Training Course

On

Hydrological Processes in an Ungauged Catchment

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CHAPTER-7

Design Storm Analysis

By

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CHPATER-7

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7.0 INTRODUCTION

While planning the construction of medium and large dams for irrigation, hydropower generation, and/or flood control, it becomes necessary to design the structure to pass a certain magnitude of critical flood generally known as design flood. The design flood to be adopted is generally decided by the type of the hydrologic structure. To this end, the structures are classified as:

i) Large or medium structures such as dams,
ii) Medium structures like barrages and minor roads and railway bridges, and
iii) Small or minor structures like cross drainage works and minor irrigation tanks and minor road bridges.

According to the criteria laid down by Central Water Commission, New Delhi, the following types of spillway design flood are recommended for major and medium dams and other small structures.

Table 7.1 Recommendations for major and medium dams

Type of Dam	Capacity (Million m^3)	Hydraulic head (m)	Inflow design flood
Small	0.5 – 10	7.5 - 12	100 year
Intermediate	10 – 60	12 - 30	Standard Project Flood
Large	> 60	> 30	Probable Maximum Flood

For minor structures, a flood of 50 or 100 year frequency is adopted depending on the importance of the structure.

Since long term runoff data are generally not available, rainfall data of longer period are used to estimate the 'design storm' for the estimation of design flood using a suitable rainfall-runoff model. Thus, rainstorm analysis is a first step in the design storm estimation procedure.

7.1 DESIGN STORM

The design storm or rainfall is the critical rainfall hyetograph. It is developed for the design of specific type of structures described above. It has following three components:

i) Rainfall amount,
ii) Arial distribution of rainfall, and
iii) Time distribution of rainfall.

These are generally described with the aid of the following components:

(a) Scale of design storm

The scale of design storm is linked with the scale of the design flood which, in turn, depends on the size of the structure and the risk associated with it.

(b) Types of design storm

The basic types of design storm include those derived from statistical and physical approaches. Statistical approach involves frequency analysis and the physical approach involves the use of a physical model. Generally, two types of storms are considered for design purposes. They are the 'Probable Maximum Precipitation (PMP)' or 'Maximum Probable Storm' and 'Standard Project Storm (SPS)'.

Probable Maximum Precipitation (PMP): For a given duration, PMP is theoretically the greatest depth of precipitation that is physically possible over a given area at a particular geographical location at a certain time of the year.

Standard Project Storm: It is the rainstorm that is reasonably capable of occurring in the region of problem basin. It is generally the most severe rainstorm that has occurred in the region during the period of available records.

7.1.1 Duration Of Design Storm

The duration of design rainfall is determined considering the size of the drainage basin, duration of the flood, and the type of design structures. It is necessary that the selected duration be at least as long as the supply duration. Based on studies conducted on small watersheds in USA, it was concluded that the ratio of the volume of the rainstorm to peak discharge might be the most appropriate duration of design rainfall.

7.1.2 Storm Selection and Analysis

The first step in rainstorm analysis is a thorough understanding of the meteorology of large storms in the region of analysis. A judicious selection of a few storms which are representative of the whole catchment should be made. Before deciding the appropriate storm depth for design purposes, storm analysis based on either basin centered or storm centered is carried out based on the guidelines discussed below.

To arrive at dependable estimates of design storm depths, it is necessary to make a judicious selection of pertinent storms over the river catchment or sub-catchment. To this end, it is essential to be aware of the size and location of the catchment under study, nature of the project envisaged, etc. The preliminary selection of the storm is based on the review of relevant records such as:

i) Daily rainfall data,
ii) Depression/storm tracks,
iii) Recent and historical storm details, and
iv) Flood and discharge data.

The first step is to list all the rain periods of maximum rainstorms, such as 1 day, 2 day, 3 day, 4 day, and 5 day major rainstorms, for long term data of all raingauge stations. The next step is to fix up an appropriate threshold value for storm selection keeping in mind the following:

- If the catchment lies in a semi-arid region, a lower depth of rainfall is adopted as threshold while a higher depth is taken for humid regions. In India, the threshold value of 25 cm is taken as appropriate for humid regions, and 5 cm for semi-arid regions.
- For smaller catchment areas, a higher threshold value and for larger catchment areas, a smaller threshold value is used. An average catchment depth of 10 cm, for catchment areas up to 5000 sq. km, 5 to 8 cm for catchment areas between 5000 and 10000 sq. km, and 5 cm for catchment areas greater than 10000 sq. km may be appropriate.

