HYDROLOGICAL ASPECTS OF WATER RESOURCE PROJECTS

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1. General:

Hydrological inputs play a major role in planning, design and successful implementation and operation of a water resources project. The economics and sizing of every structural and non-structural component of the project is dependent on hydrology. Water resource projects are big in nature and involve a huge public investment, and therefore it is necessary to carry out the detailed hydrological studies of Water Resources Projects.

The planning of a project has two stages. One is Preliminary Report and other is Detailed Project Report (DPR). When the feasibility of the project is ascertained at preliminary stage, then the work of preparation of DPR is taken up.

2. Basic Guidelines:

Central water Commission and Central Electricity Authority as regulators for the Major and Medium projects have come up with following publications:

- Guidelines for preparation of Detailed Project Report of Irrigation and Multipurpose Projects by Ministry of Water Resources (2010)
- (read with Guidelines for Submission, Appraisal and Clearance of Irrigation and Multipurpose Projects (2010) (CWC))
- Guidelines for formulation of detailed project reports for hydro electric schemes, their acceptance and examination for concurrence (CEA-2007)

These are the broad guidelines and deal with outlines of the DPR, but formulators of DPR may have to refer to a number of other related Technical Documents (other than the standard technical text on the specific subject) which are helpful in preparation of chapters on DPR. Some of them are listed below:

- Guidelines for preparation of project estimates for major irrigation and multipurpose project issued by CWC
- Guidelines for “Investigation of major irrigation and hydro-electric projects” issued by CWC
- Manual on estimation of Design flood, 2001 (CWC)
- CBIP – Technical Report No.19 “Life of Reservoir” (1977)
- IS 4890 : Method for measurement of suspended sediment in open rivers
- IS 4186 : Guide for preparation of project report for river valley projects.
- IS 4877 : Guide for preparation of Estimate for River Valley Projects
- IS 5477 : Methods for fixing the capacities of reservoirs. (Part 1-4)
- IS 7323 : Method for determining evaporation from reservoirs.

- IS 7323 : Guidelines for operation of reservoirs.
- IS 13028 : Guidelines for overall planning of river basin.

3.0 Hydrological Inputs

The amount and type of hydrological inputs required for detailed studies of project depends upon the type of storage and purpose of the projects

- Storage
  - Diversion without Pondage
  - Diversion with Pondage
  - Within Year storage
  - Over the Year storage (Carryover storage)

- Purpose
  - Irrigation
  - Hydropower
  - Water Supply and Industrial
  - Flood Control
  - Others (Navigation, Salinity Control, WQ Control, Drainage, Recharge etc)

The inputs required for different types of detailed studies in DPR are listed below:

- For Simulation Studies
  - Water Availability Studies (Inflow series)
  - Lake evaporation
  - PET and Return Flow
  - Sediment inflows and New Zero Elevations, Revised Area Capacity
  - Water Quality
  - Low Flow Requirement, Ground water etc

- Design Flood Studies and levels for
  - Safety of Structure
  - Flood Control works
  - Drainage works
  - Diversion works
  - Locating structures and outlets in vicinity of river bank/ reservoir
  - Tail water rating curve

4.0 Hydrological Studies and Data Requirements:

Whenever a project is conceived, the first and most important step is to establish a G&D site and start taking data which shall be very helpful in studies.

Hydrological studies required for the preparation of a Chapter on Hydrology of a DPR on water resources project can be categorized into following broad groups:

- Water Availability Assessment
- Design flood for design of spillway capacity for structural safety
- Diversion flood for design of coffer dam during construction
- Sedimentation studies to compute revised area capacity curves and life of reservoir

These studies require a long term Hydrological and Hydro-meteorological data of good quality and sufficient quantity. The data requirement as per CWC guide lines is as follows:

River Gauge	10 yrs	Three daily (During Flood- Hourly)	Daily
River flow discharge	10-15 yrs	20-30 during flood season	Weekly
Sediment flow and grain size composition	5 yrs	Along with discharge observation	Weekly
Water quality and salinity	3 yrs	Once in a month with discharge	More frequency
Rainfall ORG and SRRG -1 per 600 sq km (150 sq km in Orographic area) - 25% SRRG	10 yrs and more	Daily and hourly with discharge	
Pan evaporation	3 years	daily	daily

The quality of data observation needs to be maintained as per national and international standards. WMO, IMD, and CWC guidelines along with BIS standards for various types of data observations are available.

The methods of discharge observation needs to be updated to have accurate and reliable data being the corner stone of Hydrological studies but most neglected part in investigations of projects. It must be done by Area Velocity method/ calibrated (model testing) Hydraulic structure.

