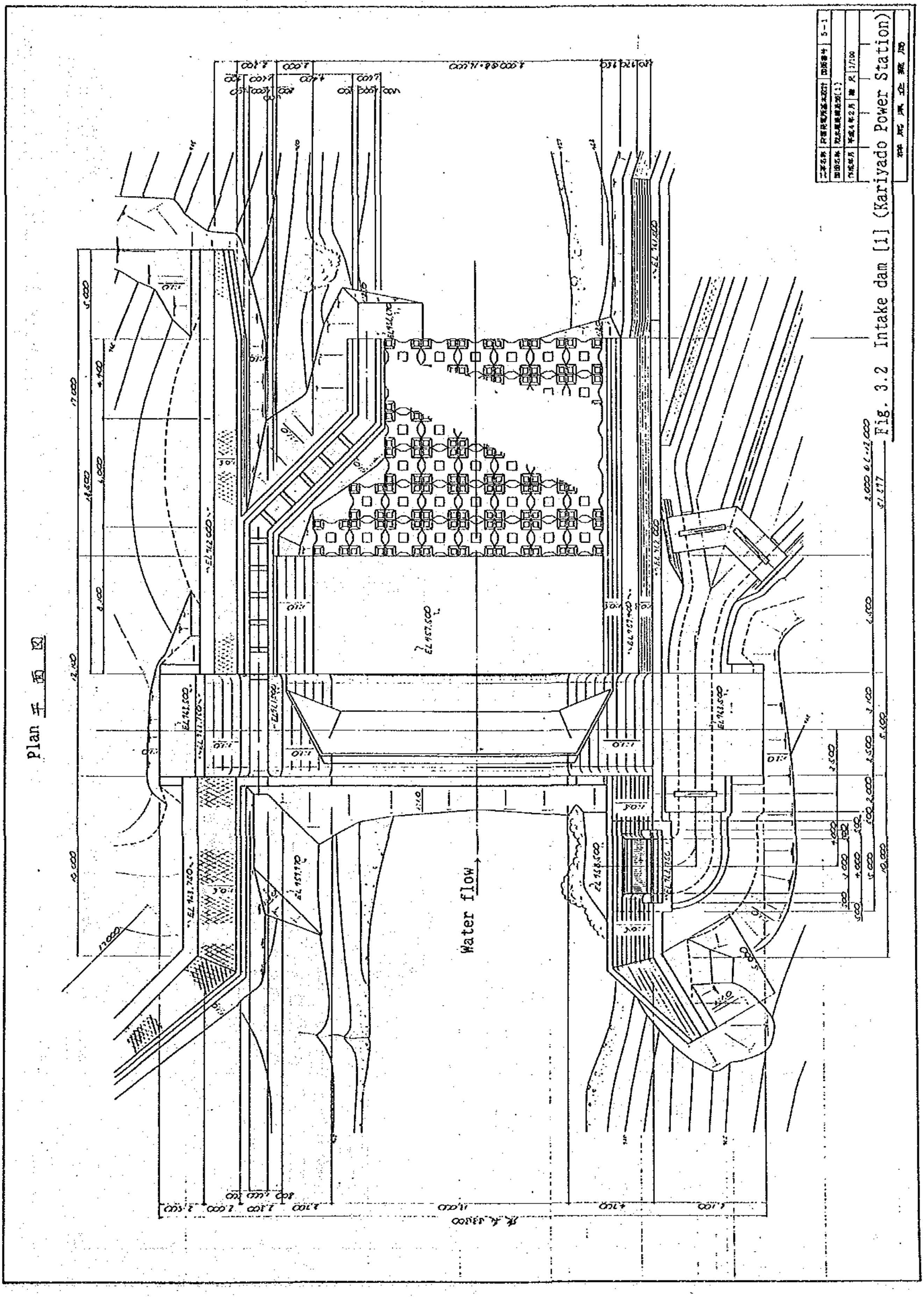

Fig. 3.2 Intake dam [1] (Kariyado Power Station)

