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INDUSTRIAL DEVELOPMENT ORGANIZATION

Technical Guidelines for the
Development of Small Hydropower Plants

DESIGN

Part 4: Hydraulic Engineering and Energy Calculation

SHP/TG 002-4: 2019

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Further recommendations and suggestions for application for the update would be highly welcome.

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Foreword

The United Nations Industrial Development Organization (UNIDO) is a specialized agency under the United Nations system to promote globally inclusive and sustainable industrial development (ISID). The relevance of ISID as an integrated approach to all three pillars of sustainable development is recognized by the 2030 Agenda for Sustainable Development and the related Sustainable Development Goals (SDGs), which will frame United Nations and country efforts towards sustainable development in the next fifteen years. UNIDO's mandate for ISID covers the need to support the creation of sustainable energy systems as energy is essential to economic and social development and to improving quality of life. International concern and debate over energy have grown increasingly over the past two decades, with the issues of poverty alleviation, environmental risks and climate change now taking centre stage.

INSHP (International Network on Small Hydro Power) is an international coordinating and promoting organization for the global development of small hydropower (SHP), which is established on the basis of voluntary participation of regional, subregional and national focal points, relevant institutions, utilities and companies, and has social benefit as its major objective. INSHP aims at the promotion of global SHP development through triangle technical and economic cooperation among developing countries, developed countries and international organizations, in order to supply rural areas in developing countries with environmentally sound, affordable and adequate energy, which will lead to the increase of employment opportunities, improvement of ecological environments, poverty alleviation, improvement of local living and cultural standards and economic development.

UNIDO and INSHP have been cooperating on the World Small Hydropower Development Report since year 2010. From the reports, SHP demand and development worldwide were not matched. One of the development barriers in most countries is lack of technologies. UNIDO, in cooperation with INSHP, through global expert cooperation, and based on successful development experiences, decided to develop the SHP TGs to meet demand from Member States.

These TGs were drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of these TGs may be subject to patent rights. UNIDO and INSHP shall not be held responsible for identifying any such patent rights.

Introduction

Small Hydropower (SHP) is increasingly recognized as an important renewable energy solution to the challenge of electrifying remote rural areas. However, while most countries in Europe, North and South America, and China have high degrees of installed capacity, the potential of SHP in many developing countries remains untapped and is hindered by a number of factors including the lack of globally agreed good practices or standards for SHP development.

These Technical Guidelines for the Development of Small Hydropower Plants (TGs) will address the current limitations of the regulations applied to technical guidelines for SHP Plants by applying the expertise and best practices that exist across the globe. It is intended for countries to utilize these agreed upon Guidelines to support their current policy, technology and ecosystems. Countries that have limited institutional and technical capacities, will be able to enhance their knowledge base in developing SHP plants, thereby attracting more investment in SHP projects, encouraging favourable policies and subsequently assisting in economic development at a national level. These TGs will be valuable for all countries, but especially allow for the sharing of experience and best practices between countries that have limited technical know-how.

The TGs can be used as the principles and basis for the planning, design, construction and management of SHP plants up to 30 MW.

- The Terms and Definitions in the TGs specify the professional technical terms and definitions commonly used for SHP Plants.

- The Design Guidelines provide guidelines for basic requirements, methodology and procedure in terms of site selection, hydrology, geology, project layout, configurations, energy calculations, hydraulics, electromechanical equipment selection, construction, project cost estimates, economic appraisal, financing, social and environmental assessments—with the ultimate goal of achieving the best design solutions.

- The Units Guidelines specify the technical requirements on SHP turbines, generators, hydro turbine governing systems, excitation systems, main valves as well as monitoring, control, protection and DC power supply systems.

- The Construction Guidelines can be used as the guiding technical documents for the construction of SHP projects.

- The Management Guidelines provide technical guidance for the management, operation and maintenance, technical renovation and project acceptance of SHP projects.

Technical Guidelines for the Development of Small Hydropower Plants-Design
Part 4: Hydraulic Engineering and Energy Calculation

1 Scope

This Part of the Design Guidelines specifies the methods and steps of hydraulic engineering and energy calculations for small hydropower (SHP) development, and covers the aspects might be involved in hydropower station design, such as the load forecast and electric power and energy balance.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

SHP/TG 001, *Technical guidelines for the development of small hydropower plants—Terms and definitions*.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in SHP/TG 001 apply.

