CHAPTER 1

INTRODUCTION

1.1 GENERAL

A catchment may be defined as a topographically delineated area which catches the water through precipitation and drains the water through ordered streams to a common outlet. Watershed can also be described as a geomorphologic, biological, socio-economic or physical unit for planning and management of water resources. Catchment may be classified as either Gauged or ungauged. A gauged catchment is the one which has rain gauges installed at the gauging site. In such catchments, adequate rainfall runoff data is available. These sites are generally larger in size. An ungauged catchment is the one for which very less or no rainfall data is available for the region. In such sites, very few or no rain gauges are installed. These sites are very small in size and size of such catchments varies between 25-2500 km^2**.**

Various methods that have been in practice are Flood is an unusually high depth of water in a river. During floods, river overflows its banks and destroys the nearby area. The havoc caused by floods in terms of life, property and economic losses are well known. Flood estimation is very important for construction of any hydraulic structure and prediction of Flood Peak of a required return period is required for construction of structures like bridges, culverts, spillways for dams etc. For design of any hydraulic structure as per CWC, India a minimum 50-Year Return Flood (RF) and as per IS: 11223-1985 for small dam, a 100-Year RF is required. For construction of a large structure which has very high national importance, data for a large period should be collected and then calculation of SPF or PMF should be done for hydraulic design of the structure.

Rational Method, various Empirical formulas are available for few regions, SCS-CN, flood frequency analysis by Gumbel’s Method etc. Use of all these methods depends upon the desired output and the data available.

Rational method is used for calculation of Peak Discharge in small sized catchments having area less than 50 Km^2. This method has various limitations. Various *empirical formulas* are developed by Dickens (1865), Ryves (1884), Inglis (1930) etc relating Peak Discharge with Area of the catchment. These formulas are applicable for a particular region. *Unit Hydrograph* method can be used for flood estimation. Unit hydrograph is drawn which is then used for calculation of flood hydrograph. this method is applicable for regions having area less than 5000 Km^2. Flood Frequency analysis study can be done to if data for a large time is available for a site. For estimation of extreme floods using this method, probability distribution functions like Gumbel's, Log Pearson etc are used for flood estimation.

Regional Hydrometeorological approach is usually adopted for estimation of floods in ungauged catchments. Due to very high cost involved in setting up gauging stations, it is not possible to observe data over a long period or at many locations of the catchment drainage network. Because of economic considerations, all stations cannot be made gauged. Estimation of design floods for a very large number of bridges, culverts, cross drainage works and small scale river valley projects is extremely difficult due to inadequate hydrologic data known for the catchments. Central Water Commission has divided India into 23 Hydrometeorological homogenous subzones having many small ungauged catchments covering the entire geographic area of the country. For the purpose of flood estimation, various departments like IMD, Railways, and RDSO etc have collected rainfall data for 329 bridge sites for a period of 2-10 years.

In small and medium catchments having inadequate rainfall data, usual methods of flood estimation cannot be applied. In such case regional methods like synthetic unit hydrograph or probability functions like gamma distribution can be used as an alternative to derive flood hydrograph. In this method, unit hydrograph is developed for the region using the methods discussed above and this unit hydrograph can then be used to find the flood hydrograph and peak of the flood hydrograph for the region. This estimated Flood Hydrograph can be used for construction of small hydraulic structure in the catchment.

Regional approach of flood estimation can be applied only in homogenous regions so it is very important to study the homogeneity of the region. Study is required to be done to check whether the subzones defined as hydraulically homogeneous by CWC are actually homogenous or not. Various parameters are calculated to find whether the geology, rainfall-runoff characteristics & infiltration and shape of all the bridge sites located in the subzone are similar throughout the region or not. If all the catchments characteristics of bridge sites are similar then it can be said to be homogenous.

1.2 SYNTHETIC UNIT HYDROGRAPH

Hydro meteorological approach has been adopted to develop a regional method for estimating design flood for ungauged catchments in homogeneous subzones. The design storm after converting to effective rainfall is applied to unit hydrograph to obtain design flood. Collection of regional data for every new site is uneconomical on a large scale;

regional method for developing representative Synthetic unit hydrograph is resorted. In Synthetic Unit Hydrograph method, unit hydrograph is derived from areal characteristics rather than rainfall-runoff data. If data of past 3-4 flood events is available, a reliable UH can be developed. It is developed from relations established between physiographic and unit hydrograph parameters of the catchment in homogeneous subzones. This method is a regional method; the results obtained for a particular homogenous region are not applicable outside this region.

In these methods, parameters of Unit Hydrograph are related with various derived geological parameters and that parameter is selected which shows highest correlation coefficient.

Multiple variable regression equations can also be developed to find the relations between unit hydrograph parameter (q_p, T_p, W_{50}, W_{75}, WR_{50}, WR_{75}) and Geological parameters (A, L, L_C, S)

1.3 GAMMA HYDROGRAPH

Unit hydrograph can be developed using the probability density functions like Weibull, Gumbel, Beta, Gamma functions etc. These functions have the benefit that area under these functions is always unity and shape of the distribution is also known.

Gamma hydrograph is developed using gamma distribution function defined as:

$$\boldsymbol{q(t) = \frac{e^{-\frac{t}{k}} * \left(\frac{t}{k}\right)^{n-1}}{k * \Gamma(n)}}$$

Where k & n are parameters of Gamma Distribution Function

Gamma function is used to develop unit hydrograph for the ungauged sites of a hydraulically homogenous region. In Gamma Unit Hydrograph, only two parameters; peak discharge per unit are per unit effective rainfall (Q_p/Area/Effective Rainfall) and Time to Peak (T_P) of a unit hydrograph of very small duration is required to develop the instantaneous unit hydrograph as compared to synthetic hydrograph method which requires $\mathbf{q_p}$**,** $\mathbf{T_P}$**,** $\mathbf{T_b}$**,** $\mathbf{W_{50}}$**,** $\mathbf{W_{75}}$**,** $\mathbf{WR_{50}}$**,** $\mathbf{WR_{75}}$ and simultaneous adjustment through these points to draw the Unit Hydrograph. Thus gamma hydrograph method is easy as compared to the synthetic hydrograph method used for estimation of flood hydrograph. The Unit Hydrograph developed using Gamma Function can be compared with the UH developed by C.W.C., India using the SUH method to compare both the methods. Since shape of the gamma distribution function is known and area under the curve is always Unity, no adjustments of points is required and the UH can be derived very easily using this method.

Gamma Hydrograph has been used for studying the sediment graph of the ungauged catchments, prediction of Runoff, etc. Studies have shown that gamma hydrograph predicts recession curve of UH better than most methods used. Accession Curve of UH being a probability function can be easily drawn with the help of Gamma Function. Thus Gamma Function can be used for drawing the Unit Hydrograph for a region.

In this thesis, author has used Gamma Hydrograph for estimation of design flood in ungauged sites of Chambal Subzone, one of the 26 hydrometereologically homogeneous subzone of the country. Comparison of results of Peak of Flood calculated by Gamma Hydrograph and Synthetic Unit Hydrograph method used by Central Water Commission in the Flood Estimation Reports.

1.4 OBJECTIVES

1. To find All India variation of parameters of Unit Hydrograph (Q_p, T_p, T_b, q_p) with the geological parameters area, length, slope etc and various derived dimensional and dimensionless parameters.
2. To determine whether the subzone 1(b) defined as hydrometereologically homogenous sub zones by Central Water Commission are homogenous or not.
3. To draw the gamma unit hydrograph for ungauged sites of subzone 1(b).
4. To compare the Gamma Unit Hydrograph and Various Synthetic Hydrographs (Multiple regression, method used by CWC) with Representative Unit Hydrograph parameters as reference to find the most accurate method of all.
5. To develop 50-year Return Flood hydrograph of all the bridge sites of a subzone using Gamma Hydrograph Method and to compare the hydrograph so developed with the hydrograph provided in the CWC report.
6. To develop flood formula for the peak of 50-year Return Flood developed by gamma hydrograph and to compare with the one developed by CWC in the flood estimation report of Chambal Subzone and to find which formula is more suitable for the subzone.

CHAPTER 2

LITERATURE REVIEW

Reviews of Literature

Literature review has been reviewed and arranged in following sections:

First Section: Studies related to Synthetic Unit Hydrograph. In this various methods are studied to form the Synthetic Hydrograph for a small region.

Second Section: Studies related to Gamma Hydrograph. In this studies related to parameters of Gamma Distribution and various factors affecting its behavior.

Third Section: Studies related to estimation of flood in a catchment. In this studies are done to find behavior of floods & estimation of flood.

Fourth Section: Studies related to Geomorphology of a region. In this studies related to homogeneity of the region, fractal nature of the watersheds, categorizing various homogenous regions etc.

2.1 SYNTHETIC HYDROGRAPH

These hydrographs have been used by researchers to estimate flood for the small ungauged catchments where reliable data or suitable data is not available to estimate flood for the region using usual methods. Synthetic Hydrographs have been very handy in calculation of Unit Hydrograph by relation rainfall Unit Hydrograph data with the Geological Parameters.

James and Winsor (1987) used records of 283 storm events in 85 catchments to develop and verify the synthetic equations. The equations use basin characteristics to estimate the parameters of the unit hydrograph.

Bhaskar et al (1997) used Geomorphologic Unit Hydrograph to estimate Flood in an Ungauged Hydrograph in Jira River having storm data from 12 events. In this Geomorphological Parameters are related to Nash Instantaneous Unit Hydrograph to find the shape of the Hydrograph.

Allen and Wang (1994) have used data of 24 sites to find the single representative unit hydrograph for a region from various flood events. In this the instantaneous unit hydrograph is developed considering unit hydrograph as variable parameter.

Lee and Yen (1997) have related parameters of UH with stream orders. Geomorphologic UH is the most promising of all methods to relate geomorphology with the hydrograph

Parameters. Comparison between and simulated and observed hydrograph is done to find the suitability.

Bhunya et al (2005) have used Hybrid model for derivation of Synthetic Hydrograph. This method is then compared with Snyder, SCS and Gamma Distribution on four catchments from India. Empirical equations are given for calculation of two storage coefficients q_p and T_p.

Bhunya et al. (2005) studied traditional methods of SUH derivation, e.g., Snyder, SCS, traditional methods like Snyder and TS method that does not yield satisfactory results, and their application to the practical engineering problems is tedious and combursome

Ellouze-Garzouri & Bargaoui (2012) used Geomorphologic Instantaneous Unit Hydrograph for runoff estimation of ungauged catchment. In this Monte Carlo Simulation and Copulas is used. Effective rainfall is estimated with the help of infiltration index. Using Copulas Hydrographs are formed which are used to study various characteristics of the catchments.

2.2 GAMMA HYDROGRAPH

Gamma Hydrograph is the hydrograph depending on Gamma Distribution Function. In this the shape of the Hydrograph is known as it is dependent on the well-known gamma function. It very accurately describes the behavior of unit hydrograph in an ungauged catchment which otherwise requires a lot of subjectivity in drawing the Unit Hydrograph.

Chang-Xing Jin (1992) used gamma hydrograph to find SUH according to paths that water follows in the catchment and found that there are different hydrographs for different storms as a function of flow velocity showing dynamic nature of the catchment.

Aksoy and Bayazit (1999) used gamma distribution in hydrological analysis and found that the ascension curve of the hydrograph is a probabilistic process rather than a deterministic process and hence that it follows gamma hydrograph and 2-parameter gamma distribution fits to the daily rainfall data.

Sushil K. Singh (2000) has transmuted Gamma Distribution in synthetic hydrographs. The gamma distribution can be transmuted in Synthetic Hydrograph like those of SCS, Snyder etc and smooth shape of IUH can be established without any fitting of points. In this calculation of various parameters like W_{50} W_{75} etc are omitted because of simple nature of Gamma Distribution requiring only two parameters as compared to conventional parameters.

Bhunya, Mishra (2003) have used two parameter Gamma Distribution Function for drawing Synthetic Unit Hydrograph. Most methods involve subjectively fitting of the points to draw the IUH but gamma distribution being a known function and since area of this function is always unity so subjectivity in fitting the hydrograph is removed. Marquardt algorithm is used to develop nonlinear relationships

Raymond and Giles (2003) have studied true form of IUH in linear reservoirs. Gamma distribution has been very popular in calculation of Instantaneous Unit Hydrograph and is quite acceptable. In this three parameter gamma distribution function is used in predicting Runoff is done to compare with characteristic IUH to find the application of both the methods.

Sushil K. Singh (2005) compared Gamma hydrograph with Clark and Espey's base unit hydrograph and found that gamma UH can represent the hydrograph recession better than the Clark's UH does. Gamma UHs obtained without optimization are found consistent with their physical meanings and better than the Clark's UH in reproducing runoff.

Cleaveland et al. (2006) have evaluated IUH in catchments of central and north Texas. They have shown that fixed shape hydrographs can better predict the IUH in these catchments thus gamma hydrograph can be used as a method to estimate IUH in small catchments.

Sushil K. Singh (2009) related parameters of the gamma hydrograph with the time base of the hydrograph. Time to base is connected with Time to peak and lag time of the unit hydrograph as these parameters are more convenient than other parameters. Using equations for time to peak gamma hydrograph is fitted.

Bhunya et al. (2011) showed that probability distribution functions like Gamma, Beta, Gumbell based SUH methods are easy to apply, and easily meet the UH criterion than Synthetic Hydrograph technique. They showed that Gamma and Chi-Square have similar behavior and Beta is a limiting case of Gamma Distribution.

Singh and Mishra (2011) fitted the two parameter Gamma Hydrograph for estimation of sediment graph from ungauged catchments. It is used because of partial data available in case of sediment studies and the graph generated is compared with the already available graph on sediments. Comparison have shown that this method have shown much better results than other methods for estimation of Sediment Hydrograph in ungauged catchments and can be satisfactorily used. This method is very simple as compared to other methods requiring rigorous calculations.

2.3 FLOOD ESTIMATION

Knowledge of flood is very important for construction of any hydraulic structure in any region. in gauged sites probabilistic approach can be used for this purpose but for small and medium catchments various regression approaches involving geo-morphological parameters are used.

Wall et al. (1987) combined regional methodology and historic site data for predicting the flood hydrograph and found that the results of flood, when compared with the observed field data of a gauged site are better as compared to situation when single method is used for this purpose.

Jahir and Stedinger (1991) studied T- distribution for studying the confidence interval (CI) of flood of a large return period and found that if the uncertainty is ignored the CI generated performed poorly as compared to methods which have included the skew and uncertainty. thus skewness is important factor to be studied for studying design flood.

Swamee et al. (1995)estimated flood peaks using the dimensionless variables involving flood and geo morphological parameters and prediction of annual flood using these models is done in Indian basins of size varying from 15 to 90000 km^2.

Bhabhagrahi et al. (2006) estimated flood using Clark's and Nash model for small and ungauged sites of country using GIS for calculating the geomorphologic data and have found that the hydrograph developed using these methods is very accurate for flood estimation works when very little flood data was used.

Scawthorn et al. (2006) have used Hazus-MH methodology to estimate the loss incurred because of flood event. Studies were done to find how losses are reduced because of flood event when warning is provided. These methods can be used for studying the after effects of flood hazards.

Countryman (2007) used P.D.F's to calculate 500 year return flood and stated that extrapolation should not be done when probability function are used.

Li-Chuan et al. (2008) have suggested the use of probabilities for flood estimation of larger return periods (≥ 500 years) for all sites. Regression model has been used o evaluate probabilities of different events.