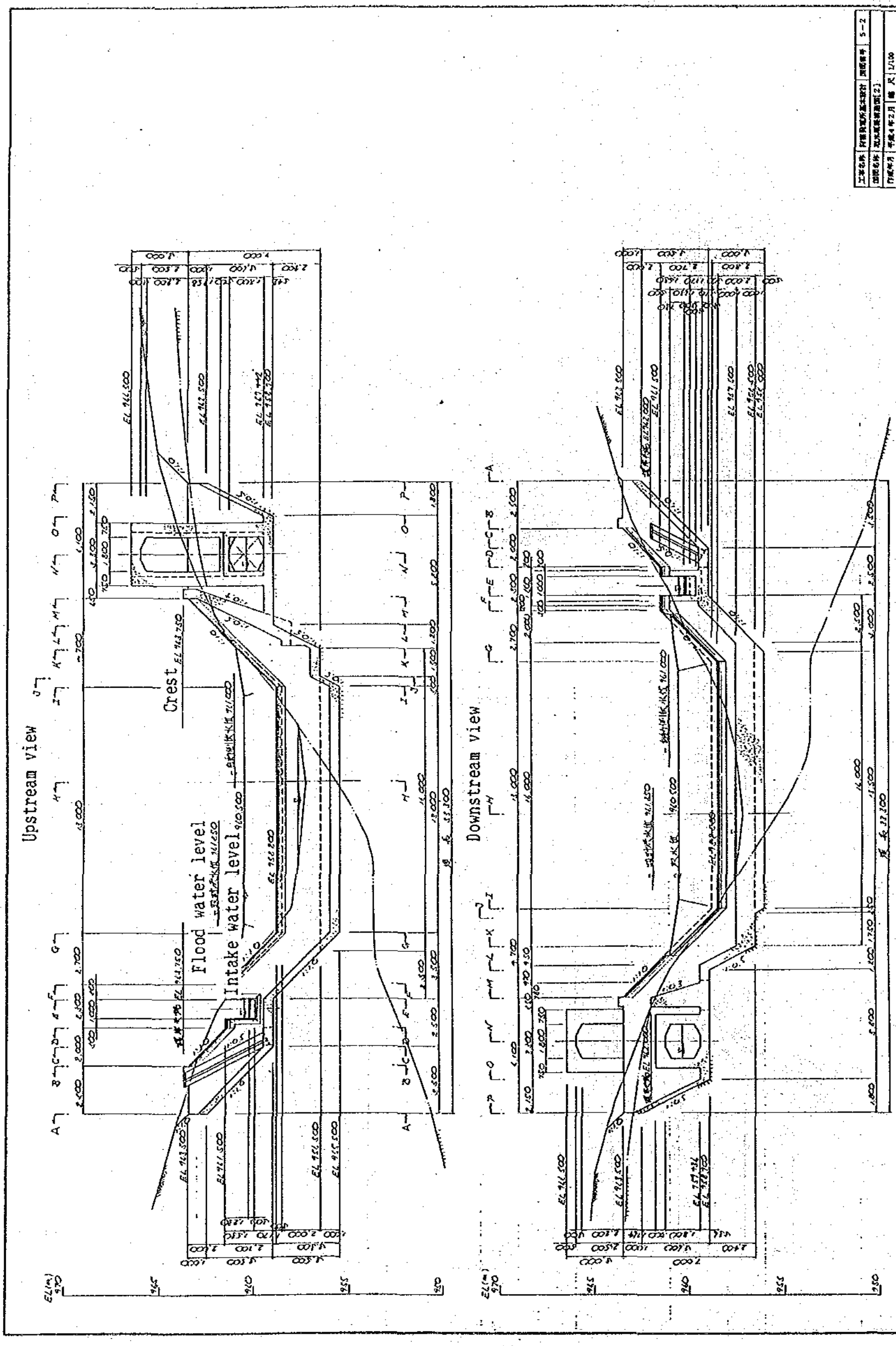

Fig. 3.3 Intake dam [2] (Kariyado Power Station)

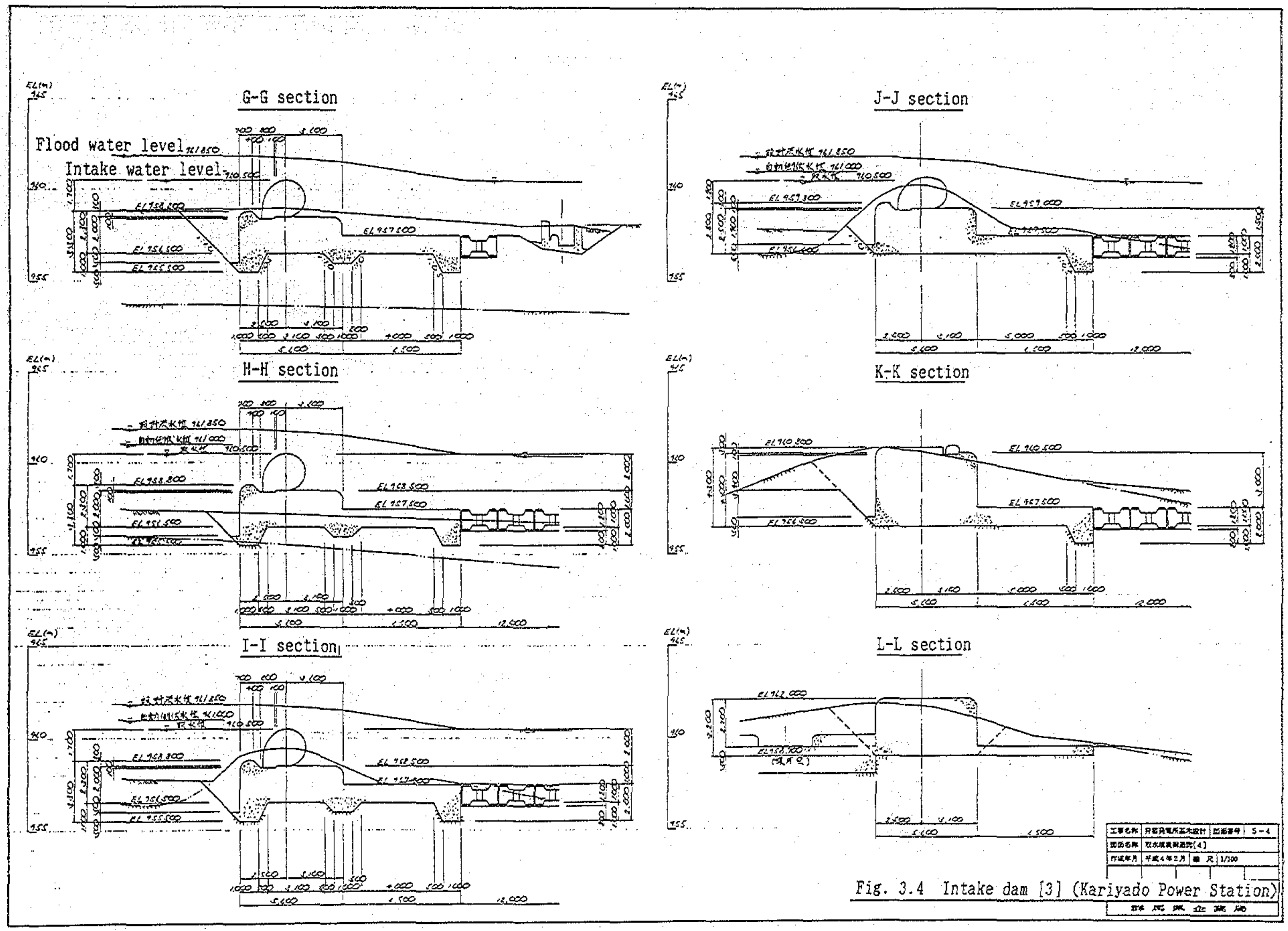

Fig. 3.4 Intake dam [3] (Kariyado Power Station)