4 General principles

4.1 Hydraulic engineering and energy calculation shall adhere to the principles of comprehensive utilization of water resources, properly handle the relationship between needs and potentialities, short-term and long-term perspectives, the mainstream and the branches, upstream and downstream interests, as well as the relationship between water resource development and the ecological environment, and land acquisition and resettlement. Water resources shall be developed economically and rationally.

4.2 Hydraulic engineering and energy shall be calculated on the basis of the integrated planning of river basin and city or river (reach) planning and power planning. According to the comprehensive utilization requirements, the development task and the power supply scope of the hydropower station shall be determined, the design dependability and design target year shall be selected, the scale and characteristic values of the hydropower station shall be determined, the operational modes of the reservoir and hydropower station shall be researched and the engineering benefits shall be stated.

4.3 Hydraulic engineering and energy calculation shall be based on the collection and analysis of the basic data of local social and economic conditions, natural conditions, electric power system and ecological environmental protection, as well as the comprehensive utilization requirements. The basic data shall include:

a) The economic-social data, including the status quo and development data of regional national economy, comprehensive basin planning, development status and planning data of the hydropower resource development of the drainage basin, water environment protection status and planning data, regional power grid status and planning needed for comprehensive utilization benefit calculation;

b) The landform data, including the topographic map of the reservoir area (the scale shall not be less than 1 : 1 000), the longitudinal and cross-section profiles of the upstream and downstream of the dam site and the longitudinal and cross-section profiles of the downstream reach of the plant site;

c) The professional planning and water demand data for the various purposes, including the water consumption, ecological water demand and fishery, tourism, navigation and other water demands of upstream and downstream water intake departments of reservoirs.

4.4 The design level of the power station may be three to five years after the first unit is put into operation, which should be consistent with the national economic development plan.

5 Computation of runoff regulation

5.1 According to the regulation performance of the power station and all kinds of water demand, the calculation of runoff regulation shall be carried out to balance the water quantity. The firm output, multi-year average generation and characteristic head of the power station shall be calculated, and the operational characteristics and benefits of the power station shall be illustrated. When the water balance computation is carried out, all kinds of water consumption, water process and water guarantee rate of upstream and downstream areas shall be considered.

5.2 In the calculation of the water every indicators of the reservoir hydropower station with water requirements for ecology, irrigation, living and navigation, the demand of all aspects shall be considered as a whole, and the necessary storage capacity and dead water level of the reservoir shall be reasonably determined. The calculation of power generation shall take into account all kinds of water demand and water supply requirements in an extraordinary dry year, and calculate the energy indicators.

5.3 The energy calculation of cascade hydropower station shall fully consider the connection relationship of flow, flow path and water level between the upstream and the downstream cascade stations as well as the mutual compensation utility among the cascade stations; the tailwater level of an upstream hydropower station shall be designed with consideration given to the influence of the backwater of the downstream reservoir.

5.4 The design dependability of an SHP station shall meet the following requirements:

a) The design dependability of a hydropower station may be selected according to the hydropower capacity proportion in the power system described in Table 1.

Table 1 Design dependability of the hydropower station

Hydropower capacity proportion in the power system (%)	Below 25	25～50	Above 50
Design dependability of a hydropower station (%)	80～85	85～90	90～95

b) The design dependability of a reservoir hydropower station with irrigation as the main or other water supply tasks shall be selected according to the requirements of main water consumption sectors.

c) The frequency of the typical high-flow year, median-flow year and low-flow year should be selected respectively as that $P_{high} = 100\% - P_{low}$; $P_{median} = 50\%$; P_{low} = design dependability.

5.5 The chronological series method shall be applied in the computation of runoff regulation according to the following requirements:

a) For non-regulated or daily regulated hydropower stations, the runoff regulation should be calculated by adopting a long series of daily average flow or the average daily flow rate of a typical year. Three representative years, i.e. the high-flow year, median-flow year and low-flow year, should be selected as the typical years, and the representative partial-high-flow year and partial-low-flow year may also be added.

b) For the multi-year regulated reservoir and the annual regulated reservoir, long series shall be adopted for the calculation as per the average monthly (ten-day) flow. When the typical years are selected, the water volume frequency in the design low-flow year should be roughly equal to the design dependability, and the annual mean runoff values in the high-flow year, median-flow year and low-flow year should all be equal to or close to the mean annual runoff.