For the storm periods listed above, the arithmetic average data of raingauges located within and around the basin are worked out and compared with the threshold value. All such storms whose daily depths equal or exceed the threshold value are considered for further analysis. The storms selected on the basis of the threshold criterion are then subjected to further analysis by preparing isohyetal maps. The map scale generally used for preparation of isohyetal maps is 1 cm = 10 km. It is customary to prepare the total storm depth maps of 1 day, 2 days, and 3 days depending on the storm duration and requirement of the design storm duration. In some cases, where movement of the storm over elongated catchments is involved, daily isohyetal maps will be required to be prepared.

7.2 DEPTH-AREA-DURATION (DAD) ANALYSIS

The World Meteorological Organization (WMO) guide to hydro-meteorological practices (1971) and the report on operational hydrology (Rep. No. 1, 1973) recommend depth-area-duration (DAD) technique for storm analysis, described below in components.

a) Depth-area analysis

Data on precipitation volume of severe storms are important to examine and study storms suitable for design purpose. Such information is generally presented in the form of tables of maximum average depth of storm precipitation for various standard areas, such as 100 km^2, 500 km^2, etc. Such information is known as depth-area relation and it can be presented in tabular as well as graphical form.

b) Depth-duration analysis

The depth-duration analysis implies development of a relation between storm depth and its duration for a catchment. This relation can utilize both in-situ and transposed storms. The average depths of precipitation for different durations, such as 1 day, 2 days, and 3 days are computed similar to that of the isohyetal method. The depths thus determined for different durations constitute the depth-duration data.

Where a good network of recording raingauges is available, the depth-duration analysis can also be performed for shorter duration (1 hr, 3 hr, 6 hr, 12 hr, 18 hr, etc.) rainfall. Alternatively, the analysis can be performed by distributing the rainfall observed at non-recording stations using the data of nearby representative recording raingauge station using the procedure described above.

c) Depth-area-duration analysis

The depth-area-duration (DAD) analysis is carried out for storms occurred over different regions during principal flood seasons. The DAD analysis aims at determining the largest (maximum) depth of precipitation amounts for various sizes (areas) during storm periods of 1 day, 2 days, 3 days, etc. durations. Such values when determined for each transposable storm provide the requisite information (data) for estimation of the design storm for a basin in question. The steps involved in the DAD analysis are given below:

i) The selected storm is assigned a definite beginning and ending with the help of available rainfall records of stations in the region. Ideally, the storm is assigned a value for duration starting from a period of no rain to the next period of no rain. This ensures that the storm totals from all stations are for exactly the same time interval. The storm analysis is then carried out for the period of the principal burst.
ii) For each day of the total storm period, rainfall values of each raingauge station in the storm region are listed in a tabular form.
iii) Separate isohyetal maps for each duration, viz., maximum 1 day, 2 days, 3 days, etc. are drawn.

Since the greatest rainfall of 1-day may not occur over all the areas under consideration, it becomes necessary to analyze for two alternative days, for establishing maximum 1-day rainfall for areas of all sizes. Therefore, a 2-day duration map is also prepared. After the maps for each duration are prepared, the DAD analysis is carried out as follows using catchment boundary or last closed isohyets as boundary.

a) The isohyetal maps are divided into zones to represent principal rainfall centres. Starting with the central isohyets in each zone, the area encompassed by each isohyets is planimetered and net area between isohyets is determined.
b) In case of storm centered DAD analysis, the last closed isohyet's is taken as boundary and in case of catchment centered analysis, the catchment boundary is considered.
c) The average isohyetal value is multiplied by the area to compute the volume. The volumes are cumulated for every successive isohyetal range and then divided by the total area encompassed by a particular isohyets to determine the maximum storm depth for the corresponding area.
d) The analysis at steps (a) through (d) is repeated for other durations, if adequate data of recording stations are available. Incremental maps can also be prepared for shorter durations such as 3, 6, 9, 12, and 18 hours. For further details, WMO manual (1969) of depth-area-duration analysis may be referred.

