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INDUSTRIAL DEVELOPMENT ORGANIZATION

Technical Guidelines for the Development of Small Hydropower Plants

DESIGN

Part 2: Hydrology

SHP/TG 002-2: 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 2: Hydrology

1 Scope

This Part of the Design Guidelines covers the basic hydrological data as well as the computation methods and rationality analysis of the main hydrological parameters such as rainfall, runoff, flood and sediment applicable during the planning, design, construction and operation of an small hydropower (SHP) plant.

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 provisions

4.1 For the hydrological computation of the SHP station, the following hydrological parameters shall be analysed and computed in view of the engineering design requirements:

a) Collection of the basic data;

b) Analysis and computation of the runoff;

c) Flow duration curve;

d) Low water analysis;

e) Design flood estimation;

f) Preparation of the stage-discharge relation curve;

g) Analysis and computation of the sediment, evaporation and ice regime;

h) Basic information about the water quality;

i) Water regime measuring and reporting system;

j) Rationality check of the result.

4.2 The information on which the hydrological computation is performed shall be reliable, consistent and representative.

4.3 A variety of methods shall be adopted for the hydrological computation, and the results shall be comprehensively analysed and reasonably selected. Frequency analysis is usually adopted. Pearson curve III or other lines may be used.

4.4 The deduction of hydrological data and hydrological design parameters shall meet the following requirements:

a) The hydrologic design parameters should be calculated by the flow data in the basin with sufficient flow data.

b) The hydrologic design parameters may be calculated by the rainstorm data in the basin where the flow and rainfall data are insufficient.

c) For the basin lacking data, the hydrologic design parameters shall be calculated by using displacement or a proper model, and the hydrologic results shall be assessed by using the regional comprehensive analysis.

d) For the basin with no data, the hydrologic results should be obtained based on the regional hydrological simulation and the similarity analysis.

e) The temporary weather stations and water level stations shall be set up from the beginning of the project motion in the basin lacking data or with no data, so as to provide the reference basis for the hydrological investigation and the hydrological analysis and calculation. If necessary, a long-term water regime monitoring and reporting system should be set up.

4.5 The rationality of hydrological computation results shall be checked in the entire process of hydrological analysis and calculation.

5 Basic data

5.1 The basic data for the hydrological analysis of the SHP project shall include the hydrological and meteorological data, river basin characteristics and geographic data, information about the human activities impact, hydrological computation results of the basin and nearby areas and the other relevant data, and shall meet the following requirements:

a) The hydrological and meteorological data include:

1) Basic information such as the rainfall, evaporation, water level, flow, sediment and ice regime;

2) Other information concerning the air temperature, water temperature, water quality, water chemistry, wind speed, wind direction, humidity, air pressure, sunlight, frost and snow;

3) The geographical location, coordinates, elevation, construction time, observation items and other relevant information of each gauging station, hydrologic station and precipitation station.

b) The basin characteristics and the geographic data, including the geographic position, altitude characteristic, shape feature, catchment area, length and longitudinal bed slope of the river/stream within the catchment area from the relevant regional topographic map on a scale of 1 : 10 000 or 1 : 50 000 and the topographic survey map on a scale of 1 : 500 or 1 : 200.

c) The information on the effect of human activity include the existing hydropower station, reservoir, inter basin water diversion, irrigation areas, irrigation and drainage pumping station, water supply in the basin, the conservation of water and soil and forest cutting.

d) The hydrological computation results of the basin and nearby area include the approved hydrological analysis of existing hydropower project in the nearby basin.

e) The comprehensive analysis and research result of the hydrological and meteorological data in the district include the hydrologic manual, hydrologic atlas, rainstorm, runoff chart, water resources assessment, probable maximum storm atlas and historical flood investigation data.

f) Other relevant hydrological and meteorological data surveyed, designed, sorted, kept, prepared or published over the years by the concerned authorities for electric power, railway, highway, municipal administration, shipping, agriculture and forestry. This data may be used for comparison and analysis of the basic data collected from the water resources, hydropower and meteorological system for the rationality check of the results.

5.2 The data series upon which hydrological computation is based shall be checked for reliability, consistency and representativeness, and shall meet the following requirements:

a) Reliability check: The source, period, observation method, possible problems and reasons for not being compiled and published shall be checked for the original data not formally compiled.

b) Consistency check: The influence of human activities on the hydrologic data as well as the data inconsistency caused by the dam break, glacial lake outburst flood (GLOF) or river channel burst shall be checked.

c) Representativeness check: In cases where the data series is short and there might be a large discrepancy between the sample and the totality, the representativeness of the data shall be checked.

d) Gap analysis: Analysis or examination of discrepancies, missing or unrecorded data for a particular date or period shall be conducted, and the discrepancies shall be filled in by reasonable estimates, such as interpolation, extrapolation or other feasible methods.

e) If available, the verification and local assessment shall be conducted through local resources involving the historical flow events.

5.3 The investigation of the historical flood, recent flood mark, flood level measurement, normal water level survey and measurement, dry season survey, river reach survey and sedimentation study should be carried out for the regions with insufficient or no data; if the conditions permit, observation and survey of water level, flow and sediment shall be carried out.

