Module
2
The Science of Surface and Ground Water

Lesson 4

Design Flood Estimation

Instructional Objectives

The student, after completion of this lesson, shall know:

1. How is a design flood described for a particular hydraulic structure?
2. How are design floods designated for: a) Storage Dams; b) Barrages and weirs; c) Diversion works and Coffer dams; and d) Cross drainage works, according to the Indian Standard guidelines.
3. What are the methods to calculate design floods, viz, a) The hydro-meteorological approach, and b) The statistical approach
4. The steps followed in finding out design flood by the hydro-meteorological approach, which is generally adopted for large and intermediate sized dams.
5. The steps followed in finding out design flood by the statistical approach, either by probability distributions or by the method of plotting positions.

2.4.0 Introduction

A flood is commonly considered to be an unusually high stage of a river. For a river in its natural state, occurrence of a flood usually fills up the stream up to its banks and often spills over to the adjoining flood plains. For a hydraulic structure planned within the river (like a dam or a barrage) or on an adjoining area (like flood control embankments), due consideration should be given to the design of the structure so as to prevent it from collapsing and causing further damage by the force of water released from behind the structure. Hence an estimate of extreme flood flow is required for the design of hydraulic structures, though the magnitude of such flood may be estimated in accordance with the importance of the structure. For example, the design flood for a large dam like the ***Bhakra*** (Figure 1) or the ***Hirakud*** (Figure 2) would be estimated to be more than a medium sized dam like ***Chamera*** (Figure 3). It must be remembered that proper selection of design flood value is of great importance. While a higher value would result in an increase in the cost of hydraulic structures, an under-estimated value is likely to place the structure and population involved at some risk.