Example 7.1

Carryout a depth-area-duration analysis for 1-day storm occurred on 30th August 1982 as per IMD data (refer Table 7.2).

Table 7.2: Depth-Area-Duration analysis for a typical 1-day storm of Aug. 30, 1982

Point Isohyetal value	Planimetered area (Sq. cm)	Area (Sq. km)	Net area (Sq. km)	Average depth (mm)	Incremental volume= 4 x 5	Cumulative volume (mm x Sq.km)	Average rainfall (mm) 7/3
1	2	3	4	5	6	7	8
488	-	-	-	-	-	-	488.0
450	13.4	1340	1340	469	628460	628460	469.0
400	38.1	3810	2470	425	1049750	1678210	440.5
300	91.2	9120	5310	350	1858500	3536710	387.8
200	177.1	17710	8590	250	2147500	5684210	321.0

For the depth-area-duration analysis, an isohyetal map for given 1-day storm is prepared, and other computations are given in the following Table 4.5. In this table, Col. 1 presents the isohyetal value, Col. 2 presents the planimetered area between a isohyets and the catchment boundary which is converted to actual area in Col. 3. Col. 4 presents the net area between the two consecutive isohyets. Col. 5 shows the average depth of precipitation occurring between the two consecutive isohyets and its volume is shown in Col. 6. Col. 7 cumulates the rainfall volume and Col. 8 presents the ratio of the value in Col. 7 to that of Col. 3. Thus, the values of Col. 3 and Col. 8 are the data of depth-area relation for 1-day duration.

d) DAD curve

The total storm depth-area curve for each duration is constructed by plotting the average depth against the accumulated area. The starting point on the curve is taken as the central storm precipitation (highest value). Because of the sparse network of precipitation stations, there exists remote probability of stations' recording the highest point precipitation. In the study of most large area storms, it is considered reasonable to assume that the highest station precipitation represents the average depth over an appreciable area rather than the maximum point precipitation. The depth-area curves are plotted for different durations for each of the major rain storms. Conventionally, a logarithmic scale is used for area, and linear scale for precipitation depths. A typical set of DAD curves for the 28-30 August 1982 storm are shown in Fig. 4.13.

7.3 INTENSITY-DURATION-FREQUENCY RELATIONSHIP

Storm intensity decreases with increase in storm duration. Further, a storm of any given duration will have a larger intensity if its return period is large. In other words, for a storm of given duration, storms of higher intensity in that duration are rarer than storms of smaller intensity. In many design problems related to watershed management, such as runoff disposal and erosion control, it is necessary to know the rainfall intensities of different durations and different return periods. The interdependency between intensity i (cm/h), duration D (h), and return period T (years) is commonly expressed in a general form as

$$i = \frac{KT^x}{(D+a)^n} \qquad (1)$$

where K, x, a, and n are constants for a given catchment. Typical values of these constants for a few places in India are given in Table 7.3. These values are based on the reported studies of the Central Soil and Water Conservation Research and Training Institute, Dehradun,

Table 7.3 Typical values of constants in Eq. 1

Place	K	x	a	n
Bhopal	6.93	0.189	0.50	0.878
Nagpur	11.45	0.156	1.25	1.032
Chandigarh	5.82	0.160	0.40	0.750
Bellary	6.16	0.694	0.50	0.972
Raipur	4.68	0.139	0.15	0.928

Extreme point rainfall values of different durations and return periods have been evaluated by India Meteorological Department and iso-pluvial (lines connecting equal depths of rainfall) maps covering the entire country have been prepared. These are available for rainfall durations of 15 min, 30 min, 45 min, 1 h, 3 h, 6 h, 9 h, 12 h, 15 h and for return periods of 2, 5, 10, 25, 50, and 100 years. A typical 50- year 3 hour maximum rainfall map of the southern peninsula can be referred in reference (3).

REFERENCES

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Table 7.3: 31-card daily rainfall data format from IMD figures.

CATCHMENT NUMBER	SUB-DIV. NUMBER	LATITUDE	LONGITUDE	STATION NUMBER	HEIGHT OF STATION IN TENGTHS OF FEET	YEAR	DATE	DAILY RAINFALL (.01 INCHES) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
3	5	9	13	15	19	23	25	29	33	37	41	45	49	53	57	61	65	69	73

24-card daily rainfall data format.