6 Runoff

6.1 According to the design requirement and data availability, all or part of the following design runoff results shall be provided:

a) Annual mean runoff as well as the annual runoff, runoff in flood season, runoff during dry season and the driest month runoff with the designated frequency or the design representative years;

b) The annual distribution of the runoff in the design representative years.

6.2 When there is high data availability, all the results specified in 6.1 shall be provided; when the data availability is low, the annual runoff and the annual distribution in the design representative years shall be given at least.

6.3 According to data availabilities, the design runoff should be calculated by the following method:

a) When sufficient measured runoff data is available on the project site, the frequency analysis shall be used.

b) When there is a runoff gauging station in the downstream/upstream of the project site, in the river basin, adjacent basin or nearby basin with similar hydrological and homogeneous meteorological conditions, the hydrologic analogy method should be adopted.

c) In case measured runoff data is not available, the rainfall-runoff relationship or model method may be adopted according to the precipitation data.

d) When the runoff data is not available, it may be estimated by relevant hydrological manual and calculated on the basis of comprehensive analysis of regional results.

6.4 The gauging stations mainly consist of two categories, namely the precipitation gauging station and the runoff gauging station, which shall meet the following requirements:

a) The conditions of the runoff gauging station shall be subject to the provisions of 6.9.

b) The precipitation gauging station with the longest series may be selected as the annual precipitation gauging station from nearby area to remote area, within this basin, the adjacent basin, nearby region with similar hydrological and meteorological conditions or the region with consistent meteorological conditions when there are few limitations for the precipitation basic benchmark station.

6.5 The runoff frequency computation shall meet the following requirements:

a) In the n-term consecutive runoff series, the empirical frequency P_m of term m in descending order, shall be computed using the Formula (1).

$$P_m = \frac{m}{n+1} \times 100\% \qquad (1)$$

where

n is the number of terms of the observation series;

m is the order in the observation series;

P_m is the m_{th} empirical frequency.

b) The runoff frequency curve should use the Pearson curve Ⅲ, while the other types adaptive to the local conditions may also be selected according to the geological, meteorological and hydrological conditions of the project location. The statistical parameters of the Pearson curve Ⅲ are expressed as the mean value $\overline{X}$, coefficient of variation C_V and coefficient of skewness C_S and computed by the Formula (2), (3) and (4):

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} Xi \qquad \cdots\cdots (2)$$

$$C_V = \frac{1}{\overline{X}}\sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n}(K_i - 1)^2}{n-1}} \qquad \cdots\cdots (3)$$

$$C_S = \alpha C_V \qquad \cdots\cdots (4)$$

where

X_i is the observation series, $i = 1, 2, 3, \cdots, n$;

K_i is the Modulus coefficient, $K_i = \frac{X_i}{\overline{X}}$;

α is the multiple ratio coefficient, determined according to the hydrological characteristics of the local basin.

c) When the frequency curve is ascertained according to the empirical frequency points, the statistical parameters should be preliminarily estimated by the formula given in this article, and then adjusted and determined by the curve-fitting method.

d) When adjusting with the curve-fitting method, the point data of the normal/low flow year shall be particularly considered on the basis of the trend of the fitting point group.

6.6 The consecutive runoff series for the frequency analysis and computation should meet the following requirements:

a) The runoff series shall not be less than 20 years, but may be appropriately shortened to 10 to 20 years when the data is scarce.

b) When the measured runoff data is insufficient, the interpolation shall be adopted to extend the runoff series and then the frequency analysis shall be calculated; the relevant parameters of the interpolated and extended runoff series shall be measured continuously or discontinuously for more than 8 years, and the extension amplitude of the relevant line shall not be more than 50% of the measured variation amplitude.

6.7 The interpolation and extension of the runoff series may be computed from the stage-discharge correlation, the precipitation-runoff correlation, catchment area analogy, runoff correlation, rainfall-runoff mathematical model or the other inspection and demonstration methods on the basis of the data concerning this basin, the upstream/downstream areas, the adjacent basin or nearby basins with similar hydrological and meteorological conditions.

6.8 In the correlation analysis, the multivariate correlation should not be performed, the physical genetic relationship between the independent variable and the dependent variable as well as the corresponding correlation coefficient shall be considered, and the regression formula shall be selected. The correlation coefficient should be more than 0.8.

6.9 When the hydrologic analogy or the interpolated to extend series is used, the following requirements shall be met:

a) The meteorological and climatic conditions shall be similar in the design and reference basins.

b) The geologic, topographic and vegetation conditions as well as the effect of human activities shall be basically the same or similar in the design and reference basins.

c) The annual precipitation or the precipitation in the corresponding period shall be used to correct the analogy results of the catchment area.

6.10 When the hydrological analogy is used to calculate and design the runoff series of the hydropower station, the Formula (5) may be used:

$$Q_S = \frac{F_S P_S Q_C}{F_C P_C} \qquad \cdots\cdots (5)$$

where

Q_C is the discharge at the gauging station, in m^3/s;

F_C is the drainage area at the gauging station, in km^2;

P_C is the rainfall in the drainage basin of the gauging station, in mm;

Q_S is the design discharge of the hydropower station, in m^3/s;

F_S is the design drainage area of the hydropower station, in km^2;

P_S is the design rainfall in the drainage basin of the hydropower station, in mm.