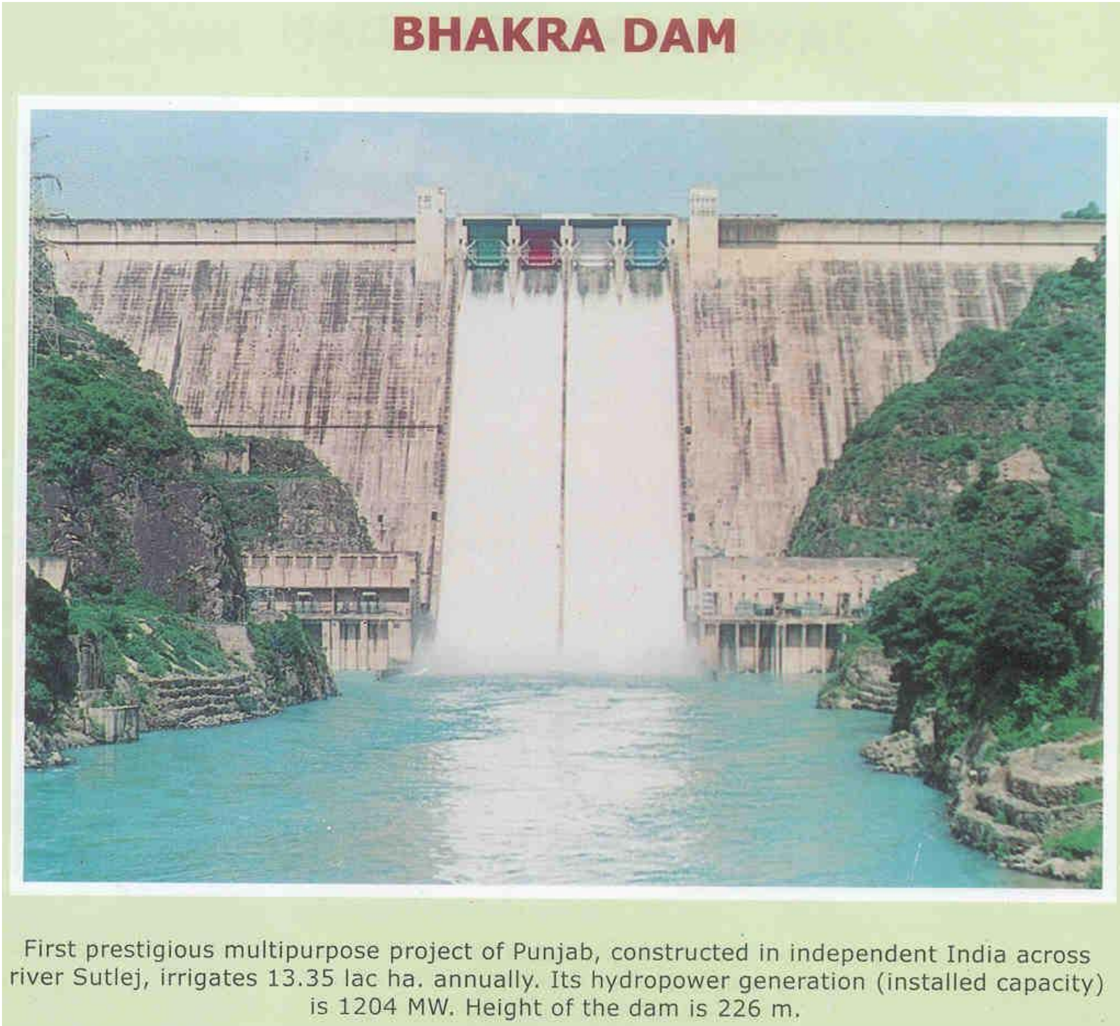
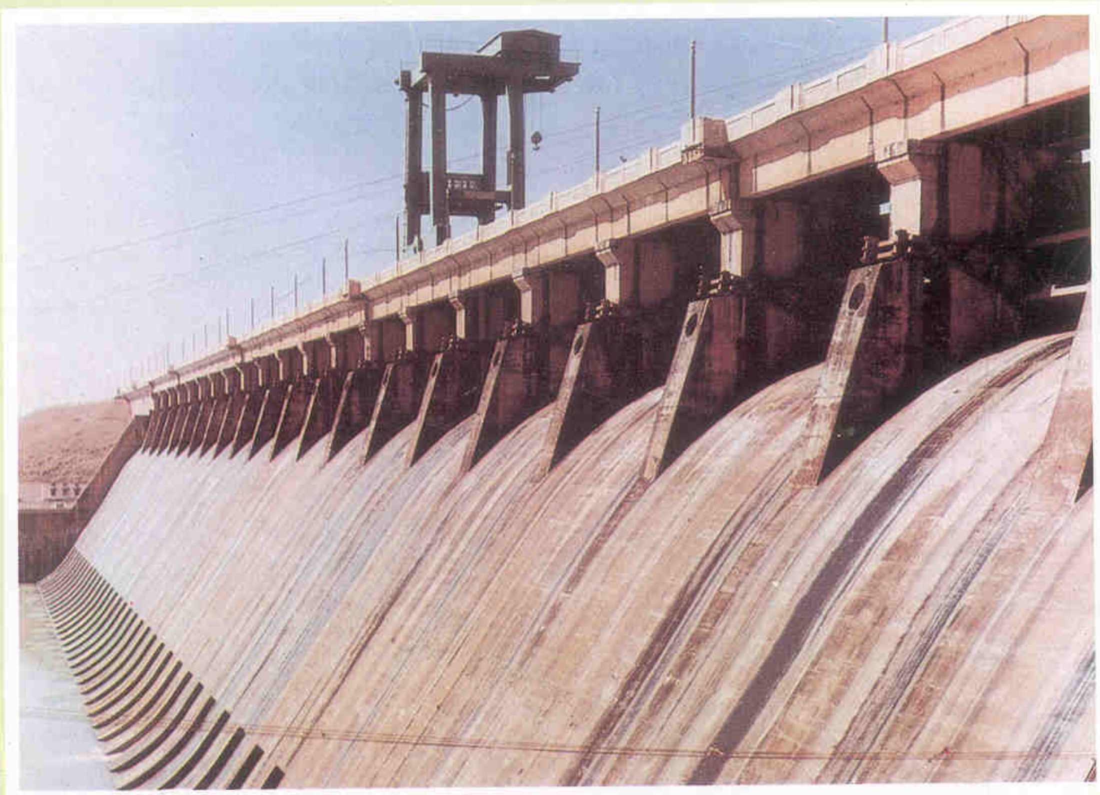