5.6 When there are existing water conservancy and hydropower projects upstream or downstream of the hydropower station under design or there are water conservancy and hydropower projects to be built within the design target year, the computation of runoff regulation of the cascade hydropower station shall be carried out accordingly.

6 Hydraulic energy calculation

6.1 The chronological series method shall be applied in the calculation of hydraulic energy; the water balance computation shall be made according to the regulation performance of the hydropower station as well as the water requirements of ecology, irrigation, living and navigation, to calculate the firm output, mean annual energy output, peak-load electric quantity, valley-load electric quantity and characteristic head of the hydropower station.

6.2 The calculation of firm output shall meet the following requirements:

a) For a multi-year regulated hydropower station, the water supply period is the low-flow year group; for an annually (quarterly) regulated hydropower station, the water supply period is several months (10 days). The firm output shall be obtained by frequencyanalysis method according to the output in the long-series calculation period.

b) The average output during low-flow period may be designed as the as the firm output for the hydropower stations with no data or less than 5 MW of capacity.

6.3 The calculation of the characteristic head shall meet the following requirements:

a) Maximum working head should be the difference between the normal pool level and the downstream tailwater level corresponding to the firm output for power generation. If the hydropower station performs the daily regulation task, the minimum output in the daily regulation shall be selected to calculate the downstream tailwater level; if there is a flood control task in the downstream of the reservoir, the maximum head shall be verified in the flood control regulation and a larger value shall be taken as the maximum working head. The maximum working head may be calculated without consideration given to the head loss in the water conductor system; with regard to the diversion hydropower station, the water delivery head may be calculated as per the low flow condition encountered, and a certain allowance may also considered.

b) Minimum working head should be the difference between the dead water level and the downstream tailwater level corresponding to the maximum discharge capacity of the hydropower station, with head loss in the water conductor system deducted. With regard to the hydropower station with low head, the possible minimum head of power generation in the flood period shall be studied.

c) Arithmetic average head shall be the arithmetic average value of the average heads in each calculation period of a long series of calculation results.

d) Weighted average head shall be the ratio of the sum of the products of the average head multiplied with the average output in each calculation period of a long series of calculation results to the sum of the average outputs in each calculation period.

6.4 The hydraulic energy indicator of the daily regulated hydropower station may be calculated by the daily or the hourly time interval. The hydraulic energy indicator of the non-regulated hydropower station shall be calculated by the daily time interval. Both daily and hourly time interval methods shall meet the following requirements:

a) When the daily time interval method is used, the calculation shall be carried out as per the following provisions:

1) According to the daily mean runoff series at the water intake over the years (for the SHP station with a scale less than 5 MW, three or more typical years including the high-flow year, median-flow year and low-flow year may be used), the daily flow-duration curve or the daily flow-dependability curve shall be drawn.

2) According to the heads corresponding to various flows and the selected output coefficient, the output duration curve or the output-dependability curve shall be calculated and drawn. The power output corresponding to the design dependability of the hydropower station is the firm output.

3) According to the output-dependability curve of the hydropower station, the relationship curve between installed capacity and power generation shall be calculated and drawn, and then in combination with the selection of the installed capacity of the hydropower station, the mean annual power generation shall be determined. See Appendix A for the specific calculation method.

b) When the hourly interval method is used, the calculation shall be carried out as follows:

1) According to the peak-load operating time in the local daily load diagram, and according to the principle of making the best use of peak load to generate electricity and maintain high water level operation, the daily runoff regulation shall be calculated within 24 hours and the daily mean flow is taken as the inflow in hours per day.

2) When the daily mean flow is greater than the rated flow of the unit, the reservoir regulation may not be considered. The upstream water level of the reservoir employs the normal pool level for calculating the hydraulic energy output.

3) When the hydropower station does not generate electricity and the reservoir could not reach full storage during the valley-load period, the hydropower station will not generate electricity during the entire period of valley load and at the beginning of the peak load until the reservoir is full; during the rest of the peak-load period, the sum of the total inflow and the regulation storage will be used as the average for electricity generation.