6.11 The regional synthesis analysis and computation shall include two aspects:

a) To use the existing regional synthesis diagrams. The regional synthesis diagrams shall mainly include the contour map of the annual runoff mean value of the watershed versus the coefficient of variation Cv and the partition map of Cs/Cv values, the contour map of the regional annual precipitation mean values versus Cv as well as the Cs/Cv values, and the regional synthesis annual precipitation-runoff relation diagram or the contour map of the annual runoff coefficient.

b) To further analyse and synthesize the relevant results in accordance with the data availability as well as the engineering design demands and the depth of the work.

6.12 The annual runoff series adopted shall be analysed for the representativeness and consistency in the following methods:

a) For relatively longer runoff series, the moving average method, the cumulative average method and the difference product curve may be used to analyse and evaluate the representativeness of the series or the representative segment series.

b) For relatively shorter runoff series, the representativeness of the corresponding short series of the long-series precipitation gauging station in the basin or in the areas with similar hydrological and meteorological conditions may be analysed so as to evaluate the representativeness of the station runoff series.

c) The consistency of the annual runoff series may be checked by analysing the inter-annual and long-term variation of the relationship between annual precipitation and the runoff, or by investigating the historical development of water use and hydropower projects in the basin.

6.13 The annual frequencies design in the high flow season, normal flow season and low flow season may be 5% to 25%, 50% and 75% to 95% respectively. The frequency in the low flow season should be consistent with the design dependability of the hydropower station.

6.14 The annual distribution in the design representative year may be determined by the homogeneous multiple adjustment method over the controlled annual water flow.

6.15 The design representative year may be determined in line with the following three principles:

a) The empirical frequency is close to the design frequency.

b) The annual measured runoff data is complete or becomes complete after interpolation.

c) The situation is adverse to the future operation of the power station, which means that the power station will abandon a lot of water when the runoff is heavier than that in the normal year as there are many floods during the flood season; the power station will produce insufficient output for a long period and even stop due to the drying up of the flow if the runoff is less than that in the normal year as there is little incoming water during the dry season.

6.16 When the measured runoff data is insufficient, the following methods should be used to determine the annual runoff and its annual distribution in the design representative year according to the different rainfall and runoff data availabilities:

a) The data of the gauging station shall be used directly or after comprehensive analysis in the proportion of the catchment area.

b) The existing runoff area synthesis chart shall be used.

c) The years with measured runoff data shall be selected as the design representative years from several typical years of annual precipitation with similar frequencies in the precipitation benchmark stations. The annual runoff of the corresponding design representative year shall be determined by the regional synthesis method.

d) If the precipitation and annual distribution of the runoff are favourably similar, the annual distribution in the design representative year may be determined according to the proportion of the monthly precipitation at the precipitation benchmark station to the yearly precipitation in the design representative year, and with consideration of the appropriate base flow.

e) The mean monthly data shall not be the only, and the standard is the daily data. The hourly data may be used for some specific operating mode.

6.17 When the runoff is significantly affected by human activities, the annual runoff reduction calculation should be carried out according to the following methods:

a) The item-by-item investigation method or the rainfall-runoff model shall be used to calculate year by year and month by month (ten days by ten days).

b) When the required data for yearly reduction is insufficient, the reduction estimation may be made by the typical years of high-flow, median-flow and low-flow year as per the different development periods of human activities.

c) When the required data for monthly reduction is insufficient, the reduction estimation may be made by the main water-consuming period and non-essential water-consuming period.

6.18 The design runoff of the SHP project shall consider the effects of the complex topographical features such as the extremely uneven or extremely unstable river channels, the special geological conditions such as karst, and natural events such as a flash flood resulting in a dike break.

6.19 The runoff of each hydropower station in a cascade shall be calculated according to the water release/diversion mode of the hydropower stations, the intervening catchment area between the stations and the relevant data if the stations upstream have a remarkable influence on the hydrological regime of the cascade.

7 Flow duration curve

7.1 For the hydrological computation results of the run-off or diversion hydropower stations, the daily mean flow duration curve at the inlet section or the dam site section of the power station shall be provided.

7.2 When the runoff data is sufficient, the daily mean flow ranking statistics of long series or the daily mean flow in the typical high-flow year, median-flow year and low-flow year shall be used with the following methods:

a) For hierarchical ranking statistics, the runoff data shall be divided into several flow levels within a descending order, the occurrence frequency of each flow level shall be counted and the frequency of each flow level shall be calculated.

b) For non-hierarchical ranking statistics, the runoff data within a descending order shall be arranged and the frequency of each flow in the runoff data shall be calculated.

7.3 The flow dependability shall be calculated with the mathematical expectation Formula (1) of the empirical frequency.

7.4 When the measured runoff data is insufficient, the monthly average flow duration curve may be deduced first, and then convert it to the daily average flow duration curve through comparative analysis of the daily and monthly average flow duration curves of the runoff gauging station or the regional synthesis. Comparative analysis shall be conducted according to the following requirements:

a) When there is an applicable runoff gauging station, the daily average flow duration curve of the gauging station may be zoomed and transposed according to the proportion of the catchment area and the proportion of the annual mean precipitation.

b) When there is no applicable runoff gauging station, more runoff gauging stations within a larger scope shall be selected to carry out regional comprehensive analysis and calculation. The regional flow duration curve can be represented in a dimensionless form or modulus. The dimensionless or modulus daily mean flow duration curves at the gauging stations shall be drawn on the same grid diagram, and its mean curve shall be estimated visually and drawn manually as the regional daily mean flow duration curve.

c) When the drainage area is relatively small, and there is only one runoff gauging station, the dimensionless or modulus daily mean flow duration curve of this gauging station may be directly used as the regional daily mean flow duration curve of this basin.