FIGURE 1. Upstream view of Bhakra dam showing spillway gates and chute

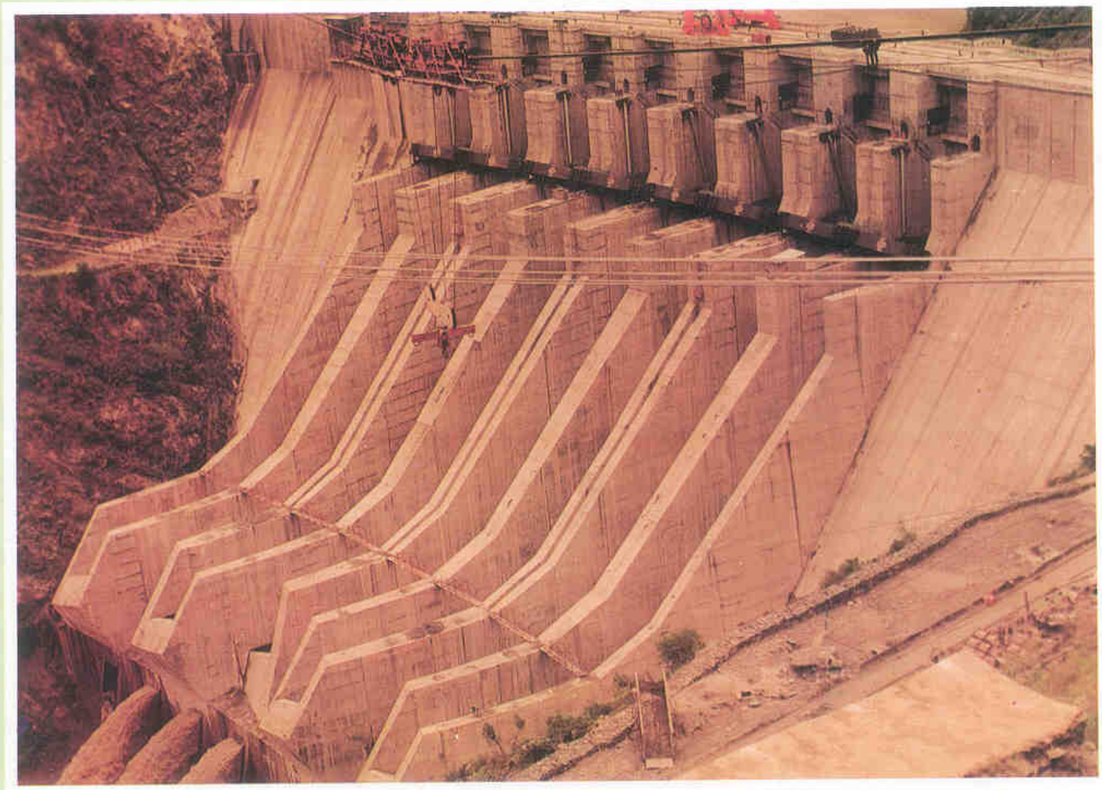
Image Cortesy: Ministry of Water Resources, Government of India, Web-site: http://www.wrmin.nic.in/

HIRAKUD DAM



The project across river Mahanadi in the state of Orissa, completed in 1957, provides annual irrigation to 2.51 lac ha. Length of the dam (including Dykes) is 25.5 Km.

CHAMERA PROJECT
(STAGE – I)



The project is located across river Ravi in the state of Himachal Pradesh. Its hydel power generation (installed capacity) is 540 MW.

Images of some other important water resources projects may be obtained from the web-site of the Ministry of Water Resources, Government of India Web-site: http://www.wrmin.nic.in/

2.4.1 Defining the design flood

The Design Flood for a hydraulic structure may also be defined in a number of ways, like:

- The maximum flood that any structure can safely pass.
- The flood considered for the design of a structure corresponding to a maximum tolerable risk.
- The flood which a project (involving a hydraulic structure) can sustain without any substantial damage, either to the objects which it protects or to its own structures.
- The largest flood that may be selected for design as safety evaluation of a structure.

Design Flood is also known as the Inflow Design Flood (IDF). It is the flood adopted for design purpose, and could be:

- The entire flood hydrograph, that is, the possible values of discharge as a function of time.
- The peak discharge of the flood hydrograph.

2.4.2 Choice of design flood

The Bureau of Indian standard guidelines IS: 5477 (Part IV) recommends that the Inflow Design Flood (IDF) of a structure, depending on its importance or risk involved, may be chosen from either one of the following:

- **Probable Maximum Flood (PMF):**
  This is the flood resulting from the most severe combination of critical meteorological and hydrological conditions that rare reasonably possible in the region. The PMF is computed by using the Probable Maximum Storm (PMS) which is an estimate of the physical upper limit to storm rainfall over the catchment. This is obtained from the studies of all the storms that have occurred over the region and maximizing them for the most critical atmospheric conditions.

- **Standard Project Flood (SPF):**
  This is the flood resulting from the most sever combination of meteorological and hydrological conditions considered reasonably characteristic of the region. The SPF is computed from the Standard Project Storm (SPS) over the watershed considered and may be taken as the largest storm observed in the region of the watershed. It is not maximized for the most critical atmospheric conditions but it may be transposed from an adjacent region to the watershed under consideration.

- **Flood of a specific return period:**
  This flood is estimated by frequency analysis of the annual flood values of adequate length. Sometimes when the flood data is inadequate, frequency analysis recorded storm data is made and the storm of a particular frequency applied to the unit hydrograph to derive the design flood. This flood usually has a return period greater than the storm.

The IDF's for different types of structures constructed across rivers are different. Some of the structures which are of importance to water resources engineering are:

- Storage Dams.
- Barrages and Weirs
- Diversion Works and Coffer dams
- Cross drainage works

A brief description of the structures and their corresponding IDF's are discussed subsequently.

2.4.3 Design flood for storage dams

Dams are important hydraulic structures which are constructed to serve a variety of purpose, more of which shall be discussed in detail in lesson 3.2. Most dams have a capacity to store substantial amount of water in the reservoir, and a portion of the inflow flood gets stored and the excess overflows through the spillways. According to Bureau of Indian Standard guidelines IS: 11223-1985, "Guidelines for fixing spillway capacity", the IDF to be considered for different requirements

2.4.3.1 IDF for the safety of the dam

It is the flood for which, when used with standard specifications, the performance of the dam should be safe against overtopping, structural failures, and the spillway and its energy dissipation arrangement, if provided for a lower flood, should function reasonable well.

