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	Engineering and Design HYDROLOGIC ENGINEERING FOR HYDROPOWER	
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DEPARTMENT OF THE ARMY
US Army Corps of Engineers
CECW-EH Washington, DC 20314-1000

Regulation
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Engineering and Design
HYDROLOGIC ENGINEERING FOR HYDROPOWER

1. Purpose

This regulation defines the scope, authorities, and requirements for hydrologic engineering studies performed in support of hydropower studies for both conventional and pumped-storage hydroelectric projects.

2. Applicability

This regulation applies to all HQUSACE/OCE elements, major subordinate commands, districts, laboratories, and full operating activities having civil works engineering and design responsibilities.

3. References

a. ER 1110-2-1. "Provisions for Future Hydropower Installation at Corps of Engineers Projects."

b. ER 1110-2-1454. "Corps Responsibilities for Non-Federal Hydroelectric Power Development Under the Federal Power Act."

c. ER 1110-2-1460. "Hydrologic Engineering Management."

d. EM 1110-2-1701. "Hydropower."

4. Scope of Hydrologic Engineering Activities

The scope of hydrologic engineering and study management is presented in Reference 3c.

5. Development of Hydrologic Data

a. *General*. Data used to support the study will be as comprehensive and as accurate as possible.

b. *Types of Data*. The most important hydrologic data element required for a hydropower study is the long-term streamflow record that represents the flow available for power production. Other hydrologic data includes tailwater rating curves, reservoir storage-elevation-area tables, evaporation rates, flows not available for power generation, streamflow routing criteria, instream flow requirements, and downstream channel constraints. The level of detail used to develop this data depends upon the stage of study in the hydropower analysis.

c. *Streamflow Data*.

(1) Length of historical period used for analysis. To accurately estimate the energy potential of a hydroelectric project, a streamflow record of at least 20 to 30 years should be used. If a record of this length is not available, it should be extended using one of the standard techniques for extending streamflow records. The only cases where a shorter period is acceptable would be for reconnaissance level energy estimates, and even then there should be some assurance that the shorter record is representative of the long-term record.

(2) Adjustment of historical records. Streamflow data may not be immediately usable for hydropower site analyses. Historical streamflow records, particularly if they span a long period of time, may have to be adjusted to account for diversions, reservoir regulation, and upstream land use changes. These adjustments are made so that the streamflow record is consistent throughout the period of record and so that it properly reflects conditions at some well-defined base level.

6. Analysis of Project Energy Output

a. *Types of analysis*

(1) The three types of analyses generally used to determine the energy output of a hydroelectric project are the duration curve method, the sequential streamflow routing (SSR) method, and the hybrid method, which is a combination of the first two.

(2) The duration curve method is based on a flow-duration curve and is used only for run-of-river projects where head does not vary independently of discharge.

(3) The sequential streamflow routing method is based on the continuity equation and accounts for changes in streamflow due to storage regulation. This method is used for evaluating the energy output of storage projects or projects that are part of a system which includes one or more storage projects.

(4) The hybrid method performs power computations sequentially and arrays the results in duration curve format for further analysis. This method is used to examine the addition of power to projects where head varies independently of streamflow but where there is no regulation of seasonal storage for hydropower. An example would be an existing flood control reservoir or storage project where conservation storage is regulated entirely for nonpower purposes and where a substantial historical operation record is available.

(5) Chapter 5 of Reference 3d contains detailed descriptions of each of these methods, as well as additional discussion on situations where each method is appropriate.

b. Operating Assumptions.

(1) General. When performing a duration curve analysis, specific project operating assumptions do not need to be made because the basis of the analysis is a set of historic streamflows that already reflect a specific mode of operation. However, in an SSR energy analysis, one of the main purposes of the analysis is to test an assumed reservoir or system operation plan. Hence, a set of operating assumptions must be defined to control the operation of the reservoir.

(2) Nonpower reservoir operating criteria. Most Corps of Engineers projects having a hydropower function also serve other functions, such as flood control, water supply, navigation, or recreation. In modeling the operation of a given reservoir, it is necessary to specify operating criteria for each of the project functions. These would be in the form of flow objectives, reservoir elevation objectives, or a combination of the two. The reservoir will then be regulated to produce the highest possible power benefits while still meeting nonpower requirements. The nonpower operating criteria may already be well-defined, as in the case of a hydropower addition to an existing project. For new projects, both hydropower and nonpower operating criteria must be developed concurrently.

(3) Power operating criteria. There are several alternative strategies that might be considered in regulating the power storage at a project. Traditionally, hydropower projects have been operated to ensure that firm energy capability will be provided in all or nearly all of the years in the period of record. It is now preferable in some power systems to operate hydroprojects to maximize average annual energy or to maximize dependable capacity. A project might also be operated for variable draft for energy production (basing the draft of power storage for energy production on the market value of energy at specific times). Such an operation might be superimposed on the primary objective of maximizing firm energy output. These alternative strategies are discussed further in paragraphs 5-8 through 5-14 of Reference 3d. Close coordination is required with the Federal power marketing agency[1] (PMA) and/or the utility system where the power is to be used to ensure that the proper reservoir operating criteria are being used.

c. Study output

(1) Output from a duration curve analysis. The output resulting from a duration curve analysis will include an annual generation-duration curve, an estimate of the site's total energy potential, the average annual energy for each plant size tested, and the monthly distribution of generation. A generation-duration curve for the peak demand months and monthly generation-duration curves are also useful.