8 Low water analysis

8.1 According to the data availability and the engineering design requirements, the minimum daily mean flow, the mean flow in the lowest-water month, the guaranteed low water flow, the impact of human activities on low water as well as the evaluation results of the low water runoff should be provided for the low water analysis.

8.2 The analysis and computation of the low water runoff should meet the following requirements:

a) When sufficient low water runoff data is available, the runoff frequency analysis and computation method shall be used in accordance with the characteristics of the low water runoff.

b) When zero value appears in the low water series, the frequency computation method containing the zero value term may be used.

c) When the low water runoff data is insufficient, the special low-flow investigation may be performed. The special low-flow investigation shall meet the following requirements:

1) The special low-flow investigation shall be performed in the dry season of the year.

2) The special low-flow investigation shall include: the low water level and flow of the river channel; the historical dry years, occurrence time, water level, flow and duration, or the year, occurrence time and duration of the river blanking; the impact of human activities on the low water runoff.

8.3 The measured and investigated low water flow level shall be determined by comparative analysis in accordance with the annual and low precipitation and the corresponding annual and low precipitation frequencies in the same year of the representative precipitation station or the benchmark precipitation station.

9 Flood

9.1 According to the data availability and the engineering design requirements, all or part of the following design flood results shall be provided:

a) Annual maximum peak flow at various design frequencies;

b) Staged maximum peak flow at various design frequencies;

c) Annual and staged period flood at assigned design frequency;

d) Annual and staged design flood hydrograph at assigned design frequency.

9.2 When sufficient measured flood data is available, frequency analysis and computation shall be carried out to deduce the design fold based on the measured flood data.

9.3 The annual (staged) peak flow and the flood volume series of different periods in the frequency calculation shall be composed of the maximum values each year (stage).

9.4 In the n-term consecutive flood series, the empirical frequency P_m of term m arranged in descending order shall be computed by the mathematical expectation Formula (1).

9.5 Whereas a catastrophic floods occur in N years during the recorded period and l floods happen in n-term consecutive series, the empirical frequency of the floods at various terms in the non-consecutive flood series may be computed by the mathematical Formula (6) and (7):

a) The empirical frequency of term M arranged in descending order, P_M, in a catastrophic floods is computed by the Formula (6):

$$P_M = \frac{M}{N+1} \qquad \cdots\cdots (6)$$

where

N is the investigation period of the historical flood;

M is the order of the extraordinary values, $M = 1, 2, 3, \cdots, a$;

P_M is the empirical frequency of term M extraordinary value.

b) In $n - l$ consecutive flood series, the empirical frequency at term m arranged in descending order, P_M, is computed by the Formula (7):

$$P_m = \frac{m}{n+1} \qquad \cdots\cdots (7)$$

where

l is the Number of extraordinary values sampled from the n-term observed consecutive series;

n is the total number of terms in the observed series;

m is the Order in observed series after the extraordinary value l, $m = l + 1, \cdots, n$;

P_m is the empirical frequency of term m.

9.6 The frequency curve usually employs the Pearson curve Ⅲ, while the other line types adaptive to the local conditions may also be selected according to the geological, meteorological and hydrological conditions of the project location. The statistical parameters of the Pearson curve Ⅲ are expressed by mean value $\overline{X}$, coefficient of variation C_V and coefficient of skewness C_S. See Formula (8), (9) and (10):

a) With regard to term-n consecutive series, the mean value $\overline{X}$ is computed using the Formula (2), and the coefficient of variation C_V is computed using the Formula (3):

b) With regard to the non-consecutive series, mean value $\overline{X}$, the coefficient of variation C_V and the coefficient of skewness C_S are computed using the Formulas (8), (9) and (10):

$$\overline{X} = \frac{1}{N}\left(\sum_{j=1}^{a} X_j + \frac{N-a}{n-l}\sum_{i=l+1}^{n} X_i\right) \quad \text{......................... (8)}$$

$$C_V = \frac{1}{\overline{X}}\sqrt{\frac{1}{N-1}\left(\sum_{j=1}^{a}(X_j-\overline{X})^2 + \frac{N-a}{n-l}\sum_{i=l+1}^{n}(X_i-\overline{X})^2\right)} \quad \text{............ (9)}$$

$$C_S = \alpha C_V \quad \text{............................. (10)}$$

where

X_j is the extraordinary value variable, $j=1, 2, 3, \cdots, a$;

X_i is the measured series variable, $i=l+1, \cdots, n$;

α is the Multiple ratio coefficient, determined according to the hydrological characteristics of the local basin.

9.7 When ascertaining the frequency curve by using the empirical frequency points, the statistical parameter should be estimated preliminarily by the formula in 9.6, and then adjusted and determined by the curve-fitting method. When adjusting with the curve-fitting method, the relatively reliable big flood data shall be considered more on the basis of the fitting point group trend.