- For large dams (defined as those with gross storage greater than 60 million m^3or hydraulic head greater than 30 m), IDF should be based on PMF.
- For intermediate dams (gross storage between 10 and 60 million m^3 or hydraulic head between 12 m and 30 m), IDF should be based on SPF.
- For small dams (gross storage between 0.5 to 10 million m^3 or hydraulic head between 7.5 m to 12 m), IDF may be taken as 100 years return period flood.

Floods of larger or smaller magnitude may be used if the hazard involved in the eventuality of a failure is particularly high or low. The relevant parameters to be considered in judging the hazard in addition to the size would be:

- Distance to and location of the human habitations on the downstream after considering the likely future developments; and
- Maximum hydraulic capacity of the downstream channel at a level which catastrophic damage is not expected.

2.4.3.2 IDF for efficient operation of energy dissipation system

It is a flood which may be lower than the IDF for the safety of the dam. When this flood is used with standard specifications or other factors affecting the performance, the energy dissipation arrangements are expected to work most efficiently.

2.4.3.3 IDF for checking extent of upstream submergence

This depends upon local conditions, type of property and effects of the submergence for very important structures upstream like power house, mines, etc. Levels corresponding to SPF or PMF may be used to determine submergence effects. For other structures consideration of smaller design floods and corresponding levels attained may suffice. In general, a 25 – year flood for land acquisition and 50 – year flood for built up property acquisition may be adopted.

2.4.3.4 IDF for checking extent of downstream damage in the valley

This depends on local conditions, the type of property and effects of its submergence. For very important facilities like powerhouse, outflows corresponding to the inflow design flood for safety of the dam, with all spillway gates operative or of that order may be relevant. Normally damage due to physical flooding may not be allowed under this condition, but disruption of operation may be allowed.

2.4.4 Design flood for barrages and weirs

Weirs and barrages, which are diversion structures, have usually small storage capacities, and the risk of loss of life and property would rarely be enhanced by failure of the structure. Apart from damage/loss of structure the failure would cause disruption of irrigation and communications that are dependent on the barrage. According to the bureau of Indian Standard guidelines IS: 6966(Part-I) - 1989, "Hydraulic design of barrages and weirs-guidelines for alluvial reaches", the following are recommended

- SPF or 500 year return period flood for designing ***free board***
- 50 year return period flood for designing of items other than free board.

2.4.5 Design flood for diversion works and coffer dam

Whenever a hydraulic structure like a dam or a barrage is constructed across a river, a temporary structure called a coffer dam is built first for obstructing the river flow and the water diverted though a diversion channel or tunnel. The Bureau of Indian Standards in its guideline IS: 10084 (Part I) -1982, "Criteria for design of diversion works - Part I: Coffer Dams" recommends the following:

> "The coffer dam being a temporary structure is normally designed for a flood with frequency less than that for the design of the main structure. The choice of a particular frequency shall be made on practical judgment keeping in view the construction period and the stage of construction of the main structure and its importance. Accordingly, the design flood is chosen.
>
> For seasonal cofferdams (those which are constructed every year and washed out during the flood season), and the initial construction stages of the main structure, a flood frequency of 20 years or more can be adopted. For coffer dams to be retained for more than one season and for the advanced construction stage of the main structure, a flood of 100 years frequency may be adopted".

2.4.6 Flood for cross drainage works

Cross drainage works are normally encountered in irrigation canal network system. Generally canals flow under gravity and often are required to cross local streams and rivers. This is done by either conveying the canal water over the stream by overhead aqueducts or by passing below the stream though siphon aqueducts. These structures are called cross drainage works and according to the Bureau of Indian Standard guidelines IS:7784 (Part I) – 1993, "Code of practice for design of cross – drainage works" the following is recommended.

"Design flood for drainage channel to be adopted for cross drainage works should depend upon the size of the canal, size of the drainage channel and location of the cross drainage. A very long canal, crossing drainage channels in the initial reach, damage to which is likely to affect the canal supplies over a large area and for a long period, should be given proper importance.

Cross drainage structures are divided into four categories depending upon the canal discharge and drainage discharge. Design flood to be adopted for these four categories of cross drainage structures is given as in the following table:

Category of structure	Canal discharge (m^3/s)	Estimated Drainage discharge Note* (m^3/s)	Frequency of design flood
A	0 – 0.5	All discharges	1 in 25 years
B	0.5 – 15	0 – 150 >150	1 in 50 years 1 in 100 years
C	15 – 30	0 – 100 >100	1 in 50 years 1 in 100 years
D	>30	0 – 150 >150	1 in 100 years Note **

Notes:

* This refers to the discharge estimated on the basis of river parameters corresponding to maximum observed flood level.

