Hydrological Resource

This guideline expands on what is expected by the criteria statements in the Hydropower Sustainability Tools (HST) for the Hydrological Resource topic, relating to assessment and management. The good practice criteria are expressed for the preparation and operation stages.

In the Hydropower Sustainability Assessment Protocol (HSAP), this topic is addressed in P-7 for the preparation stage and O-4 for the operation stage. In the Hydropower Sustainability ESG Gap Analysis Tool (HESG), this topic is addressed in Section 11.

As a significant water resource development, a hydropower project requires a very good understanding of water inflows to and outflows from the project site and the future operating hydropower facility. Poor estimations of water availability can lead to inefficient design and operation of the hydropower facility and reduce its production potential. Misunderstanding of the magnitude, timing, variability and extremes of the patterns of water inflows can also present significant infrastructure safety risks. Overestimation of water availability can lead to overinvestment in the hydropower facility and future financial viability issues. Insufficient consideration of other water users, including downstream, can lead to water resource use conflicts.

River flows are **stochastic** in nature, meaning they have a random probability distribution or pattern. The degree of hydrological variability can be extreme in many areas of the world. The correct analysis of water resources and proper allocation between competing uses for that resource are critical to the viability and operation of a hydropower facility. The longer the period of field data collected to inform project design, the higher the confidence in planning for hydrological resource risks. Management of uncertainty and extreme climatic conditions, especially given climate change and potentially competing needs for water resources, require close attention throughout the project life cycle.

This guideline addresses the level of understanding regarding the hydrological resource availability and reliability for the project or operating hydropower facility, and the planning for generation operations based on these flows. The intent is that power generation planning and operations take into account a good understanding of the hydrological resource availability and reliability in the short- and long-term, including other needs, issues or requirements for the inflows and outflows, as well as likely future trends (including climate change) that could affect the facility.

Assessment

Assessment criterion - Preparation Stage: An assessment of hydrological resource availability has been undertaken utilising available data, field measurements, appropriate statistical indicators, and a hydrological model; issues which may impact on water availability or reliability have been identified and factored into the modelling; and scenarios, uncertainties and risks have been evaluated.

The determination of the hydrological resource for a hydropower project requires a combination of investigations and analyses by field hydrographers, hydrologists, and hydropower and hydraulics engineers. The initial hydrological resource assessment will normally take place early in the investigation and assessment phase of a project and will continue through the feasibility studies and detailed design stages. Assessment activities involve gathering and measuring basic rainfall and streamflow data, statistical analyses and statistical extension of this data, modelling of the reservoir, optimisation of the project siting and design, and optimisation of the construction planning and scheduling (e.g. taking into account diversion dam design with respect to flood frequency analyses).

The degree of reliability of flow, and thus of future power generation, primarily depends on three factors:

- the magnitude and variability of reservoir inflows, taking into account natural flows and upstream water users;
- the required generation (and equivalent turbine flow); and
- the size of the storage (largely dictated by the site characteristics).

The generation output and the storage size and head should be optimised for the specific site characteristics (see the Siting and Design guideline).

Data requirements for hydrological assessments include: climatic data (e.g. rainfall, air temperature, humidity, wind, evapotranspiration); topographic data (e.g. slopes, river length, land use); stream flow (e.g. discharge, snow melt, floods); groundwater data (e.g. infiltration, discharge); and patterns of other water resource uses. Data should be validated as being of good quality and checked for consistency to identify gaps and non-conformances with typical hydrological patterns. Recognised methods should be used to fill short-term data gaps and to correct any systematic errors, with modelled data also checked for consistency. Consistency checks should include various forms of analyses of stage-discharge relationships, average flows, flow volumes, flow time series, and rainfall-runoff. Where feasible, consistency checks should involve comparisons with observed data in comparable adjacent catchments or sub-catchments.