5.0 Data Processing:

Processing of data needs to be done for following purposes

- Quality of data
- Filling up of short gaps
- Adjustment of records
- Consistency – Internal and external
- Data extension and generation

The processing involves mostly the plotting of data, mass curve, statistical techniques of time series analysis, checking of randomness and homogeneity of series, correlations and regressions etc. The various data needs to be checked for consistency (internal and external). The data observed at various Hydrological sites of CWC under Hydrology Project employ a detailed procedure of primary and secondary data validation.

6.0 Water Availability Studies:

Hydrologically, runoff is the portion of precipitation which has neither evaporated nor deep percolated, which ultimately joins the stream. The runoff can be classified as:

1. Surface runoff which flows over the land and is first to reach the streams, and
2. *Sub-surface runoff* which is infiltrated into surface soil and reaches to stream through sub-surface flow

A project other than hydro-power needs to be analyzed for conjunctive use of surface and sub-surface runoff.

A water availability series is worked out for surface runoffs on monthly basis for storage projects and 10–daily basis for diversion projects particularly Hydropower projects. Ideally, the series should be of length of about 20-35 years and should have all types of dry and wet cycles.

After finalizing the long term series, dependable flows are computed by arranging the series in descending order. The dependability criteria are given below:

Irrigation Projects	75%
Hydropower Projects	90%
Water Supply	100%

The series can also be analyzed for specific yield (flow per sq km expressed as depth) and runoff factor (runoff/ rainfall as dimensionless parameters)

7.0 Design flood studies:

A flood hydrograph or instantaneous peak discharge adopted to design a river control structure after accounting for hydrological and economic factors is called Design flood:

- Corresponds to maximum tolerable risk
- Project can sustain without substantial damage to its components as well as life of people and property
- CAN BE EXCEEDED

- Risk of damage is equivalent to probability of occurrence of floods larger than Design Flood.

  It depends on
  - Purpose: Safety of project components and affected people and property in the event of extreme Flood
  - Proper selection: Additional cost of structures v/s risk of losses to structures and affected people and property
  - *Absolute protection: Unrealistic*
  - *Increased risk: Unacceptable*

  Thus Design flood is selected from hydrologic as well as economic considerations.

  The design flood for a project is used for different purposes viz:

  1. For safety of dam
  2. For energy dissipation system
  3. Extent of upstream submergence
  4. Downstream damages
  5. Design of cross drainage structures

The damages on the failure of a water resources structure depend on its storage capacity and hydraulic head.

The storage dams are classified according to their size by using the static head (H) and storage. Following table based on IS: 11223-1985 gives the classification and the design flood criteria:

Classification.	**Gross storage (S) Mm^3**	**Head (H) m**	**Design flood.**
Small	0.5 to 10	7.5 to 12	100 Yr. flood
Intermediate	10 to 60	12 to 30	SPF
Large	>60	>30	PMF

For diversion projects, a design flood for assessment of free board, a 500 year return period flood or SPS whichever is higher is recommended where as for other purposes, a 50 years return period flood is considered good enough by IS 6966: Part I

For CD works IS 7784 Part I 1993 specifies 50 to 100 year return period floods depending upon importance of works and size of canal.

For diversion during construction period, IS 10084 Part I 1982 may be adopted which specifies about 20 to 100 years return period floods depending upon the temporary seasonal nature or more than one season nature of diversion works.

The following approaches can be adopted for design flood computation of projects for pre construction designs

1. Formulae Approach.
2. Statistical approach, commonly known as Flood Frequency Approach.
3. Hydro-meteorological approach, commonly known as the Unit Hydrograph Approach.

In these approaches, adequate data inputs are required for processing and obtaining the design flood outputs. The inputs are generally the:

- Long term and Short term rainfall and runoff records,
- Annual flood peak series,
- Catchment or physiographic characteristics
- Gauge data
- Antecedent soil condition etc.

The detailed methodology to be adopted in a particular case depends upon the data availability.

7.1 Formulae Approach:

a) Empirical formulae

When hydrological data are not available, the designer may have to take the help of flood formulae, developed for different regions. It should be noted that the flood values obtained from these formulae are good only for preliminary estimates, and will have to be firmed up by any other suitable methods after collecting the minimum necessary data.

b) Envelope curves

This is based on concept that the maximum floods per unit area experienced in one basin is quite likely to be experienced in nearby basin in the same region having similar climatological and physiographic characteristics.

The PMF figures for a number of projects estimated by Central Water Commission and other organizations during the period 1980-91 have been utilized for developing envelope curves for PMF peaks. These curves corresponded to following equation:

Upper envelopes $Q_u = 1585\ A^{0.35}$
Average line, $Q_{av} = 398\ A^{0.425}$
Lower envelope, $Q_L = 100\ A^{0.5}$

Where Q is PMF in cumec and A is catchment area in sq. km.