9.8 When the measured flood data is available, the design flood hydrograph shall be deduced by amplifying the typical flood hydrograph, and the big flood which could reflect the flood characteristics and is unfavorable to the flood control of the project shall be selected as the typical flood.

9.9 The analysis and calculation of the design storm shall meet the following requirement:

a) When long-series measured storm data is available, the design storm shall be determined with the frequency computation method.

b) When the storm data is insufficient, the latest design storm parameter contour map of the region shall be checked.

c) When the extraordinary storm happens recently in the region or nearby area, the computation results shall be checked.

9.10 When the design flood is deduced from the design storm, the regional synthesis results of the rainstorm flood charts shall be used for the design of the rainfall pattern, runoff yield and runoff concentration parameters and the design flood hydrograph. It is necessary to make comprehensive selection based on the analysis and synthesis according to the measured rainstorm flood data of the gauging station, see Appendix-A for the specific method. Alternatively, the empirical formula of flood peak flow in this region may be used.

9.11 According to the catchment area of the site and the comprehensive analysis results of the measured storm flood data from the gauging station, the short-duration peak rainstorm period controlled by the same frequency in the design rain pattern shall be reasonably determined.

9.12 When the measured storm flood data is insufficient or the design basin storm flood parameters could not be determined, the relation curve of the "measured and investigated big flood peak flow modular (M)-catchment area (F)-recurrence interval (N)" at the gauging stations in the region or the nearby areas may be ascertained, and the design flood may be estimated with the regional synthetic method.

9.13 The investigation and review of historical flood shall be paid high attention.

a) Reliable or relatively reliable of major or relatively major historical flood results shall be used in the frequency analysis and computation, or to verify design flood results determined by regional synthesis results, or to assist the derivation of the stage-discharge relation curve.

b) When the data is seriously scarce, the design flood may be estimated according to historical flood results.

c) When the investigated flood results are available, the relevant data may be directly cited, and the flood survey may also be conducted in the river reach and river basin of the project. In the nearby river reach upstream/downstream of the project site, two or more flood marks should be verified, with two or more computation cross-sections provided, and then the flood peak flow is estimated by using the arithmetic mean of two cross-sections or by the gradient method of two cross-sections. Additionally, the flood elevation shall be proposed based on the appropriate recurrence period to define the force majeure caused by the flood during the construction period.

9.14 The design flood of cascade hydropower stations shall be calculated according to the layout of cascade projects, the discharge or diversion modes of the station and the intervening catchment areas between two stations.

9.15 When computing the design flood by construction stages, it is necessary to consider the design requirements of the engineering construction stages, and the variation rules and characteristics of flood causes shall be basically compiled with in the period from the beginning to the end.

10 Stage-discharge relation curve

10.1 For the hydrological calculation of the SHP stations, the stage-discharge relation curve of the upstream inlet section and the downstream tailwater section shall be drawn up. The influence of the downstream water level shall be considered in calculating the stage-discharge relation of the section.

10.2 The water level elevation system of the stage-discharge relationship shall be consistent with the elevation system adopted in the design of the hydropower station.

10.3 When there is a gauging station near the upstream/downstream areas of the project site, the temporary gauge may be established at the design cross-section to observe the water level; the variation rules of the water surface curve or water surface slope of each representative water level may be analysed through water level correlation or investigation and measurement. After the water level is corrected, the stage-discharge relationship at the design cross-section will be obtained.

10.4 The high water level extension of the stage-discharge relationship may be calculated by slope method and determined by the comprehensive analysis of flood investigation.

10.5 When there is no gauging station in the river reach of the project site, the stage-discharge relationship shall be determined with the single-section slope method formula according to the profile diagram of the river reach and the designed cross-section profile, and with reference to the average bed slope of the main channel/river as well as the water surface slope and its estimated flow during flood and dry season survey.

10.6 When determining the stage-discharge relationship with the single-section slope method, the Formulas (11) and (12) may be used for the computation:

$$Q = AC\,(Ri)^{1/2} \qquad \cdots\cdots (11)$$

$$C = \frac{1}{n}\,(R)^{1/6} \qquad \cdots\cdots (12)$$

where

Q is the flow, in m^3/s;

A is the cross-sectional area, in m^2;

R is the hydraulic radius, in m;

C is the Chezy coefficient;

i is the water surface slope;

n is the manning's roughness coefficient.

10.7 In the design stage, the stage-discharge relationship should be verified by measuring the flow at low, medium and high water levels at the design section.

10.8 For the stage-discharge relationship at the station location which is influenced by the return water, scouring and silting, flood fluctuation as well as the waterweed growth, it shall be verified by observation, analysis or actual measurement; when the dispersion degree of the correlation point group is not great, the average value may be taken.

11 Sediment, evaporation, ice regime and others

11.1 With regard to the location of the project on the river carrying significant sediment or carrying more sediment during the flood season, all or part of the following sediment computation results shall be provided according to the data availability and the engineering design requirements:

a) Multi-year average suspended sediment concentration and sediment runoff (ratio);

b) Average monthly suspended sediment concentration of the annual maximum cross-section and the month of occurrence;

c) Multi-year average suspended sediment grain gradation or average grain diameter and the maximum grain diameter;

d) Result of bed load sediment in the flood season. If conditions permit, the Sediment Rating Curves (Discharge vs Sediment Concentration) may be developed for analysis.