The length of flow record used to inform project design would ideally be 10 years for a relatively small project (e.g. run-of-river or small impoundment) and up to 25 years for a major storage project. As flow records are rarely available at or close to the intended project site, shorter-term field data should be correlated with longer-term records of nearby and comparable sites, with hydrological modelling used where required to build flow records. It would be expected that real-time data is collected and analysed throughout the development and operation of a more complex hydropower project.

If the project is to be operated largely in run-of-river mode, there should be evidence of proposed or actual daily operational plans that match the desired station output with the available flow. If the project is able to retain water as storage for later release, there should be evidence of reservoir management analysis in the form of seasonal reservoir rule curves and operating rules. The complexity of analysis and data requirements relates to the economic, safety and environmental risk of the project. Where a derived flow sequence has been used for the primary hydrological resource analysis, the method of data simulation needs to be carefully considered. For lower levels of project risk a simplified regression method may be appropriate, whereas for high risk and complex projects a more rigorous statistical and regional method and/or appropriately calibrated hydrological model will be required. Hydrological models should be scientifically recognised and well-calibrated using multiple gauging stations and at least 12 months of rainfall-runoff measurements over a range of flow types and magnitudes. The impacts of glaciers, snow cover, and climate change should also be taken into account.

Future climate change trends should be informed by scaled-down regional climate models. Analyses should assess site-specific temperature and precipitation changes over the short- and long-term, using one or more global climate models (also known as general circulation models) as well as evaporation and runoff modelling to estimate changes in net water yield. Sensitivity analyses should be conducted to consider various climate change scenarios and the results using different global climate models.

Analyses to determine the electricity generation potential need to align with any national requirements regarding dependability values for the energy produced and the timesteps used for the analyses (e.g. daily or monthly inflow values). These analyses are a critical input to the financial models as they provide an estimation of revenues and hence the project's financial viability (see the Financial Viability guideline). Electricity generation calculations must take into account water needs for other purposes (see the Downstream Flow Regimes guideline).

Flood estimations and analyses are a major component of the preparation stage assessments. These estimates inform spillway design and are used for planning river diversions during construction. Flood assessments require high resolution rainfall data and concurrent runoff data. Spillway design relates to the inflow design flood, the size of the reservoir, and the hydraulic head. Methods for calculating design floods vary by country and with dam type. Requirements may relate to the Standard Project Flood (SPF), being the flood generated by the most severe rainstorm on record, and the Probable Maximum Flood (PMF), which is a calculated value and not based on observed records. Any estimates should take into account Glacier Lake Outburst Floods (GLOFs) if relevant to the region.

The International Commission on Large Dams (ICOLD) requires that large dam design should be based on the PMF, and this is adopted as the standard for many modern dam projects. The PMF should be calculated based on the Probable Maximum Precipitation (PMP), following the method specified by the World Meteorological Organization (WMO). The spillway design flood needs to further take into account acceptable hydraulic conditions, adequate freeboard on the dam crest, and assumptions on gate operation for gated spillways. Hydrological studies should calculate the PMF, SPF and floods with return periods up to 10,000 years. Design engineers should choose and justify the design floods appropriate to the hydropower development based on national requirements, reservoir size, hydraulic head, and a thorough understanding of downstream and operational risks.

Hydrological assessments that inform the design of river diversion works for the construction period should underpin construction planning considerations relating to timing, cost, safety, resources and convenience. Time requirements for the diversion depend on the asset being protected (i.e. dam, power house) and type, scale and location. The appropriate annual flood return period needs to be established in relation to construction needs and risks, and flood frequency analyses conducted for dry season and annual flood frequency.

For planning of reservoirs, flood volume is more important than the floods with the highest peaks. Flood hydrographs should be developed based on different rainfall durations, which will depend on the catchment size. Flood volumes should be routed through the reservoir to determine the decisive design flood that leads to the highest reservoir water level.