Lim & Voeller (2009) have found that L- Moment method can be applied as a regional method for flood estimation on a global scale. results obtained using this method is generally higher than that obtained using methods traditionally used for estimation of flood peak.

Aziz et al. (2010) have used A.N.N technique for estimation of flood in small catchments instead of the rational method used frequently. Results indicate that this technique is much more suitable than rational method flood estimated is quite reasonable. Various models are tested and the one which involves area and intensity of rainfall are most applicable for this purpose.

Hitesh and Ataur (2010) used Monte Carlo simulation & RORB model as a joint model for the probability and rainfall data. This method should replace the probabilistic approach for studying and developing the storm hydrograph.

Zaman et al. (2010) used regional approach for prediction of flood for about 450 small catchments. on studying very small catchments using this method they found that larger runoff/area is calculated as compared to observed data and different methods should be developed for such sites.

Alvaro et al. (2014) studied flood curves for flood of return period lying between hundreds to ten thousand to study the safety in catchments of small size and found thatsafety from flood would decrease if size of the study area & time of concentration of discharge increases.

2.4 HOMOGENEITY

Determination of homogeneity of the region is very essential in a subzone so that equations applicable can be applied with fair accuracy to calculate various parameters of the hydrograph and estimation of flood in ungauged catchments having scarcity of reliable data.

Thandaveswara and Sajikumar (2000) applied ANN for clustering technique for defining boundary of homogenous regions. ANN being a rational rather than subjective and judgmental method will give similar results will give similar results when two different experts are delineating. Thus this method can be applied for reducing subjectivity of clustering technique.

Binaya Kumar et al. (2009) used NRCS curve technique for delineation of homogenous regions instead of clustering technique and found that heterogeneity was found within range and this method is very less subjective than the commonly used methods for testing homogeneity.

Ilorme and Griffies (2009) stated that inclusion of ungauged sites into homogenous regions is necessary for applying regional methodology. The sites are classified as homogenous if flood parameters similar. catchment showing similar results can be included into a homogenous subzone.

Kar et al. (2012) studied the homogeneity of Mahanadi Basin using Fuzzy logic clustering and found that region is non homogenous and divided area into two different homogenous regions. Clustering technique helps to know the regions that can be included in a homogenous subzone.

Basu & Srinivas (2013) studied the already classified homogenous regions of Ohio using Fuzzy clustering & conventional approaches and results indicate that those regions are non homogenous. The results using the new group of homogenous regions for studying flood gave better results compared to regional regression method used previously.

.

CHAPTER 3

ALL INDIA VARIATION OF IMPORTANT FLOOD PARAMETERS

ALL INDIA VARIATION OF IMPORTANT FLOOD PARAMETERS

Flood hydrograph in a region depends upon various geological characteristics of the region like Length, Area and Slope. Flood hydrograph is derived with the help of unit hydrograph whose important parameters are Peak Discharge and the time at which the peak discharge occurs. So for studying the parameters of flood hydrograph variation of various parameters of unit hydrograph are studied for small and medium catchments throughout the India in various subzones in which the country is divided.

In this chapter variation of Time to peak, Peak Discharge and Peak Discharge per unit area of the Unit Hydrograph are studied with the geological properties of catchment. Impact of various factors is seen to find out which factor affects the behavior of unit hydrograph the most.

India has been divided into 26 homogeneous subzones which have been assumed to have uniform rainfall and geological properties throughout the region. In these subzones there are various un-gauged sites of which data is available in CWC's flood estimation reports in the form of UH and Geological parameters. All the data for whole of the region is combined to find the effect of various parameters on important Flood parameters like Maximum Discharge and the time of maximum discharge of a particular duration of Unit Hydrograph.

Central Water Commission has derived various parameters using geological properties like $\boldsymbol{L\,L_c\,S^{-0.5}}$, $\boldsymbol{L\,S^{-0.5}}$ etc for different subzones and correlated the Unit Hydrograph parameters to estimate flood hydrograph of various time peaks. The selection of the parameter is primarily on the basis of higher correlation coefficient. In this we can find whether various parameters can be used to replace the parameters used by CWC or not.

Also fractal nature of various subzones is to be studied to check whether the values provided in the CWC report of various subzones are accurate or need modification. Hack's Law can be used to study whether a region is fractal or not depending upon the exponent of the best fit power function curve between Length and Area of the catchment.

Hack's law :-

$$\boldsymbol{Length = constant * Area^{\frac{x}{2}}}$$

3.1 CWC's EQUATIONS FOR TIME TO PEAK (T_p) AND PEAK DISCHARGE PER UNIT AREA (q_p) IN TERMS OF GEOLOGICAL PARAMETERS

For all the subzones, CWC has derived one parameter using geological parameters and correlating either q_p or T_p and then correlating other parameters of UH with the parameter that has been correlated with this derived geological parameter. Except for Luni Subzone they have used non linear single variable correlation method to derive the flood hydrograph for all the bridge sites in which they have used multiple variable regression technique.

The determination coefficient (R^2) for all the subzones by CWC has been found to be very most in range of 0.85 ~ 0.95.

Table 3.1: Tp and qp in terms of L, Lc, Area (A) and Slope (S)

NO.	Subzone name	Area (km^2)	1-hour UH parameters in terms of L, L_C, S, A	
			T_p	q_p
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	$0.257A^{0.409}\,S^{0.432}$	$7.284A^{0.365}\,S^{0.386}$
1(b)	**Chambal basin (1989)**	**1,46,630**	$\mathbf{0.339\left(\frac{L}{\sqrt{S}}\right)^{0.826}}$	$\mathbf{2.42\left(\frac{L}{\sqrt{S}}\right)^{0.504}}$
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	$2.875\left(\frac{L}{S}\right)^{0.464}$	$1.331\left(\frac{L}{S}\right)^{0.492}$
1(d)	Sone basin & right bank tributaries(1988)	44,861	$0.314\left(\frac{L}{\sqrt{S}}\right)^{1.102}$	$0.544\left(\frac{L}{\sqrt{S}}\right)^{1.064}$
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	$3.875\left(\frac{L}{\sqrt{S}}\right)^{0.674}$	$2.030\left(\frac{L}{\sqrt{S}}\right)^{0.649}$
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi & others (1985) (6 HOUR UH)	1,71,350	$3.067\left(\frac{L}{\sqrt{S}}\right)^{-0.472}$	$0.409\left(\frac{L}{\sqrt{S}}\right)^{-0.456}$
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)	1,30,280	$1.1808\left(\frac{LL_C}{\sqrt{S}}\right)^{0.285}$	$1.798\left(\frac{LL_C}{\sqrt{S}}\right)^{0.264}$
2(a)	North Brahmaputra basin. (1991)	1,21,444	$2.272\left(\frac{LL_C}{\sqrt{S}}\right)^{0.409}$	$1.0005\left(\frac{LL_C}{\sqrt{S}}\right)^{0.384}$
2(b)	South Brahmaputra basin. (1984)	73,556	$3.121\,A^{-0.203}$	$0.905\,A^{-0.242}$
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	1,38,418	$0.433\left(\frac{LL_C}{\sqrt{S}}\right)^{0.704}$	$0.682\left(\frac{LL_C}{\sqrt{S}}\right)^{0.447}$
3(b)	Lower Narmada & Tapi basin(1982)	77,000	$0.583\left(\frac{LL_C}{\sqrt{S}}\right)^{0.302}$	$1.268\left(\frac{LL_C}{\sqrt{S}}\right)^{0.2304}$
3(c)	Upper Narmada & Tapi basin (1983 & revised in 2002)	86,353	$0.995\left(\frac{LL_C}{\sqrt{S}}\right)^{0.2654}$	$1.659\left(\frac{LL_C}{\sqrt{S}}\right)^{0.192}$

3(d) .	Mahanadi basin including Brahmani and Baitarani River. *(1982)*	1,95,256	$1.757\left(\frac{LL_C}{\sqrt{S}}\right)^{0.261}$	$0.837\left(\frac{LL_C}{\sqrt{S}}\right)^{-0.189}$
3(e)	Upper Godavari basin (1986)	88,870	$0.727\left(\frac{L}{\sqrt{S}}\right)^{0.59}$	$2.674\left(\frac{L}{\sqrt{S}}\right)^{-0.519}$
3(f)	Lower Godavari basin except coastal region *(1981)*	1,74,201	$0.348\left(\frac{LL_C}{S}\right)^{0.454}$	$4.309\left(\frac{LL_C}{S}\right)^{-0.365}$
3(g)	Indrāvati basin *(1993)*	41,330	$0.353\left(\frac{LL_C}{\sqrt{S}}\right)^{0.45}$	$4.73\left(\frac{LL_C}{\sqrt{S}}\right)^{-0.379}$
3(h)	Krishna sub-zone including Penner basin except coastal region (1983)	2,80,881	$0.258\left(\frac{LL_C}{\sqrt{S}}\right)^{0.49}$	$2.057\left(\frac{LL_C}{\sqrt{S}}\right)^{0.245}$
3(i)	Cauvery & east flowing rivers except coastal region (1986)	96,051	$0.553\left(\frac{LL_C}{\sqrt{S}}\right)^{0.405}$	$3.425\left(\frac{LL_C}{\sqrt{S}}\right)^{-0.353}$
4(a)(b) & (c)	East Coast subzone	2,26,400	$0.376\left(\frac{LL_C}{\sqrt{S}}\right)^{0.434}$	$2.388\left(\frac{LL_C}{\sqrt{S}}\right)^{-0.30}$
5(a)& (b)	West Coast region subzone	1,09,885	$0.9178\left(\frac{L}{S}\right)^{-0.4313}$	$1.712\left(\frac{L}{S}\right)^{0.466}$
7	J & K Kumaon Hills (Indus Basin) (1994)	3,22,170	$2.498\left(\frac{LL_C}{S}\right)^{0.156}$	$0.908\left(\frac{LL_C}{S}\right)^{0.244}$

3.2 TIME TO PEAK (T_p) AND PEAK DISCHARGE PER UNIT AREA (q_p) IN TERMS OF GEOLOGICAL PARAMETER, $\frac{L}{\sqrt{S}}$:

For most of the subzone, parameter L_c is not provided in the report. $\frac{L}{\sqrt{S}}$ Parameter is correlated with T_p & q_p for whole of the region to check whether a single variable can be used to estimate flood in un-gauged sites of whole of India rather than various parameters.

Power Function is used for correlation as used by CWC in all the reports.

$$Y = \text{either } T_p \text{ or } q_p \;\&\; X = \frac{L}{\sqrt{S}}$$

$$Y = C * X^B$$

$$LOG_{10}Y = A + B * LOG_{10}X,\ R^2 = \_\_\_\_$$

If correlation coefficient of this variable is higher than that found using the parameter derived by Central Water Commission, this can be used for flood estimation in that subzone.

Table 3.2 T_p and q_p in terms of $\frac{L}{\sqrt{S}}$

1. T_p

Subzone	Subzone Name	Area Km^2	A	B	R^2
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	0.14238947	0.369	0.185
1(b)	**Chambal basin (1989)**	**1,46,630**	**-0.4689045**	**0.8269**	**0.918**
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	0.05671433	0.548	0.5008
1(d)	Sone basin & right bank tributaries(1988)	44,861	-0.5041782	1.0125	0.816
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	-0.1672995	0.748	0.6142
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi & others (1985)	1,71,350	0.49557209	0.466	0.4467
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)	1,30,280	0.44666141	0.187	0.3975
2(a)	North Brahmaputra basin. (1991)	1,21,444	-0.0466753	0.731	0.5493
2(b)	South Brahmaputra basin. (1984)	73,556	0.91706416	0.0293	0.0116
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	1,38,418	-0.3637127	0.705	0.8612
3(b)	Lower Narmada & Tapi basin(1982)	77,000	-0.1801929	0.571	0.8876
3(c)	Upper Narmada & Tapi basin (1983 & revised in 2002)	86,353	-0.124071	0.571	0.8602
3(d) .	Mahanadi basin including Brahmani and Baitarani River. *(1982)*	1,95,256	0.41373552	0.368	0.8329
3(e)	Upper Godavari basin (1986)	88,870	0.69214161	0.383	0.6119
3(f) & 3(g)	Lower Godavari basin except coastal region *(1981) & Indrāvati basin (1993)*	1,74,201	-0.2150263	0.649	0.6876
3(h)	KRISHNA & PENNAR SUB-ZONE	41,330	-0.3129172	0.712	0.7252
3(i)	KAVERI SUB-ZONE	2,80,881	-0.1086856	0.699	0.8519
4(a)(b) & (c)	East Coast subzone	96,051	-0.3536943	0.791	0.8426
5(a)& (b)	West Coast region subzone	2,26,400	0.24812046	0.452	0.1581
7	J & K Kumaon Hills (Indus Basin) (1994)	1,09,885	0.36765405	0.287	0.784

SUBZONE	**SUBZONE NAME**	**AREA Km^2**	**A**	**B**	**R^2**
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	0.804637	0.3041	0.237
1(b)	Chambal basin (1989)	1,46,630	0.376431	-0.498	0.6095
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	0.082785	-0.57	0.555
1(d)	Sone basin & right bank tributaries(1988)	44,861	-0.572027	0.264	0.017
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	0.2697	-0.617	0.6108
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi & others (1985)	1,71,350	-0.388277	-0.456	0.6269
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)	1,30,280	-0.092535	-0.177	0.3111
2(a)	North Brahmaputra basin. (1991)	1,21,444	0.477136	-0.83	0.8178
2(b)	South Brahmaputra basin. (1984)	73,556	-0.554085	-0.032	0.0094
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	1,38,418	0.300182	-0.451	0.6395
3(b)	Lower Narmada & Tapi basin(1982)	77,000	0.416358	-0.438	0.6565
3(c)	**Upper Narmada & Tapi basin (1983 & revised in 2002)**	**86,353**	0.425208	-0.498	0.7153
3(d) .	Mahanadi basin including Brahmani and Baitarani River. *(1982)*	1,95,256	-0.251347	-0.22	0.4618
3(e)	Upper Godavari basin (1986)	88,870	0.41135	-0.503	0.7103
3(f) & 3(g)	Lower Godavari basin except coastal region *(1981) & Indrāvati basin (1993)*	1,74,201	0.429688	-0.519	0.4979
3(h)	KRISHNA & PENNAR SUB-ZONE	41,330	0.165304	-0.368	0.5209
3(i)	KAVERI SUB-ZONE	2,80,881	0.451863	-0.633	0.5788
4(a)(b) & (c)	East Coast subzone	96,051	0.340325	-0.555	0.5474
5(a)& (b)	West Coast region subzone	2,26,400	0.002598	-0.473	0.2506
7	J & K Kumaon Hills (Indus Basin) (1994)	1,09,885	-0.048614	-0.059	0.511

It can be seen from the found relations between the UH parameters and derived parameter $\mathbf{LS^{-0.5}}$ that for most of the subzones correlation coefficient lies in the range of 0.05~0.60 which is very less when compared to the derived parameter used by CWC in a particular subzone.

The subzones which have higher correlation between the variables is the ones in which CWC has used this derived variables for calculation in their report.

Thus $\frac{L}{\sqrt{S}}$ cannot be used as a single variable throughout the country for the calculation of flood parameters of the hydrograph and derived parameter used by CWC in flood estimation report for a particular subzone should be preferred.