** in case of very large cross drainage structures where estimated drainage discharge is above 150 m^3/s and canal discharge greater than 30 m^3/s, the hydrology should be examined in detail and appropriate design flood adopted, which is no case shall be less than 1 in 100 years flood

2.4.7 Methods for design flood computations

The criteria for choosing the design flood for various types of hydraulic structures were discussed. For each one of these, any of the following three methods are suggested:

- ***Probable Maximum Flood (PMF)***
- ***Standard Project flood (SPF)***
- ***Flood of a specific return period***

The methods for evaluating PMF and SPF fall under the hydrometeorological approach, using the unit hydrograph theory. Flood of a given frequency (or return period) is obtained using the statistical approach, commonly known as flood frequency analysis. In every method, adequate data for carrying out the calculations are required. The data which are required include long term and short term rainfall and runoff values, annual flood peaks series, catchment physiographic characteristics, etc.

Within the vast areal extent of our country, it is not always possible to have observations measured on every stream. There are a large number of such ungauged catchments in India which has to rely on synthetically generated flood formulae. The Central Water Commission in association with the India Meteorological Department and Research Design and Standard Organization unit of the Indian Railways have classified the country into 7 zones and 26 ***hydro-meteorologically homogeneous sub-zones***, for each one of which flood estimation guidelines have been published. These reports contain ready to use chart and formulae for computing floods of 25, 50 and 100 year return period of ungauged basins in the respective regions.

In the subsequent section, we look into some detail about the calculations followed for the computation of

- PMF and SPF by the hydrometeorological approach.
- Evaluation of a flood of a given frequency by statistical approach.

2.4.8 The hydro-meteorological approach

The probable maximum flood (PMF) or the standard project flood (SPF) is estimated using the hydro-meteorological approach. For the PMF calculations the worst possible maximum storm (PMS) pattern is estimated. This is then applied to the unit hydrograph of the catchment to obtain the PMF. For the calculation so the SPF, the worst observed rainfall pattern (called the Standard Project Storm or SPF) is applied to the unit hydrograph derived for the catchment.

For the estimation of the PMS or the SPS, which falls under the hydro-meteorological approach, an attempt is made to analyze the causative factors responsible for the production of severe floods. The computations mainly involve estimation of a design storm hyetograph (from past long-term rainfall data within the catchment) and derivation of the catchment response function used which can either be a lumped model or a distributed-lumped model. In the former, a unit hydrograph is assumed to represent the entire catchment area. In the distributed-lumped model, the catchment is divided into smaller sub-regions or sub-catchment and the unit hydrographs of each sub-region are applied together with ***channel routing*** and sometimes ***reservoir routing*** to produce the catchment response.

PMF/SPF calculation method by the hydro-meteorological approach involves the following steps:

- ***Data requirement for PMF/SPF studies***

- ***Steps for evaluating PMF/SPF***

- ***Limitation of PMF/SPF calculations***

These are explained in detail in the additional section 2.4.12 at the end of this lesson.

2.4.9 The statistical approach

The statistical approach for design flood estimation, otherwise also called flood frequency analysis, may be performed on the past recorded data of annual flood peak discharges either directly observed at the site or estimated by a suitable method. Alternatively, frequency analysis may be carried out on the available record of annual rainfall events of the region.

The probability of occurrence of event (say, the maximum flood discharge observed or likely to occur in a year at a location on a river), whose magnitude is equal to or in excess of a specified magnitude X is denoted by P. A related term, the reccurrence interval (also known as the return period) is defined as T = 1/P. This represents the average interval between the occurrence of a flood peak of magnitude equal to or greater than X.

Flood frequency analysis studies interpret past record of events to predict the future probabilities of occurrence and estimate the magnitude of an event corresponding to a specific return period. For the estimation of flood flows of large return periods, it is often necessary to extrapolate the magnitude outside the observed range of data. Though a limited extrapolation to about twice the length of the record (that is, the number of years of data that is available) expected to yield reasonable accuracy, often water resources engineers are required to project much more than that.

2.4.10 Calculations for flood frequency

Basic to all frequency analyses, is the concept that there is a collection of data, called the 'population'. For flood frequency studies, this population are taken as the annual maximum flood occurring at a location on a river (called the site). Since the river has flooded during the past years and is likely to go on flooding over the coming years (unless something exceptional like drying up of the river happens!), the recorded flood peak values which have been observed for a finite number of years are only a sample of the total population. Here, 'flood peak' means the highest recorded discharge value for the river at any year. The following assumptions are generally made for the data:

- The sample is representative of the population. Thus, it is assumed that though only a finite years' data of peak flow has been recorded, the same type of trend was always there and would continue to be so in future.

- The data are independent. That is, the peak flow data which has been collected are independent of each other. Thus, the data set is assumed to be random. In a random process, the value of the variant does not depend on previous or next values.

