LECTURE 9

REGIONAL FLOOD FREQUENCY ANALYSIS

OBJECTIVES

The objective of this lecture is to focus on the usefulness of regional flood frequency analysis, some of the widely used methodologies including their limitations and data requirements for analysis.

9.1 INTRODUCTION

Water resources decision making problems such as flood plain zoning, design of hydraulic structures etc., are based on design flood estimate defined as the discharge for a specified probability of exceedance is usually obtained by statistical modelling of annual peak floods at a given site. The entire analysis is based on the premise that these floods are random and the floods to follow bear similar statistical properties of floods that have occured in the past. Most of the time the assumptions are not fully met because of techniques used to model these floods do not quantity the flood mechanism in a systematic manner.

In addition to these, when quantiles have to be estimated for sites where no observations have been recorded or observations recorded only for a very small period, then the estimates using frequency analysis is neither possible nor reliable. Regional flood frequency analysis is one of the means to overcome such problems while reasonably quantifying the flood estimates at desired frequencies for sites within a more or less hydrologically homogeneous region.

Out of several procedures recommended for regional flood frequency analysis, this lecture covers the procedures recommended by U.S. Geological Survey (U.S.G.S.) and National Environmental Research Council, (N.E.R.C.) U.K.

9.2 INDEX-FLOOD METHOD (U S.G.S. METHOD)

Basically, the Index-Flood method (Dalrymple, 1960) extrapolates statistical information of runoff events for flood frequency analysis from gauged catchments to ungauged catchments in the vicinity having more or less similar catchment and hydrological characteristics. The Index-Flood method for estimating design flood for ungauged catchments consists of following sequential steps :

1. Select gauged catchments within the region having more or less similar hydrological characteristics to that of the ungauged catchments.
2. Determine time base period to be used for study.

3. Establish flood frequency curves for data at each gauging site using Gumbel (EV–I) probability paper.

4. Estimate the mean annual flood, $Q_{2.33}$ at each station.

5. Test for homogeneity of data obtained from various stations.

6. Establish relationship of mean annual flood and catchment characteristics (usually drainage area) at each station.

7. Rank ratios of selected return period floods estimated from the analysis to the mean annual flood of each station.

8. Compute median flood ratio for each of the selected return periods of step (7).

9. Mulriply the estimated mean annual flood estimated for the ungauged catchment using the relationship established at step (6) and plot them versus corresponding return periods on a Gumbel probability paper.

The end results of these nine sequential steps is a flood frequency curve for an ungauged catchment.

9.2.1 Selection of Gauged Catchments

The first step is to select gauged catchments in the vicinity of the ungauged catchments having similar physiographic, hydrologic and meteorologic characteristics. Although the similarity would include characteristics such as average elevation, geology, climate, soil structure etc., the measure of the similarity will be determined by the data in the homogeneity tests described by Dalrymple (1960), as the runoff from a catchment is the integrated result of all the characteristics of thc catchment. Since the effect of one or a combination of several characteristics of a catchment on ruhoff is not well defined nor quantified, it is reasonable to look only at the statistical characteristics of the runoff event to determine homogeneity.

9.2.2 Data Requirements

Annual peak flood data observed under unregulated/uncontrolled, undisturbed site conditions for as long a period as possible at all the gauging sites of the identified region are essential.

The reliability of statistical parameters computed from about 30 years of annual peak flood series is considered adequate for frequency analysis. In case some sites have short term records, the proper choice of parameter estimation technique be made or else its adequacy evaluated by analysis of record from a long term base gauging station in the region.

The homogenity of data can however be established as given in Section 9.2.6.

9.2.3 Base Period Determination

Before the homogenity of the data can be tested, a time base period, the longest period of record during which data from each gauging site is utilised for analysis must be established.

In order to bring the flood peak records at all the stations to the same base period, relationship between the peak floods of each station and that of the nearby station need be estalished using regression technique. Using these established relationships the missing data for the station under consideration be computed.

