UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Technical Guidelines for the Development of Small Hydropower Plants

DESIGN

Part 2: Hydrology

SHP/TG 002-2: 2019

DISCLAIMER

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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 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 2: Hydrology

1 Scope

This Part of the Design Guidelines covers the basic hydrological data as well as the computation methods for the required rational analysis of the main hydrological parameters such as rainfall, runoff, flood and sedimentapplicable 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

4.1 For the hydrological computation of the SHP station, it is necessary to analyse and compute the following hydrological parameters 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 the basis of which the hydrological computation is performed shall be reliable, consistent and representative.

4.3 In case of a data shortage, a variety of methods shall be adopted for the hydrological analysis and calculation, and the results shall be comprehensively analysed and reasonably selected.

4.4 Frequency analysis method is usually adopted for the hydrological calculation. Pearson curve III or other lines can be used for the design values of the different frequencies.

4.5 The design flood of the hydropower station is calculated by using the flow data in the basin with sufficient flow data. The design flood can be calculated from the rainstorm data in the basin where the flow data and rainfall data are insufficient.

4.6 For the basin lacking data, the hydrologic data and design parameters shall be calculated using displacement or a proper model and the hydrologic results can be assessed using the regional comprehensive analysis method. For the basin with no data, the hydrologic results shall be obtained based on the regional hydrological simulation and the similarity analysis. 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. Once the project is approved, a long-term water regime monitoring and reporting system should be set up.

4.7 The hydrological computation results shall be subjected to the rational test and shall be performed throughout the entire hydrological computation process.

5 Basic data

5.1 The basic data for the hydrological analysis required for the SHP project should include the hydrological and meteorological data, the basin characteristics, geographic data, information about the human activities, the hydrological computation results of the basin and nearby area and the other relevant data, which 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, wind speed, wind direction, humidity, atmosphere pressure, sunlight, frost and snow;

   3) The geographical location, coordinates, altitude, construction time, observation items and other relevant information for each gauging station and rain gauging 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 topographicsurvey map on a scale of 1:500 or 1:200 the layout of the project components.

c) The information on the effect of human activity include the existing hydropower station, reservoir, inter basin water diversion, water extractions vs drainage returns from irrigation, the 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, water conservation and 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, municipaladministration, 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 hydrological computation shall be based on careful investigations and the collection of the basic data/information on the hydrology and meteorology. The hydrological computation method, and the check computation charts shall be properly utilized according to the data availability and the engineering characteristics.

5.3 The measured available data may be sufficient, insufficient or not available. The 30 years data measured at the site or on the same river/stream is desirable, the 15 to 20 years data measured may be considered to be sufficient for carrying out the reliable analysis for the determination of the hydrological design parameters for the project. If so much recorded data is not available, then rainfall-runoff modelling shall be done for assessment of the flows at the site and the hydrological design parameters.

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

a) Reliability check: The data source, period, observation method, possible problems and reasons for it not being compiled and published shall be checked with respect to the measured raw data which has not been formally compiled;

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

c) Representativeness check: The representativeness of the data shall be checked if there are relatively fewer data series or a greater deviation might exist between the sample and the totality；

d) Gap Analysis: The gaps or missing/non-recorded data, if any, of the specific day(s) or period shall be analysed/checked and the gaps shall be filled with reasonable estimations e.g. by interpolation/ extrapolation or with some other realistic methods;

e) If conditions permit, the verification and local assessment by involving local sources related to the historical flow events.

5.5 The investigation of the historical flood, recent flood mark, flood level measurement, normal water level survey and measurement, low water survey, river reach survey and sedimentation study shall be carried out for the regions with insufficient measured data or without data; if the conditions so permit. It is necessary to observe the water level, flow and sediment so as to verify the accuracy of the hydrologic design data.

6 Design Runoff

6.1 For the hydrological computation of the SHP project, it is necessary to determine the design runoff according to the design requirement and data availability:

a) Annual mean runoff as well as the annual runoff, seasonal run off flood, runoff during low flow and monthly runoff of the non-rainy period 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, it is necessary to provide all the results specified in 6.1; when the data availability is low, it is necessary to give the annual runoff and the annual distribution in the design representative years.

6.3 According to different data availabilities, the design runoff computation should be performed with the following method:

a) It is necessary to perform the frequency analysis and computation when sufficient measured runoff data is available on the project site.

b) It is necessary to transpose the frequency analysis and computation results of the gauging station with the hydrological analogy method when there is a runoff gauging station that lies in the downstream/upstream areas of the project site, in the river basin, adjacent basin or nearby basin with similar hydrological and homogeneous meteorological conditions.

c) In case measured runoff data are not available, the runoff results can be calculated based on the precipitation and other data.

d) When the runoff data is not available, it is necessary to perform the regional synthesis analysis using pluviography in combination with the rainfall data.