3.3 ALL INDIA VARIATION OF PEAK DISCHARGE(Q_P), PEAK/ AREA, PEAK TIME AND TIME TO BASE WITH LENGTH, L_C, SLOPE AND AREA

The variation of parameters of flood hydrograph is studied with all the basic geological parameters of a catchment i.e. length (L), L_c, Area (A) and Slope (S). In this the behavior of flood parameters is seen in all the regions to find the trend of flood parameter with the geography of the region.

As generally expected if the slope of the region ceases towards hilly region, discharge will reach the outlet fast and higher peak will be there thus Unit Hydrograph will be skewed towards left..

Similarly as it is generally observed that with increase in Area and Length of the catchment higher discharge and larger time to peak is observed i.e. the parameters increasing with increase of these geographical features.

Table 3.3 T_p vs Area, Length, L_c & Slope

SUBZONE	SUBZONE NAME	AREA	vs a		VS L		VS Lc		vs S	
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	$0.420x^{0.426}$	$R^2 = 0.705$	$0.726x^{0.499}$	$R^2 = 0.287$	$1.137x^{0.475}$	$R^2 = 0.284$	$1.193x^{0.775}$	$R^2 = 0.113$
1(b)	Chambal basin (1989)	1,46,630	$0.2465x^{0.5076}$	$R^2 = 0.8281$	$0.1584x^{0.9609}$	$R^2 = 0.8307$			$8.9322x^{-1.2}$	$R^2 = 0.5896$
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	$2.5858x^{0.1796}$	$R^2 = 0.0992$	$0.9511x^{0.5609}$	$R^2 = 0.292$	$1.5328x^{0.5406}$	$R^2 = 0.3244$	$10.312x^{-0.879}$	$R^2 = 0.6913$
1(d)	Sone basin & right bank tributaries(1988)	44,861	$0.2168x^{0.6142}$	$R^2 = 0.6835$	$0.0525x^{1.3496}$	$R^2 = 0.6861$	$0.1274x^{1.3806}$	$R^2 = 0.7075$	$23.512x^{-1.199}$	$R^2 = 0.7146$
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	$1.2051x^{0.3924}$	$R^2 = 0.2197$	$0.322x^{0.9212}$	$R^2 = 0.3931$			$11.927x^{-0.622}$	$R^2 = 0.4898$
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi & others (1985)	1,71,350	$3.5778x^{0.326}$	$R^2 = 0.2616$	$3.7496x^{0.4697}$	$R^2 = 0.2744$			$11.632x^{-0.541}$	$R^2 = 0.4061$
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)		$0.8205x^{0.3606}$	$R^2 = 0.5148$	$2.2158x^{0.2108}$	$R^2 = 0.438$	$1.1404x^{0.5826}$	$R^2 = 0.549$	$5.5182x^{-0.093}$	$R^2 = 0.0094$
2(a)	North Brahmaputra basin. (1991)	1,30,280	$2.6256x^{0.2095}$	$R^2 = 0.0715$	$0.741x^{0.6414}$	$R^2 = 0.1949$	$0.6811x^{0.7962}$	$R^2 = 0.3002$	$11.968x^{-0.302}$	$R^2 = 0.2704$
2(b)	South Brahmaputra basin. (1984)	1,21,444	$3.9513x^{0.1541}$	$R^2 = 0.1686$	$7.2557x^{0.0589}$	$R^2 = 0.0366$	$4.7621x^{0.2269}$	$R^2 = 0.1148$	$8.4768x^{0.0534}$	$R^2 = 0.0242$
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	73,556	$0.4022x^{0.4035}$	$R^2 = 0.571$	$0.1793x^{0.8636}$	$R^2 = 0.8548$			$5.176x^{-0.481}$	$R^2 = 0.2241$
3(b)	Lower Narmada & Tapi basin(1982)	1,38,418	$0.5748x^{0.3271}$	$R^2 = 0.4415$	$0.2482x^{0.7244}$	$R^2 = 0.8147$	$0.534x^{0.6349}$	$R^2 = 0.7842$	$6.3048x^{-0.413}$	$R^2 = 0.3559$
3(c)	**Upper Narmada & Tapi basin (1983 & revised in 2002)**	77,000	$0.808x^{0.321}$	$R^2 = 0.7853$	$0.585x^{0.5603}$	$R^2 = 0.8192$	$1.0542x^{0.5069}$	$R^2 = 0.7344$	$4.918x^{-0.093}$	$R^2 = 0.0085$
3(d) .	Mahanadi basin including Brahmani and Baitarani River. *(1982)*	**86,353**	$1.7631x^{0.2749}$	$R^2 = 0.8319$	$1.3323x^{0.5061}$	$R^2 = 0.7888$	$1.5217x^{0.588}$	$R^2 = 0.8666$	$10.864x^{-0.33}$	$R^2 = 0.4651$
3(e)	Upper Godavari basin (1986)	1,95,256	$3.0821x^{0.2895}$	$R^2 = 0.5822$	$2.4299x^{0.5256}$	$R^2 = 0.6093$			$24.213x^{-0.471}$	$R^2 = 0.4149$
3(f) & 3(g)	Lower Godavari basin except coastal region *(1981) & Indrāvati basin (1993)*	88,870	$0.3049x^{0.4805}$	$R^2 = 0.6422$	$0.1648x^{0.9465}$	$R^2 = 0.6351$	$0.3596x^{0.9563}$	$R^2 = 0.5524$	$6.3812x^{-0.534}$	$R^2 = 0.4149$
3(h)	KRISHNA & PENNAR SUB-ZONE	1,74,201	$0.2999x^{0.4401}$	$R^2 = 0.7048$	$0.1192x^{1.0089}$	$R^2 = 0.7381$	$0.2585x^{0.9926}$	$R^2 = 0.6505$	$4.006x^{-0.22}$	$R^2 = 0.1265$
3(i)	KAVERI SUB-ZONE	41,330	$0.2918x^{0.5193}$	$R^2 = 0.8677$	$0.1713x^{0.9494}$	$R^2 = 0.8949$	$0.4359x^{0.8647}$	$R^2 = 0.8552$	$6.9065x^{-0.326}$	$R^2 = 0.18$
4(a)(b) & (c)	East Coast subzone	2,80,881	$0.2561x^{0.5031}$	$R^2 = 0.8319$	$0.21x^{0.8515}$	$R^2 = 0.7769$	$0.44x^{0.8312}$	$R^2 = 0.7849$	$5.7035x^{-0.253}$	$R^2 = 0.0779$
5(a)& (b)	West Coast region subzone	96,051	$2.8001x^{0.1014}$	$R^2 = 0.0105$	$1.7433x^{0.2904}$	$R^2 = 0.0418$	$3.057x^{0.162}$	$R^2 = 0.0129$	$12.342x^{-0.712}$	$R^2 = 0.3848$
7	J & K Kumaon Hills (Indus Basin) (1994)	2,26,400	$1.2344x^{0.2176}$	$R^2 = 0.5674$	$1.0857x^{0.3775}$	$R^2 = 0.5424$	$1.1261x^{0.459}$	$R^2 = 0.5305$	$7.8547x^{-0.227}$	$R^2 = 0.5875$

Table 3.4 Tb vs Area, Length, Lc & Slope

SUBZONE	SUBZONE NAME	AREA	VS A		VS L		VS Lc		vs S	
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	$3.1608x^{0.2938}$	$R^2 = 0.6297$	$4.1458x^{0.3782}$	$R^2 = 0.3096$	$5.7768x^{0.3627}$	$R^2 = 0.3127$	$9.7351x^{0.2297}$	$R^2 = 0.0188$
1(b)	Chambal basin (1989)	1,46,630	$2.914x^{0.3049}$	$R^2 = 0.612$	$2.1546x^{0.5887}$	$R^2 = 0.6385$			$25.019x^{-0.712}$	$R^2 = 0.4258$
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	$8.6522x^{0.2062}$	$R^2 = 0.1196$	$3.3473x^{0.5867}$	$R^2 = 0.2923$	$6.2687x^{0.5184}$	$R^2 = 0.2728$	$40.869x^{-0.938}$	$R^2 = 0.7199$
1(d)	Sone basin & right bank tributaries(1988)	44,861	$1.6995x^{0.504}$	$R^2 = 0.5384$	$0.4778x^{1.1385}$	$R^2 = 0.5712$	$1.1067x^{1.1301}$	$R^2 = 0.5546$	$106.24x^{-1.214}$	$R^2 = 0.8559$
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	$10.413x^{0.2725}$	$R^2 = 0.1563$	$3.8776x^{0.659}$	$R^2 = 0.2967$			$53.403x^{-0.588}$	$R^2 = 0.6456$
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi & others (1985)	1,71,350	$30.202x^{0.2533}$	$R^2 = 0.2705$	$29.487x^{0.3828}$	$R^2 = 0.3124$			$70.263x^{-0.506}$	$R^2 = 0.6089$
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)		$3.8387x^{0.3405}$	$R^2 = 0.5457$	$12.04x^{0.1427}$	$R^2 = 0.2386$	$5.0023x^{0.5689}$	$R^2 = 0.6223$	$19.264x^{0.0318}$	$R^2 = 0.0013$
2(a)	North Brahmaputra basin. (1991)	1,30,280	$12.463x^{0.177}$	$R^2 = 0.0622$	$4.0388x^{0.5577}$	$R^2 = 0.1796$	$4.2424x^{0.6523}$	$R^2 = 0.2456$	$50.069x^{-0.332}$	$R^2 = 0.3987$
2(b)	South Brahmaputra basin. (1984)	1,21,444	$9.4816x^{0.2188}$	$R^2 = 0.2221$	$22.596x^{0.0821}$	$R^2 = 0.0466$	$11.796x^{0.3385}$	$R^2 = 0.1671$	$29.642x^{0.0306}$	$R^2 = 0.0052$
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	73,556	$4.5635x^{0.2339}$	$R^2 = 0.4753$	$3.5079x^{0.4393}$	$R^2 = 0.5478$			$18.857x^{-0.216}$	$R^2 = 0.112$
3(b)	Lower Narmada & Tapi	1,38,418	$0.5748x^{0.3271}$	$R^2 = 0.4415$	$0.2482x^{0.7244}$	$R^2 = 0.8147$	$0.534x^{0.6349}$	$R^2 = 0.7842$	$6.3048x^{-0.413}$	$R^2 = 0.3559$
3(c)	**Upper Narmada & Tapi basin (1983 & revised in 2002)**	77,000	$4.3464x^{0.2264}$	$R^2 = 0.7024$	$3.6131x^{0.3833}$	$R^2 = 0.6895$	$5.5998x^{0.3344}$	$R^2 = 0.5749$	$16.395x^{-0.119}$	$R^2 = 0.0253$
3(d) .	Mahanadi basin	**86,353**	$9.6407x^{0.2003}$	$R^2 = 0.5229$	$8.4742x^{0.3473}$	$R^2 = 0.4398$	$8.4398x^{0.4376}$	$R^2 = 0.5685$	$37.443x^{-0.273}$	$R^2 = 0.3767$
3(e)	Upper Godavari basin (1986)	1,95,256	$3.0821x^{0.2895}$	$R^2 = 0.5822$	$2.4299x^{0.5256}$	$R^2 = 0.6093$			$24.213x^{-0.471}$	$R^2 = 0.4149$
3(f) & 3(g)	Lower Godavari basin except coastal region	88,870	$1.39x^{0.455}$	$R^2 = 0.6605$	$0.8266x^{0.8773}$	$R^2 = 0.6257$	$1.8795x^{0.8462}$	$R^2 = 0.496$	$23.157x^{-0.439}$	$R^2 = 0.3218$
3(h)	KRISHNA & PENNAR SUB-ZONE	1,74,201	$3.7494x^{0.2364}$	$R^2 = 0.6155$	$2.4456x^{0.5206}$	$R^2 = 0.5949$	$3.7543x^{0.5005}$	$R^2 = 0.5005$	$15.178x^{-0.123}$	$R^2 = 0.1192$
3(i)	KAVERI SUB-ZONE	41,330	$1.9813x^{0.389}$	$R^2 = 0.8349$	$1.3801x^{0.6994}$	$R^2 = 0.833$	$2.924x^{0.6111}$	$R^2 = 0.7327$	$19.748x^{-0.21}$	$R^2 = 0.1276$
4(a)(b) & (c)	East Coast subzone	2,80,881	$3.2234x^{0.3155}$	$R^2 = 0.6331$	$2.9304x^{0.5256}$	$R^2 = 0.5728$	$4.6471x^{0.5113}$	$R^2 = 0.5749$	$20.666x^{-0.094}$	$R^2 = 0.0206$
5(a)& (b)	West Coast region subzone	96,051	$18.285x^{0.047}$	$R^2 = 0.0034$	$10.984x^{0.2163}$	$R^2 = 0.0353$	$15.11x^{0.155}$	$R^2 = 0.0179$	$50.435x^{-0.581}$	$R^2 = 0.3908$
7	J & K Kumaon Hills (Indus Basin) (1994)	2,26,400	$10.894x^{0.0544}$	$R^2 = 0.0863$	$12.249x^{0.049}$	$R^2 = 0.0223$	$12.249x^{0.049}$	$R^2 = 0.0223$	$20.346x^{-0.107}$	$R^2 = 0.3175$