(2) Output from a sequential streamflow routing analysis. The output resulting from a sequential streamflow routing analysis will include the plant's average annual energy output and the month-by-month generation, discharges, and reservoir elevations for the

[1]The Federal agency responsible for marketing the power output of the Corps project.

period of record. For projects that are operated to maximize firm energy output, the critical period must be identified and estimates developed for firm and secondary energy production.

7. Analysis of Project Dependable Capacity

a. Dependable capacity.

(1) Dependable capacity has traditionally been defined as the load-carrying ability of a powerplant under adverse load and flow conditions. This definition still applies in hydrobased power systems. However, in thermal-based power systems, other techniques may be more appropriate. Dependable capacity is used in load-resource analyses and in power sales contracts, but in the planning of hydroprojects, its major use is in estimating a project's capacity benefits.

(2) There are four methods for estimating hydroplant dependable capacity: (a) the critical month method, which assesses the hydroplant's load-carrying capability under adverse flow and load conditions; (b) the firm plant factor method, which is based upon the amount of firm energy required to make the capacity marketable; (c) the specified availability method, which is based on the amount of capacity available for a specified percentage of the time, and (d) the average availability method, which is based on the assumption that variation of hydroplant generating capability due to variation in streamflow and reservoir elevation is equivalent to variation in thermal plant availability due to outages.

(3) Generally, the average availability method is to be used for hydroprojects that are operated in thermal-based power systems, while either the critical month method or the firm plant factor method is to be used for projects located in hydrobased power systems. The specified availability method is suitable only for reconnaissance level studies. The four methods are described in detail in paragraph 6-7 of Reference 3d, along with additional discussion of the situations where each method is appropriate.

b. Hydrologic Studies Required. All of the methods for computing dependable capacity require output from one of the models used for computing project energy output (paragraph 6). In addition, hourly sequential streamflow routing studies may be required to test the adequacy of pondage to support the capacity and to ensure that nonpower operating constraints do not limit the usability of the capacity (paragraph 8).

c. Marketable capacity. As noted in paragraph 7.a.(2), the average availability method is usually the preferred approach for evaluating the dependable capacity of a hydroproject operating in a thermal-based power system. The dependable capacity thus computed would be used for computing capacity benefits in an NED (National Economic Development) economic analysis. However, it is also sometimes necessary to provide an estimate of the project's dependable capacity to the Federal PMA, so that they can perform the marketability studies for the project. The PMA usually bases its analyses on the capacity that can be supported under adverse water conditions. This is appropriate, because in most cases the PMA has only hydropower to market, so they are interested in the contribution the hydroproject makes to its own (all-hydro) load-carrying capability rather than its contribution to the entire regional power system, as would be the case in an NED economic analysis. To avoid confusion with the NED dependable capacity, the value provided to the PMA should be identified as the marketable capacity. The marketable capacity would be computed using either the critical month or firm plant factor method, depending on the practices of the specific PMA.

8. Water Surface Fluctuation Studies

a. Because of their ability to come on line quickly and to respond quickly to changes in load, hydroprojects are highly valuable to power systems when operated as peaking projects. However, peaking operation often results in rapid fluctuations in discharge and in water surface elevations both upstream and downstream from the powerplant. If a hydroproject is being considered for peaking operation, it is necessary to evaluate the effect of the power operations on the shoreline of the reservoir and on riparian land downstream from the project site. Studies of this type are particularly important at the advanced feasibility and General Design Memoranda stages and are required for both conventional and pumped-storage hydroprojects.

b. Areas of concern may include safety of and access to shoreline areas for commercial and recreational activities; maintenance of safe depths and velocities for navigation; adequate depth for operation of water supply and irrigation pumping facilities and sewage treatment plant outfalls; and damage to waterfowl nesting areas, fish migration channels and spawning areas, and habitat areas of rare or endangered species.

c. Water surface fluctuation studies will usually require hydraulic modeling techniques based on unsteady flow theory when there are rapid fluctuations in discharge.

9. Pumped-Storage Hydropower Projects

a. Average annual energy output and dependable capacity are computed differently for pumped-storage projects than for conventional hydropower projects. In addition, the average annual pumping energy required to support the pumped-storage operation must be computed. The details of such analyses are described in Chapter 7 of Reference 3d; however, several key points should be noted.

b. Close coordination must be maintained with the Federal PMA and/or the utility that will be using the output of the project at all stages of the study to ensure that the project output will be usable in the system load, that sufficient low-cost pumping energy will be available to support the project, and that sufficient storage will be available in both the upper and lower reservoirs to support the power operation and to meet other project purposes.

c. Average annual generation and pumping energy requirements should in most cases be estimated by simulating the operation of the project in an hourly production cost model of the power system in which the project would be operating. This is the preferred method of analysis, because it simulates the operation of the project under a range of conditions similar to those in which the project would be expected to operate. An alternative method is based on an assumed operating cycle. This method involves more guesswork, and experience has proven that it often overestimates the amount of generation a project would produce. It should be used only where the project would operate according to a fixed dispatch schedule instead of the economic dispatch mode. In such cases some assurance should be received from the PMA or the utility customer that the proposed operating schedule can be supported with economical pumping energy. Even when this method is used, the proposed operation should also be tested in a system production cost model to verify that such an operation is possible within the system load shape.

10. Documentation and Reporting

Hydrologic studies for hydropower are documented in technical reports or in technical appendices to project reports. The report or appendix presents a description of the data used, methods employed, assumptions made, and results obtained. A complete and well written report is required and must be of sufficient detail to allow an independent reviewer to follow the described analyses and support the study findings. Appendix A of Reference 3d lists the type of information that should be included in a feasibility report.

FOR THE COMMANDER:

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