6.4 The gauging stations mainly consist of two categories, namely the rain 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 reported in 6.9;

b) It is allowed to select the rainfall gauging station with the longest series 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 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 the m_{th} empirical frequency.

b) The runoff frequency curve usually called 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):

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} Xi \quad \text{.....(2)}$$

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

$$C_S = (2-3)C_V \quad \text{.....(4)}$$

where

X_i is the observation series, in i = 1, 2, 3, ..., n;

K_i is the modulus coefficient, in $K_i = \frac{X_i}{\overline{X}}$.

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 paragraph, and then adjusted and determined by the curve-fitting method;

d) When adjusting with the curve-fitting method, it is necessary to consider the point data of the normal/low flow year particularly 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 30 years in principle, but may be appropriately shortened to 15 to 20 years when the data is scarce;

b) The frequency analysis and computation shall be performed after interpolation and extension of the runoff series when the measured runoff data is insufficient;

c) The relevant parameters of the interpolated and extended runoff series should contain the continuous or discontinuous synchronously measured series 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, water-collecting 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 During the correlation analysis, the multivariate correlation shall 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 in order to select the regression formula. The correlation coefficient should be more than 0.8.

6.9 When hydrologic analogy or the interpolated and extended series are used, the following requirements shall be met:

a) The meteorological and climatic conditions should be similar in the design and certification of the basins;

b) The geologic, topographic and vegetation conditions as well as the effect of human activity should be basically similar in the design and certification of the basins;

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

6.10 For computing the runoff series in the design project by hydrologic analogy, the formula (5) may be used:

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

where

Q_C is the discharge at the 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 consist of the work in two aspects: One is to use the existing regional synthesis diagrams and other is 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 regional synthesis diagrams 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.

6.13 If the measured runoff data and the regional synthesis diagrams are not available or the long-series precipitation data is available, the runoff coefficient and the base flow proportion of the basin may be determined after synthesis and analysis in accordance with the runoff and concentration conditions of the basin, and then the annual runoff is computed. Finally, the monthly runoff is determined according to the proportion of the monthly precipitation to the yearly precipitation and the magnitude of the base flow.

6.14 The representativeness and consistency analysis shall be performed for the annual runoff series which are to be used. The main methods are as follows:

a) For relatively longer runoff series, the representativeness of the series or the series in the representative segment may be analysed and evaluated with the moving average method, the cumulative average method and the difference product curve;

b) For relatively shorter runoff series, the representativeness of the corresponding short series of the long-series rainfall gauging station in the basin and in the areas with similar hydrological and meteorological conditions may be analysed so as to evaluate the representativeness of the runoff series of the station upon which the design is based;

c) The consistency of the annual runoff series may be checked by analysing the inter-annual and long-term variation of the annual precipitation, the runoff and their relationship, including determining the water consumption and the historical development of the water resources and the hydropower project in the basin.

6.15 The annual frequencies design in the high flow season, normal flow season and low flow season can be 5% to 25%, 50% and 75% to 95% respectively. The frequency of the low water season should be consistent with the guarantee rate of the power plant design.

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

6.17 The year with complete annual measured runoff data and with the potentially adverse situation for the future operation of the power station shall be selected as the design typical year, which may be determined in line with the following three principles:

a) The empirical frequency is approximately 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 have to abandon a lot of water when it operates in the future if 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.

6.18 When the measured runoff data is insufficient, it is necessary to determine the annual runoff and its annual distribution in the design representative year with the following method according to the different rainfall and runoff data availabilities:

a) It is necessary to directly transpose the data of the gauging station in the proportionate ratio of the catchment area;

b) It is necessary to use the existing synthesis catchment area plan;

c) It is necessary to select the year with measured runoff data over several design typical years with similar frequencies of annual precipitation from the rainfall gauging station as the typical year for the annual runoff design. The annual runoff for the corresponding design representative year shall be determined with the regional synthesis method;

d) If the above said data is unavailable, but 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 typical year, and with consideration given to the appropriate base flow.

e) Avoid facilitation towards the mean monthly data only. The standard is the daily data; in some cases, and for specific operating modes even the hourly data might be used.