Issues which may impact on water availability and reliability need to be well-identified and factored into planning. Examples include: upstream and downstream hydropower operators and water resource users; future water resource use developments; future development of water-reliant land uses (e.g. agriculture, industry, population growth); catchment conditions; climate change; and negotiations over water allocation. If the project is reliant on water resources that extend beyond the jurisdictional boundaries in which the project is located, the implications of this need to be fully considered.

Assessment

Assessment criterion - Operation Stage: Monitoring is being undertaken of hydrological resource availability and reliability, and ongoing or emerging issues have been identified; inputs include field measurements, appropriate statistical indicators, issues which may impact on water availability or reliability, and a hydrological model.

Further to the guidance above, assessment of the hydrological resource is required throughout operation of the hydropower facility in order to maintain optimal performance according to the short- and long-term operational requirements.

Real-time monitoring of rainfall and flow should be undertaken in the catchment to provide data on water resource availability and trends. Field data needs to be regularly calibrated and validated, and data quality should be recorded. All data collected should be stored in a database that allows ready access to the data and retrieval of historical analyses.

A range of hydrological and generation models can be used to manage one or a fleet of operating hydropower facilities and will depend on the context and market situation. For example, models may be set up separately for analyses and projections of:

- inflows to storages based on rainfall and water levels;
- short- and long-term electricity generation based on market demand and available generating and transmission assets;
- water value based on forecast inflows and power trading signals; and
- flood forecasting linked to reservoir management and dam safety emergency planning.

Issues that may affect generation need to be monitored and assessed to inform generation decisions, including inflow trends, effects of climate change, drought, energy forecasts and price predictions, asset maintenance, other (and possibly changing) resource demands, environmental constraints, and social uses of the water resources (e.g. new developments, water recreation events). Outputs of models and other monitoring mechanisms should be available to data users and decision-makers as needed.

Periodic studies should be undertaken to consider longer-term scenarios and sensitivities. These studies are closely linked to those needed to inform asset management planning (see the Asset Reliability and Efficiency guideline) and infrastructure safety assessments (see the Infrastructure Safety guideline).

Management

Management criterion - Preparation Stage: A plan and processes for generation operations have been developed to ensure efficiency of water use, based on analysis of the hydrological resource availability, a range of technical considerations, an understanding of power system opportunities and constraints, and social, environmental and economic considerations including downstream flow regimes.

Management criterion - Operation Stage: Measures are in place to guide generation operations that are based on analysis of the hydrological resource availability, a range of technical considerations, an understanding of power system opportunities and constraints, and social, environmental and economic considerations.

Generation operations should be informed by short- and long-term modelling of water availability and reliability as described above and should be guided by clearly stated operating rules. Operating rules help inform generation operators of thresholds for decision-making (e.g. drawing a reservoir down before the flood season, releases required for environmental flow objectives) and should factor in not only technical and financial considerations but also social, environmental and economic needs (see also the Downstream Flow Regimes guideline).

At the preparation stage, planning for generation operations should seek to ensure efficiency of water use while meeting other water resource needs, including those of external stakeholders upstream and downstream of the project. At the operation stage, systems should be in place to ensure that emerging issues are rapidly identified and inform management responses. Generation operations should be informed by regularly updated risk assessments and forward plans should be developed for a range of time scales. Power system opportunities and constraints should be well-monitored, for example patterns of demand for energy (e.g. base vs peak load), power prices, other generators and their capacities and constraints, and transmission issues.

Over the long-term, communities surrounding the hydropower facility in the catchment, around the assets, and along the downstream river will evolve, with consequent changes in water abstraction, land use, and expectations for shared water resources. Awareness of environmental and social values and needs, both within the reservoir and downstream, is growing as societies become more educated and allocations of water for environmental and social needs are increasingly becoming embedded in legislation. Competing water uses and other developments in a catchment can lead to more rigid water allocation rules and more rigid standards on water quality and biodiversity indicators. The business will need to be aware of and prepared to adapt to changing societal needs and should be able to demonstrate this through risk assessments and community engagement processes.