9.2.4 Flood Frequency Curves

Having established the base period, flood frequency curve using the ranked annual maximum series and the corresponding plotting positions is developed by plotting these points on the Gumbel (EV-I) probability paper. Care should be taken not to incorporate the estimated/extrapolated missing flood data for developing the frequency curve as they are used only for assigning the rank statistics to the observed peak floods. The data are plotted on Gumbel probability paper with the abscissa being the probability of non-exceedance or exceedance or the reduced variate of EV-I distribution and the ordinate being the magnitude of observed peak floods. Gringorten plotting-position as recommended in the Flood Studies Report (NERC, 1975) has been used for plotting the observed peak floods on the Gumbel (EV-I) probability paper. The Gringorten plottting position formula for evaluating the probability of non-exceedence for a any flood event is given by.

$$P = \frac{i - 0.44}{N + 0.12} \qquad (9.1)$$

where, i is the rank of flood arranged in ascending order and N is the sample size.

A straight line is drawn through the plotted points to represent the frequency curve. Suitability of the straight line, fitted for the observations plotted on Gumbel probability paper by eye judgement as envisaged by Dalrymple, is checked by constructing 95% confidence interval for each of the individual predicted value by the fitted relationship. The lower and upper confidence interval respectively are given by the expressions (Hann, 1977).

$$Q_{K_l} = Q_K - S_{Q_K}\, t_{(1-\alpha/2),\,(N-2)} \qquad (9.2)$$

$$Q_{K_u} = Q_K + S_{Q_K}\, t_{(1-\alpha/2),\,(N-2)} \qquad (9.3)$$

Where $t_{(1-\alpha/2),\,(N-2)}$ is the value obtained from t-distribution corresponding to the confidence limit of $(1-\alpha)$ and (N—2) degrees of freedom, and Q_K is the predicated value of flood Q for the given reduced variate of Gumbel (EV-I) distribution. Q_{K_l} and Q_{K_u} respectively are the lower and upper level of confidence limits. S_{Q_K} is the standard error of Q_K which is expressed as (Hann, 1977) :

$$S_{Q_K} = S\,[1 + 1/N + (y_k - \bar{y})^2 / \Sigma\,(y_i - \bar{y})^2]^{1/2} \qquad (9.4)$$

in which S is the residual standard deviation, y_k is the reduced variate of Gumble (EV-I) distribution corresponding to the k^{th} observation and $\bar{y}$ is the mean of the reduced variates of all observations at a gauging site.

9.2.5 Determination of Mean Annual Flood

The mean annual flood, which is the Index-Flood, is estimated from the flood frequency curves, determined in step (3) as the flow having an average return period of 2.33 years. The reason of prefering a graphical technique rather than deriving it arithmetically is to overcome the effect of outliers in the sample, if any.

9.2.6 Homogeneity Test

The ratio of the 10-year flood to the mean annual flood is the statistic to be used to measure homogeneity of the runoff data from the gauged catchments. The 10-year flood, which is equivalent to the flood magnitude having a probability of non-exceedance of 90 percent, is estimated from the flood frequency curves. Each 10-year flood should be divided by the mean flood to get the 10-year ratio and a regional average of these ratios should be obtained. For each station of the region the return period corresponding to a discharge equal to the regional average flood ratio times the mean flood is computed.

The computed return period for each station is plotted on the probability scale against its length of record (years) on linear scale. If the plotted points for all stations under consideration fall within the upper and lower regional confidence limits (T_U and T_L) developed by the USGS (Table 9.1), then the data are regionally homogeneous and applicable for analysis. Any station for which the plotted point lies outside the envelope curve, is excluded from homogeneous region and hence from analysis.

The upper and lower limits as listed in Table 9.1 have been computed for a return period of 10-years. The reduced variate (y) for T = 10 in the Gumbel distribution is 2.25, and the limits are given as

$$y \pm 2\, e^{y} / \sqrt{N\,(T-1)} \qquad (9.5)$$

where, N = Length of record

or

$$2.25 \pm 6.33 / \sqrt{N} \qquad (9.6)$$

Table 9.1 Confidence Limits for Index-Flood Homogeneity Test (after Dalrymple, 1960)

Length of Record N	Lower Confidence Limits		Upper Confidence Limit	
	Reduced variate	Return Period, T_L	Reduced variate	Return Period, T_U
5	–0.59	1.2	5.09	160
10	0.25	1.8	4.25	70
20	0.83	2.8	3.67	40
50	1.35	4.4	3.15	24
100	1.62	5.6	2.88	18
200	1.80	6.5	2.70	15
500	1.97	7.7	2.53	13
1000	2.05	8.3	2.45	12