6.19 It is necessary to perform the reducing computation for the annual runoff with the following method when the upstream basin of the project site or the gauging station is affected by the human activities:

a) It is necessary to compute year by year and month by month (ten days by ten days) with the item-by-iteminvestigation method or the rainfall-runoff model.

b) It is necessary to estimate by reducing the runoff in the typical high-flow year, median-flow year and low-flow year as per the different development periods of human activities when the data for reduction year by year is insufficient;

c) It is necessary to estimate by reducing the runoff during the main water-consuming period and the non-essential water-consuming period when the data for reducing month by month (ten days by ten days) is insufficient.

6.20 The design runoff of the SHP project shall be determined with consideration given to the complex landform such as the extremely uneven or extremely unstable river channel. The special geological conditions such as karst as well as the influence on the runoff by natural events like a flash flood resulting in a dike break.

6.21 The runoff of the hydropower stations 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 of the hydropower station in the cascade remarkably influence the hydrological regime of the cascade.

7 Flow duration curve

7.1 Among the hydrological computation results of the run-off or run-of-river hydropower station it is necessary to provide the daily mean flow duration curve at the cross-section of the power intake or the cross-section of the dam site. Daily mean flow data, arranged in a flow-duration curve and at the site of the power intake showing the full available water quantity for possible generation, being the basis for the turbine selection and the design of the water conveyance in case of flow diversion.

7.2 When sufficient runoff data is available for the project location or the stream-gauging station, it is necessary to compile the hierarchical or non-hierarchical sequential statistics with the following methods according to the long series or the daily mean flow in the typical high-flow year, median-flow year and low-flow year:

a) When compiling the hierarchical sequential statistics, divide the runoff data in a descending order into several flow grades, compile the statistics for the occurrence frequency of the flow in the various grades and calculate the frequency of the various flow grades;

b) When compiling the non-hierarchical sequential statistics, arrange the runoff data in a descending order and calculate the frequency of every flow in the runoff data;

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, it is necessary to ascertain the monthly average flow duration curve, and then convert it to the daily average flow duration curve through comparison and analysis of the daily and monthly average flow duration curves of the runoff gauging station or the regional synthesis.

a) When there is an applicable runoff gauging station near the project location, it is allowed to zoom and transpose the daily average flow duration curve of the gauging station according to the proportion of the catchment area and the proportion of the annual mean precipitation.

b) When there is no applicable or representative single runoff gauging station near the project site, it is necessary to select more runoff gauging stations within a larger scope of the regional synthesis. 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 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 run off gauging station, the dimensionless or modulus daily mean flow duration curve of this station may be used directly 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 dependable low water flow, the effect of human activity on low water as well as the evaluation results for 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, runoff frequency analysis and computation method shall be used in accordance with the low water runoff characteristics;

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.

8.3 Special low-flow investigation shall be performed in the dry season.

8.4 Main contents of 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 effect of human activity on the low water runoff.

8.5 The measured and investigated low water flow level shall be determined through comparison and analysis in accordance with the annual and dry-season precipitation of the representative gauging station or the benchmark gauging station in the basin, as well as the corresponding annual and dry-season precipitation frequencies in the same year.

9 Design flood

9.1 For the hydrological computation of the SHP project, it is necessary to provide the following design flood results in whole or in part according to the data availability and the engineering design requirements:

a) Annual maximum peak flow at various design frequencies;

b) Staged maximum peak flow at various design frequencies;

c) Annual and staged period flood volume at various design frequencies;

d) Annual and staged design flood hydrograph at various design frequencies.

9.2 When sufficient measured flood data near the project site or upstream/downstream area is available, it is necessary to perform the frequency analysis and computation, and ascertain the design flood according to the measured flood data.

9.3 The annual (staged) peak flow in the frequency computation and the flood series in different periods shall be composed of the maximum values every 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 following 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):

$$P_M = \frac{M}{N+1} \quad \text{.....(6)}$$

where

N is the investigation period of the historical flood;

a is the number of extraordinary values;

M is the order of the extraordinary values, in M = 1, 2, 3, ..., 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):

$$P_m = \frac{m}{n+1} \quad \text{.....(7)}$$

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, in $m = l+1,...,n$;

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 curveIII 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 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):

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

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

$$C_S = (3-5)C_V \quad \text{.....(10)}$$

where

X_j is the extraordinary value variable, in j = 1, 2, 3,..., a;

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

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 determined after adjustment with the curve-fitting method. When adjusting with the curve-fitting method, it is necessary to give emphasis to the relatively reliable big flood events on the basis of the fitting point group trend.

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

9.9 When the measured flood data is insufficient, the design flood may be derived from the design storm, and 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, it is necessary to check and compute the latest design storm parameter contour map of the region;

c) When the extraordinary storm happens recently in the region or nearby area, it is necessary to examine the computation results.