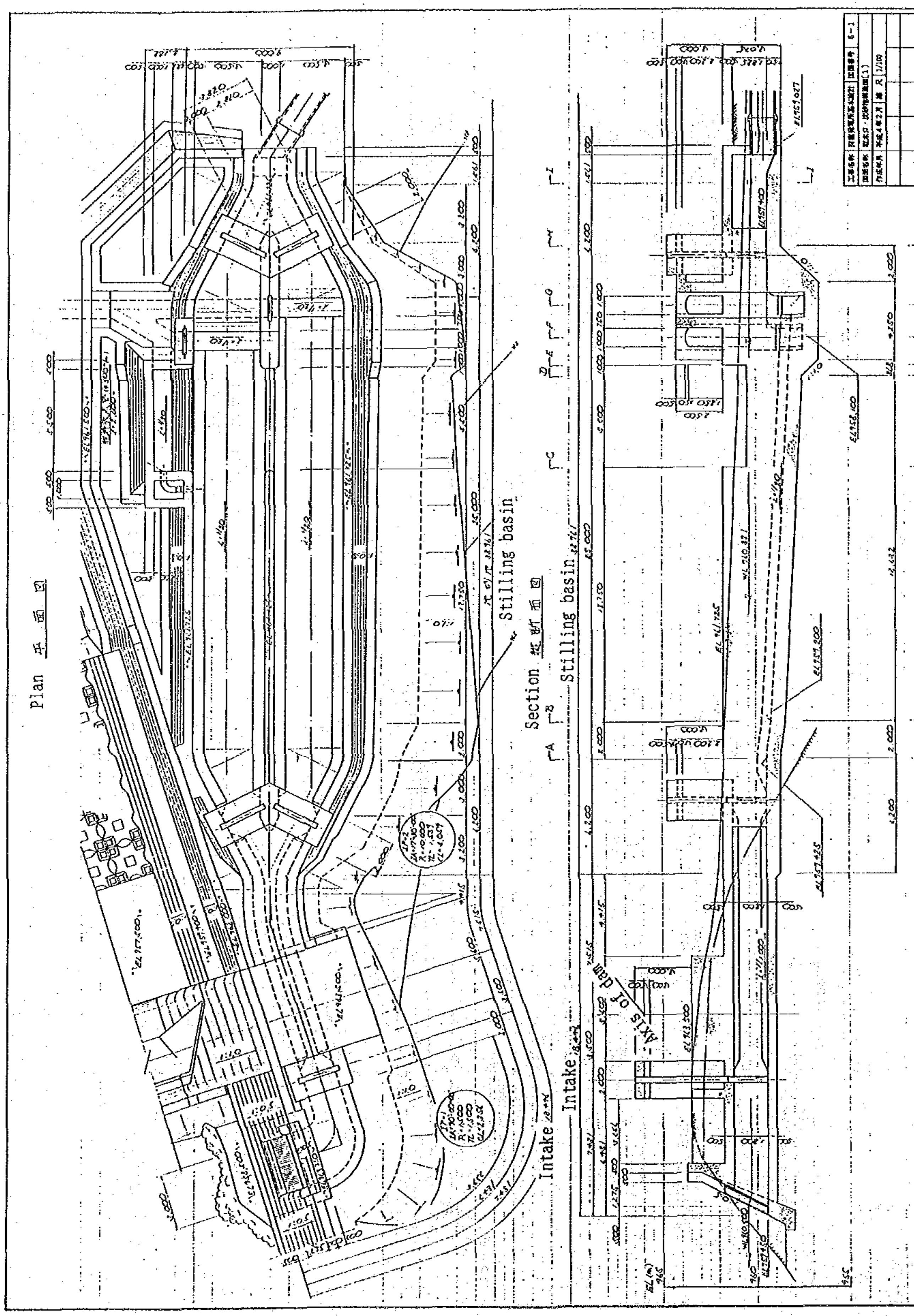

Fig. 3.5 Sattling basin (Kariyado Power Station)

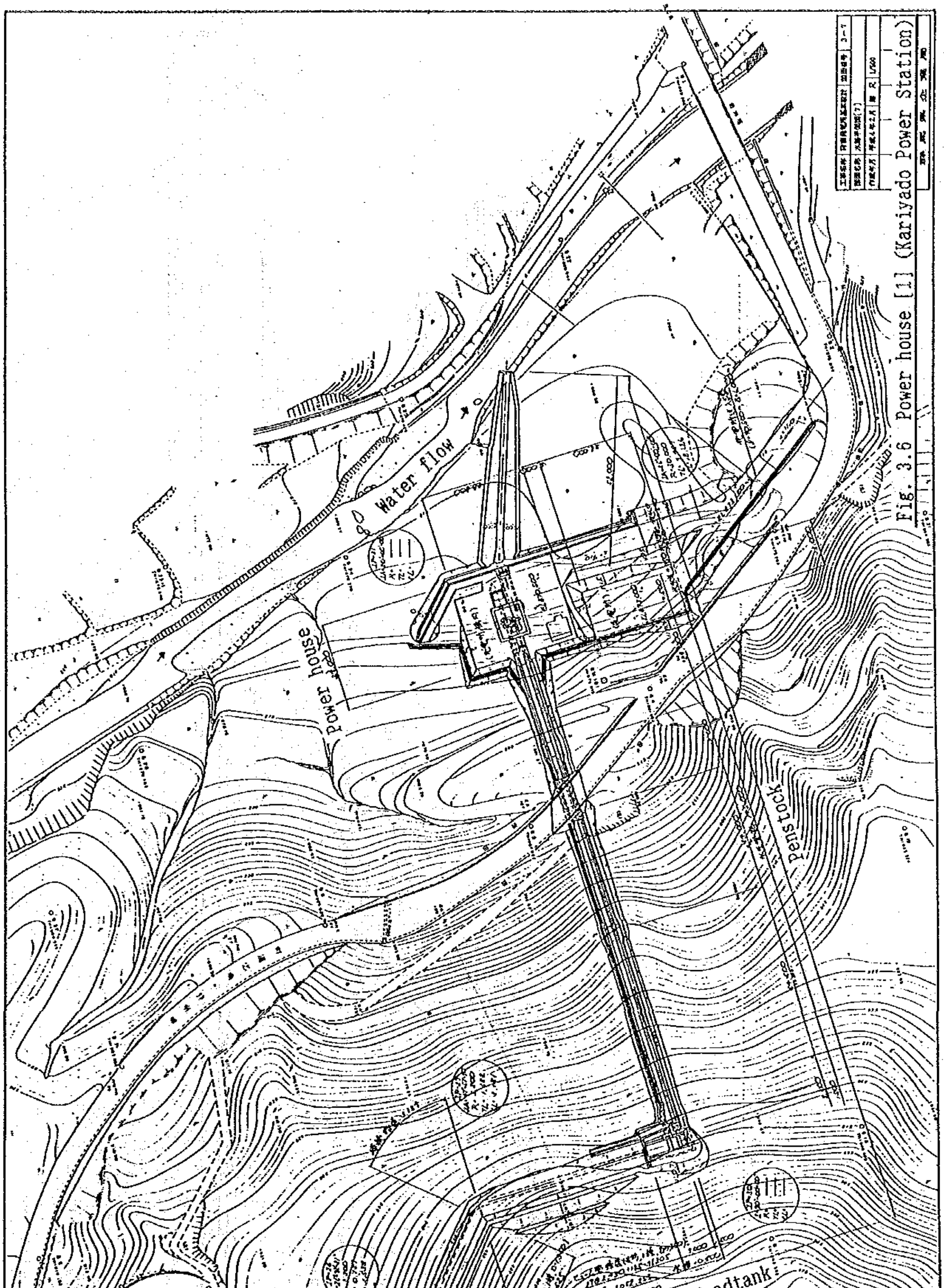

Fig. 3.6 Power house [1] (Kariyado Power Station)