4) When the hydropower station does not generate electricity but the reservoir could reach full storage and there is surplus water during the valley-load period, the hydropower station

may not generate electricity at the beginning of the valley-load period; the reservoir may firstly reach full storage, and then the hydropower station could generate electricity at full water level as per the reservoir inflow in the later stage of the valley-load period; during the entire period of peak load, the sum of the total inflow and the regulation storage is used for electricity generation.

5) When the hydropower station does not generate electricity but the reservoir could reach full storage and there is surplus water during the valley-load period, and the regulation storage and the inflow may satisfy the fully-loaded running demand of the unit while there is surplus water released during the peak-load period, to avoid releasing surplus water during the peak-load period, the hydropower station may not generate electricity at the beginning of the valley-load period until the reservoir reaches full storage, and could generate electricity as per the sum of the reservoir inflow and the released surplus water during the peak-load period at the later stage of the valley-load period. The sum of the total inflow and the regulation storage during the entire period of peak load, after deducting the released surplus water, will be used for electricity generation.

6.5 The hydraulic energy indicator of the annual regulated hydropower station may be calculated by the equal output regulation and the equal flow discharge regulation, see Appendix B for the specific method, and the following provisions shall be met:

a) For the annual energy output calculated with a long series of runoff data, the mean value shall be used to obtain the multi-year average power indicators. The firm output shall be calculated by the frequency analysis method as per the output in the long-term series.

b) For a hydropower station lacking data or with a capacity less than 5 MW, the mean annual energy output may be calculated as per the runoff in the design typical high-flow year, median-flow year and low-flow year. The designed average output during the low-flow year may be regarded as the firm output of the hydropower station.

6.6 The hydraulic energy output of the hydropower station with multi-year regulation performance may be calculated with reference to the calculation of the annually-regulated hydropower station. At the beginning of the calculation, the dead water level may be regarded as the initial reservoir level so as to obtain the storage process of the reservoir over the years, and then the initial reservoir storage levels in each year shall be recorded with their average value taken as the initial water level for further calculation; the calculation may also be simplified by taking the water level from the dead water level to two-thirds of the normal pool level as the initial water level.

7 Load forecast and electric power and energy balance

7.1 Power supply scheme selection, power supply mode determination, electric power and energy balance and flow distribution calculation shall be carried out on the basis of the load prediction;

meanwhile, the power system development speed determination and phased development plan preparation of the hydropower station shall also be based on the load prediction.

7.2 Load forecast shall be mainly based on the existing forecast results in the power department which shall be adopted after analysis. Its main reference data shall include the capacity of the various electrical equipment in the system; the comprehensive maximum load for monthly electricity consumption, the monthly electricity consumption and the annual total electricity consumption of the system; the comprehensive maximum load of the monthly power supply, the monthly power supply and the annual total power supply of the system; comprehensive grid loss rate of the system; and the power consumption rate and the load growth rate of the each power station.

7.3 With regard to the critical power station dominating a larger proportion of the system, the load forecast results provided by the electric power department shall be verified with multiple methods. In general, the application coefficient method, unit consumption method and other basic forecasting methods shall be selected.

7.4 The selection of the installed capacity of hydropower stations being a smaller proportion of the system may be determined by economic evaluation and scheme comparison according to the actual situation of the local power demand, while the computation of electric power and energy balance is not required. If the plant is not connected to the grid (i.e. an isolated power plant), its installed capacity may be selected based on twenty years of the power demand in the surrounding areas. A phased development of this isolated project may also be considered.

7.5 The installed capacity of the critical hydropower station, which accounts for a large proportion of the system and are incorporated into the isolated power grid, must be selected on the basis of the balance of the entire network. The balance of electric power and energy shall meet the following requirements:

a) The electric power and energy may be balanced according to the capacity, electric quantity and load of various power stations in the representative high-flow year, median-flow year and low-flow year. The frequencies of the representative high-flow year, median-flow year and low-flow year may be selected according to the following methods:

   1) The frequency P_{low} of the low-flow year may be consistent with the comprehensive power supply dependability of the electric power system as required in the planning.

   2) The frequency P_{median} of the median-flow year is 50%.

   3) The frequency P_{high} of the high-flow year may be determined as per $P_{high} = 100\% - P_{low}$.

b) The electric power and energy balance shall be carried out with a daily load chart in the design target year. The daily load chart shall be selected and plotted among two to four months with the most prominent power-supply conflict within the specific operation situation in the grid.

