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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.

Table of Contents

Foreword	VI
Introduction	VII
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 General principles	1
5 Runoff calculation	2
6 Hydraulic energy calculation	3
7 Load prediction and electric power load balance	5
8 Selection of the characteristic water level for flood regulation and flood control	6
9 Selection of the normal and dead reservoir levels	7
10 Selection of the installed capacity and unit size	8
11 Selection of the head race dimension and the daily regulating pond volume	8
12 Analysis of the reservoir sediment accumulation and calculation of the backwater	8
13 Reservoir operating modes and operational characteristics over the years	9
14 Figures	9
Appendix A (Informative) Hydropower calculation for unregulated or daily regulated hydropower stations	10
Appendix B (Informative) Hydropower calculation for an annually regulated reservoir hydropower station	12

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 30MW.

- 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 assessment and the electric power load 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 The hydraulic engineering and energy calculation shall be carried out with adherence to the principles of the comprehensive utilization and management of water resources, while taking fully into account the correlations between requirements and potentialities, short term and long term perspectives, the mainstream and the branches, upstream and downstream interests, as well as the correlations between water resource development and the ecological environment/land requisition and resettlement for the purpose of developing the water resources in an economical and rational manner.

4.2 The hydraulic engineering and the energy shall be calculated on the basis of the integrated planning of the drainage basin or the overall planning of the river (reach) and the electrical power planning. According to the requirements for the various purposes, 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 the 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 The hydraulic engineering and the energy shall be calculated on the basis of collecting and analysing the basic data concerning the local social and economic conditions, natural conditions, electric power system and ecological environmental protection, as well as the multi-purpose requirements. The basic data include:

- a) The economic-social data shall include the current status and development of the regional/ national economy, the integrated planning of the drainage basin, the current status of the hydropower resource development of the drainage basin as well as the planning data, the current status and planning data of the water environment protection, the regional electrical network status and planning and the data for the calculation of the multi-purpose benefits;
- b) The landform data shall include the topographic map of the reservoir/diversion area (the scale shall not be less than 1:1 000), the river longitudinal/cross-section profiles of the upstream/downstream of the dam/diversion site and the longitudinal/cross-section profiles of the downstream reach of the power station;

- c) The professional planning and water demand data for the various purposes shall include the water consumption by the water sectors upstream/downstream of the reservoir/diversion weir, the ecological water demand and the water demands for fishing, tourism and shipping.

4.4 Three to five years after the first unit from the power station starts working refers to the power station’s design level year, which shall be consistent with the national economic development plan.

5 Runoff calculation

5.1 For the runoff calculation, the water balance computation shall be done, the guaranteed output, the mean annual energy output and the characteristic head of the hydropower station shall be calculated, and the operational characteristic and benefits shall be stated according to the performance of the hydropower station and the water demand for various purposes. When the water balance computation is done, all the kinds of water consumption in the upstream and downstream areas, and the dependability of the water consumption shall be considered.

5.2 The hydraulic energy output of the reservoir hydropower station with water requirements for ecology, irrigation, living and shipping shall be calculated based on the overall planning and with due consideration of all the factors, so as to reasonably determine the necessary storage capacity and dead storage level. The electric energy output shall be calculated with comprehensive consideration given to all the kinds of water demands, and with due consideration given to the water supply requirement in an extraordinary low-flow year. The relevant hydraulic energy output shall be calculated according to the net availability of water.

5.3 The hydraulic energy of a cascade hydropower station shall be calculated with full consideration given to the integrated approach with reference to the flow, flow path and water level relationship between the upstream and the downstream cascade stations as well as the mutual impact 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) According to the hydroelectric capacity proportion in the power system, select the hydropower station design guarantee rate in accordance with content described in Table 1.

Table 1 - Design dependability of the hydropower station

Hydroelectric capacity proportion	Hydroelectric capacity proportion in the power system(%)		
	Below 25	25~50	Above 50
Hydropower station design guarantee rate (%)	80~85	85~90	90~95

- b) With regard to the reservoir-based hydropower station mainly for irrigation purposes or other water supply proposed, its design dependability shall be selected according to the requirements of the main water use.
- 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 reliability.

5.5 The chronological series method shall be applied in the runoff calculation.

- a) For unregulated or daily regulated hydropower stations, the calculation may be made by adopting the mean daily discharge of the long series or the mean daily discharge in a typical year as per the data availability. 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) With regard to the multi-year regulated reservoir and the annually regulated reservoir, long series shall be adopted for the calculation as per the monthly (ten-day) mean 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 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 runoff calculation of the cascade hydropower station shall be carried out accordingly.