7.2 Flood Frequency Approach:

Statistical analysis is based on the assumption that combination of numerous factors which produce floods are a matter of pure chance and therefore are subject to analysis according to the theory of probability. Statistical analysis for review of Design Flood may be performed on the discharge data either directly observed at the site of study or estimated by the suitable method.
Two types of sample data series as mentioned below may be used for flood frequency analysis

(1) Annual peak flood series and
(2) Partial duration

The annual peak flood series which is commonly used is a selection of the maximum peak flood value from each year. Such a selection excludes the second maximum value of flood peak of a particular year even though this may be higher than the maximum of some other years. Annual peak flood series, however, may be considered to be purely random. In partial duration series, all the events above a certain threshold are included in the analysis. However, care must be taken not to include those peaks which are dependent as the assumption of randomness would be violated.

Hydrological data are mostly available as samples of limited size. Using statistical principles, the needed information (such as mean, standard deviation, skewness co-efficient, kurtosis co-efficient etc.) are extracted from the available sample data and are assumed to be the characteristics of the population. Whatever, be the length of the sample, it cannot exhaust all possible elements of a variable. Therefore, the sample is assumed to be representative of the population. In the application of the statistical analysis methods, it is assumed that the occurrences are individual events independent of each other i.e., they are assumed to be evolved from a purely random process. A time series of events is said to be homogeneous if it does not exhibit systematic variation in time (e.g., cyclic variation, an increasing or a decreasing trend or a jump). The factors which affect the homogeneity of peak flows are the developments in the catchment over time such as deforestation, urbanization, flood control works, earthquake etc.

It may be difficult to find data which conform to all the requirements. As a preliminary step, the basic data should be properly processed, screened and adjusted to remove, as far as possible, any non-conformity that may exist. The data series is to be checked for the randomness and presence of trends, jump and outliers.

After arriving at the series, the series is analysed to test as to which of the known probability distribution provide best fit. Thus the approach includes:

a. Fitting various probability distribution to the sample and estimation of the parameters of the distribution;

b. Applying suitable test to identify the various distributions which provides best fit; and
c. Estimating the floods of different return period.

Fitting of various probability distributions can be carried out either mathematically or graphically. Computer programmes are also available.

However, the statistical analysis method has certain limitations as:

- It yields only the peak, not volume or shape of the hydrograph.
- Correct inference about the distribution, which fits the sample data for a site as different distributions fitted to same data results in different estimated values especially in the extrapolated range and poses to the planner economic appraisal problem of the project.
- Non availability of sufficiently long data length to allow reliable estimation of population parameters from the sample data.
- Elements of risk and uncertainty are inherent in any flood frequency

7.3 Unit Hydrograph (UG) Approach:

In this method, design flood computation mainly involves estimation of a design storm hyetograph and derivation of catchment response function. The catchment response function used can be either a lumped system model or a distributed lumped system model. In the former, a unit hydrograph is assumed to represent the entire catchment area. In the distributed model, the catchment is divided into smaller sub-regions, and the unit hydrographs of each sub-region applied with channel and/or reservoir routing will define the catchment response.

The main advantage of this approach is that it gives a complete flood hydrograph and this allows making a realistic determination of its moderating effect while passing through a reservoir or a river reach.

This method has been found to be a useful tool in design flood studies. Hydro meteorological approach preferably based on site specific information is suggested for the estimation of design flood of intermediate/ large dams, especially when the storage has a significant effect on modifying the design flood hydrograph as it flows through the reservoir.

If short interval data of the storm of uniform intensity and corresponding flood hydrograph are available then one can derive unit hydrograph as per standard practice.

This approach however is subjected to certain limitations such as:

- Availability of SRRG data for historical storm is too poor.

- Many of the assumption in the UG theory are not satisfied in practice.
- Many times, data of good quality and adequate quantity is not available for derivation of UG.

7.3.1 Use of PMP Atlas

The first step towards computing PMF is estimation of Probable Maximum Precipitation or PMP. Computation of PMP is an intricate process, requiring considerable judgment on the part of the meteorologist, judgment that can come only through long experience. Since computation of PMP requires expertise in meteorology, most of the time Engineers find it difficult to compute PMP. Under Dam Safety Assurance and Rehabilitation Project (DSARP), PMP studies for various river basins were carried out and the results presented in the form of charts/atlas for use by design engineers.

In these Atlases a catchment with a drainage area of less than 1000 km^2 is considered as small , whereas a catchment involving a drainage area of 1000 to 10000 km^2 is taken as medium.