Table 3.5 q_p vs Area, Length, Lc & Slope

SUBZONE	SUBZONE NAME	AREA	VS A		VS L		VS Lc		vs S	
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	$6.5051x^{-0.448}$	$R^2 = 0.5254$	$4.5558x^{-0.596}$	$R^2 = 0.2754$	$2.708x^{-0.572}$	$R^2 = 0.2793$	$0.6856x^{0.049}$	$R^2 = 0.0003$
1(b)	Chambal basin (1989)	1,46,630	$2.4752x^{-0.276}$	$R^2 = 0.4476$	$3.6234x^{-0.566}$	$R^2 = 0.5286$			$0.3182x^{0.7757}$	$R^2 = 0.4514$
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	$0.9431x^{-0.211}$	$R^2 = 0.1408$	$2.2025x^{-0.566}$	$R^2 = 0.3037$	$1.2106x^{-0.502}$	$R^2 = 0.286$	$0.1928x^{0.953}$	$R^2 = 0.8312$
1(d)	Sone basin & right bank tributaries(1988)	44,861	$6.5887x^{-0.573}$	$R^2 = 0.5449$	$26.442x^{-1.279}$	$R^2 = 0.5639$	$11.486x^{-1.311}$	$R^2 = 0.5836$	$0.0636x^{1.3297}$	$R^2 = 0.803$
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	$0.9113x^{-0.278}$	$R^2 = 0.162$	$2.3212x^{-0.653}$	$R^2 = 0.2896$			$0.172x^{0.5896}$	$R^2 = 0.6452$
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi & others (1985)	1,71,350	$0.3226x^{-0.298}$	$R^2 = 0.3196$	$0.3268x^{-0.445}$	$R^2 = 0.3617$			$0.1157x^{0.555}$	$R^2 = 0.6259$
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)		$3.2471x^{-0.388}$	$R^2 = 0.5212$	$0.997x^{-0.197}$	$R^2 = 0.3328$	$2.0793x^{-0.591}$	$R^2 = 0.4921$	$0.3912x^{0.1408}$	$R^2 = 0.0188$
2(a)	North Brahmaputra basin. (1991)	1,30,280	$0.8008x^{-0.219}$	$R^2 = 0.0897$	$2.7415x^{-0.645}$	$R^2 = 0.2271$	$2.4181x^{-0.732}$	$R^2 = 0.2924$	$0.1522x^{0.3694}$	$R^2 = 0.468$
2(b)	South Brahmaputra basin. (1984)	1,21,444	$0.7068x^{-0.191}$	$R^2 = 0.1792$	$0.2615x^{-0.009}$	$R^2 = 0.0006$	$0.9776x^{-0.477}$	$R^2 = 0.3515$	$0.2292x^{0.0784}$	$R^2 = 0.0361$
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	73,556	$2.1556x^{-0.264}$	$R^2 = 0.4432$	$3.3326x^{-0.538}$	$R^2 = 0.5997$			$0.3926x^{0.3451}$	$R^2 = 0.2085$
3(b)	Lower Narmada & Tapi basin(1982)	1,38,418	$2.9409x^{-0.253}$	$R^2 = 0.333$	$5.1203x^{-0.535}$	$R^2 = 0.5579$	$3.4605x^{-0.528}$	$R^2 = 0.6815$	$2.6083x^{-0.438}$	$R^2 = 0.6565$
3(c)	**Upper Narmada & Tapi basin (1983 & revised in 2002)**	77,000	$2.2114x^{-0.257}$	$R^2 = 0.5507$	$3.0537x^{-0.467}$	$R^2 = 0.6203$	$1.8479x^{-0.418}$	$R^2 = 0.5453$	$0.4588x^{0.1987}$	$R^2 = 0.0428$
3(d) .	Mahanadi basin including Brahmani and Baitarani River. *(1982)*	**86,353**	$0.6429x^{-0.147}$	$R^2 = 0.3696$	$0.7336x^{-0.266}$	$R^2 = 0.3373$	$0.7051x^{-0.32}$	$R^2 = 0.397$	$0.2258x^{0.2503}$	$R^2 = 0.4155$
3(e)	Upper Godavari basin (1986)	1,95,256	$5.144x^{-0.396}$	$R^2 = 0.73$	$6.0993x^{-0.67}$	$R^2 = 0.6657$			$0.2984x^{0.6687}$	$R^2 = 0.5608$
3(f) & 3(g)	Lower Godavari basin except coastal region *(1981) & Indrāvati basin (1993)*	88,870	$4.4285x^{-0.373}$	$R^2 = 0.4398$	$6.8338x^{-0.722}$	$R^2 = 0.4192$	$3.5457x^{-0.705}$	$R^2 = 0.3401$	$0.398x^{0.46}$	$R^2 = 0.3493$
3(h)	KRISHNA & PENNAR SUB-ZONE	1,74,201	$2.244x^{-0.261}$	$R^2 = 0.6688$	$3.4777x^{-0.564}$	$R^2 = 0.623$	$2.1038x^{-0.527}$	$R^2 = 0.4949$	$0.5086x^{0.0893}$	$R^2 = 0.0561$
3(i)	KAVERI SUB-ZONE	41,330	$9.2772x^{-0.532}$	$R^2 = 0.7554$	$14.817x^{-0.949}$	$R^2 = 0.7406$	$5.3527x^{-0.829}$	$R^2 = 0.6516$	$0.4855x^{0.1907}$	$R^2 = 0.0511$
4(a)(b) & (c)	East Coast subzone	2,80,881	$3.4943x^{-0.369}$	$R^2 = 0.5875$	$3.5962x^{-0.59}$	$R^2 = 0.4912$	$2.0471x^{-0.557}$	$R^2 = 0.464$	$0.3567x^{0.192}$	$R^2 = 0.059$
5(a)& (b)	West Coast region subzone	96,051	$0.935x^{-0.18}$	$R^2 = 0.0477$	$1.3683x^{-0.386}$	$R^2 = 0.1068$	$0.7084x^{-0.245}$	$R^2 = 0.0428$	$0.1501x^{0.646}$	$R^2 = 0.4593$
7	J & K Kumaon Hills (Indus Basin) (1994)	2,26,400	$0.9716x^{-0.035}$	$R^2 = 0.2318$	$1.0058x^{-0.066}$	$R^2 = 0.2526$	$0.9911x^{-0.077}$	$R^2 = 0.2276$	$0.6786x^{0.0546}$	$R^2 = 0.5247$

Graphical variation of T_p, T_b, q_p, Q_p with A, L, L_c & S for Chambal Subzone

1. **T_p :-**

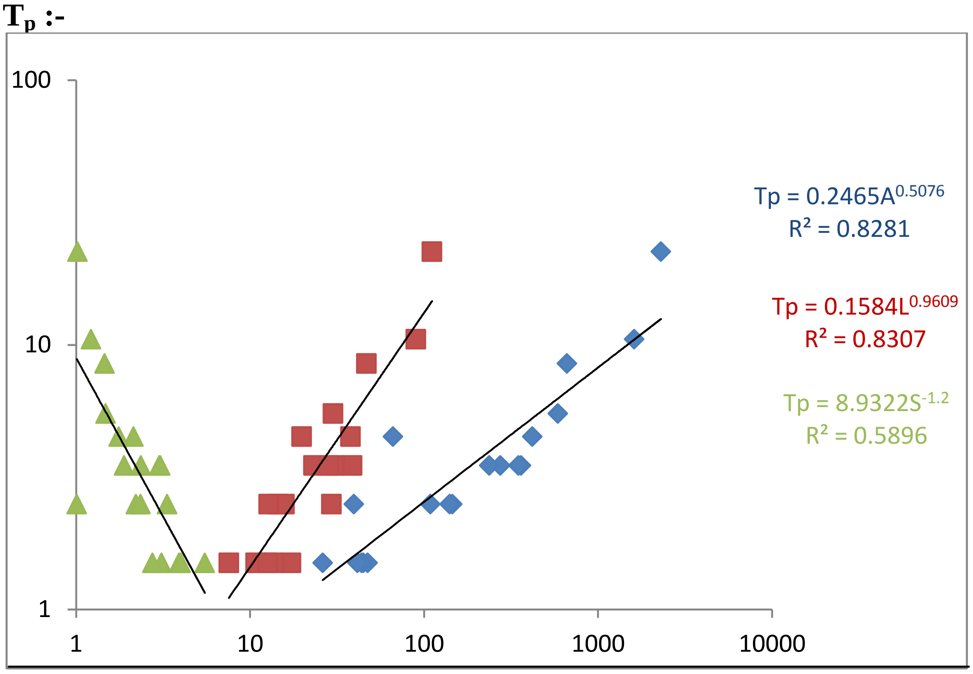


Figure 3.1: T_p vs A, L & S

2. **T_b:-**

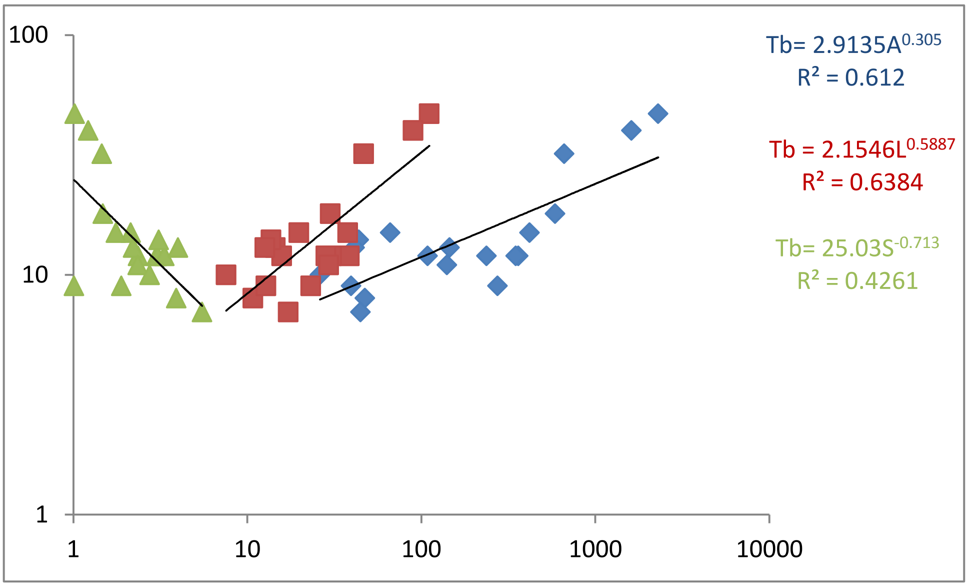


Figure 3.2: T_b vs A, L & S

3. q_p:-

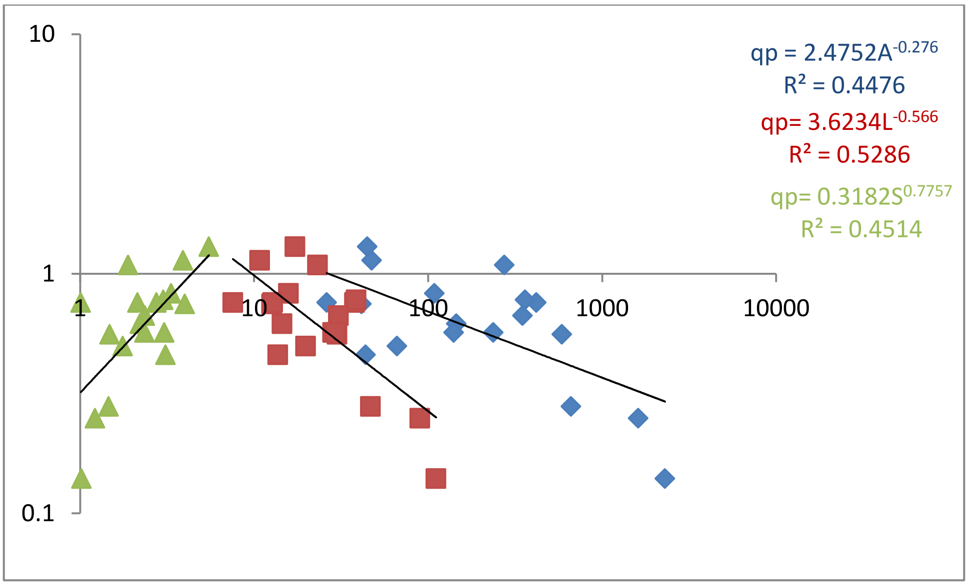


Figure 3.3: q_p vs A,L, & S

4. Q_p:-

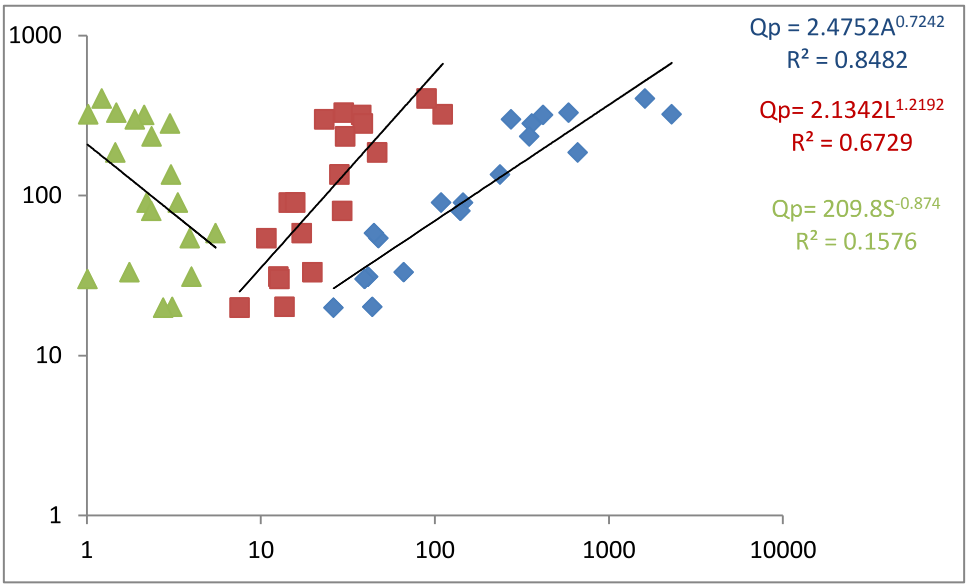


Figure 3.4: Qp vs A, L & S

3.4 VARIATION OF FLOOD PARAMETERS WITH DERIVED DIMENSIONLESS PARAMETERS

Various parameters can be derived using the basic geographical features of the country like $\frac{LL_c}{A}, \frac{LL_c}{AS}, \frac{A}{L^2}, \frac{AS}{L^2}$ etc and variation of various flood parameters is found with these parameters to check whether these parameters can be used to prediction of flood in the un-gauged catchments.

For most of the subzones of India, these variables are very poorly correlated with Unit Hydrograph of the regions with R^2 values lying between 0.05~0.15.

3.5 FRACTAL NATURE OF WATERSHED

Fractal nature of watershed indicates whether the values of various parameters of the catchment are accurate or not. Smaller the unit of measurement higher is the value of the variable calculated. More fractal is the nature of the catchment; more difference will be there in the calculated and original values of the variable.

First parameter of the fractal nature is calculated as the exponent between Area and Length of the subzone. If the value, "b" lies between 0.4~0.6, it is considered NON-FRACTAL

Table 3.6: Fractal Nature of Watersheds

NO.	Subzone name	Area (km^2)	Fractal parameter	
			B	D=2b
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	36,527	0.438	0.876
1(b)	Chambal basin (1989)	1,46,630	0.499	0.998
1(c)	Betwa Basin & other Tributaries (1989)	1,06,469	0.528	1.056
1(d)	Sone basin & right bank tributaries(1988)	44,861	0.430	0.860
1(e)	Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)	2,26,000	0.569	1.138
1(f)	Gangetic plains including Gomti,Ghagra,Gandak,Kosi&others (1985)	1,71,350	0.667	1.334
1(g)	Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)	1,30,280	0.549	1.108
2(a)	North Brahmaputra basin. (1991)	1,21,444	0.499	0.998
2(b)	South Brahmaputra basin. (1984)	73,556	0.286	0.572

3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)	1,38,418	0.500	1.000
3(b)	Lower Narmada & Tapi basin(1982)	77,000	0.499	0.998
3(c)	Upper Narmada & Tapi basin (1983 & revised in 2002)	86,353	0.550	1.100
3(d) .	Mahanadi basin including Brahmani and Baitarani River. *(1982)*	1,95,256	0.512	1.024
3(e)	Upper Godavari basin (1986)	88,870	0.526	1.052
3(f) & 3(g)	Lower Godavari basin except coastal region *(1981)* & Indravati basin *(1993)*	1,74,201 & 41,330	0.482	0.964
3(h)	Krishna sub-zone including Penner basin except coastal region (1983)	2,80,881	0.428	0.856
3(i)	Cauveri & east flowing rivers except coastal region (1986)	96,051	0.537	1.074
4(a),4 (b) & 4(c)	East Coast subzone	2,26,400	0.534	1.068
5(a)& 5(b)	West coast region subzone	1,09,885	0.667	1.334
7	J & K Kumaon Hiils (Indus Basin) (1994)	3,22,170	0.536	1.072

For all the subzones, exponent is generally between 0.4~0.6, so except Subzone 2(c) and West coast Subzone all subzones are NON FRACTAL.

3.6 CONCLUSIONS

1. For the entire homogenous subzone of India, time to peak discharge increases with increase of Area, Length, L_c and decreases with increase of slope of the catchment.

   For the subzones which have good correlation between T_p and Area, exponent lies between 0.4~0.6.
2. Time to base of the Unit Hydrograph shows a trend similar to that of time to peak for whole of the country.

   T_b increases with increase of Length, area and decreases with Slope(S).