8 Selection of flood regulation and characteristic flood-control level

8.1 In the calculation of flood regulation, technical and economic comparison shall be made for the scale of dedicated discharge structures and limit water level during flood season according to the flood control standard of the project and downstream flood control requirements, so as to determine the flood season limit level, the design flood level and the check flood level.

8.2 The characteristic water level for flood control shall be determined through technical and economic comparison in combination with the layout and scale of flood discharge structure.

8.3 The limiting water level in flood season shall be determined, according to the principle of combining flood control with utilizable capacity, based on a comprehensive analysis of the influences of the different limiting water levels in flood seasons on the main benefit objectives, downstream flood control, sediment accumulation, reservoir area inundation and project investment.

8.4 With regard to a cascade reservoir, the flood control standard, flood control task and flood dispatching principle of the reservoirs in the cascade shall be analysed to coordinate the flood control operation modes of the designed hydropower station with other reservoirs in the cascade.

9 Selection of normal water level and dead storage water level

9.1 The selection of normal water level of the reservoir shall be determined by several schemes, which are proved by technical and economic analysis, according to the cascade development plan, comprehensive utilization requirement, engineering construction conditions, sediment deposition, reservoir inundation and ecological environment. The reservoir inundation and ecological environment shall be regarded as important factors in the comparison of schemes.

9.2 In addition to the comparison of the economic energy indexes in different schemes, the normal water level selection must with consideration given to the following factors. In the selection of normal reservoir water level, the following factors must be considered in addition to the comparison of kinetic economic indicators of each scheme:

a) The topography and geology of the dam site, the layout of the hydraulic structures, the construction conditions, cascade connection, ecological environment, and the comprehensive utilization of the water resources;

b) The inundation, immersion and salinization loss of the reservoir area as well as the impact on the farmland, cities and towns, traffic, diggings and important cultural relics and historic sites;

c) The impact of sediment accumulation due to rise of backwater and the cascade connection with regard to the heavy silt-carrying river, the influence of sedimentation on the storage capacity, benefit and cascade relationships and the variation of the benefits due to the sedimentation process of the reservoir.

9.3 The selection of dead storage water level of the reservoir shall be determined by comprehensive analysis according to both the comparison of electric power and energy benefit (firm output and power generation) in different schemes, and the consideration of scouring and silting of sediment, restrictions of the turbine working conditions on the elevation at the inlet, as well as the requirements of other departments on the water level and flow.

10 Selection of installed capacity and type of unit

10.1 The power supply scope of the hydropower station should be determined by analyzing the development planning of local power system, scale of the hydropower station and its function in the power system.

10.2 The installed capacity shall be determined after comprehensive comparison in combination with electric power and energy balance by calculating the annual power output, generation benefit and corresponding expenses of each installation scheme on the basis of the analysis of the regulation performance of the reservoir, the comprehensive utilization requirement, the load and characteristics of the system in the design target year, the power supply scope and the power supply structure.

10.3 With regard to the reservoir hydropower station with water requirements for ecology, irrigation, living and navigation, on the premise of meeting the water supply for ecology, irrigation, living and navigation, various schemes shall be selected for technical and economic comparison.

10.4 In the selection of the installed capacity, the intake flow shall be coordinated with the upstream and downstream cascade hydropower stations.

10.5 The rated water head of the turbine shall be determined according to the variation characteristics of the head and the weighted average head. The rated water head may be selected between the range from 0.85 to 0.95 of the ratio of rated head to weighted average head. The rated head should not be higher than the weighted average head during flood season.

10.6 The types of the turbine and the number of units shall be selected after comprehensive analysis and comparison according to such factors as power station output, head variation characteristics, layout of the hydropower station, equipment manufacturing level and power system operation requirements.

11 Selection of dimensions of headrace and volume of daily regulation pool

11.1 The selection of the headrace dimension and the daily regulating pond volume for the diversion hydropower station shall be determined through analysis and comparison according to the topographic and geological conditions, ice, sediment deposition, installed capacity of the hydropower station and the daily operation modes, while appropriate space shall be reserved.

11.2 The headrace (channel/tunnel) dimension shall be selected by optimization through scheme comparison by calculating the head loss, the electricity benefits and the expenses in various schemes.

11.3 The volume of daily regulation pool may be determined based on the storage capacity that can meet the daily load operation requirement under the design dependability condition after regulation. The safety factor may be 1.1 to 1.2.