9.10 When deriving the design flood from the design storm, the design rainfall pattern, runoff yield and runoff concentration parameters and the design flood hydrograph shall be subject to the regional synthesis results of the rainstorm runoff charts, and should be selected through analysis and synthesis according to the measured rainstorm flood data of the gauging station, if necessary. See Appendix-A for the specific method. Alternatively, it may also be computed by using the formally published peak discharge empirical formula of the region.

9.11 The design storm duration of the SHP station should be 24h, 6h and 1h. The storm period controlled at same frequency in the design rainfall pattern, in which the flood peak is formed in a short duration, shall be

reasonably determined according to the synthesis and analysis results for the catchment area of the basin and the measured storm flood data at the gauging station.

9.12 When the measured storm flood data of the project site or its upstream/downstream areas 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 area may be ascertained, and the design flood may be estimated with the regional synthetic method.

9.13 It is necessary to pay attention to the investigated historical flood. The reliable or relatively reliable catastrophic or relatively major historical flood shall be used in the frequency computation, to verify the design flood determined according to the regional synthesis results, or to assist the derivation of the stage-discharge relation curve. When the data is scarce, it is allowed to estimate the design flood according to the magnitude of the historical flood.

9.14 When the investigated flood results for the project site or nearby upstream/downstream areas are available, the relevant data may be directly referenced; otherwise, it is necessary to investigate the flood in the river reach of the project site; with regard to the SHP station which may have a major influence. It is necessary to perform an investigation and review even if the published flood results of the river reach are available.

9.15 The flood peak flow of the investigated flood should be estimated by the formula of the slope method. In the nearby river reach upstream/downstream of the project site, two or more flood marks should be verified, with at least two computation cross-sections provided, and then the flood peak flow is estimated by using the arithmetic mean of two cross-sections or by means of the slope method formula on the basis of two cross-sections.

9.16 With regard to the design flood of a cascade hydropower station, it is necessary to compute the combination of the flood by the design flood between two stations and the design flood discharged after being regulated by the hydropower station upstream of the cascade, according to the layout of cascade projects, the discharge or diversion modes of the station and the intervening catchment area between two stations.

9.17 When computing the design flood by construction stages, it is necessary to consider the design requirements of the engineering construction stages, and the start and completion time for the work shall basically comply with the flood caused variation rules and characteristics. Additionally, propose a flood elevation based on the appropriate return period to define the flood caused force major during the construction work.

10 Stage-discharge relation curve

10.1 For the hydrological calculation for the SHP stations, the water level-flow relationship curve between the upstream inlet section and the downstream tailwater section of the power station should be drawn up. The influence of the downstream water level should be taken into account in calculating the water level flow relationship of the section.

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

10.3 When there are gauging stations 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 water surface profile of the river reach at various representative water levels or the change rule of the water surface slope may be

analysed through water the level correlation or investigation 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 determined through slope method computation and the synthesis and analysis of the investigated flood.

10.5 When there is no gauging station in the river reach of the project site, the stage-discharge relationship may be determined with the single-section slope method formula according to the profile diagram of the river reach and the cross-section profile of the design section, 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 flooding and low water.

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:

$$Q = AC(Ri)^{1/2} \quad \text{.....} \quad (11)$$

$$C = \frac{1}{n}(R)^{1/6} \quad \text{.....} \quad (12)$$

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 flows at the low, medium and high water levels at the design section.

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

11 Sediment, evaporation, ice regime and others

11.1 With regard to the location of the SHP project on the river carrying significant sediment all year around or carrying more sediment during the flood season, it is necessary to provide the following sediment computation results in whole or in part according to the data availability and the engineering design requirements:

a) Annual average suspended sediment and sediment runoff (ratio);

b) Monthly average suspended sediment at the annual maximum cross-section and the month of occurrence;

c) Annual average suspended sediment grain gradation or average grain diameter and maximum grain diameter;

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

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

a) When there are sediment gauging stations in the upstream/downstream area of the project site or in the basin, the sediment yield modulus should be used.

b) When there is no sediment gauging station in the upstream/downstream area of the project site or in the basin but there are sediment gauging stations in other nearby basins, the sediment yield modulus may be used directly if their climatic conditions and underlying surface conditions are similar, or can be used after being corrected if the conditions are not similar.

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

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

11.4 With regard to the dam toe scheme, the yearly average evaporation from the water surface of the design station and its annual distribution should be reckoned according to the data from the evaporation measuring station in the basin or the region with similar hydrological and meteorological behaviour or the existing regional synthesis diagrams of the evaporation.