3. Increase of time to base is slow as compared to peak time as ratio of T_b & T_p shows decreasing trend for all the subzones with Area, L & L_C and increases with slope of the catchment.
4. Peak discharge per unit area, q_p(=Q_p/Area) is more in regions which are hilly as compared to plain regions. It shows a decreasing trend in all the subzones with increase in Length and Area of the subzone.
5. Peak discharge increases with all the geographical parameters of the country. Rate of increase is fastest with slope of the region exponent is generally greater than one (>1) for most of the subzones.
6. Peak discharge is not linearly varying with area of the catchment. The assumption used in unit hydrograph that Q_p is linearly dependent on Volume of the rainfall is not true in most of the cases but can be applied with fair accuracy.
7. Derived parameters used by CWC in flood estimation reports are better correlated to Unit Hydrograph of the catchment as compared to various other dimensionless parameters and the factor $\frac{L}{\sqrt{S}}$, for flood estimation.
8. For better estimation of flood hydrograph for the catchments than method proposed by C.W.C., Multiple Regression Method or probability distribution functions like Gamma, Chi square etc can be used.

CHAPTER-4

STUDY AREA AND HOMOGENEITY

4.1 LIST OF VARIOUS SUBZONES IN INDIA

The committee of engineers headed by Dr A N Khosla, recommended to develop regional methodology for estimating design flood for small medium catchment. On their recommendation, the country was divided into 7 zones and 26 hydro-meteorological homogenous subzones. These are:

1(a) Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch) .
1(b) Chambal basin (1989)
1(c) Betwa Basin & other Tributaries (1989)
1(d) Sone basin & right bank tributaries(1988)
1(e) Punjab plains including Parts of Indus, Yamuna, Ganga and Ramganga basins(1984)
1(f) Gangetic plains including Gomti, Ghsgrs, Gandak, Kosi& others (1985)
1(g) Lower Gangetic plains including Subarnarekha &other east-flowing river between Ganga & Baitarani (1978)
2(a) North Brahamputra basin. (1991)
2(b) South Brahamputra basin. (1984)
2(c) Lower Assam
3(a) Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra (1987)
3(b) Lower Narmada & Tapi basin(1982)
3(c) Upper Narmada & Tapi basins(1983)
3(d) Mahanadi basin including Brahmani and Baitarani River. *(1982)* .
3(e) Upper Godavari basin (1986)
3(f) Lower Godavari basin except coastal region *(1981)*
3(g) Indravati basin *(1993)*
3(h) Krishna sub-zone including penner basin except coastal region (1983)
3(i) Cauveri& east flowing rivers except coastal region (1986)
4(a) Circars including east flowing rivers between Mahanadi & Godavari (1987)
4(b) Coromandal coast including east flowing rivers between Godavari & Cauveri *(1987)*
4(c) Sandy Comorin belt (east flowing rivers between the cauveri & KanyaKumari (1987)
5(a) Konkan coast (west flowing rivers between the Tapi & Panaji (1992)

5(b) Malabar coast (west flowing rivers between Kanyakumari & Panaji (1992)

6. Tarai Sub-Himalayan foot-hills.

7. J & K Kumaon Hiils (Indus Basin) (1994)

4.2 CHAMBAL SUBZONE 1(b)

Chambal subzone 1(b) is one of the 26 hydrometeorological homogenous subzones lying in the state of Rajasthan, Madhya Pradesh, and small parts of Uttar Pradesh. The Chambal, which is the principle tributary of the Yamuna, is the main river of the subzone .The river Chambal rises in the Vindhya range near Mhow in the Indore district of Madhya Pradesh at an elevation of 854 m. The total length of the river from its source to confluence with Yamuna is about 960 km, of which 320 km are in Madhya Pradesh,226 km in Rajasthan, 250 km from the common boundary between Madhya Pradesh and Rajasthan, 117 km form the boundary between Madhya Pradesh and Uttar Pradesh and the balance 46 km area in the Uttar Pradesh . drainage areas of Chambal river and their tributaries included in subzone 1(b) are:

Table 4.1 Drainage areas of the sub basins of subzone 1(b)

S. No.	**Basin/Sub-basin**	**Drainage Area (km^2)**
1	Banas	48,577
2	Kali Sind	25,741
3	Parbati	14,192
4	Kunu	4,507
5	Kunwari	7,610
6	Main chambal and other minor tributaries	46,073
	Total area of subzone 1(b)	**1,46,630**

The present report of Chambal subzone is based on detailed rainfall and runoff studies of 19 representative catchments. The data at each of the 22 catchments was collected for a period varying from 1 to 10 years by Western and Central railways under the guidance of RDSO.

Equivalent slope has been used in the revised report in place of statistical slope in previous slope.

In present study IMD has used data from 182 Ordinary Raingauge (ORG) stations in and around the basin & 62 stations self recording raingauge (SRRG) data.

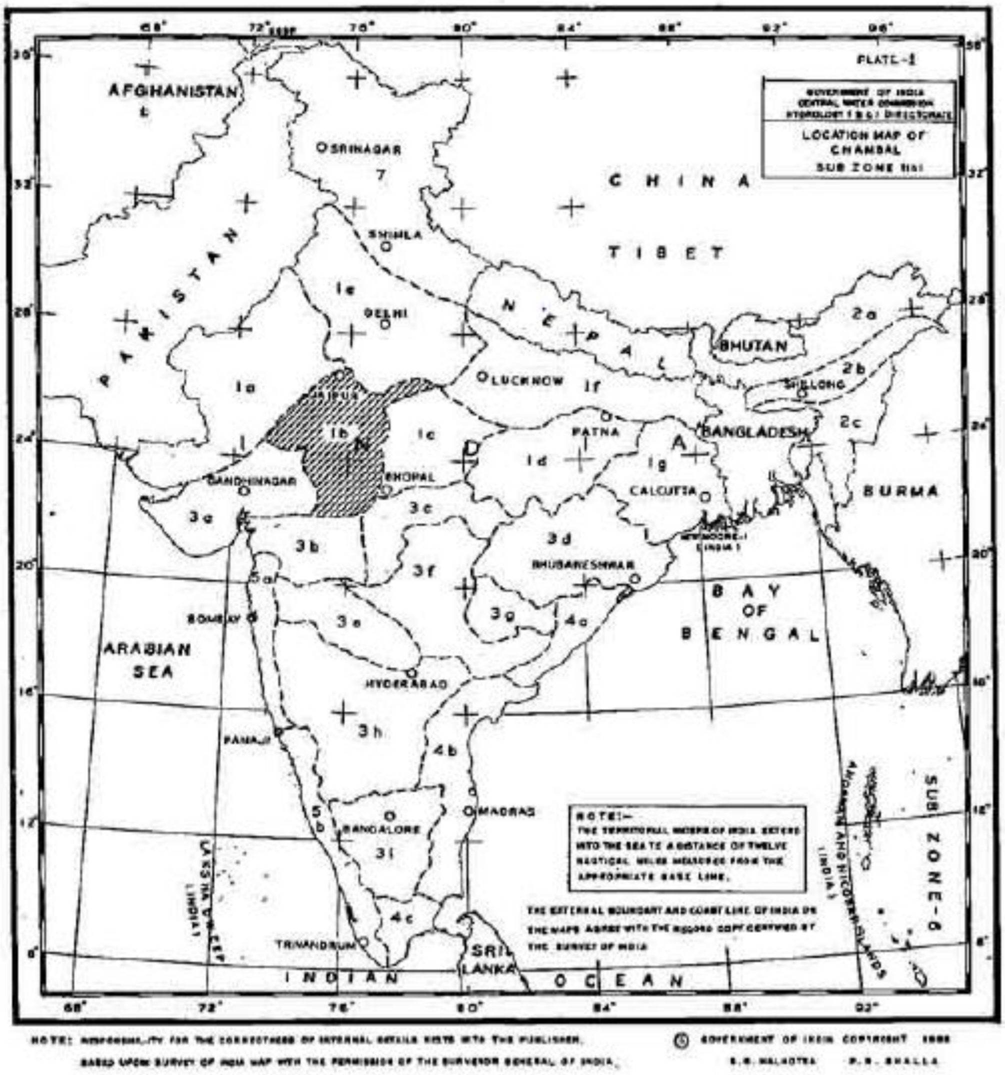


Figure 4.1: Location of Chambal Subzone 1(b) in India (source:Flood Estimation Report for Chambal subzone 1(b),CWC,INDIA)

4.2.1 Topography

The Chambal sub-zone 1(b) lies between east longitudes 73° 20', to 79° and north latitudes of 22° -30' to 27° -15'.The sub-zone covers the states of Madhya Pradesh, Rajasthan and Uttar Pradesh. The sub-zone is bounded on the north by Upper Indo Ganga subzone (1e) and on the east by Betwa subzone 1(c), and on the south by Upper Narmada and Tapi subzone (3c) and Lower Narmada and Tapi subzone (3b) , and by Luni subzone 1-(a) and Mahi-Sabarmati subzone 3 (a) on the west. Important cities and towns within the sub-zone are Indore, Ujjain, Ratlam, Guna, Gwalior in Madhya Pradesh, and Jaipur, Udaipur, Chittorgarh, Nasirabad, Kota, Sawao Madhopur in Rajasthan.

The Chambal has a total fall of about 734 km from its source down to its junction with Yamuna tributary of which 244m is in the first few km and 122 m in a distance of about 100 km from Chaurasigarh Fort to Kota city. For the rest of its course the river passes through flat fertile areas of Malwa Plateau and later in Gangetic Plains.

4.2.2 Climatology

1. Rainfall: Mean annual rainfall of the sub-zone varies approximately from 500 to 1400 mm. The sub-zone receives most of the rainfall from the South-West monsoon from June to September. the rainfall is more in Madhya Pradesh and less in Rajasthan.
2. Temperature: The areas of Madhya Pradesh of the sub-zone is having mean annual temperature of 22.5°C to 25°C except Gwalior where temperature is 25°C to 27°C, while the western parts of Rajasthan is having mean annual temperature of 25°C to 27.5°C. The maximum temperature has been recorded in the month of April and May and minimum temperature has been recorded in the month of December and January.
3. Soil: There are mainly three types of soil present in the sub-zone i.e. medium black soil(38%), mixed red and black soil(21%) and alluvial soil (29%). In addition, deep black soil, grey brown soil, red and yellow soil and skeletal soil are also observed in pockets.
4. Land Use: The subzone is having extensive area of about 52% under arable land, 23% of area under forest, 19% under grassland and scrub and remaining under wasteland, urban etc. Many new projects are proposed to come up in this subzone.

5. Communication :The following railway sections partly or wholly traverse the Area of the subzone

A)	Ajmer- Indore
B)	Ajmer-Udaipur
C)	Gangapur-Sawai Madhopur
D)	Guna-Indore via Maksi
E)	Nagda-indore via Ujjain dewas
F)	Agra-Ujjain
G)	Dholpur-Bhind

The major highways in the sub-zone are:

(i) National Highway No. 8 (Jaipur to Ajmer)
(ii) National Highway No.12 (Jaipur Bhopal via kota Biaora)
(iii) National Highway No. 11 (Jaipur to Agra)
(iv) National Highway No. 8 (Jaipur-Delhi)
(v) National Highway No. 11 (Jaipur-Fatehpur)
(vi) National Highway No.3 (Dholpur Indore via Guna)

4.2.3 Data Available

Western and Central Railway of India had observed rainfall, gauge and discharge data for 22 bridge catchments for a period of 115 bridge years under the supervision of research designs and standard organizations (RDSO). Indian meteorological Department has obtained rainfall data from its own network consisting of both self – recording (SR) and ordinary rain gauges (ORG) in and around the subzone. The catchment area varies from 28.18 Km^2 to 5729.08 Km^2 covering a very wide range and data for 5 year or more for each site was available. Central Water Commission has also prepared detailed plans of gauged catchments.

The data provided by the agencies is both basin characteristics and representative 1 hour unit hydrograph parameters. Using this data for a subzone, relation between basin characteristics and 1 hour RUG are attempted and best possible equation is selected which gives maximum reliability.

Table 4.2: Data for the subzone 1(b) as per flood estimation report of CWC

BASIN CHARACTERISTICS					REPRESENTATIVE 1 HR U.G PARMRS						
No.	A (Sq.km)	L (Km)	S (mm/m)	$L / S^{0.5}$	T_p (hr)	q_p ($m^3/s/Km^2$).	T_b (hr)	W_{50} (hr)	W_{75} (hr)	WR_{50} (hr)	WR_{75} (hr)
1.	2297.33	111.1	1.02	110.11	22.5	0.14	47	18.8	11.35	10.6	6.2
2.	1613.6	89.77	1.22	81.31	10.5	0.25	40	7.5	4	3.73	2
3.	662.81	46.69	1.46	38.59	8.5	0.28	32	8.65	4.65	2.75	1.58
4.	587.63	30	1.48	24.63	5.5	0.56	18	3.6	2.4	1.5	1
5.	419.13	37.81	2.14	25.86	4.5	0.76	15	2.62	1.4	0.98	0.68
6.	361.05	38.62	3.01	22.26	3.5	0.78	12	2.6	1.5	1	0.7
7.	349.13	30.57	2.36	19.9	3.5	0.67	12	3.3	1.65	1.5	0.75
8.	274.33	23.18	1.89	16.86	3.5	1.09	9	2.1	1.2	1	0.6
9.	237.14	28.32	3.05	16.22	3.5	0.57	12	4.2	2.1	1.2	0.8
10.	145.45	14.5	2.21	9.75	2.5	0.62	13	3.9	2.1	1.5	0.9
11.	140.43	29.38	2.35	19.16	2.5	0.57	11	4.5	2.5	1.7	1.1
12.	108.78	15.78	3.34	8.64	2.5	0.83	12	2.85	1.4	0.95	0.45
13.	66.3	19.8	1.76	14.92	4.5	0.5	15	4.7	2.2	1.6	0.8
14.	47.44	10.78	3.91	5.45	1.5	1.14	8	1.95	1.05	0.75	0.45
15.	44.75	17.2	5.5	7.34	1.5	1.3	7	1.65	1.05	0.85	0.55
16.	43.77	13.7	3.1	7.78	1.5	0.46	14	5.4	3.6	1.4	1.2
17.	41.44	12.63	4	6.3	1.5	0.75	13	2.49	1.14	0.95	0.54
18.	39.52	12.81	1.01	12.73	2.5	0.76	9	3.1	1.6	1.4	0.8
19.	26.18	7.56	2.75		1.5	0.76	10	3.3	1.65	.90	.45

4.3 HOMOGENEITY OF THE REGION

Regional flood frequency analysis deals with the identification of homogenous regions of which the distribution of peak flows from sites from such a region are similar.

A region can be considered as homogenous for flood frequency analysis if there is sufficient evidence that data from various sites of a region corresponds to similar response of catchment for the input rainfall for runoff, infiltration etc. & catchment has similar properties throughout the area. It can be said that data from sites of a homogenous region are drawn from same distribution (except the scale parameter). The regional distribution after dividing by scale parameter is called Regional Growth Curve. Geographical proximity does, however, not guarantee hydrological similarity. Therefore, it is better to define similarity between sites based on catchment related characteristics or statistical flow characteristics. Various tests to estimate the homogeneity of the region is L-Moment ratio Diagrams Test, STU index method etc. In L-Moment ratio Test, all the sites of a homogenous region have same population L-moments. STU index method is based on numerical difference between the arithmetic averages of the site data.

In cases where rainfall or rain flow records are not available at or near the site of interest, it is very difficult for engineers and hydrologists to derive reliable flood estimates directly and regional studies are useful. Once a homogenous region is identified, data from various sites from such a region can be pooled together and curves applicable to the region can be derived.