11.2 The suspended sediment may be computed with the following methods:

a) When there is a sediment gauging station in the basin of the site, the sediment yield modulus of the gauging station should be used.

b) When there is no sediment gauging station in the basin of the site, the sediment yield modulus may be used directly if their climatic conditions and underlying surface conditions are similar, otherwise may be used after being corrected.

c) When the above data is not available, the existing regional synthesis diagrams of the sediment may be used; the sediment may be measured temporarily if necessary.

11.3 The bed load sediment may be computed with the suspended and bed load ratio.

11.4 For a reservoir hydropower station, it is advisable to calculate the annual average water surface evaporation capacity and its annual distribution according to the data from the evaporation measuring station in the basin or the regional synthesis diagrams of the evaporation capacity in similar areas of the basin or hydrometeorology.

11.5 For the hydrological analysis and computation in cold regions, the following ice regime at the station site shall be provided according to the statistical data of local hydrological and meteorological characteristics:

a) River conditions during freezing up and unfreezing; occurrence of shore ice and flowing ice and the freezing-up characteristics of the whole river;

b) Earliest, latest and multi-year average icing and melting dates;

c) Ice thickness, ice clogging, ice wall and floating ice and their potential hazards during the freezing period.

11.6 For the hydrological computation in the karst region, the following water chemical data at the station location shall be provided:

a) Content of corrosive free ions CO_3^{2-} and HCO_3^- which would cause serious damage to the turbine, and their seasonal variations;

b) PH value and its seasonal variations.

12 Rationality check of the outcomes

12.1 The rationality check of the outcomes shall meet the following requirements:

a) The measured data and the analysis and computation results from all the gauging stations and design stations shall be used.

b) The comparative analysis of the results of multiple methods in a single station and the study of the surface distribution of the results of multi-stations with the same methods shall be carried out.

c) The final results shall follow up the principle of "based on one method, compared with multiple methods, by analysing comprehensively and selecting rationally".

12.2 The rationality check of the results shall include the following main parameters or items:

a) Annual runoff mean value;

b) Design flood peak flow and flood volume;

c) *n* value of the bed roughness in the formula of the investigated flood peak flow and the slope method;

d) Shape and characteristics of the flow-duration curve and the stage-discharge relation curve;

e) Characteristics of the flow pattern changes.

12.3 The rationality check of the design annual runoff and the design flood peak flow results shall meet the following requirements:

a) The computed results shall be consistent with the results from the regional synthesis contour map, the correlation curve or the empirical formula.

b) The distribution in the basin, region and along the upstream/downstream segment and the mainstream and tributaries shall be basically rational. The result shall be basically adaptive to the spatial variation of the precipitation.

c) If there is a big difference in the computed results, or unreasonable, or there is a big difference with the spatial variation of the precipitation, the causes shall be found out in time and re-analysed/computed if necessary.

12.4 The reliability and rationality of the flood peak flow estimation results shall be investigated in the design flood calculation, and the following contents shall be compared:

a) The spatial distribution of floods and rainstorms at each site in the same year;

b) The flood sequence of the same site in different years;

c) The magnitude of the measured and known investigated flood in the same basin or region for the flood investigation in a certain recurrence interval.

12.5 The reasonable magnitude range of the recurrence interval of the investigated flood peak flow may be examined with the relation of the "measured and investigated high flood peak flow modular (M)-catchment area (F)-recurrence interval (N)" through regional synthesis; when it is found that the estimated value of the flood peak flow is too high or too low, the value *n* of the bed roughness in the slope method formula shall be firstly checked whether it is reasonable, and the measured data of the gauging station shall be used to verified and compared.

12.6 The rationality check of the flow duration curve and the stage-discharge relation curve shall include the following contents:

a) The relationship between the flow duration curves as well as the influence of the flow variation amplitude and the base flow on the curve shape;

b) The relationship between the cross-section feature and the stage-discharge relation curve.

Appendix A
(Informative)
Computation of storm and runoff yield and runoff concentration

A.1 Computation of the design storm

A.1.1 Storm computation of the design surface

a) If the precipitation station network is relatively dense, and the observation series are relatively long, it is suggested to perform the frequency analysis according to the yearly maximum areal rainfall series of the design basin to ascertain the design areal rainfall of the basin.

b) If the drainage area is relatively small, and it is difficult to calculate the data of the frequency analysis of the areal storm directly, the design areal rainfall may be calculated indirectly by the design point rainfall and the relationship between the point rainfall and the areal rainfall of the corresponding duration. The design areal rainfall H_A may be worked out from the design point rainfall H_0 and the point-area conversion coefficient α_A:

$$H_A = a_A H_0 \quad \text{(A.1)}$$

c) The point-area relationship shall be a comprehensive relationship (i.e. the relationship between the fixed point and the fixed area) between the rainfall at a fixed point and the rainfall in a fixed basin area obtained through analysis of the regional rainfall data. The point-area conversion coefficient α_A shall involve the different duration and frequency (or rainfall intensity) difference. The design point rainfall corresponding to the relationship between the fixed point and the fixed area shall be the design value at a certain fixed point in the basin. In the basin with the relatively consistent statistical parameter of the point rainfall, the design point rainfall measured by the gauging station in the centre of the basin may be used; if the variation amplitude of the statistical parameter of the point rainfall measured by the gauging stations in the basin is high, the design point rainfall may employ the value from the single station approaching the average situation in the basin.