11.4 If not restricted by other the comprehensive utilization departments, the volume of daily regulation pool of the cascade hydropower stations should be selected according to the synchronous operation of cascade hydropower stations.

12 Analysis of reservoir sediment deposition and calculation of backwater

12.1 For high-head hydropower station, the impacts of sediment size on the erosion of turbine blades shall be analysed, and the allowable sediment concentration through the turbine shall be proposed.

12.2 In the calculation of sediment scouring and silting of the reservoir, various calculation methods may be selected according to the sediment characteristics, sediment management mode and availability of the hydrologic data. When the data is insufficient, the calculation may be carried out with the analogue method or the empirical method. When the data is relatively sufficient, the mathematical model may be used for the calculation, and the main parameters shall be calibrated with the measured data, and the results related to the corresponding sediment accumulation positions, the siltation volume and the influence on regulation storage shall be proposed.

12.3 In the calculation of reservoir backwater, the natural water surface profile before building the reservoir and the water surface profile of backwater in the reservoir within the predicted duration of sedimentation after building the reservoir shall be derived from the design discharge according to the river course conditions, characteristics and operation mode of the reservoir. In the basic data for the backwater calculation, the backwater sectional layout and the basis for the roughness coefficient selection shall be stated; the calculated section shall be able to reflect the basic characteristics of the river course and the characteristics of the river bed after sedimentation. For a silt-carrying river, the effect of reservoir sedimentation shall be considered for the backwater calculation.

13 Reservoir operation mode and operational characteristics over multiple years

13.1 The reservoir operation mode shall be proposed according to the defined parameters and with consideration of multi-purpose requirements and the situation of existing cascade reservoirs.

13.2 The operation characteristics over multiple years shall be proposed according to the reservoir operating modes.

14 Figures

The figures for the hydraulic engineering and energy calculation shall include:

a) Schematic diagram of the project geographic location;

b) Schematic diagram of the power supply scope of the project;

c) Schematic diagram of the engineering layout in the drainage basin (region) hydropower planning;

d) Map of the inundation area of the reservoir;

e) Reservoir water level-area-capacity curve;

f) Water Stage-discharge curve of the hydropower plant site;

g) Generation output dependability curve;

h) Longitudinal section of the reservoir sediment accumulation and backwater curve;

i) Reservoir operation graph for the design flood;

j) Reservoir operation Rule Curve (based on the requirements for releases for irrigation, water supply);

k) Reservoir operation graph for the check flood;

l) Flows series for meeting water demands other than power (e.g. irrigation, water supply).

Appendix A
(Informative)
Hydropower calculation for non-regulated or daily regulated hydropower stations

A.1 When calculating the hydraulic energy for non-regulated or daily regulated hydropower stations, the runoff data to be used may be categorized into several flow bands in ascending order from small to large, and the occurrence frequency of the various flow bands shall be calculated, as shown in Table A.1.

Table A.1 Statistical table of the occurrence frequency of the daily mean flow of non-regulated or daily regulated hydropower stations over the years

Flow bands (m^3/s)	Mean flow $\overline{Q}$(m^3/s)	Occurrence frequency of the flow at various flow bands over the years							Total of occurrence Times n_i
		XX year	XX year	XX year	XX year	XX year	XX year	XX year	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$Q_1 \sim Q_2$									
$Q_3 \sim Q_4$									
$Q_5 \sim Q_6$									
NOTE The number of years in this table shall be determined according to the actually available data, but shall at least include three typical years, i.e. the high-flow year, median-flow year and low-flow year.									

A.2 For the non-regulated or the daily regulated hydropower station, the hydraulic energy calculation shall be carried out with the tabulation method in accordance with Table A.2. According to the results of Table A.2, the output-frequency or the output-duration curve shall be drawn, and its hydraulic energy index shall be worked out.

Table A.2 Calculation of the hydraulic energy output of non-regulated or daily regulated hydropower stations

No.	Mean flow $\overline{Q}_i$ (m^3/s)	Upstream water level Z_{si} (m)	Downstream water level Z_{xi} (m)	Net head H_i (m)	Output N_i (kW)	Output difference ΔN_i (kW)	Occurrence times n_i	Accumulative number of times S_{ni}	Dependability P_i (%)	Duration t_i (h)	Electric energy E_i (kW·h)	Accumulative electric energy SE_i (kW·h)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)=(7)×(11)	(13)
1 2												

NOTE 1 In column (2), $\overline{Q}_i$ is arranged in an ascending order as per their values from top to bottom in the table.