9.2.7 Relationship of Mean Annual Flood and Cathement Area

The mean annual flood of an ungauged catchment can be determined from a plot of the log of the drainage area versus the log of the mean annual flood estimated from the developed frequency curve on Gumbel probability paper using observed floods at gauged catchments of the region. The relatianship can be written as :

$$\log \bar{Q} = \log c + a \log A \qquad (9.7)$$

where $\bar{Q}$ = mean annual flood (cumecs)

A = drainage area (km^2)

c and a are the constants of regression

The Equation can be rewritten in the natural domain as :

$$\bar{Q} = cA^a \qquad (9.8)$$

Some of the typical values of c and a for various regions of the country are given below.

		c	a
1.	Mahanadi basin; subzone 3-d, (Gupta, 1980)	3.366	0.774
2.	Sub-Himalayan region (Venkataraman and Gupta, 1986)	15.84	0.75
3.	Lower Godavari basin subzone 3-f (for small and medium catchments) (Venkataraman et. al., 1986)	7.10	0.755
4.	Krishna Basin (small and medium catchments) (Thirumalai and Sinha, 1986)	3.35	0.682
5.	Chaliyar Basin of Western Ghats region (James et al., 1987)	3.35	0.37

9.2.8 Regional Flood Frequency Relationship

Following the test for homogeneity and determining the relationship between mean annual flood and catchment area, the estimates of peak discharge for selected return period for each gauging site are computed and they are divided by the respective site specific mean annual flood. The estimated flood ratios corresponding to each selected return period for all stations are ranked in ascending or descending order and the median flood for that recurrence interval is noted. Similarly, the median flood ratios for all stations are computed. These median flood ratios are plotted on the Gumbel (EV-I) distribution probability paper and this plot forms the regional flood frequency relationship.

9.3 N.E.R.C. METHOD

This method described in the Flood Studies Report (1975) involves the following steps of computation and is based on similar general principles of the USGS method but not attempting to define the Q_T / $\overline{Q}$ relationship, by the Dalrymple's (1960) standardisation of record length concept.

(i) Select the gauged catchments in a more or less hydrologically similar region.

(ii) Compute the mean of annual peak floods for each station of the region. Where short records are available, suitably augment the record by regression.

(iii) Find the best fit equation for ($\overline{Q}$) with the catchment characteristics using multiple regression technique or as described in USGS method.

(iv) For each station in the region plot the ranked annual maximum series $Q_{(i)}$ / $\overline{Q}$ against Gumbel plotting position $E(y_{(i)})$.

(v) Select intervals on y scale (reduced variate scale) viz., (—2.0 to 1.5), (—1.5 to 1.0), ... , (3.0 to 3.5) and for each interval compute mean of all $E(y_{(i)})$ and mean of all $Q_{(i)}$ / $\overline{Q}$ and plot them as a smooth mean curve.

(vi) Use this curve as the regional curve for quantile estimation of ungauged catchments.

9.3.1 Catchment Characteristics

The physical characteristics of a catchment considered by the method may broadly be grouped under a number of general headings.

(i) Size and shape (Area)

(ii) Density and distribution of streams (Stream frequency)

(iii) Overland and channel slope

(iv) Catchment storage (Lake index)

(v) Soil Index/Geology

(vi) Rainfall/climate (Mean annual rainfall)

9.3.2 Data Requirements

Annual peak flood data observed under unregulated and undisturbed site conditions for as long a period as possible at all the gauging sites of the identified region are essential alongwith different catchment characteristics as given in Sec. 9.3.1.

9.4 LIMITATIONS

Both methods described above for carrying out regional flood frequency analysis have the following limitations :

(i) The relationships developed by both the methods are limited to that particular region and need to be updated from time to time with the availability of more historic information.

(ii) In case of NERC method extrapolation for T year return period beyond 1.7 times largest record length available in the region is subjective.

(iii) The USGS method considers the catchment area as the only catchment characteristic on which the mean flood depends. However, other factors may also affect the mean annual flood considerably.

(iv) The Index-flood (mean annual flood) for stations with short periods of record may not be typical. This means that the ratios of flood of different return periods to the index flood may vary widely between stations.

(v) In the USGS method, although hemogeneity is apparently established at 10-year level, the individual curves show wide and sometimes systematic differences at higher levels.

(vi) Augmentation of short records by regression relations with data from longer neighbouring records are also subjective.

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