d) If the data for analysing the comprehensive relationship between the fixed point and the fixed area in the design basin is not available, the design areal rainfall may be ascertained according to the relationship between the movable points and the movable area, but several basins or regions with a similar design drainage area near the design basin shall be selected to establish the relationship between the fixed point and the fixed area within the limited area and the duration for verifying the representativeness of the relationship between the movable point and the movable area in the region. If the relationship between the movable point and the movable area differs significantly from the relationship between the fixed point and the fixed area, it shall be corrected appropriately.

e) If it is difficult to analyse the relationship between the movable point and the movable area, the point-area deduction synthesis diagram may be directly checked.

f) When the drainage area is smaller than 100 km^2, the point-area relationship may not be considered, while the areal rainfall may be directly replaced by the point rainfall.

A.1.2 The design storm rainfalls in the various durations may be computed according to the following provisions

a) With regard to the basins of a large scale project, with many durations to be computed and sufficient rainfall data, the frequency analysis may be performed by respectively compiling statistics for the maximum point rainfalls of each year for the design obtained from several rainfall stations in this basin and nearby areas.

b) When the drainage area is relatively small, the design point rainfalls in several standard durations may be calculated by the approved contour maps of it is point storm statistical parameter for various durations.

c) To compute the design rainfall of any duration, the design rainfalls in n standard durations may be calculated first, and then the rainfall duration curves may be drawn on the double logarithmic paper, from which the design rainfall over the required duration may be interpolated. When the staged rainfall duration relationship is close to a straight line, the storm decline exponent formula may be adopted and the corresponding rainfall H_i over the required duration t_i may be interpolated according to the design rainfalls H_a and H_b over two adjacent standard durations, as well as the storm decline exponent n_{ab} for this interval and expressed as per the Formulas (A.2), (A.3) and (A.4):

$$H_i = H_a \ (t_i/t_a)^{1-n_{ab}} \quad \cdots\cdots (A.2)$$

$$H_i = H_b \ (t_i/t_b)^{1-n_{ab}} \quad \cdots\cdots (A.3)$$

$$n_{ab} = 1 - \lg(H_a/H_b)/\lg(t_a/t_b) \quad \cdots\cdots (A.4)$$

where

H_i is the design rainfall within duration t_i, in mm;

H_a is the design rainfall within duration t_a, in mm;

H_b is the design rainfall within duration t_b, in mm;

t_i is the design duration, in h;

t_a is the standard duration a , in h;

t_b is the standard duration b, in h;

n_{ab} is the storm decline exponent.

A.1.3 Design rainfall pattern

a) The synthesized or typical rainfall pattern may be used as the time-interval distribution rainfall pattern of the design storm; the design storm process may be controlled, zoomed and ascertained at the same frequency with the design rainfall over various durations. The comprehensive rainfall pattern should be selected on the basis of the analysis of the rainfall pattern characteristics of several heavy storms. The analysis of the rainfall pattern characteristics include the number of rainfall peaks, the duration of the rainfall peak, the interval between two rainfall peaks and the occurrence time sequence of the main rainfall peaks. When synthesizing, the influence of the rainfall intensity and the weather conditions shall be also considered.

b) The areal distribution diagram of the design storm may be determined according to the local synthesized or typical distribution diagram. The synthesized rainfall pattern should be based on the analysis of the areal rainfall pattern characteristics.

A.2 Computation of the runoff yield and concentration of the storm flood

A.2.1 The rainfall runoff shall be computed with the following method.

a) Rainfall-runoff correlation method (including correlation curve) see the Formula (A.5);

$$R = f(P, P_a, t_r) \qquad \text{(A.5)}$$

where

R is the runoff depth, in mm;

P is the rainfall, in mm;

P_a is the preceding affected rainfall or water content of the basin unsaturated zone before rain, in mm;

t_r is the duration of rainfall, in h.

b) Loss reduction method.

1) Initial loss and the later loss method see the formula (A.6):

$$\bar{f}_t = \frac{I_f - I_0 - P_{t-t_0-t_r}}{t_r} \quad \cdots\cdots (A.6)$$

where

$\bar{f}_t$ is the average loss ratio in the later stage, in mm/h;

I_f is the total loss of the basin, in mm;

I_0 is the loss in the initial stage, in mm;

$P_{t-t_0-t_r}$ is the rainfall capacity without the runoff yield during the period ($t - t_0 - t_r$), in mm;

t_0 is the duration corresponding to I_0, in h;

t_r is the duration of the runoff yield, in h.

2) Initial loss method: All loss occurs in the initial stage of the rainfall, and all rainfall will turn to runoff after total loss is reached.