NOTE 2 The value in column (7) is equal to the difference between the value in column (6) of this line and the value in column (6) of the previous line, $\Delta N_i = N_i - N_{i-1}$.

NOTE 3 The value in column (8) is taken from Table A-1.

NOTE 4 The value in column (9) is the accumulation of the values of column (8) from the last line upwards, i.e. $S_{ni} = Sn_{i+1} + n_i$。

NOTE 5 In column (10), $P_i = S_{ni}/(S_{n1}+1)$。

NOTE 6 In column (11), $t_i = 8\,760 \times (P_i + P_{i-1})/200$ when $i \geqslant 2$.

NOTE 7 The value in the first line of column (12) $E_1 = N_1 \times t_1$.

NOTE 8 The value in column (13) is the accumulation of the values of column (12) from the first line downwards, i.e. $SE_i = SE_{i-1} + E_i$.

Appendix B
(Informative)
Hydropower calculation for an annually regulated reservoir hydropower station

B.1 Equal output regulation calculation: the calculation of the equal output regulation is usually carried out by the trial computation, that means to first assume the firm output and then to carry out the trial computation for the electricity generation regulation flow according to the known output (assumed firm output) period by period. If the water level during a certain period is higher than the normal pool level and the surplus water is released (or the failure of power generation occurs as the water level is lower than the dead water level), it is necessary to increase (or decrease) the electricity generation regulation flow and to calculate the corresponding output. After completing the regulation calculation for the whole series, the assumed output will be regarded as the obtained firm output if the output damage situation meets the dependability requirement; otherwise, it is necessary to re-assume and re-calculate it until the requirement is met. The hydraulic energy output like the firm output and the mean annual energy output obtained by the equal output regulation calculation shall be verified according to the dispatching regulation diagram when necessary.

B.2 When the required utilizable capacity and the storage/discharge process of the reservoir are determined for the known hydropower station according to the output variation process of the load diagram, the water consumption of the other departments and the characteristic water level of the reservoir (normal pool level or dead storage water level), or when the utilizable capacity is known and it is required to calculate the storage/discharge process of the reservoir and the firm output, the calculation may be carried out with the trial method for simultaneous solution of the Formula (B.1), Formula (B.2) and Formula (B.3). See Table B.1 for the calculation table.

$$N = AQ_p(\overline{Z}_s - \overline{Z}_x - \Delta h) \quad \cdots\cdots (B.1)$$

$$V_m = V_c + (Q_i - Q_p - Q_y)\Delta t \quad \cdots\cdots (B.2)$$

$$V_m = V_c - (Q_p - Q_i - Q_y)\Delta t \quad \cdots\cdots (B.3)$$

where

N is the output of the hydropower station, in kW;

A is the comprehensive output coefficient of the power station;

Q_p is the Intake flow of the hydropower station, in m^3/s;

$\overline{Z}_s$ is the average water level of the upstream reach, in m;

$\overline{Z}_x$ is the average water level of the downstream reach, in m;

Δh is the head loss, m;

V_m is the reservoir storage capacity at the end of the period, in m^3;

V_C is the reservoir storage capacity at the beginning of the period, in m^3;

Q_i is the upstream inflow, in m^3/s;

Q_y is the water consumption of the other departments, evaporation and leakage loss and release of the surplus water, in m^3/s;

Δt is the duration, in s.

Table B.1 Hydraulic energy calculation of the annually regulated reservoir when the output of the hydropower station is known

Month	Outpour of the hydropower station N_i (kW)	Natural water inflow Q_1 (m^3/s)	Water-using flow (m^3/s)			Water storage and supply of reservoir (m^3)		Total water storage of reservoir (m^3)			Head (m)				Output N_i (kW)	Electric energy production E_i (kW·h)
			Electric energy production Q_{pi}	Others Q_{yi}	Total Q_i	Water storage $+\Delta W_i$	Water supply $-\Delta W_i$	At the beginning of the month V_{ci}	At the end of the month V_{mi}	Monthly average $\overline{V}_i$	Upstream water level Z_{si}	Downstream water level Z_{xi}	Head loss Δh_i	Net head H_i		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)

NOTE 1 Column (4) is Q_{pi} in the water supply period, is Q_{xi} in the water storage period but shall not exceed the maximum flow of the hydropower station.