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

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

b) Earliest, latest and yearly 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 CO32- and HCO3- which would cause serious damage to the turbine, and their changing rule during various seasons;

b) PH value and its changing rule during various seasons.

12 Rationality check of the outcomes

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

a) It is necessary to use the measured data and the analysis and computation results for all the gauging stations and design stations;

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 should be carried out;

c) It is necessary to determine the formal results “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; design flood peak flow and flood volume;

b) Determination of the flood peak flow, and the roughness coefficient (n) in the computational formula of the slope method;

c) Shape and characteristics of the flow-duration curve and the stage-discharge relationship curve;

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

c) If the difference between the computed results is relatively high or the results are obviously unreasonable, or the spatial variation of the precipitation has significant differences, it is necessary to find the causes in a timely manner and re-analyse/compute when necessary.

12.4 During the design flood computation, it is necessary to attach importance to the reliability and the rationality check for the estimation results of the investigated flood peak flow, and the following contents should be compared:

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

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

c) The magnitude of the measured and known investigated flooding in the same basin or region for flood investigation at 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) - water-collecting area (F) - recurrence interval (N)" through regional synthesis; when the estimated value of the investigated flood peak flow is found to be too high or too low, it is necessary to first examine whether the bed roughness value n in the slope method formula is reasonable, and verify and compare it with the data measured at the gauging station.

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

a) The inter 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 relationship 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 rain gauge network is relatively dense, and the observation series are relatively long, it is suggested to directly 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 compile data statistics for the frequency analysis of the areal storm, it is allowable to indirectly ascertain the design areal rainfall according to the design point rainfall during the corresponding duration and the relationship between the point rainfall and the areal rainfall. The design areal rainfall H_A may be worked out from the design point rainfall H_O and the point-area conversion coefficient a_A a A using the formula (A.1):

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

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 a_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, it is also allowable to ascertain the design areal rainfall according to the relationship between the movable points and the movable area but it is necessary to select several basins or regions with a similar design drainage area near the design basin 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 is necessary to correct it appropriately.

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

f) When the drainage area is smaller than 100 km^2, the point-area relationship may not be considered, whilethe 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 annual point rainfalls over various durations for the design obtained from several rainfall stations in this basin and nearby areas.

b) When the drainage area is relatively small, it is usually necessary to compute the design point rainfalls in several standard durations with reference to the approved contour maps of it is point storm statistical parameter for various durations.

c) To compute the design rainfall for any duration, it is necessary to compute the design rainfalls in n standard durations first, and then draw the rainfall duration curves on the double logarithmic paper and interpolate the design rainfall over the required duration. When the staged rainfall duration relationship is close to a straight line, it is also allowable to use the storm decline exponent formula and interpolate the corresponding rainfall H_i over the required duration t_i 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):

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

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

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

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 analysing the rainfall pattern characteristics of several heavy storms. The

analysis contents 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, it is also necessary to consider the influence of the rainfall intensity and the weather conditions.

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);

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

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):

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

where

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

I_f is the total loss of thebasin, 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):

$$\overline{f}_c = \frac{R_g - R_{t_R - t_g}}{t_c} \quad \text{(A.7)}$$

where

$\overline{f}$ is the arverage 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) Overland runoff (net runoff) process. The overland 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. (formula (A.8)):

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

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. It is necessary to select the data concerning the separate flood peak with the relatively uniform rainfall, the relatively short net rainfall duration and the relatively high rainfall intensity, and ascertain the unit hydrograph 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 it is necessary to select the unit hydrograph that matches with the design rainfall pattern.

b) Instantaneous unit hydrograph

1) Fundamental formula (A.9):

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

where

$U(0,t)$ 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 $m_1(nk)$ 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, formula (A.10)

$$m_1 = ai^{-b} \quad \text{(A.10)}$$

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. It is necessary to determine the amplitude of the non-linear extension of the critical rainfall $i_{Temporary}$ in the control formula (A10).

c) Rational formula

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

$$Q_m = 0.278\frac{h}{t}F \quad \text{(A.11)}$$

$$t = 0.278\frac{L}{mh^{1/3}Q_m^{1/4}} \quad \text{(A.12)}$$

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;

t 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 referred to for determining the value of m corresponding to, $q = L / J^{1/3}$.

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			
		θ=1~10	θ=10~30	θ=30~90	θ=90~400
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 andpebbles are scattered in the basin; both banksare overgrown with weeds, with long-thinbig floods and short-wide medium and smallfloods.	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

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