3) Average loss ratio method, see the Formula (A.7):

$$\bar{f} = \frac{P - R - P_{t-t_R}}{t_R} \quad \cdots\cdots (A.7)$$

where

$\bar{f}$ is the average loss ratio, in mm/h;

P is the rainfall, in mm;

R is the runoff depth, in mm;

P_{t-t_R} is the rainfall in non-runoff yield period, in mm;

t_R is the duration of runoff yield, in h.

c) Surface runoff (net runoff) process. The surface runoff process is usually distinguished by deducting the subsurface runoff time-interval distribution from the runoff yield process. The time-interval distribution of the subsurface runoff, R_g, may be performed by equal distribution, i.e. the Formula (A.8):

$$\overline{f}_c = \frac{R_g - R_{t_R - t_g}}{t_c} \qquad \text{(A.8)}$$

where

$\overline{f}_c$ is the average stable infiltration rate of the basin, in mm/h;

R_g is the shallow subsurface runoff flow, in mm;

$R_{t_R - t_c}$ is the runoff yield without generating overland runoff during the period $t_R - t_c$, in mm;

t_c is the net rainfall duration, in h.

A.2.2 The flood concentration may be computed with the following provisions.

a) Empirical unit hydrograph. The data concerning the separate flood peak with the relatively uniform rainfall, the relatively short net rainfall duration and the relatively high rainfall intensity shall be selected, and the unit hydrograph may be ascertained according to the surface runoff hydrograph corresponding to the net rainfall process. The unit hydrograph period is usually about 1/3 of rising duration of the unit hydrograph or the lag time of the flood peak duration. The unit hydrograph obtained through analysis usually varies along with the different spatial and temporal distributions of the measured storm, so in the computation, the unit hydrograph that matches with the design rainfall pattern shall be selected.

b) Instantaneous unit hydrograph

1) Fundamental formula (A.9):

$$U(0,t) = \frac{1}{k\Gamma(n)}(t/k)^{n-1} e^{-t/k} \qquad \text{(A.9)}$$

where

$U(0,t)$ is the instantaneous unit hydrograph, in m^3/s;

Γ is the gamma function;

n, k is the parameter, usually computed with the moments method or used as an initial value for the optimized calculation.

2) Non-linear correction: Establish the relationship between n, k or m_1 (nk) or and the rainfall intensity; the duration of the rainfall intensity may be determined by one of the following factors such as the flow concentration time in the basin, the runoff yield period, flood peak rising duration and the magnitude of the drainage area.

$$m_1 = ai^{-b} \qquad \cdots\cdots (A.10)$$

where

m_1 is the first moment about the origin of the instantaneous unit hydrograph;

i is the rainfall (or net rainfall) intensity, in mm/h;

a, b is the constants.

The application of the Formula (A10) is limited. The amplitude of the non-linear extension of the critical rainfall $i_{\text{Temporary}}$ in the control Formula (A10) shall be determined.

c) Rational formula

1) Fundamental formula (Formula (A.11) and (A.12)):

$$Q_m = 0.278\,\frac{h}{\tau}F \qquad \cdots\cdots (A.11)$$

$$\tau = 0.278\,\frac{L}{mJ^{1/3}Q_m^{1/4}} \qquad \cdots\cdots (A.12)$$

where

Q_m is the peak discharge, in m^3/s;

h is the Maximum net rainfall in period τ during the comprehensive confluence, or the net rainfall of the single flood peak during partial confluence, in mm;

F is the drainage area, in km^2;

τ is the confluence duration of the basin, in h;

m is the confluence parameter;

L is the maximum distance along the main river from the outlet section to the watershed, in km;

J is the average gradient along the flow L (in decimals).

2) If no data is available, Table A.2.2 may be used as a reference for determining the value of m corresponding to, $\theta = L/J^{1/3}$.

Table A.1 Classification table of the underlying surface conditions of the small basin

Category	Brief description of the rainfall flood characteristics, river characteristics and soil and vegetation conditions	Parameter value m of the flood confluence parameters in the rational formula			
		$\theta = 1 \sim 10$	$\theta = 10 \sim 30$	$\theta = 30 \sim 90$	$\theta = 90 \sim 400$
Ⅰ	Semi-arid region, poor vegetation condition, earth-rock mountainous region dominated by barren slopes, terraced fields or a few sparse forests, dry crop, a wide and shallow river channel, an intermittent stream and steep rising and dropping of flooding.	1.00～1.30	1.30～1.60	1.60～1.80	1.80～2.20
Ⅱ	General vegetation condition, earth-rock mountainous region dominated by sparse forest, coniferous forest and young forest or many cultivated lands are in the basin.	0.60～0.70	0.70～0.80	0.80～0.90	0.90～1.30
Ⅲ	Wet hilly regions, good vegetation conditions, and rocky mountainous region dominated by shrubwood and bamboo forest, or with a forest coverage rate of 40% to 50%, or paddy fields and pebbles are scattered in the basin; both banks are overgrown with weeds, with long-thin big floods and short-wide medium and small floods.	0.30～0.40	0.40～0.50	0.50～0.60	0.60～0.90
Ⅳ	Wet mountainous region with abundant rainfall, excellent vegetation conditions, with forest a coverage rate of 70%, are mostly regions dominated by old-growth forest with thick litter layer; relatively rich interflow; mountainous riverbed, river channel contains big cobblestone and gravels; with head falls; most floods rise and fall steeply.	0.20～0.30	0.30～0.35	0.35～0.40	0.40～0.80