Flood frequency analysis starts by checking the consistency of the data and finding the presence of features such as trend, jump, etc. Trend is the gradual shift in the sample data, either in the increasing or decreasing directions. This may occurs due to human interference, like afforestation or deforestation of the watershed. Jump means that one or a few of the data have exceptional values – high or low, due to certain factors, like forest fire, earthquake, landslide, etc which may change the river's flow characteristics temporarily.

The next step is to apply a convenient probability distribution curve to fit the data set. Here, it is assumed that yearly observed peak flow values are random numbers and which are also representative of the population, which includes all flood peak values, even these which have not been recorded or such floods which are likely to happen in future. Each data of the set is termed as a variate, usually represented by '*x*' and is a particular value of the entire data range '*X*'.

The probability of a variable is defined as the number of occurrences of a variate divided by the total number of occurrences, and is usually designated by '*P*'. The total probability for all variates should be equal to unity, that is, $\sum P = 1$. Distribution of probabilities of all variates is called Probability Distribution, and is usually denoted a *f(x)* as shown in Figure 4.

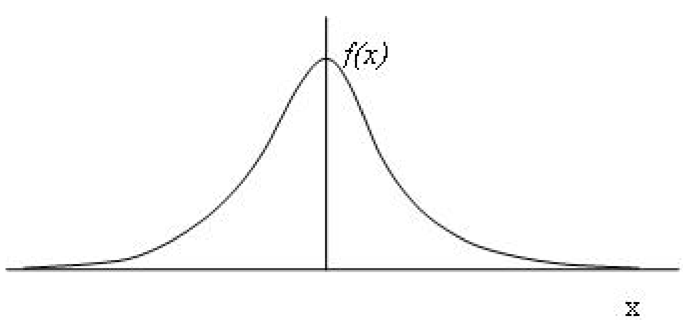


FIGURE 4. A typical probability distribution

The cumulative probability curve, F(*x*) is of the type as shown in Figure 5.

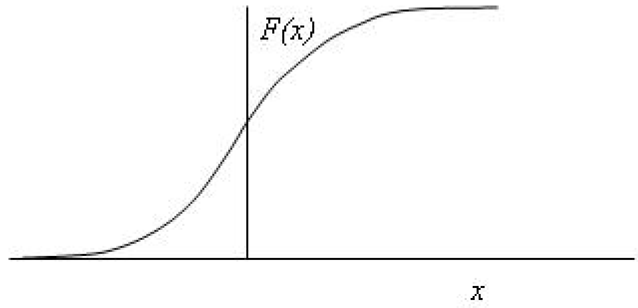


FIGURE 5. Cumulative probability curve

The cumulative probability, designated as P(x ≤ *x*), represents the probability that the random variable has a value equal to or less than certain assigned value *x* is equal to 1 – P(x ≤ *x*), or P(x ≥ *x*).

In the context of flood frequency analysis, we may use the above concepts by assuming the recorded yearly flood peaks as the variate '*x*'. Then, if the functions f(*x*) or F(*x*) becomes known, then it is possible to find out the probability with which certain high flood peak is likely to occur. This idea may be used to recalculate the high flood peak that is likely to be equalled or exceeded corresponding to a given frequency (say, 1 in 100 years).

There are a number of probability distributions f (x), which has been suggested by many statisticians. Of these, the more common are

- ***Normal***
- ***Log – normal***
- ***Pearson Type III***
- ***Gumbel***

Which one of these fits a given data set has to be checked using certain standard statistical tests. Once a particular distribution is found best, it is adopted for calculation of floods likely to occur corresponding to specific return periods.

Details of the above methods may be found in the additional section 2.4.12 at the end of this lesson.

2.4.11 Plotting positions

So far we talked about extrapolation of the sample data. However, if probability is to be assigned to a data point itself, then the 'plotting position' method is used. Here, the sample data (consisting of, say, N values) is arranged in a decreasing order. Each data (say the event X) of the ordered list is then given a rank 'm' starting with 1 for the highest up to N for the lowest of the order. The probability of exceedence of X over a certain value x, that is $P(X \geq x)$ is given differently by different researchers, the most common of which are as given in the table below:

Sl. No	Name of formula	$P(X \geq x)$
1	California	m/N
2	Hazen	(m-0.5)/N
3	Weibull	m/(N+1)

Of these, the Weibull formula is most commonly used to determine the probability that is to be assigned to data sheet.

Example showing application of plotting positions:

The application of the method of plotting may be explained better with an example. Assume that the yearly peak flood flows of a hypothetical river measured at a particular location over the years 1981 to 2000 is given as in the following table. The data is to used to calculate the flood peak flow that is likely to occur once every 10 years, and once every 50 years.