NOTE 2 Column (5) Q_{yi}, including the water consumption of the other departments, the evaporation and leakage loss and the released surplus water.

NOTE 3 Column (6), $Q_i = Q_{pi} + Q_{yi}$.

NOTE 4 Columns (7) and (8), $\Delta W_i = \pm(Q_{1i} - Q_i)T$, where T refers to seconds in the current month.

NOTE 5 Columns (9) and (10), $V_{mi} = V_{ci} \pm \Delta W_i$.

NOTE 6 Columns (12), the upstream water level Z_{si} is obtained with $\overline{V}_i$ by referring to the reservoir stage and the storage capacity relation curve.

NOTE 7 Columns (13) is obtained with the discharged flow by referring to the downstream stage and the discharge relation curve.

NOTE 8 Columns (15), $H_i = Z_{si} - Z_{xi} - \Delta h_i$.

NOTE 9 Columns (16), $N_i = A \times H_i \times Q_i$.

NOTE 10 Columns (17), $E_i = N_i \times T$; where T refers to hours in each month; accumulative amount for the entire year is $\sum E_i$, i.e. the annual energy output.

NOTE 11 In the table, the subscript i of the symbols refers to month, i = January, February, …, December.

B.3 Equal flow regulation calculation:

a) In the equal flow regulation calculation, it is assumed that different flows are diverted for the hydropower station during the storage period and the supply period; the intake flows during the storage period and the supply period should be derived through trial computations.

1) The intake flow during the supply period is calculated by means of the Formula (B.4).

$$Q_p = \frac{W_{gl} + V_x - W_{gs} - W_{gy}}{T_g} \qquad \text{(B.4)}$$

where

Q_p is the intake flow of the hydropower station during the supply period, in m^3/s;

W_{gl} is the upstream water inflow during the supply period, in m^3;

V_x is the utilizable capacity, in m^3;

W_{gs} is the water loss during the supply period, in m^3;

W_{gy} is the water consumption of the other departments during the supply period, in m^3;

T_g is the duration of the supply period, in s.

2) The intake flow during the supply period is calculated by means of the Formula (B.5).

$$Q_x = \frac{W_{xl} - V_x - W_{xs} - W_{xy}}{T_x} \qquad \text{(B.5)}$$

where

Q_x is the intake flow of the hydropower station during the storage period, in m^3/s;

W_{xl} is the upstream water inflow during the storage period, in m^3;

V_x is the utilizable capacity, in m^3;

W_{xs} is the water loss during the storage period, in m^3;

W_{xy} is the water consumption of the other departments during the storage period, in m^3;

T_x is the duration of the storage period, in s.

b) The equal flow regulation may be calculated with the tabulation method, as shown in Table B.2. The corresponding hydraulic energy indexes are obtained with the results for the design low-flow year or multiple-year (or three typical years, i.e. the high-flow year, median-flow year and low-flow year) tabulation calculation. The average output during the supply period of the design low-flow year is the firm output. The average value of the annual energy output over the years or in three typical years, i.e. the high-flow year, median-flow year and low-flow year, is the mean annual energy output.

c) The equal flow regulation calculation shall take into account the influence of the operation head of the hydropower station when the water is stored in or discharged from the reservoir. During the specific calculation, the storage capacity or water level variations at the beginning and at the end of the period may be checked and calculated with the reservoir storage and the stage relation curve.

Table B.2 Electric energy calculation of the equal flow regulation for the annually-regulated reservoir

Month	Natural water inflow Q_{1i} (m^3/s)	Water-using flow (m^3/s)			Water storage and supply of the reservoir (m^3)		Total water storage of the reservoir (m^3)			Head (m)				Output N_i (kW)	Electric energy production E_i (kW·h)
		Electric energy production Q_{pi}	Others Q_{yi}	Total Q_i	Water storage $+\Delta W_i$	Water supply $-\Delta W_i$	At the beginning of the month V_{ci}	At the end of the month V_{mi}	Monthly average $\overline{V}_i$	Upstream water level Z_{si}	Downstream water level Z_{xi}	Head loss Δh_i	Net head H_i		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)

NOTE Refer to Table B.1 for the calculation methods for the columns in this table.