Maps of point PMP estimates for 1-day and 2-day using statistical techniques have been incorporated along with the Area Reduction Factor (ARF) curves to facilitate computation of areal PMP for small catchments. The 1-day or 2-day Areal PMP for a given basin of known size can be computed just by picking up point PMP value over the basin area from plates and then multiplying the same by the Area Reduction Factor (ARF) corresponding to the basin size as read from the relevant ARF Curves presented in the report.

For medium and large catchments Area PMP is estimated by physical method by considering rain storms of 1 to 3-days durations. DAD envelope curves have been drawn for various basins of the country. *For a medium size project basin the areal depth corresponding to the basin size is picked up from the relevant DAD envelope curve and multiplied by Moisture Maximization Factor (MMF) of the contributing rainstorm to obtain Areal PMP estimate, (if the contributing rainstorm is over or in the vicinity of the project basin).* Standard area values of SPS depths as read from enveloping DAD curves and the PMP depths obtained by multiplying SPS values with MMF are presented in the report.

In case, the rainstorm contributing to DAD envelope curve is far away from the project basin (medium size) the maximized DAD values have to be further adjusted for rainstorm transposition by applying Location Adjustment Factor (LAF) and Barrier Adjustment Factor (BAF) to obtain corresponding Areal PMP estimates. Moisture Adjustment Factors (product of MMF, LAF and BAF) using the relevant rainstorms have been computed at 1^0 Latitude x 1^0 Longitude interval in tables.

Areal PMP estimates at 1^0 Latitude x 1^0 Longitude interval using the transposable rainstorms is available corresponding to 1000, 2000, 3000, 4000, 5000, 7500 & 10000 km^2 area for 1, 2 and 3-day durations. For catchments of intermediate size PMP can either be interpolated from the standard area PMP values or else corresponding SPS depths can be picked up from the DAD envelope curves and multiplied by the MMF as selected from tables.

It should be noted that maximized and transposed DAD values are adopted as PMP estimates on the assumption that rainstorm Isohyetal pattern exactly fits the shape and size of the basin, a situation which is very rarely materialized. Such an assumption is bound to result in over estimates of PMP in case of large size catchments.

7.4. Selection of method:

Even though, several factors are relevant when deciding about the method to be used for design flood estimation, data availability and the purpose of study are the most important factors. Since, in general, water resources development cannot wait till hydrological data of adequate quality and in quantity become available, flood estimation has to be done using whatever data is available. Regional flood estimation reports developed by CWC can also be used as an alternative. We must aim at a safe and economical design flood value based upon sound hydrological practice.

8.0 Sedimentation Studies

The sediments coming in a surface water stream when obstructed by a dam starts accumulating in the useful storage and over the period besides the reduction in storage capacity, it reduces the planned benefits of the reservoir also.

For diversion works for irrigation purpose, the sharing of sediment in the river and canals become the key of hydraulic designs, for the hydropower projects proper silt excluders and flushing arrangements of silt to keep the structures operational becomes more important.

Storage reservoirs, however, traps most of the silt in the reservoir area. Thus a proper estimation of silt deposition is needed for the sake of

- keeping the inlets above the deposited silts, keeping them functional, estimation of New Zero Elevation at the end of the useful life of reservoir

- ensuring the economic usefulness up to the end of planned life of reservoir, estimation of revised area capacity somewhere half way of life of reservoir

The planned useful life depends upon the purpose of the project. While for Irrigation and Multipurpose projects it is 100 years, it is 75 years for Hydropower projects.

8.1 Methods of Sediment Distribution

Regarding the distribution pattern Borland and Miller have suggested two methods in predicting the distribution pattern. The first method is empirical procedure based on the observations of sediment distribution in several reservoirs and is known as Empirical Area Reduction Method. The second method is strictly mathematical and is called Area-Increment Method.

8.2 Empirical Area Reduction method

Once an assessment of expected volume of total sediment deposition for the required time period has been made, the revised elevation-area-capacity curves of the reservoir area are prepared by using Empirical Area Reduction Method. This method is based on the analysis of data of sediment distribution obtained from resurvey of reservoirs. In this method, reservoirs are classified into four types, namely (a) gorge, (b) hill, (c) flood plain-foot hill, and (d) lake, based on the ratio of the reservoir capacity to the reservoir depth plot on a log-log scale. The empirical sediment distribution-area design curves for each of the four types of reservoir are used to distribute the sediment throughout its depths.

8.3 Area Increment method

This procedure is based on the assumption that the sediment deposition in a reservoir can be approximated by reducing the reservoir area at different elevation by a fixed amount. A series of approximations are involved in this. The reservoir capacities are calculated based on the reduced areas applying either Prismoidal formula or end area method, such that the capacity below maximum normal level is the same as predetermined capacity obtained by subtracting the sediment accumulation with time from the original capacity.

CBIP – 19 and **IS 5477** gives the details of these computations based on empirical area reduction method.