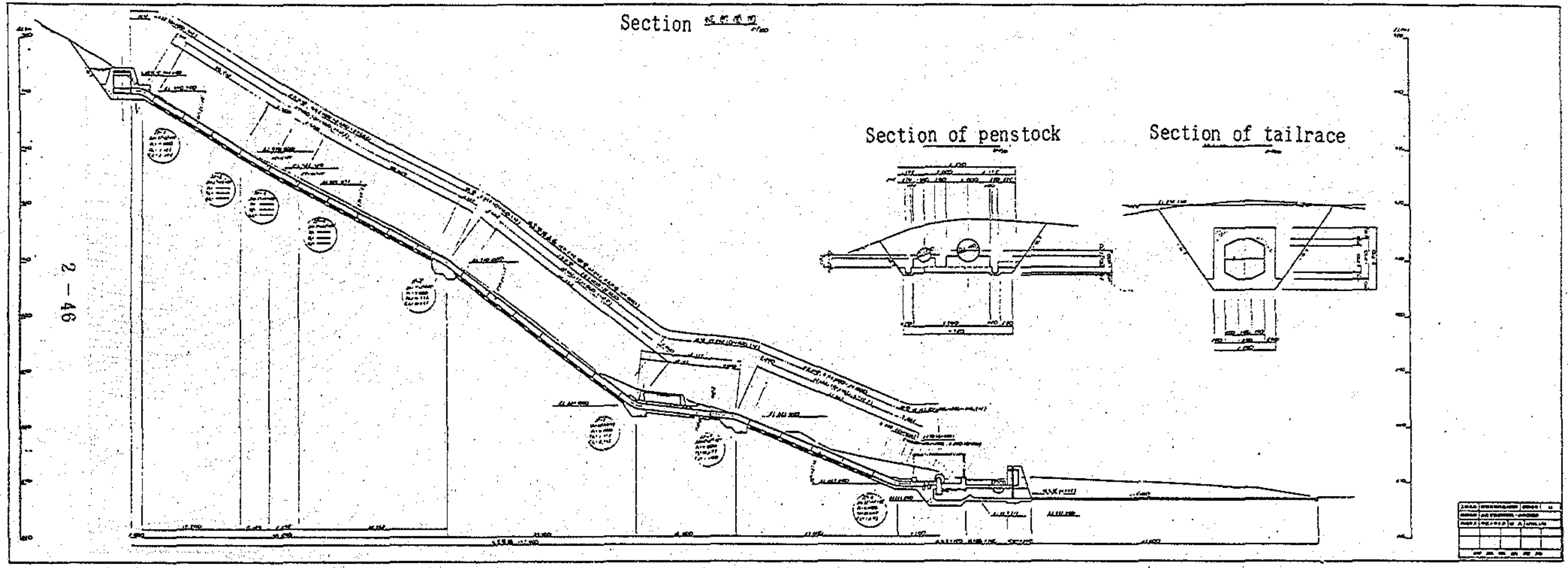

Fig. 3.7 Penstock (Kariyado Power Station)