6 Hydraulic energy calculation

6.1 The hydraulic energy output is calculated mainly with the chronological series method; the water balance computation shall be made according to the performance of the hydropower station as well as the water demands for ecological, irrigation, domestic and shipping purposes, to calculate the guaranteed output, mean annual energy output, peak-load electric quantity, valley-load electric quantity and characteristic head of the hydropower station.

6.2 Calculation of guaranteed output:

- a) For a multi-year regulated hydropower station, its calculation period is the low-flow year group; for an annually (quarterly) regulated hydropower station, its calculation period is several months (10 days). The guaranteed output shall be obtained by frequency analytic method according to the output in the long-series calculation period.
- b) For the hydropower station lacking available data or with a capacity of less than 5MW, the average output in the calculation period in the design low-flow year may be used as the guaranteed output for substituting the output corresponding to the design guarantee rate obtained after analysing the frequency of average output in the calculation period.

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

- a) Maximum working head usually refers to the difference between the normal pool level and the downstream tailwater level corresponding to the guaranteed output for power generation. If the hydropower station performs the daily regulation task, the minimum output in the daily regulation shall be selected for the calculation of the downstream tailwater level; if there is a flood control purpose task downstream of the reservoir, the maximum working head shall be verified with the possible maximum head during the flood control dispatching process, and the larger value is 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-type hydropower station, the water delivery head may be calculated as per the low flow condition encountered, and a certain allowance may also be considered.
- b) Minimum working head usually refers to the difference between the minimum draw down 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 for power generation in the flood period shall be taken into consideration.

- c) Arithmetic average head refers to the arithmetic average value of the average heads during various calculation intervals among the long-series calculation results.
- d) Weighted average head refers to the ratio of the sum of the products of average head multiplied with the average output during various calculation intervals among the long-series calculation results to the sum of the average outputs during various calculation intervals.

6.4 The hydraulic energy outputs of the daily regulated hydropower station may be calculated by using the daily or the hourly time interval. The hydraulic energy outputs of the unregulated hydropower station shall be calculated by using the daily time interval.

- 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 5MW, 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, the power-duration curve or the power-dependability curve shall be calculated and drawn. The power output corresponding to the design dependability of the hydropower station is the guaranteed output.
 - 3) According to the output-dependability curve of the hydropower station, the installed capacity-electric energy output relation curve shall be calculated and drawn, and then in combination with the selection of the installed capacity of the hydropower station, the mean annual energy output 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 computation shall be made as that the runoff is regulated 24 hours a day 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 until the reservoir reaches full storage; in the later stage of the valley-load period, the hydropower station could generate electricity at full water

level as per the reservoir inflow; 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 outputs of the annually-regulated hydropower station may be calculated as per the equal output regulation and the equal flow discharge regulation. See Appendix B for the specific method.

6.6 The hydraulic energy outputs of the annually-regulated hydropower station shall be calculated as per the following provisions:

- a) For the energy output year after year calculated with the runoff long term series, the mean value shall be used to obtain the mean annual energy output. The guaranteed output shall be obtained 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 of less than 5MW, 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 average output of the design low-flow year may be regarded as the guaranteed output of the hydropower station.

6.7 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; or the calculation may be simplified in such a way that the water level at the 2/3 position from the dead water level to normal pool level is taken as the initial water level.

7 Load prediction and electric power load balance

7.1 The selection of the power supply scheme, the determination of the power supply mode, the computation of the electric power and energy balance and the calculation of flow distribution shall be carried out on the basis of the load(power demand) assessment; meanwhile, the determination of the development growth of the electric power system and the preparation of the phased development plan for the hydropower station shall also be based on the load.

7.2 The load assessment shall be completed mainly by analysing and making use of the existing assessment results from the electric power department. Its main reference data shall include the capacity of the various electrical systems; the maximum comprehensive load for monthly electricity consumption, the monthly electricity consumption and the annual total electricity consumption of the system; the maximum comprehensive 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 various station service power consumption rate and the load increase rate of the power stations.

7.3 With regard to the critical power station dominating a relatively larger proportion of the system, the load prediction results provided by the electric power department shall be verified with multiple methods. In general, the basic load assessment methods demand factor and unit consumption shall be comprehensively selected.