Year	Peak flood (m^3/s)
1981	700
1982	810
1983	470
1984	300
1985	440
1986	600
1987	350
1988	290
1989	330
1990	670
1991	540
1992	430
1993	320
1994	420
1995	690
1996	400
1997	360
1998	510
1999	910
2000	100

Rearranging table according to decreasing magnitude, designate a plotting position and calculate the probability of exceedence by, say, the Weibull formula shown in the following table which also gives the Return Period T (1/P).

m	Peak flood (m^3/s)	Probability $P = \frac{m}{N+1}$	Return period T = 1/P years
1	910	0.048	21.000
2	810	0.095	10.500
3	700	0.143	7.000
4	690	0.190	5.250
5	670	0.238	4.200
6	600	0.286	3.500
7	540	0.333	3.000
8	510	0.381	2.625
9	470	0.429	2.333
10	440	0.476	2.100
11	430	0.524	1.909
12	420	0.571	1.750
13	400	0.619	1.615
14	360	0.667	1.500
15	350	0.714	1.400
16	330	0.762	1.313
17	320	0.810	1.235
18	300	0.857	1.167
19	290	0.905	1.105
20	100	0.952	1.050

2.4.12 Additional information and definition of important terms

Free board
The marginal distance that is providing above the maximum reservoir level to avoid the possibility of water spilling over the dam is known as the free board.

Hydro- meteorologically homogeneous sub-zones
This indicates a partition of the country in terms of similar hydrological and meteorological areas. There are, in all, 26 sub-zones in the country. This has been done together by the Central Water Commission (CWC), Research Designs and Standards Organization (RDSO), and India Meteorological Department (IMD).

Channel routing
The outlet of each sub-catchment is located many km upstream of the outlet of the main catchment. The outflow of a sub-catchment will pass through the channels before finally reaching the catchment outlet. The inflow hydrograph to a channel will get modified by the temporary storage of channel; hence it is necessary to estimate the outflow hydrograph of the channel to in order to find

the flow at the outlet of the catchment outlet by a process is known as channel routing.

Reservoir routing

The hydrograph of a flood entering a reservoir will change in shape as it emerging out from the reservoir. This is due to volume of water stored in reservoir temporarily. The peak of the hydrograph will be reduced, time to peak will be delayed and base of the hydrograph will be increased. The extent up to which an inflow hydrograph will be modified in the reservoir will be computed by the process is known as reservoir routing.

Data requirement for PMF/SPF studies

1. Watershed data
   - Total watershed area, snowbound area, minimum and maximum elevations above the mean sea level and length of river up to the project site;
   - ***Lag time***, ***travel times*** of reaches, and time of concentration;
   - Contributing areas, mean overland flow distances and slopes;
   - Design storm water losses, ***evaporation***, ***infiltration***, ***depression*** and ***interception*** losses, infiltration capacities.
   - Land use practices, soil types, surface and subsurface divides

2. Channel data
   - Channel and valley cross sections at different places under consideration to fix the gauge discharge rating curves.
   - Manning's n or the data required to estimate channel roughness coefficient

3. Runoff data
   - ***Base flow*** estimates during design floods.
   - Available historical data on floods along with the precipitation data including that of self-recording rain gauges, if available.

4. Storm data
   - Daily rainfall records of all rain gauge stations in and around the region under study
   - Rainfall data of self-recording rain gauges
   - Data of the storm dew point and maximum dew point temperatures

Steps for evaluating PMF/SPF

1. Estimate duration of design storm

   Duration of design storm equivalent to ***base period*** of ***unit hydrograph*** rounded to the next nearest value which is in multiplier of 24 hours and less than and equal to 72 hours is considered to be adequate. For large catchments, the storm duration for causing the PMF is to be equivalent to 2.5 times the travel time from the farthest point ***(time of concentration)*** to the site of the structure.

2. Selection of design storm
   A design storm is an estimate of the rainfall amount and distribution over a particular drainage areas accepted for use in determining the design flood. This could either be the ***Probable Maximum Storm*** (PMF) or the ***Standard Project Strom*** (SPS)**.**

3. Time adjustment of design storm and its critical sequencing
   The design hyetograph should be arranged in two bells (peak) per day. The combination of the bell arrangement and the arrangement of the rainfall increments within each of the bell shaped spells will be representing the maximum flood producing characteristics.

   The critical arrangement of increment in each bell should minimize the sudden hill or sluggishness and maximizing the flood peak. Hence, the arrangement is to be such that the time lay between peak intensities of two spells may be minimum. The cumulative pattern of all the increments in the order of their positioning should resemble the natural mass curve pattern as observed by a ***Self Recording Rain gauge*** (SRRG) of the project region.

4. Estimate the design ***Unit Hydrograph***
   Depending upon the data availability and characteristics of flood hydrograph etc, the unit hydrograph may be derived using any of the following techniques.
   - Simple method of unit hydrograph derivation from a flood event with isolated peak
   - Collin's method
   - Nash method
   - Clarke model.