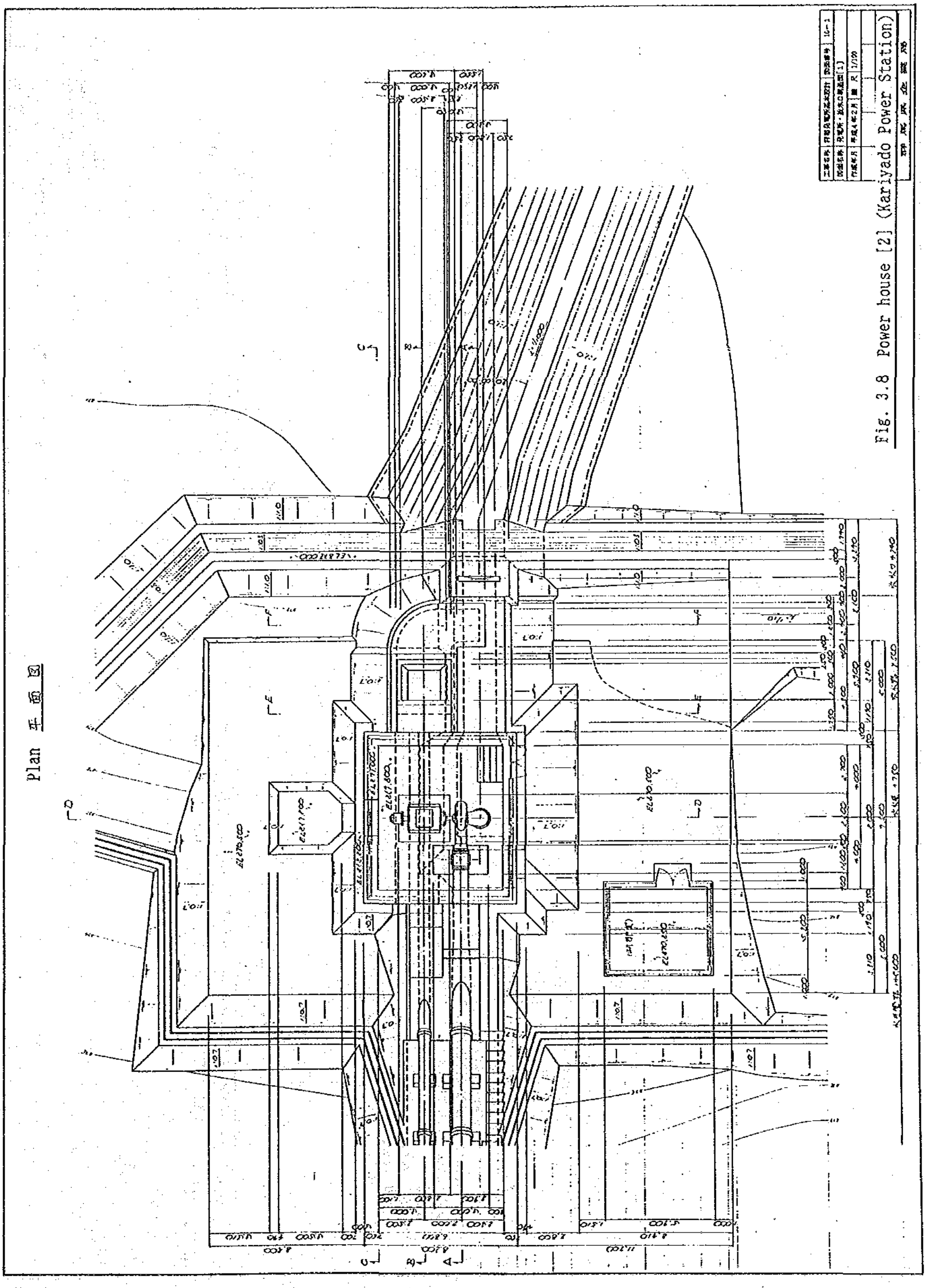

Fig. 3.8 Power house [2] (Kariyado Power Station)

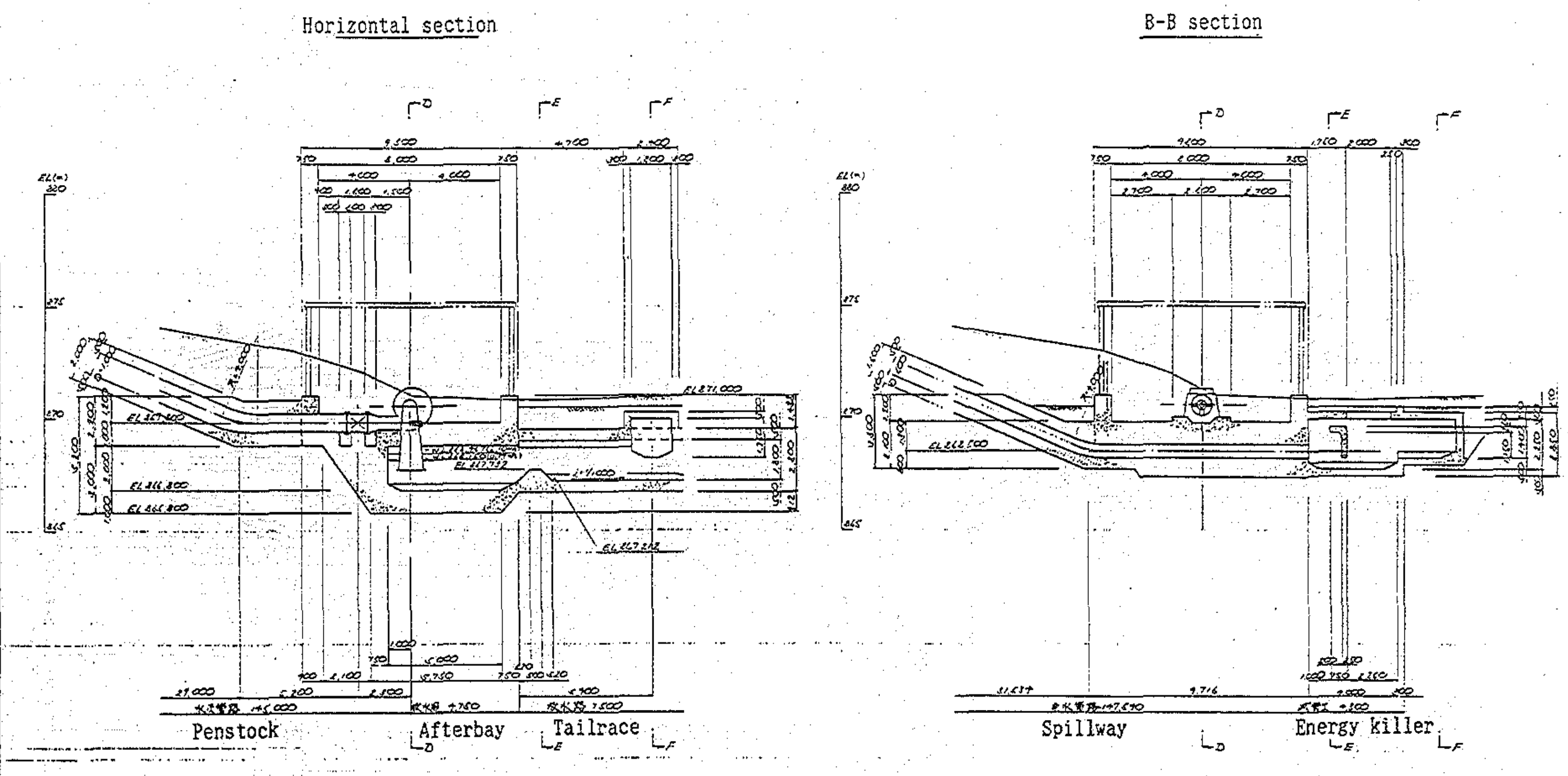

Fig. 3.9 Power house [3] (Kariyado Power Station)

SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT IN JAPAN

SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT IN JAPAN

Summary

Hydroelectric power is an energy purely produced domestically for Japan. Besides, this energy is renewable. A steady development of hydroelectric power is required from two points of view; one is the protection of environments and the other a stable supply of energy.

The Japanese Government has been taking a wide diversity of measures to promote the hydroelectric power development. Described herein, however, are the actual trends of hydroelectric power development in Japan, including various measures taken to promote the development.

Among a variety of measures taken, five times hydroelectric power potential surveys have been conducted, covering the entirety of out country. And it has contributed greatly to the developments of hydroelectric power in Japan, being very helpful for a reasonable development.

As far as various measures so far taken are concerned, moreover, those surveys and projects which have been and are being conducted by the new Energy Foundation will be introduced here. A brief overview of the New Energy Foundation, meanwhile, is added below.