7.4 The selection of the installed capacity for the SHP station being a smaller proportion of the system may be determined by using the economic evaluation and scheme comparison method according to the actual situation of the local power demand, while the computation of the balance of electric power and energy is not required. However, if a plant is not within the distribution system (isolated plant) then its capacity better be selected purely based on 20 years of the power demand of the surrounding areas to be fed. To save on the cost of the project, the phased development of this isolated project may be considered i.e. the entire plant would be designed for full capacity with an increased number of units and all the Civil Structures to be constructed but the E&M units on the plant building to be installed/added in phases.

7.5 With regard to the critical hydropower station dominating a relatively larger proportion of the system and being connected to the isolated SHP network, its installed capacity must be selected on the basis of the balance of electric power and energy throughout the entire network:

- a) The electric power and energy may usually 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 method:
 - 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 balance of the electric power and energy shall be carried out with a daily load chart in the design target year. The daily load chart shall be selected and plotted among 2 to 4 months with the most prominent power-supply conflict within the specific operation situation in the grid.

8 Selection of the characteristic water level for flood regulation and flood control

8.1 With regard to the flood regulation calculation, the proposed capacity of the overflow structures and the maximum water level during flood season shall be compared in technical and economic aspects according to the flood control standard for the project and the downstream flood control requirement for determining the maximizing water level in flood season, the design flood level and 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 capacity of the overflow structures.

8.3 The maximum 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 maximum 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 so as to coordinate the flood control operation modes of the hydropower station under design with other reservoirs in the cascade.

9 Selection of the normal and dead reservoir levels

9.1 The selection of the normal reservoir level shall be determined through technical-economic considerations ,comprehensive analysis of various schemes formulated according to the cascade development, the comprehensive utilization requirement, engineering construction conditions, sediment accumulation, reservoir inundation and ecological environment. During scheme comparison, the reservoir inundation and ecological environment shall be regarded as important factors.

9.2 In addition to the comparison of the economic energy indexes in different schemes, the normal reservoir level must be selected with consideration given to the following factors.

- a) The topography and geology of the dam site, the layout of the hydraulic structures, the construction conditions, cascade relationships, environment and ecology, and the comprehensive utilization of the water resources;
- b) The inundation, immersion and salinization loss of the reservoir area as well as the influence on the farmland, cities and towns, traffic, diggings and important cultural relics and historic sites;
- c) The influence of sediment accumulation due to rise of backwater and the cascade relationships 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 In addition to comparing the power and energy benefit (guaranteed output and electric energy production) in different schemes, the dead water level of the reservoir shall be selected with consideration given to the scouring and silting of sediment, restrictions of the water turbine working conditions on the elevation at the inlet, as well as the requirements of other departments on the water level and flow. With regard to the hydropower station with pressure water diversion for power generation and water supply, the dead water level shall meet the water pressure requirement of the water inlet.

10 Selection of the installed capacity and unit size

10.1 The power station supply scope should be determined according to the regional power system planning, the hydropower station's scale, and the impact of the hydropower station on the electrical system.

10.2 The installed capacity shall be determined after comprehensive comparison in combination with the balance of the electric power and energy by calculating the annual electric energy output, generation benefit and corresponding expenses indifferent installation schemes on the basis of analysing the regulation performance of the reservoir, the comprehensive utilization requirement, 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, drinking water and shipping, its installed capacity shall be selected on the basis of the flow requirement of water supplied for ecologic, irrigation, drinking water and shipping purposes; and the various schemes are selected and finalized after economic and technical comparison.

10.4 When the installed capacity is selected, the intake flow shall be coordinated with the upstream and downstream cascade hydropower stations.

10.5 The rated water head of the water turbine should be determined according to water head change characteristics and the weighted average head. The rated water head ranges from 0.85 to 0.95 according to the rated water head and the weighted average head, and cannot be greater than the average weighted water head in the flood season.

10.6 The hydraulic turbine type and number of units shall be selected through comprehensive analysis and comparison by calculating the benefits and expenses of the different schemes according to the output of the hydropower station, the head variation characteristic, project layout, equipment manufacturing level and operation requirements of the electrical power system. To ensure safe and flexible operation of the electrical power system, the number of units should not be less than two. When the water is required to be drained for ecological purpose and the head is available then it is necessary to consider the installing of an ecological unit to make additions to the power capacity of the project.

11 Selection of the head race dimension and the daily regulating pond volume

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

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

11.3 The daily regulating pond volume 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 daily regulating pond volume of the cascade hydropower station should be selected as if the cascade hydropower stations are operated synchronously.