2nd CARD																								
AS IN Ist CARD								17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		MONTHLY TOTAL
Ist CARD DAILY RAINFALL (0.1 mm)																								
CATCHMENT NUMBER	LATITUDE	LONGITUDE	STATION NUMBER	BLANK	YEAR	MONTH	CARD NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	BLANK
3	5	7	9	10	12	14	15	19	23	27	31	35	39	43	47	51	55	59	63	67	71	75	79	

24-card daily rainfall data format.

2nd CARD MAX IN 1 HR. DURATION																						
AS IN 1st CARD						16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	am t	Ti me	Hr mts						
Ist CARD HOURLY RAINFALL (0.1 mm)																						
ELEMENT CODE	INDEX NO. OF STATION	YEAR (OMIT 19)	MONTH	DATE	CARD NO.	0 1	1 2	2 3	3 4	4 5	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	
	6	8	10	12	13	17	21	25	29	33	37	41	45	49	53	57	61	65	69	73	77	

Table 7.4 Hourly rainfall data of Mandla and Jabalpur SRRG stations

Hour	Mandla			Jabalpur		
	27.8.73	28.8.73	29.8.73	27.8.73	28.8.73	29.8.73
1	0.0	0.0	0.0	0.0	0.0	23.5
2	0.0	0.0	0.0	0.0	0.0	30.5
3	0.0	0.0	0.0	0.0	0.3	10.2
4	0.0	0.0	0.0	0.0	0.5	30.8
5	0.0	0.0	0.0	0.0	0.1	16.9
6	0.0	0.0	0.0	0.0	1.0	1.9
7	3.0	1.7	0.0	0.0	24.4	0.6
8	0.0	9.0	0.0	0.0	0.2	3.1
9	0.0	2.3	0.5	0.0	0.0	5.3
10	0.9	0.0	0.4	0.0	0.0	3.8
11	0.0	1.5	0.1	0.0	23.8	0.8
12	0.0	5.5	0.0	0.0	1.3	1.5
13	0.0	0.0	0.0	0.0	0.2	0.0
14	0.0	0.0	0.0	0.0	0.0	0.3
15	0.0	0.0	0.0	0.0	0.1	0.9
16	0.0	2.5	0.3	0.0	0.6	1.5
17	0.2	1.5	0.4	0.0	29.0	0.4
18	2.1	0.8	0.3	0.0	11.0	0.5
19	0.7	3.4	0.0	25.7	7.1	0.1
20	0.3	0.6	0.0	0.0	0.4	0.5
21	0.1	2.5	0.0	0.1	2.7	0.7
22	0.1	0.0	0.0	1.0	6.8	0.0
23	4.7	0.0	0.0	6.0	20.6	0.0
24	0.0	0.0	0.0	1.3	0.0	0.0

Table 7.5 Daily rainfall distributed into hourly rainfall (28-29 August 1982)

Hour	Distributed on the basis of Mandla				Distributed on the basis of Jabalpur			
	Pendra Road		Dindhori		Niwas		Ghansore	
	28	29	28	29	28	29	28	29
1		0.0		0.0		21.5		10.5
2		0.0		0.0		28.0		13.7
3		0.0		0.0		9.3		4.5
4		0.0		0.0		28.2		13.7
5		0.0		0.0		13.4		7.5
6		0.0		0.0		1.7		0.8
7		0.0		0.0		0.5		0.2
8		0.0		0.0		2.8		1.3
9	8.9		6.4		0.0		0.0	
10	0.0		0.0		0.0		0.0	
11	5.6		4.1		21.9		10.7	
12	21.8		13.8		1.0		0.5	
13	0.0		0.0		0.2		0.1	
14	0.0		0.0		0.0		0.0	
15	0.0		0.0		0.1		0.0	
16	9.7		7.0		0.5		0.2	
17	6.5		4.7		26.6		13.3	
18	2.5		1.8		10.1		4.9	
19	13.7		9.9		6.5		3.1	
20	2.4		1.7		0.4		0.2	
21	9.7		7.0		2.4		1.1	
22	0.0		0.0		6.1		2.9	
23	0.0		0.0		18.9		9.1	
24	0.0		0.0		0.0		0.0	