*The **New Energy Foundation** was established in 1980 to meet the needs for developing and using oil substitute energies to secure a stable supply of energies. To put new energies into practical use, the New Energy Foundation has been striving to promote the studies and researches involved and to popularize oil substitute energies and enlighten their users. It comprises four centers, i.e. New Energy Promotion Center, Hydroelectric Power Development Center, Geothermal Energy Development Center and Energy Storage Engineering Development Center. To support the Government's policy for powerfully promoting the hydroelectric power development, the Hydroelectric Power Development Center has been conducting a number of projects.*

SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT IN JAPAN

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JAPAN

Mr. Nakayama was graduated form the Department of Civil Engineering, Faculty of Technology, Kyushu University in Japan, in 1987. After that, he entered Kyushu Electric Power Company and was engaged in the services of designing the modifications of hydroelectric power plants and of exploring hydroelectric power development sites. Later or in 1989, he was temporarily transferred to a foundation, New Energy Foundation. Since then, he has been studying the techniques to effectively calculate a stream discharge at a hydroelectric power development site mainly from an existing stream-gaging station while arranging in order the data relating to the current hydroelectric power potential in Japan.

Section 1 : Present Trends of Hydroelectric Power Development in Japan

1.1 Hydroelectric Power Potential in Japan

As shown in Table 1 and in Fig. 1, Japan has a hydroelectric power potential of approximately 32.8 million kilowatts as a total maximum output of conventional hydroelectric power plants. Of this total output, approximately 20.85 million kilowatts is a total installed capacity of the power plants in operation. And 570 thousand kilowatts is a potential of the hydroelectric power plants now under construction.

And the rest approximately 11.38 million kilowatts is a potential of planned sites.

The number of planned sites of hydroelectric power plants, moreover, reaches approximately 2,750 sites, a potential of which amounts to approximately 12.5 million kilowatts. And in case of not considering loss by newly developments potential per site shows so small a scale as approximately 4,600 kilowatts.

Fig. 2, furthermore, shows a distribution of hydroelectric power outputs.

Table 1 Hydroelectric Power Potential in Japan

Status of Development		Number of Hydro Plants	Installed Capacity (kW)	Annual Generation (MWh)
In Operation Under	Conventional Hydroelectric Power Plants	1,734	20,846,098	89,176,366
	Mixture Pumpt-Storage Power Plants	20	5,627,040	2,513,768
Under Construction	Conventional Hydroelectric Power Plants	71 -14	571,990 -73,910	2,407,182 -711,262
	Mixture Pumpt-Storage Power Plants	2	500,000	240,000
Planned	Conventional Hydroelectric Power Plants	2,749 -285	12,540,690 -1,075,765	47,440,684 -7,401,919
	Mixture Pumpt-Storage Power Plants	20 -13	7,956,000 -123,770	1,793,400 -711,170
Total Conventional Hydroelectric Power Plants		4,552 -299	32,809,103	130,911,051
Total Mixture Pumped-Storage Power Plants		41 -13	13,959,270	3,835,998
Total Hydroelectric Power Plants				134,747,049

* The Figures of "In Operation" are as of March 31, 1991.
* The Figures of "In Operation" are total of plants of electric power utilities and enterprises and of private power plants with a capacity 100 kilowatts or more only.
* Negative Figures describe figures of the plants which are subjected to influence of newly developments.
* All the datas above are referred to "Hydroelectric Power Potential in Japan" issued by the agency of natural Resources and Energy, the ministry of International Trade and Industry.

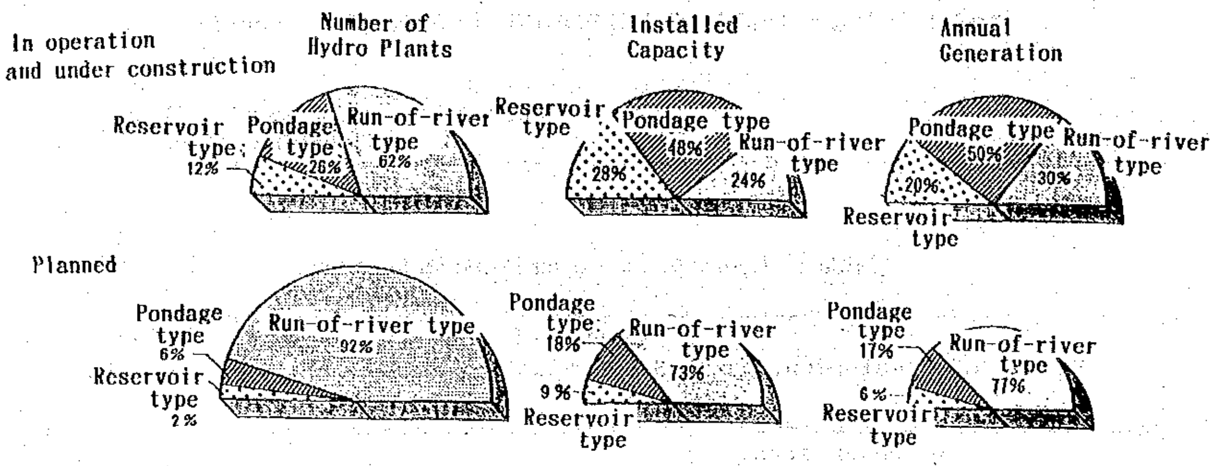

Fig. 1 The Distribution of Hydroelectric Power Potential in Japan

* The reason most of planned sites are run-of-river, is that basic plan which makes much of quantity of generation for hydroelectric developments has been beging made.