   In case of insufficient data, synthetic unit hydrograph may be derived

5. Calculating the probable maximum flood hydrograph
   The critical time sequence of the design storm rainfall is superimposed on the derived design unit hydrograph to give the direct hydrograph, when added to the base flow, gives the probable maximum flood hydrograph. Details of these calculations are given in Lecture 2.4

Limitation of PMF/SPF calculations

- Requirement of long-term hydrometeorological data for estimation of design storm parameters.

- The knowledge of rainfall process as available today has severe limitations and therefore, physical modeling of rainfall to compute PMP is still not attempted.

- Maximization of historical storms for possible maximum favorable conditions is presently done on the basis of surface dew point data. Surface dew point data may not strictly represent moisture availability in the upper atmosphere.

- Availability of self-recording rain gauge (SRRG) data for historical storms (Remember that SRRG data gives the distribution of rain fall with time).

- Many of the assumptions of the unit hydrograph theory are not satisfied in practice.

- Many a times, data of good quality and adequate quantity is not available for the derivation of unit hydrograph.

Normal Distribution

The Normal distribution is one of the most important distributions in statistical hydrology. This is used to fit empirical distributions with skewness coefficient close to zero. The probability density function (PDF) of the distribution is given by

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]; \qquad -\infty < x < \infty$$

Where, μ is the location parameter and σ is the scale parameter. The cumulative distribution function (CDF) of the normal distribution is given by:

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

Log – Normal Distribution

If the logarithms, $\ln x$, of a variable *x* are normally distributed, then the variable *x* is said to be log normally distributed so that

$$f(x) = \frac{1}{x\sigma_y\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu_y}{\sigma_y}\right)^2\right]$$

Where, μ_y and σ_y are the mean and standard deviation of the natural logarithm of *x*. Log normal distributions can be applied to a wide variety of hydrologic events especially in the cases in which the corresponding variable has a lower bound, the frequency distribution is not symmetrical and the factors causing those are independent and multiplicative.
If the variable *x* has a lower boundary x_0, different from zero, and the variable z= $x - x_0$ follows a lognormal distribution, then *x* is lognormally distributed with three parameters. The probability distribution function of the lognormal distribution with parameters is

$$f(x) = \frac{1}{(x - x_0)\sigma_y \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln(x - x_0) - \mu_y}{\sigma_y}\right)^2\right]$$

Where, μ_y, σ_y and x_0 are called the scale, the shape and the location parameters respectively. Parameter x_0 is generally estimated by trial and error.

Pearson Type III Distribution

Pearson type III is a three parameter distribution, also known as Gamma distribution with three parameters. The PDF of the distribution is given as

$$f(x) = \frac{(x - x_0)^{\gamma - 1} \exp\left[-\frac{(x - x_0)}{\beta}\right]}{\beta^\gamma \Gamma(\gamma)}$$

The CDF of the Pearson Type III distribution is given by

$$F(x) = \int_{x_0}^{x} \frac{(x - x_0)^{\gamma - 1} \exp\left[-\frac{(x - x_0)}{\beta}\right]}{\beta^\gamma \Gamma(\gamma)} dx$$

Where x_0, β, and γ are location, scale and shape parameters respectively.

Gumbel Distribution

Gumbel distribution is a member of family of Extreme Value distributions with the value of parameter k = 0. It is a two parameter distribution and is widely used in hydrology.
The PDF is given as

$$f(x) = \frac{1}{\alpha} \exp\left[-\frac{x - \mu}{\alpha} - \exp\left\{-\frac{x - \mu}{\alpha}\right\}\right]$$

And CDF is given as

$$F(x) = \exp\left[-\exp\left\{-\frac{x - \mu}{\alpha}\right\}\right]$$

$$E(X) = \mu + 0.5772\alpha$$

$$Var(X) = \frac{\pi^2\alpha^2}{6}$$

Where, u and α are location and shape parameters respectively.

Lag Time

Lag is the time between the peak flow and the centroid of rainfall.

Travel time

The time taken by the water to reach the basin outlet, from the different points in the basin, is called the travel time.

Evaporation

The process of extracting moisture is known evaporation.

Infiltration

Infiltration is defined as the slow passage of a liquid through a filtering medium.

Interception

Interception is the act of catching the precipitation by the trees or buildings without reaching to the ground surface.

Base flow

Base flow is the portion of the stream discharge that is derived from natural storage (e.g., groundwater outflow and the draining of large lakes and swamps or other source outside the net rainfall that creates surface runoff).

Base period

The time between the first watering of a crop at the time of its sowing to its last watering before harvesting is called base period. Base period is always less than crop period.

Unit hydrograph

A unit hydrograph is defined as the hydrograph of runoff produced by excess rainfall of 1cm occurring uniformly over the entire drainage basin at a uniform rate over the entire specified duration.

Time of concentration

The time of concentration of a drainage basin is the time required by the water to reach the outlet from the most remote point of the drainage area.