An ungauged (or gauged) site can then be assigned to a region based on catchment characteristics alone. The various properties of the catchment to be studied for homogeneity of the region are slope, form factor, elongation ratio, circulatory ratio, flood response etc.

Various parameters to be studied for determining Homogeneity of the region are:

1. **SLOPE**: It is the ratio of vertical difference between two points and the longitudinal distance between them. A catchment is considered as plain if slope is less than 2m/km and hilly if slope is more than that.

2. **Elongation Ratio (R_e)**: It is defined as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. Areas

with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin. The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climate and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope [7]. These values can be grouped into categories namely (a) circular (>0.9), (b) oval (0.9 to 0.80) (c) less elongated (<0.7). The values of Re varies from 0.26 to 0.46 indicates that the catchment falls in the less elongated category.

$$\boldsymbol{R_e = \frac{2}{L_b}\sqrt{\frac{A}{\pi}}}$$

3. **Form factor (F_f)**: It is defined as the ratio of basin area to the square of the basin length. The values of form factor would always be less than 0.7854 (perfectly for a circular basin). Smaller the value of (Ff) more elongated will be the basin. The form factor for all watersheds varies from 0.05 – 0.16

$$\boldsymbol{R_f = \frac{A}{L_b^2}}$$

4. **Circularity ratio:** It is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin. It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the watershed. For a pure circular area its value is 1. Lesser values of circulatory ratio correspond to elongated shape of the catchment.

$$\boldsymbol{R_c = \frac{2}{L_p}\sqrt{\pi * A}}$$

India has been divided into 26 hydrological homogeneous subzones. Chambal Subzone 1(b) is one of the homogenous subzones. It covers about 1,46,000 square km of area in states of Madhya Pradesh, Rajasthan and Uttar Pradesh.

In this subzone, there are 19 sub-basins which have very recent flood data available for estimation of flood.

Since it is a very large area, it is to be tested for homogeneity of the region for applying various regional methods for prediction of Unit Hydrograph and Flood Estimation studies. The parameters to be used for estimating homogeneity of the region are Slope, Form factor, Elongation Factor.

The geomorphological data available for the subzone in CWC flood estimation report 2002 provides Area of the various sub basins, Length of the catchments, Slope of the sub-basins. The calculations of various parameters are given below:

Table 4.3: Parameters of Homogeneity

S. No.	BRIDGE SITE	A(Km^2)	L(Km)	S(m/Km)	Form Factor	Elongation Ratio
1	94	2297.33	111.1	1.02	0.18	0.48
2	519	1613.6	89.77	1.22	0.20	0.50
3	72	662.81	46.69	1.46	0.30	0.62
4	283	587.63	30	1.48	0.65	0.91
5	198	419.13	37.81	2.14	0.29	0.61
6	221	361.05	38.62	3.01	0.24	0.55
7	272	349.13	30.57	2.36	0.37	0.69
8	140	274.33	23.18	1.89	0.51	0.80
9	437	237.14	28.32	3.05	0.29	0.61
10	39	145.45	14.5	2.21	0.69	0.93
11	51	140.43	29.38	2.35	0.16	0.45
12	44	108.78	15.78	3.34	0.43	0.74
13	495	66.3	19.8	1.76	0.16	0.46
14	406	47.44	10.78	3.91	0.41	0.72
15	1	44.75	17.2	5.5	0.15	0.43
16	306	43.77	13.7	3.1	0.23	0.54
17	118	41.44	12.63	4	0.25	0.57
18	35	39.52	12.81	1.01	0.24	0.55
19	77	26.18	7.56	2.75	0.46	.76

4.3.1 Results

1. The slope studies for the catchment indicate that whole of the subzone lies in the HILLY region.
2. The values of Elongation Ratio indicates that whole of the subzone has HIGH RAINFALL AND LOW INFILTRATION.
3. From the range of values of Elongation ratio (0.33-0.65) indicates that subzone is LESS ELONGATED and Form Factor (0.1-0.25) indicates that subzone is ELONGATED

4.3.2 Conclusion

Since almost whole of the region is HILLY, all sub-basins have similar shape (LESS ELONGATED) and rainfall and infiltration characteristics are similar (HIGH RAINFALL AND LOW INFILTRATION). It can be said with certainty that Chambal Subzone 1(b) is Hydrologically Homogenous Subzone

Regional method of regression analysis for calculation of parameters of Unit Hydrograph and estimation of Flood by Synthetic Unit Hydrograph for ungauged catchments in this subzone can be applied with fair degree of accuracy.

CHAPTER 5

SYNTHETIC UNIT HYDROGRAPH

5.1 NEED OF REGIONAL HYDROMETEOROLOGICAL APPROACH

High cost involved in setting up gauging stations, it is not possible to observe data over a long period or at many locations of the catchment drainage network. Thus, although many large catchments are gauged, a majority of small catchments still remain ungauged. Estimation of design floods for a very large number of bridges, culverts, cross drainage works and small scale river valley projects is extremely difficult due to inadequacy or total absence of hydrologic data in the catchments. To overcome this and the difficulties caused by global atmospheric changes and changes in land use pattern in the catchments, extensive studies are in progress to relate runoff to geomorphology of the catchment. Hydro meteorological approach has been adopted for developing a regional method for estimating design flood for small and medium catchments in various hydro meteorologically homogeneous subzones. The design storm after converting to effective rainfall is applied to unit hydrograph to obtain design flood. Collection of regional data for every new site is neither practicable nor economically feasible on large scale; regional method for developing representative Synthetic unit hydrograph (SUH) is resorted. The term *synthetic* in SUH denotes the unit hydrograph derived from watershed characteristics rather than rainfall-runoff data. If data of 3-4 flood events of recent years is available, a reliable UH can be developed. It is developed from relations established between physiography and unit hydrograph parameters of the catchment in hydro meteorologically homogeneous subzones. The first synthetic unit hydrograph procedure was presented by Snyder (1938) in a study of basins located in the Appalachian Mountain region. According to him, based on assumptions of theory many of the properties of the discharge hydrograph could be determined empirically from physical characteristics of the drainage basin. Equations are developed for computing the unit hydrograph for ungaged watersheds. The equations use physical characteristics of the drainage basin to predict the parameters for the unit hydrograph.

5.2 DATA REQUIRED

For developing equations for derivation of SUG, concurrent rainfall runoff data for a number of small and medium catchment located in a subzone are required for 5-8 years during monsoon season:

1. Hourly gauge data at gauging site
2. Gauge and discharge data 2-3 times a day at gauging site
3. Hourly rainfall data of RG station in the catchment.

4. Catchment area plans showing the river network, location of rain gauge station & gauge and discharge sites, contours. Roadway and railway network, forests, natural and man-made storages, habitations, forests, agricultural and irrigated areas, soils etc.
5. Cross section of river at gauging site and upstream and downstream of the bridge site
6. Longitudinal section of river upstream and downstream of the bridge site.

The size of the ungauged catchments varies from 9 km^2 to 4000 km^2. Sites catchment area less than 25 km^2 are usually not considered for the study. The field offices of India Railways under the supervision and guidance of its Research Designs and Standards organization (RDSO) observe and collect the data for various small and medium size catchments in India. After the scrutiny of data and consistency checks, catchments found suitable for SUH studies are selected.

5.3 DEVELOPMENT OF 1-HOUR S.U.H.

The sub zone may consist of two regions hilly and plain.

1. Hilly region: slope lies between 2 to 9.37 m/km
2. Plain region: slope less than 2 m/km

Subzone is bifurcated as plain and hilly considering the location of gauged catchments.

Equations correlating unit hydrograph and physiographic parameters of gauged catchments for derivation of SUG for hilly and plain regions are discussed.

One hour SUG equations for an ungauged catchment are derived by studying the physiographic features of the area and the representative unit-graph data. It is discussed as follows:

5.3.1 Physiographic parameters of the catchment

1. Catchment Area (A)**:** The gauging site is located on a toposheet and the watershed boundary is marked. The area enclosed in this boundary upto the gauging site is measured.

2. Length of the Main Stream (L): This implies the longest length of the main river from the farthest watershed boundary of the catchment area to the gauging site.

3. Length of the main stream from a point near the centre of gravity of catchment to the bridge site (Lc)

4. Stream slope (S): it is one of the physiographic parameter.

(a) Equivalent Slope*:* L-section is broadly divided into 3 to 4 segments representing the broad ranges of slopes of-the segments and the following formula is used

$$S = \frac{\sum L_i(D_{i-1}+D_i)}{L^2}$$

L_i is Length of the i^{th} segment in Km
D_{i-1}, D_i is Elevation of river bed at i^{th} intersection points of contours reckoned from the bed elevation at points of interest considered as datum and $D_{i-1}$and D_i are the heights of successive bed location at contour & intersections.

L is Length of the longest stream in km

Longitudinal section (L-section) of the main stream is prepared from the values of the contours across the stream or the spot levels near the banks with respect to their distances from the point of interest/gauging site. A line is so drawn by trials from the point of intersect on the L-section such that the areas of the L-section (profile) above and below the line are equal. This line is called equivalent stream slope line.

(b) Statistical Slope*:* It is generally not preferred to use statistical slope. Equivalent slope should be used. It is given by

$$S = \frac{L}{\sum\left(\frac{L_i}{S_i}\right)^2}$$

In working out statistical slope the sudden drops in the stream are not considered.

whereS$_1$, S$_2$... S$_n$ is slope of main stream in the reaches L$_1$, L$_2$ ... L$_n$ into which the total length (L) is divided mainly as per contour intervals.

5.3.2 Unit hydrograph Parameters of the catchment

1. Scrutiny of data and finalization of gauge and discharge rating curve

The data is scrutinized through arithmetical checks and gauge and discharge rating curve(s) are drawn either on linear scale or log-log scale. The stages for conceivable floods are converted into discharges initially identified with reference to rise and fall in the stages of the river.

2. Selection of flood and corresponding storm events

i) The flood should not have unduly stagnant water levels.

ii) The selected flood should result from rainfall excess generally not less than one cm. Based on the above criteria flood events are selected for UG studies.

3. Computation of hourly catchment rainfall

Thiessen network is drawn for the rain gauge stations on the catchment map and Thiessen Weights are computed. One hour point rainfall at each station is multiplied by its respective Thiessen Weight and added to obtain the catchment rainfall for each hour duration during the storm period.

4. Computation of Infiltration loss (ø-index) and 1-hour effective rainfall units

With the known values of 1-hour catchment rainfall and the direct runoff depth for each flood event, the infiltration loss (constant loss rate) by trials is estimated. 1-hour infiltration loss is deducted from 1-hour rainfall to get 1- hour rainfall excess units.

5. Separation of base flow:

The selected flood events are plotted on the normal graph paper. The base flow is separated through the normal procedure to obtain direct surface runoff hydrographs and the direct runoff depth over the catchment is computed for each flood event.

6. Derivation of 1-Hour Unit Hydrographs:

The unit duration of 1-hour is adopted for derivation of unit hydrograph. The 1-hour unit hydrograph are derived from the rainfall excess hyetographs and their corresponding direct runoff hydrograph by iterative method. The iterations are carried out till the observed and estimated direct runoff hydrographs compare favorably. Several unit hydrographs are derived for each of the catchments.

7 Drawing of representative Unit hydrographs measuring their parameters:

Set of Unit hydrographs as obtained above for a catchment are superimposed and an average representative Unit graph (RUG) are derived and tested on observed flood events. The parameters of RUH i.e.t_p, q_p, W_{50}, W_{75}, WR_{50}, WR_{75} & T_b for catchments are worked out and hourly ordinates of RUGS of catchments are tabulated.

Where,

T_r	Unit rainfall duration in hour.
T_p	The lag time from centre of unit rainfall duration to the peak of unit hydrograph (hours).
Q_P	Peak discharge of unit hydrograph in cumecs.
Q_p	Peak rate of discharge of unit hydrograph in cumecs per sq.km of the catchment.
T_b	Base period of unit hydrograph in hours.
W_{50}	Width of the unit hydrograph measured at 50% of the maximum peak discharge Q_p
W_{75}	Width of the unit hydrograph at 75% of the maximum peak discharge Q_p
WR_{50}	Width of the unit hydrograph at 50% of Q_p between the rising limb and the Qp
WR_{75}	Width of the unit hydrograph at 75% of the Q_p between the rising limb & Qp

5.4 Snyder's Method

For the first time Snyder established a set of empirical relationships, which relate the watershed characteristics, i.e.

A = area of the watershed (Sq. miles); L = length of main stream (miles); and L_c = the distance from the watershed outlet to a point on the main stream nearest to the centre of the area of the watershed (miles) to the three basic parameters of the UH i.e. tp = lag to time to peak Hr, Q_p = peak discharge rate (ft^3/s); and T_b = base time (hr). This is used to describe the shape of the UH, expressible as:

$$T_p = C_t (L\ L_c)^{0.3}$$

$$Q_p = 640\left(A * \frac{C_p}{T_p}\right)$$

$$T_b = 3 + 3\left(\frac{T_p}{24}\right)$$

where C_t and C_p are non-dimensional constants and in general varies from 1.8 to 2.2 and 0.56 to 0.69, respectively.

These Equations hold good rainfall-excess (RE) duration (or unit duration= T_r) as

$$T_r = \frac{T_p}{5.5}$$

Also,

W_{50}= 830 $q_p^{1.1}$

W_{75}= 470 $q_p^{1.1}$

5.5 SYNTHETIC RELATION DEVELOPED BY CWC FOR SUBZONE 1(b)

Simple regression relationships have been worked out by CWC with the parameters that can be easily determined.