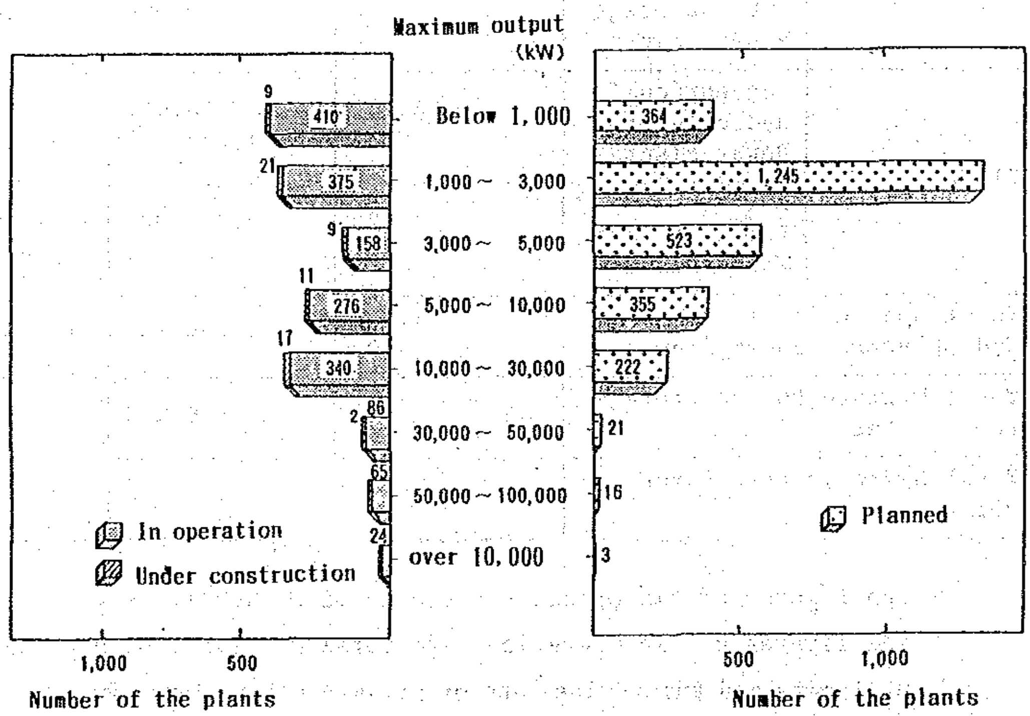

Fig. 2 The Number of the Plants Distributed by Those Maximum Output

The hydroelectric power generating facilities in Japan, moreover, are mainly owned by the following three parties:

(1) General Electric Power Utilities (9 companies)

There are nine electric power companies in each of the national districts (9 districts). They are selling general consumers both electricity which they have generated in house and have purchased from other electric power utilities.

As far as the maximum output is concerned, these nine companies have occupied approximately 66% of all the conventional hydroelectric power generating facilities in Japan. (Another electric power utility does exist (Okinawa Electric Power Company) but does not have any hydroelectric power generating facility.)

(2) Wholesale Electric Power Utilities

Falling in this category are public electric utilities in 33 prefectures and in 1 city, Electric Power Development Co., Ltd. and other private enterprises. All of them are selling their in-house generated electricity to general electric power utilities. As far as the maximum output is concerned, they occupy approximately 27% of all the conventional hydroelectric power generating facilities in Japan.

(3) Private Power Plants

The electricity generated is used as the power to be supplied for the private use only, including a factory or the like. As far as the maximum output is concerned, the private power plants occupy approximately 7% of all the conventional hydroelectric power generating facilities in Japan. (the term, private power plant, however, means a facility with a capacity of 100 kilowatts or more only.)

A breakdown of the conventional hydroelectric generating facilities referred to above is given on Table 2 below.

Table 2 A breakdown of the Pure Hydroelectric Power Generating Facilities

Division of Owners	Number of Hydro Plants	Installed Capacity (kW)	Annual Generation (MWh)
General electric power utilities	1,125	13,811,734 (66%)	61,046,289 (68%)
Wholesale electric power utilities	359	5,635,849 (27%)	20,315,761 (23%)
Private power plants	250	1,398,515 (7%)	7,814,316 (9%)
Total	1,734	20,846,098 (100%)	89,276,366 (100%)

* As for private plants, adding up power plants with a capacity 100 kilowatts or more only.

1.2 General Method of Working out a Development Plan

In Japan, a hydroelectric power development plan is generally worked out by the methods and steps as referred to below.

(1) Schematic Plan

Based on the existing data, geographical chart and the like, a schematic route is selected on a drawing to work out a schematic plan of an individual power plant site, taking into account the findings of a rough water system survey and of a field exploration.

(a) Rough Water System Survey

Both water system and river to be covered by a development plan are surveyed concerning the river from, outline of its basin, water utilization facilities already obtained, etc., based on the data already available. And the findings of this survey are used as the data fundamental to the plan.

(b) On-drawing Plan

A plan is worked out, based on the existing data (a topographic map to a scale of 1/50,000, etc.) and on the findings of rough water system survey.

1) Determining a power plant type

A hydroelectric power plant may take one of three types according to the power supply functions' characteristic of that power plant. To proceed with a development plan, it is necessary to preselect an optimum type beforehand. Three types about power plant are described below.

- Run-of-river type power plant:

  A power plant of this type does not have a storage pond, in particular, but uses natural stream discharge of a river directly to generate electric power without making any adjustment of the discharge.

- Poundage type power plant:

  Demand for electric power fluctuates remarkably in a day or in a week the natural stream-discharge of a river remains nearly constant in a day or in a week. A storage pond, therefore, is located in a dam or in the midcourse of a headrace. In the midnight or on a holiday when the electric power demand is low, the stream discharge is stored in pond so that the water so stored can be used when the electric power demand is high. Thus, the power plant is capable of responding properly to a fluctuation of electric power demand.

- Reservoir type power plant:

If the power is hydroelectrically generated while resorting merely to natural stream discharge of a river, the quantity of power generated will fluctuate from season to season in a year, resulting in an instable supply of power. As a solution to this problem, a dam is constructed to store the discharge in a wet season and to use the stored water in a dry season. As a result, the power plant can obtain an averaged quantity of water throughout the year by increasing the doughty water-discharge.

2) Calculating an Output and a Quantity of Power Generation

Both output and power generation are arithmetically obtained from a total head available on a topographic map and from a stream discharge at the water intake. A stream discharge data collected for the latest decade are to be used.

A maximum output available may be obtained as under.

$$P = 9.8 \cdot Q_{max} \cdot He \cdot \eta$$

where, P : maximum output (in kilowatts)

η	:	total efficiency ($\eta = \eta_t \cdot \eta_g$) with η_t and η_g standing for turbine efficiency and generator efficiency, respectively
Q_{max}	:	maximum usable stream discharge (in cubic meters per second)
He	:	effective head (in meters)

Described below is how to prepare a stream discharge data, which are fundamental and most important to work out a power generation plan, in particular.