12 Analysis of the reservoir sediment accumulation and calculation of the backwater

12.1 With regard to the high-head hydropower station, the impacts of sediment size on the erosion of the turbine blades should be carefully investigated/analysed to specify the allowable sediment concentration through the turbines.

12.2 When calculating the sedimentation and scouring of the reservoir, different calculation methods may be selected according to the sediment flow 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 calculations, while 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 With regard to the reservoir backwater calculation, the natural water flow profile before the construction of the reservoir and the reservoir area backwater flow profile in the sediment accumulation prediction years after the construction of the reservoir shall be derived as per the flow that meets the design requirement according to the river course condition, reservoir characteristics and reservoir operation mode. In the basic data for the backwater calculations, 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. With regard to a silt-carrying river, the backwater calculation shall be carried out with consideration given to the influence of reservoir sedimentation.

13 Reservoir operating modes and operational characteristics over the years

13.1 The reservoir operating mode shall be proposed according to the selected parameters and with consideration given to the comprehensive utilization requirement and the completed cascade situation.

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

14 Figures

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

- a) Schematic diagram of the geographic location of the project
- 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 stage-area-storage-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 unregulated or daily regulated hydropower stations

A.1 When calculating the hydraulic energy for unregulated 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 unregulated or daily regulated hydropower stations over the years

Flow bands (m ³ /s)	Mean flow \bar{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 With regard to the unregulated 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 unregulated or daily regulated hydropower stations

Accumulative electric energy SE_i (KW·h)	Electric energy E_i (KW·h)	Duration t_i (h)	Dependability P_i (%)	Accumulative number of times S_{ni}	Occurrence times n_i	Output difference ΔN_i (KW)	Output N_i (KW)	Net head H_i (m)	Downstream water level Z_{xi} (m)	Upstream water level Z_{si} (m)	Mean flow \bar{Q}_i (m ³ /s)	S/N_i
(13)	(12) = (7)×(11)	(11)	(10)	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)
												1 2

NOTE 1 In column (2), \bar{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. $S_{ni} = S_{n_{i-1}} + n_i$.
 NOTE 5 In column (10), $P_i = S_{ni} / (S_{n1} + 1)$.
 NOTE 6 In column (11), $t_i = 8760 \times (P_i + P_{i-1}) / 200$ when $i \geq 2$.
 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 and error method, that means to first assume the guaranteed output and then to carry out the trial computation for the electricity generation regulation flow according to the known output (assumed guaranteed 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 minimum 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 guaranteed 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 outputs like the guaranteed 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 water level), or when the utilizable capacity is known and it is required to calculate the storage/discharge process of the reservoir and the guaranteed 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.

$$N = A Q_p (\bar{Z}_s - \bar{Z}_x - \Delta h) \dots\dots\dots (B.1)$$

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

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

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 m³/s;
- \bar{Z}_s is the average water level of the upstream reach, in m;
- \bar{Z}_x is the average water level of the downstream reach, in m;
- Δh is the head loss, in m;
- V_m is the reservoir storage capacity at the end of the period, in m³;
- V_c is the reservoir storage capacity at the beginning of the period, in m³;
- Q_i is the upstream inflow, in m³/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	Output of the hydropower station N_i (kW)	Natural water inflow Q_i (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 + ΔW_i	Water supply - ΔW_i	At the beginning of the month V_{ci}	At the end of the month V_{mi}	Monthly average \bar{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), $\Delta W_i = \pm(Q_{ci} - Q_i)T$, 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 \bar{V}_i by referring to the reservoir stage and the storage capacity relation curve.

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

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

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

NOTE 10 Column (17), $E_i = N_i \times T$; where T refers to hours in each month; accumulative amount for the entire year is $\sum E_p$, 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).

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

where

- Q_p is the intake flow of the hydropower station during the supply period, in m³/s;
- W_{gl} is the upstream water inflow during the supply period, in m³;
- V_x is the utilizable capacity, in m³;
- W_{gs} is the water loss during the supply period, in m³;
- W_{gy} is the water consumption of the other departments during the supply period, in m³;
- 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).

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

where

- Q_x is the intake flow of the hydropower station during the storage period, in m³/s;
- W_{xl} is the upstream water inflow during the storage period, in m³;
- V_x is the utilizable capacity, in m³;
- W_{xs} is the water loss during the storage period, in m³;
- W_{xy} is the water consumption of the other departments during the storage period, in m³;
- 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 guaranteed 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 + ΔW_i	Water supply - ΔW_i	At the beginning of the month V_{ci}	At the end of the month V_{mi}	Monthly average \bar{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.



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