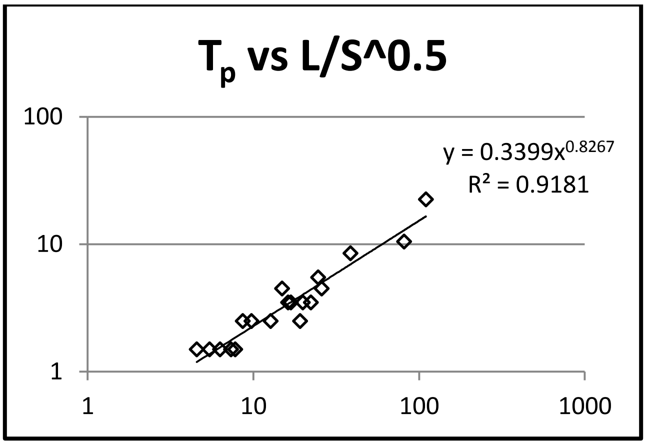
Synthetic relationship between 1 hour RUHG parameters and basin characteristics as developed by C.W.C. 2002 report are given below:

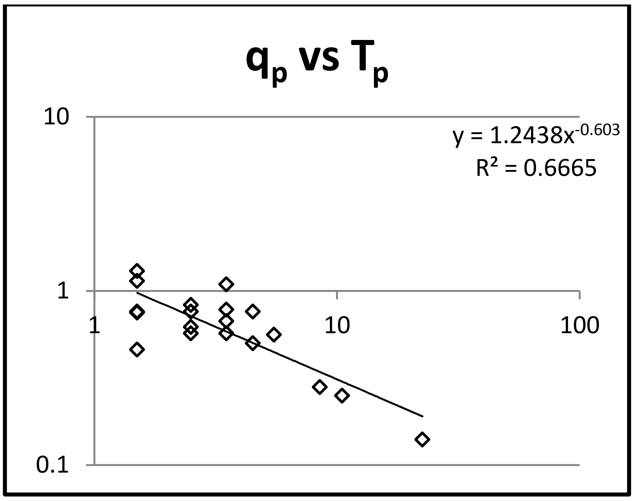
$T_p = 0.339(L / S^{0.5})^{0.826}$	**r^2=0.958**
$q_p = 1.251(T_p)^{-0.610}$	**r^2=0.817**
$W_{50} = 2.215(q_p)^{-1.034}$	**r^2=0.984**
$W_{75} = 1.191(q_p)^{-.1.057}$	**r^2=0.968**
$WR_{50} = 0.834(q_p)^{-1.077}$	**r^2=0.948**
$WR_{75} = 0.502(q_p)^{-1.065}$	**r^2=0.932**
$T_b = 6.662(T_p)^{0.613}$	**r^2=0.877**
$T_m = T_p + \frac{T_r}{2}$	

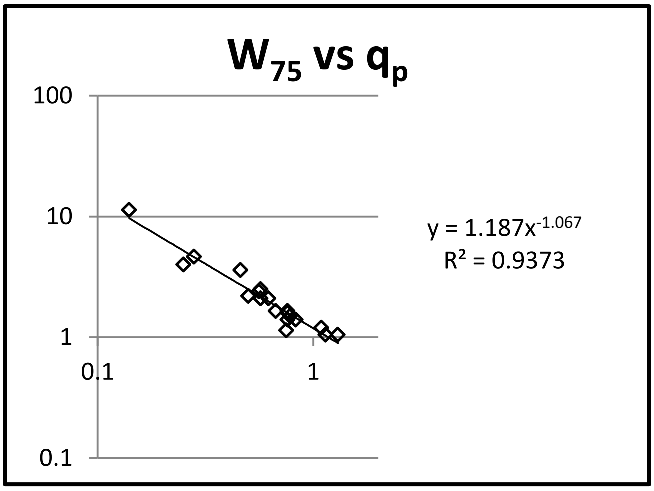
5.6 EQUATIONS DERIVED USING SPSS

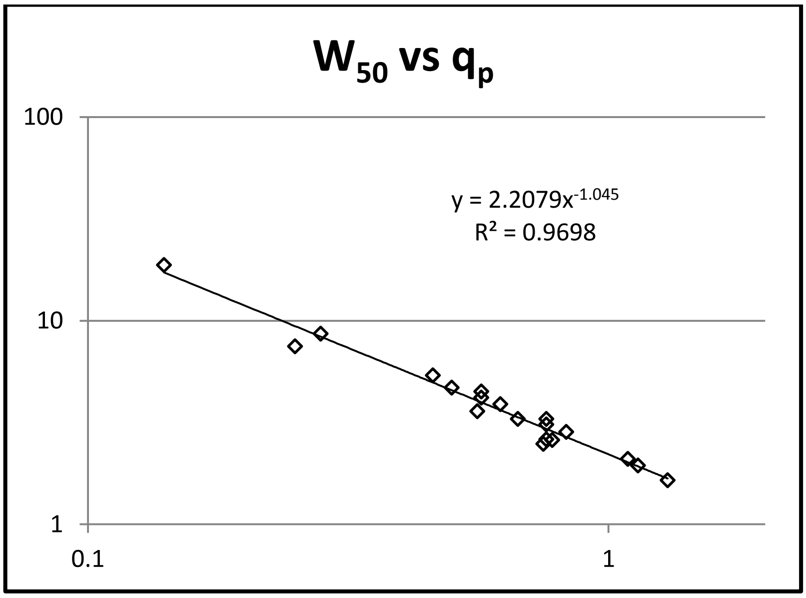
Following relationship are developed between 1-hour UH parameters and basin characteristics using Regression Analysis

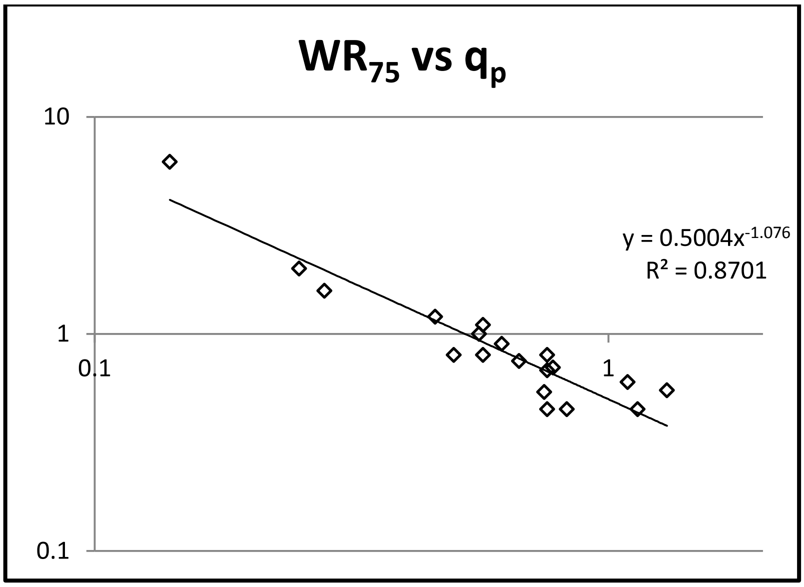
$T_p = 0.3399(L * / S^{0.5})^{0.826}$	**r^2=0.918**
$q_p = 1.243(T_p)^{-0.603}$	**r^2=0.666**
$W_{50} = 2.207(q_p)^{-1.045}$	**r^2=0.969**
$W_{75} = 1.187(q_p)^{-.1.067}$	**r^2=0.937**
$WR_{50} = .831(q_p)^{-1.087}$	**r^2=0.894**
$WR_{75} = 0.500(q_p)^{-1.076}$	**r^2=0.870**
$T_b = 6.662(T_p)^{0.612}$	**r^2=0.768**

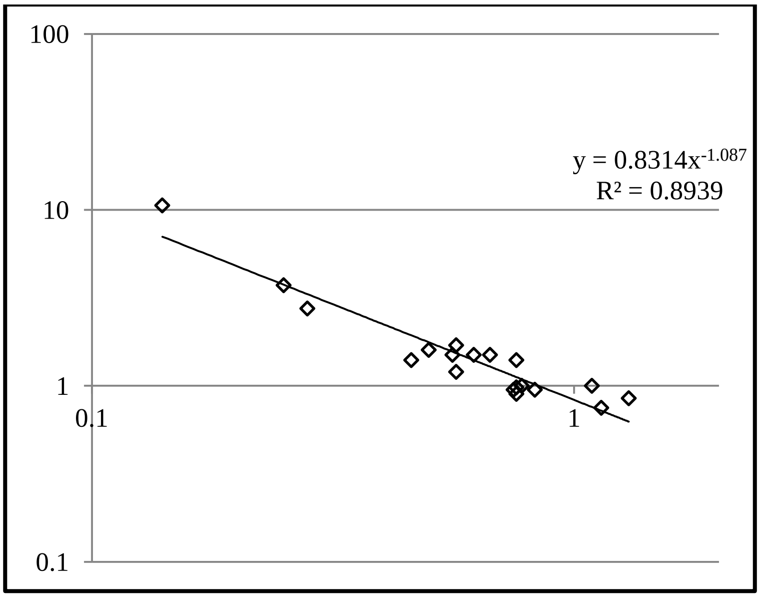

Tp vs L/S^0.5
100
10
1
1
10
100
1000
y = 0.3399x^0.8267
R² = 0.9181


qp vs Tp
10
1
0.1
1
10
100
y = 1.2438x^-0.603
R² = 0.6665


W75 vs qp
100
10
1
0.1
0.1
1
y = 1.187x^-1.067
R² = 0.9373


W_{50} vs q_p
100
10
1
0.1
1
$y = 2.2079x^{-1.045}$
$R^2 = 0.9698$


WR_{75} vs q_p
10
1
0.1
0.1
1
$y = 0.5004x^{-1.076}$
$R^2 = 0.8701$



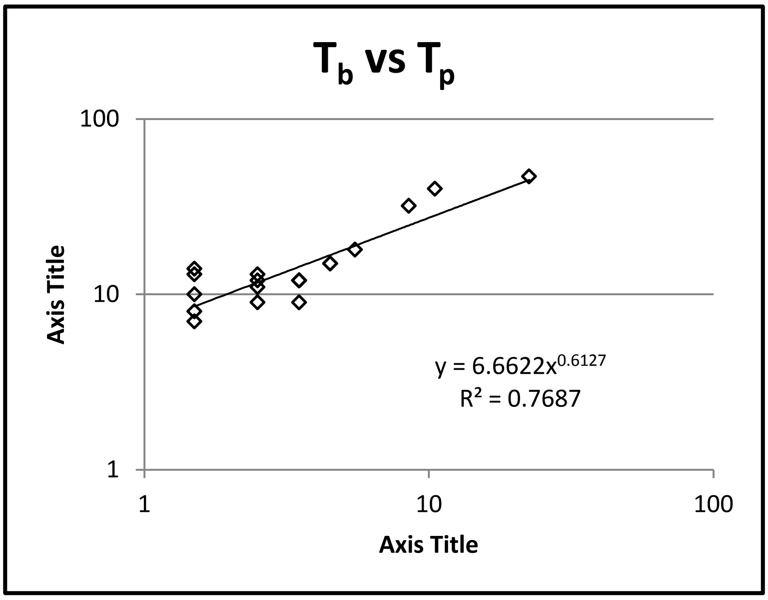


Fig 5.1: Relations between UH parameters similar to CWC

CWC in Synthetic Hydrograph study of the subzone removed the indenters which had high variation with the Trend. While developing equations by SPSS software all the data points were taken for study.

The value of Pearson Correlation Coefficient (r^2) developed using SPSS regression considering all data is less than those developed by CWC. Hence relations developed by CWC are found more satisfactory. The unit hydrograph for the region will be better approximated with the help of CWC equations.

5.7 MULTIPLE NON LINEAR REGRESSION STATISTICAL MODEL FOR SYNTHETIC UNIT HYDROGRAPH

The construction of dimensionless unit hydrograph model in this study uses regression statistical approach, which finds out the correlation between elements of unit hydrograph and observed characteristics of watershed. These elements include time to peak (T_p), peak discharge (Q_p), and base period (T_b), UH width at 0.5Qp (W_{50}), UH width at 0.75Qp (W_{75}) etc, while the observed characteristics of watershed consist of watershed area (A), average river slope (S), length of river (L), stream length from catchment centroid to outlet (L_c) and other characteristics supposed to have close correlation with unit hydrographic elements.

1. Time of Peak (T_p) Modeling:

The time of peak modeling in this study is obtained by deciding the correlation between time to peak and watershed characteristics in study area. Judgment of watershed physical characteristics may be obtained based on hydrologic analysis between watershed characteristics and time to peak as well as previous results. In such study, researchers have attempted to include parameter such as main river length (L) and river slope (S), river length from the nearest point of centroid to outlet of watershed (Lc), length of watershed (Lb), and form factor (FD).

$$Tp = f(L, S, L_c, L_b)$$

Model derivation of time of peak is conducted with multiple non-linear statistic regression models.

The proposed pattern of this model is :

$$Tp = A_o \mathbf{L}^{A1} L_c^{A2} S^{A3} L_b^{A4}$$

Where:- T_p = Time of peak (dependent variable)

L = Length of main river current (independent variable)

L_c = Length of river to the nearest point of watershed.

S = Main river slope (independent variable)

L_b = Length of watershed (km), (independent variable).

2. Peak discharge (Q_p) modeling:

Determining the correlation between peak discharge and watershed characteristic of study area is carried out for peak discharge modeling. Establishing of an watershed physical characteristic considered to have an influence on peak discharge quantity, is performed in line with analysis of hydrological connection between watershed characteristics and peak discharge as well as the results a previous research. The researchers have considered parameters of main river length (L) and watershed area (A), main river slope (S) and length of river to nearest point of watershed (Lc), time of peak (Tp) .

$$Qp = f(L, A, S, Lc, Tp)$$

The proposed equation of multiple non-linear regression is :

$$\mathbf{Qp = A_0}\, L^{A1} .\, L_c^{A2} .\, S^{A3} A^{A4} .\, Tp^{A5}$$

Q_p = Peak discharge (m^3/sc), (dependent variable)

3. Base period (T_b) modeling:

Establishing correlation between base period and watershed characteristics conducts base of time modeling in this study. The determination of watershed physical characteristics referred to having effect on base period quantity (Tb) is implemented based on hydrological connection analysis between watershed characteristics and base period as well as the results of previous research. In this case, it is proposed to include parameter of main river length (L) , watershed area (A) , Qp , main river slope (S) and time of peak (Tp) .

$$Tb = f(L, A, Qp, S, Tp)$$

The proposed equation of multiple non-linear regression is:

$$Tb= A_o L^{A1} .\, A^{A2} .\, s^{A3} .\, Tp^{A4} .\, Qp^{A5}$$

4. UH widths (W50 $_y$ W75 WR50 WR75) modeling:- The proposed equation of multiple non linear regressions is:

$$W50 = A_0\, L^{A1} .\, Qp^{A2} .\, S^{A3.}\, Tp^{A4}$$

$$W75 = A_0\, L^{A1} .\, A^{A2}\, Qp^{A3} \bullet S^{A4} \bullet Tp^{A5}$$

$$WR50 = Ao\, L^{A1} .\, A^{A2} \bullet Qp^{A3} \bullet S^{A4} \bullet Tp^{A5}$$

$$WR75 = A_0\, L^{A1} .\, A^{A2}\, Qp^{A3} \bullet S^{A4} \bullet Tp^{A5}$$

5.7.1 Multiple Non Linear Regressions For Subzone 1(b)

CWC has used simple non linear regression relations for easy application. They derived a basin characteristic parameter $\frac{L}{g^{0.5}}$ for the subzone 1(b) and hence related the parameters of unit hydrograph with this derived parameter. With availability of computer software, now it is not necessary to sacrifice reliability for the sake of simplicity. Rigorous reliability tests can be easily performed for selecting best relationship.