■ Preparing a stream discharge data:

To hydroelectrically generate power, neither possible power generation nor storage reservoir size can be determined without accurately knowing the stream discharge. A river has the stream discharge vary with the meteorological, topographical and geological features. it is necessary, therefore, to precisely gage the stream discharge for a period of long years.

For a gaging period, a stream discharge data gathered during the latest decade are used to work out a power generation plan in Japan. For the Japanese Government (Ministry of International Trade and Industry) to permit or authorize a power generation plan, any data that may have been gathered for a period of less than one decade are not recognized as the official data for a hydroelectric power development.

The Electric Enterprises Act, therefore, provides that those who have installed a hydroelectric power plant must gage the stream discharge of a river on which such power plant has been installed and that they must report the results of such gaging to the government. The equipment to gage the stream discharge and the method of gaging a stream discharge have been established in a governmental order.

Currently in Japan, there are 720 gaging stations, which have been gaging stream discharges in response to an order from the Ministry of International Trade and Industry. Except some gaging stations under direct control of the Ministry of International Trade and Industry, electric power utilities have been gaging stream discharges. If the sites where gaging were done in the psst are added, the gaging stations existing in Japan reach approximately 1,800 sites. To obtain a permit or authorization for an electric power development, it is necessary to use the stream discharge data collected in the gaging stations referred to above.

At a gaging station, a daily stream discharge is gaged every day, and accumulated and stored as the stream discharge data valuable for a hydroelectric power development.

To prepare a stream discharge data at a site planned to be hydroelectrically developed, the stream discharge data at an existing gaging station are multiplied by a simple catchment area ratio to calculate a discharge if such existing gaging station is located near the planned hydroelectric power development site. And the discharge so calculated is taken for the stream discharge data.

This calculation is to be made by the use of an expression as follows:

$$Q_A = \frac{CA_A}{CA_B} \times Q_B$$

where, Q_A : stream discharge at the planned site
Q_B : stream discharge gaged at a gaging station nearby
CA_A : catchment area at the planned site
CA_B : catchment area at the gaging station

The maximum usable discharge is generally taken at such a level that the capacity factor will reach approximately 45 through 60% in a run-of-river type power plant.

The capacity factory may be obtained as follows:

Capacity factor =

$$\frac{\textit{Annual possible power generation in kilowatt-hours}}{\textit{Maximum output in kilowatt} \times 8{,}760 \textit{ hours}}$$

Based on this maximum usable discharge, the maximum output is obtained. In addition, the annual possible power generation is calculated.

3) Roughly Integrating a Construction Cost

Based on a roughly estimated quantity, various expenses are integrated for main power plant structures, land compensation and construction to roughly estimate the construction cost.

4) Studying Economic Aspects

A rough construction cost per generation in kilowatt-hours at the planned construction site is calculated. And the economic aspects of the plan are evaluated, based on the construction cost so calculated.

Cost per generation in kilowatt-hours =

$$\frac{\textit{Total cost}}{\textit{Annual possible power generation in kilowatt-hours}}$$

(2) Field Surveys

Based on the schematic plan, field surveys are carried out concerning the topographical, geological and environmental features at the site to work out a power generation plan.

(a) Topographical Surveys

An aerophotographical survey is carried out around the site where main power plant structures are scheduled to be installed at the planned location. And a topographical map to a scale of 1/1,000 or 1/5,000 is prepared.

(b) Geological Survey

A surface geological survey is first of all carried out around the site where main power plant structures are scheduled to be installed. And the portion or portions considered necessary as a result of such surface geological survey is subjected to a seismic prospecting and a boring survey.

(c) Environmental Survey

Surveys are carried out concerning current water quality at the site where water is scheduled to take in, including the distribution and living conditions of animals and vegetables around the planned site. And in case the planned site is in a national park area, it is necessary to survey the influences to the environments.

(3) Power Generation Plan

A power generation plan is worked out in detail, based on the schematic plan and on the findings of the field surveys.

(a) Layout of Civil Engineering Facilities

The locations of main power plant structures and the route of a headrace are determined, with consideration given to the findings of the field surveys, etc.

(b) Determining a Size

Based on the findings of field surveys and on the existing data and so on, main power plant structures are roughly designed. To make this design, it is necessary to positively adopt the new technologies, in addition to the observance of the "engineering Standards relating to Water Power Facilities for Power Generation" (A ministerial ordinance of the Ministry of International Trade and Industry).

A output is calculated from the stream discharge data already referred to plus the effective head (total head -

loss of head) and total efficiency of both hydraulic turbine and generator.

The monthly quantity of power generation is calculated based on the past near ten-year stream discharge datas. As for the output and quantity of power generation, more accurate values than those in the schematic plan are calculated.

(c) Integrating Construction Costs

Construction costs are integrated on an item by item basis as shown in **Table 3**.

The construction costs referred to herein must be a more detailedly highly accurate value than that in the schematic plan.

Table 3 Integration Construction Costs

Items		Reference
(1) Land compensation		Compensation for sunk area and so on
(2) Building of power station		
(3) Civil engineering works	Waterway	Dam, Intake, Settling basin, Headrace, Headtank, Spillway, Penstock, Tailrace, Outlet, and Spoil-bank and so on
	Storage pond or Reservoir pond	Dam, Flood spillway
	Facilities	Foundation of machinery, Access road, Tree planting and son on
	Temporary facilities	Road for construction, Bridge, Temporary building and son on
(4) Turbine and electric facilities		Turbine, Generator, Transformer facilitiesand so on
(5) Management of construction work		Personnel expenses, Electric expenses for construction, Fixtures and so on
(6) A share of dam cost		This cost is added up in case multipurpose dam
(7) Interest during construction term		
(8) Expenses of instructing office		
(9) Sundry expenses		Reserve cost preparing for accidents during construction term
(10) Compensation for abolished plant		Compensation for plant which are subjected to influence of newly developments

(d) Evaluating Economic Aspects of the Plan

From the power generation and construction cost calculated as referred to (b) and (c) above, the construction cost per power generation (in kilowatt-hours) is calculated. And the value so calculated is used to evaluate economic aspects of the plan.

Cost generation in kilowatt-hours =

$$\frac{\textit{Total cost}}{\textit{Annual possible power generation in kilowatt-hours}}$$

The construction cost per generation in kilowatt-hours, meanwhile, must be obtained as a more detailedly highly accurate value than that in the schematic plan.