Relationships between Geo-morphological Parameters and 1 hour U.H. Parameters:

1. TIME TO PEAK (T_P):

$T_p = 0.52L^{0.74}S^{-0.58}$, R^2=0.926

$\boldsymbol{T_P = .573\ L^{0.32}q_p^{-0.25}S^{-0.43}A^{.19}}$, R^2=0.94

$T_P = .519\ L^{0.492}A^{0.145}S^{-0.55}$, R^2=0.933

$T_P = 0.340\left(\frac{L}{S^{.5}}\right)^{0.826}$, R^2=0.918

2. PEAK DISCHARGE (Q_P):

$\boldsymbol{Q_P = .920\ T_P^{-0..73}A^{1.27}L^{-0.31}S^{0.08}}$ **,** R^2=0.921

$Q_P = .93\ T_P^{-0.81}A^{1.27}L^{-0.27}$, R^2=0.920

$Q_P = .714T_P^{-0.89}A^{1.17}\ S^{-.007}$, R^2=0.917

$Q_p = .709\ T_p^{-.89}\ A^{1.17}$, R^2=0.917

3. BASE TIME PERIOD (T_b):

$\boldsymbol{T_b = 5.508\ Q_p^{-0.69}T_p^{0.132}A^{.76}S^{0.093}}$, R^2=0.934

$T_b = 7.16\ Q_p^{-.218}T_p^{0.709}L^{.224}S^{.133}$, R^2=0.832

$T_b = 9.09Q_p^{-0.181}T_p^{0.904}S^{0.214}$, R^2=0.823

4. W_{50}:

$\mathbf{W_{50} = 3.03\ T_P^{0.06}S^{0.005}A^{-0.02}q_p^{-1.11}L^{-0.09}}$, R^2=0.976

$\mathrm{W_{50} = 3.03\ T_p^{0.056}A^{-0.02}q_p^{-1.11}L^{-0.09}}$, R^2=0.970

$\mathrm{W_{50} = 3.26\ T_p^{0.958}A^{-0.327}L^{.209}}$, R^2=0.660

$\mathrm{W_{50} = 2.20q_p^{-1.044}}$, R^2=0.969

5. **W$_{75}$:**

$\mathbf{W_{75} = 1.267\ T_P^{-0.105} S^{-0.03} A^{0.027} q_p^{-1.14} L^{-0.026}}$, R^2=0.940

$W_{75} = 1.256\ T_p^{-0.068} A^{0.025} q_p^{-1.144} L^{-0.04}$, R^2=0.930

$W_{75} = 1.35\ T_p^{0.862} A^{-.289} L^{.270}$, R^2=0.626

$W_{75} = 1.18\ q_p^{-1.067}$, R^2=0.937

6. **WR$_{50}$:**

$\mathbf{WR_{50} = 0.75\ T_P^{0.146} S^{-0.162} A^{-0.114} q_p^{-0.78} L^{0.252}}$, R^2=0.925

$WR_{50} = 0.726\ T_p^{0.300} A^{-0.120} q_p^{-0.79} L^{0.17}$, R^2=0.921

$WR_{50} = 0.765\ T_p^{0.94} A^{-0.338} L^{.389}$, R^2=0.784

$WR_{50} = 0.831\ q_p^{-1.08}$, R^2=0.893

7. **WR$_{75}$:**

$\mathbf{WR_{75} = 0..28\ T_P^{-0.242} S^{-0.237} A^{-0.066} q_p^{-0.869} L^{0.475}}$, R^2=0.907

$WR_{75} = 0.267\ T_p^{-0.017} A^{-0.076} q_p^{-0.884} L^{0.358}$, R^2=0.897

$WR_{75} = 0.283\ T_p^{0.70} A^{-0.319} L^{.601}$, R^2=0.727

$WR_{75} = 0.501\ q_p^{-1.07}$, R^2=0.870

5.8 COMPARISON OF MULTIPLE REGRESSION METHOD &CWC'S SUH METHOD

1. By comparison of equations of both the method on the basis of regression coefficient, for few equations SUH method is more appropriate amd for few parameters multiple regression is more appropriate.
2. Results of Q_p using Multiple Regression method is much different from the RUH data available in report and should not be used.
3. Both the methods can be used together and best equation should be selected for more accurate work of flood estimation.

CHAPTER-6

GAMMA HYDROGRAPH

6.1 INTRODUCTION

Out of many ways of drawing the unit hydrograph, one of the most accurate methods of deriving is Gamma hydrograph. By gamma hydrograph we get Instantaneous Unit Hydrograph i.e. UH of zero hour (almost) duration (IUH) from the effective rainfall (Precipitation minus losses)

Synthetic unit hydrographs are used in the determination of flood peak and runoff volume, especially from ungauged watersheds. These utilize empirical equations to estimate salient points of the hydrograph, such as peak flow (Qp), lag time (t_L), time base (t_B), and UH widths at $0.5Qp$ and $0.75Qp$. A great degree of subjectivity is involved in fitting the remaining points on the UH. In addition, these fitted curves require simultaneous adjustments for the area under the SUH to represent unit runoff volume. Some of the most common and important probability distributions used in hydrology are the normal, log-normal, gamma, Gumbel and Weibull. In hydrology, the gamma distribution has the advantage of having only positive values, since hydrological variables such as rainfall and runoff are always positive (greater than zero) or equal to zero.

For the derivation of an SUH, the two-parameter gamma distribution is commonly used in various forms depending on boundary conditions, such as peak flow rate and time to peak. In gamma hydrograph method for a given UH only two parameters are required to develop the IUH: $\mathbf{q_p}$ (peak discharge) & $\mathbf{T_p}$ (time to peak). Thus calculation of various parameters like W_{50}, W_{75}, WR_{50} and WR_{75} etc in developing SUH is eliminated.

6.2 GAMMA DISTRIBUTION

The two-parameter gamma distribution has long been used for modeling event based Rainfall–runoff processes.

A two parameter gamma distribution is expressed as:

$$\mathbf{f(X)=e^{-X/k} * (X/k)^{n-1} / (k * gamma(n))}$$

n and K are parameters that define the shape and scale of the Gamma Distribution & q is the IUH (runoff depth resulting from effective rainfall).

In conceptual terms, n is the number of linear reservoirs with equal storage coefficient K (Nash, 1958, 1959; Dooge, 1959).

The area under gamma distribution curve is unity thus the rainfall and runoff depths are equal to unity.

6.3 METHOD OF DEVELOPING GAMMA HYDROGRAPH

Previous attempts to fit a Gamma distribution to hydrographs were by Croley (1980), Aron and White (1982), Hann et al. (1994), and Singh (1998).

Based on their methods, Mc Cuen (1989) listed a step-by-step procedure to obtain UH, which may be briefly described by the following equations:

$n = 1.045 + 0.5\ f + 5.6\ f^2 + 0.3\ f^3$

Where, $f = \frac{Q_p T_p}{A}$

Q_p is in cubic feet per second (ft^3/sec); Tp is in hours; and *A* is in acres.

In this method, care is to be taken of units of various parameters, while calculating the value of f and n

Hann et al. (1994) gave the following expression to calculate *n*:

$n = 1 + 6.5\left(q_p * \frac{T_p}{V}\right)^{6.5}$

Where *V* = total volume of effective rainfall.

Equation developed by Singh (1998) to obtain the value of *n:*

$n = 1.09 + 0.164\beta + 6.19\beta^2$

Where β = product of q_p & T_p (it is a dimensionless parameter)

where q_p is the peak runoff depth per unit time per unit effective rainfall and T_p is time to peak discharge.

Also, by Singh (1988, 2000);

$n=5.53\beta^{1.75} + 1.04$ $\quad 0.01<\beta<0.35$

$n=6.29\beta^{1.998} + 1.157$ $\quad \beta>0.35$

$n=0.158/\lambda^2 + 0.831$ $\quad \lambda <=0.27$

$n=21.834\lambda^2 - 23.58\lambda + 7.716$ $\quad \lambda >0.27$

Where $\lambda= 0.029 + 0.636/(1+ 4.13\ \beta^{1.52})$; $\beta >=0.54$; $\lambda =<0.27$

Assuming $\boldsymbol{q = \frac{e^{-\frac{t}{k}} \left(\frac{t}{k}\right)^{n-1}}{k * gamma(n)}}$ represents UH of unit duration, Time to peak can be found by differentiating this function with respect to 't' and equating to zero.

Tp = (n-1)K

If q_m/q_{m-1} is the recession constant**,** the recession characteristics of gamma distribution function can be written as:

$$\frac{\boldsymbol{q_m}}{\boldsymbol{q_{m-1}}} = \frac{\boldsymbol{Q_m}}{\boldsymbol{Q_{m-1}}} = \left(\frac{m}{m-1}\right)^{n-1} * (e)^{\frac{\Delta t}{K}}$$

Where Qm & Q_{m-1} are discharge values at time step m and m-1, Δt is the time step (for IUH, time step can be taken as 1 minute, 10 minutes, 1hr)

Following are the equations for computing the ordinates of a Gamma UH:

$$n = 2\pi\beta^2 + \frac{7}{6} \qquad if\ \beta \le 0.35$$

$$n = 1.09 + 0.164\beta + 6.19\beta^2 \qquad if\ \beta \ge 0.35$$

$$\frac{Q}{Q_p} = \frac{q}{q_p} = e^{(n-1)\alpha}$$

In calculation of q/qp, n to be used depends on range of β.

Gamma distribution is defined by the dimensionless parameter β= q_p* t_p

$$\alpha = 1 - \left(\frac{t}{t_p}\right) + \log_e \left(\frac{t}{t_p}\right)$$

β can also be found as

$$\beta = e^{-(n-1)} * \frac{(n-1)^{n-1}}{gamma(n-1)}$$

q_p & T_p for a given UH are known, hence for a given time T, values of q can be found using above formulas. Values of q corresponding to t can be plotted. This gives us IUH.

In calculation of "**n**" the error is decreased as value of β is increased. Singh (1998) observed that error in *n* obtained is 0.53% when β = 0.25 and 0.05% when β = 1.0. The error calculated in *n* decreases with increasing values of β. Table is given below:

Table 6.1: Error in calculation of "n"

β	0.25	0.40	0.60	0.80	1
% error in "n"	0.53	0.35	0.15	0.09	0.05

Variation of q/q_p with λ

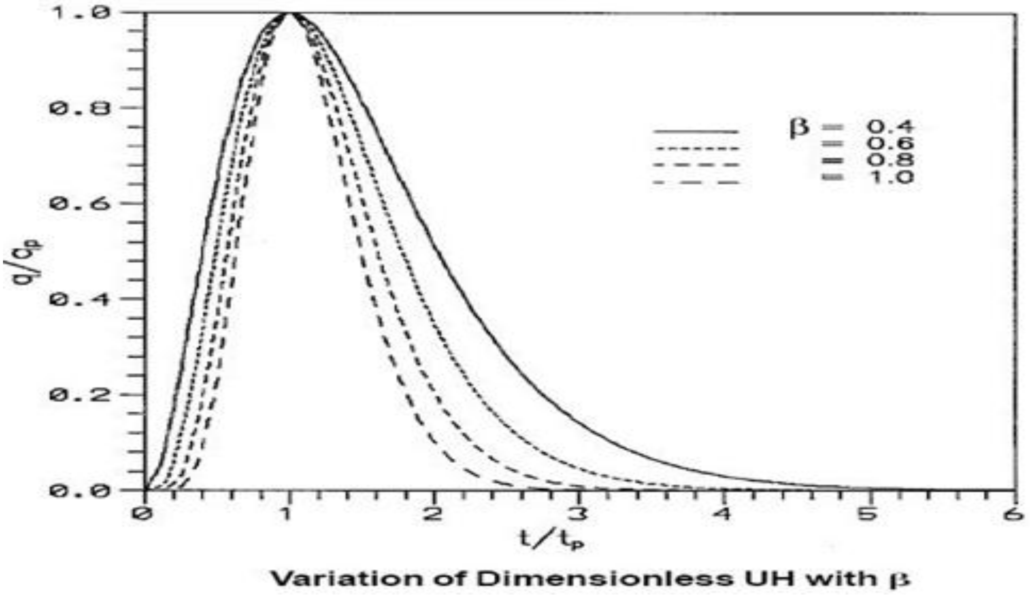


Figure 6.1: Variation of q/q_p with β (source: Bhunya et al. 2003. simplified two parameter gamma distribution for derivation of synthetic uni hydrograph. *Journal of Hydrologic Engineering*)

6.4 COMPARISION OF SUH METHOD (Clark's and Espey method) AND GAMMA HYDROGRAPH METHOD

Gamma UH represent the hydrograph recession better than the Clark's UH method. for developing the UH using Clark's Method parametric form of Time-Area curve is needed which is not available for most of ungauged sites. The use of this curve renders the method unjustified and inadequate for most of the regions. gamma method based hydrograph can be obtained without optimization and is better than the Clark's method based UH. Gamma hydrograph is generally found consistent with their physical meanings and better than the most of methods available.. Two parameters are required for developing Clark's UH i.e. recession constant & time of concentration (t_c). Due to unavailability of Time-Area curve the parameters are generally found inconsistent with their physical meaning.

1. GUH requires lesser parameters tan the Clark's method based UH. GUH is more identifiable and maintain connection with the physics of the problem. SUH developed using Espey's method when changed to gamma distribution function for peak discharge (Q_p) and time at which peak occurs. For a gauged catchment, the UH is obtained through optimized technique, can be easily drawn with the help of gamma distribution function. Thus these can also be used for developing SUH.
2. When the method used by Clark & Espey is used for drawing a SUH and is compared with gamma probability distribution function based UH, it has been found that parameters used in Clark's method lose their physical meaning because of unavailability of Time Area curve in parametric form
3. As compared to Clark's UH gamma function better represents the recession curve of the unit hydrograph because in Gamma Hydrograph method the time varying recession constant is developed whereas in other method a single cconstant value of recession constant is used for whole curve.
4. UH derived using gamma function does not need optimization. Recession constant (R) and time of concentration (t_c) of Clark's method is optimized with the help of Snyder's C_p & T_p.
5. Inconsistencies were observed in several problems of HEC-1 using the Clark's UH. These are due to the unavailability of a general parametric form of the time–area curve. The interflow and storage cannot be differentiated using this method. The use of variable R in Gamma UH take care of distinguishing the interflow and channel storages by a variable recession constant. For HEC-1 problems UH can be obtained and Hydrograph is better fitted.
6. To represent a gamma hydrograph only two parameters "n(shape) & k(size)" are required. Due to unavailable parametric form of the curve, empirical relation is not available. Even some distribution is assumed, the number of parameters required to represent Clark's curve will be 3 or 4 which will be very difficult to solve.

7. For catchments where discharge and rainfall data is available for a long period, UH can be fitted by developing the best curve or using linear programming. For such catchments UH can be easily transformed to a gamma UH. Hence parameters of gamma function can be used for developing the Hydrograph for gauged sites. This enhances the utility of numerical UH's for developing SUH.

6.5 DERIVATION OF GAMMA UNIT HYDROGRAPH

In deriving gamma hydrograph, Gamma Distribution Function is used which is given by:

$$\mathbf{q(t) = \frac{e^{-\frac{t}{k}}\left(\frac{t}{k}\right)^{n-1}}{k * gamma(n)}}$$

Where, q(t) is discharge and t is the corresponding time
n is the number of linear reservoirs and K is the shape factor of the Function

For deriving Unit Hydrograph from Gamma Distribution Function, only two parameters q_p and T_p are required and elimination of calculation of various parameters like W_{50} (time width between 50% of Q_p), W_{75}(time width between 75% Q_p), WR_{50}(time between Q_p and 50% Q_p on accession curve), WR_{75}(time between Q_p and 75% Q_p on accession curve) & T_b. Since it requires very few parameters and shape of Gamma Hydrograph is known so this method is very simple and accurate as compared to various Synthetic Hydrograph methods.

6.6 STEP BY STEP PROCEDURE FOR CALCULATION OF VARIOUS PARAMETERS OF GAMMA HYDROGRAPH

1. For the Unit Hydrograph of very small time interval(preferably 10,30 or 60 min's UH) find q_p(Discharge per unit Area)and T_p(Time to peak).
2. Find parameter, $\boldsymbol{qp = \frac{q_p}{ER}}$ where ER is effective rainfall(1cm for UH) in units of Time
3. β = product of q_P & tp (it is a dimensionless parameter),
4. Depending upon the value of β, n is found by:

$$n= 5.53\beta^{1.75} + 1.04 \qquad \mathbf{0.01<\beta<0.35}$$

$$n= 6.29\beta^{1.998} + 1.157 \qquad \mathbf{\beta>0.35}$$

5. Shape Constant for Gamma Hydrograph is, $K = \frac{T_p}{n-1}$

6. $Q/Qp = q/qp = e^{(n-1)\propto}$
7. $\alpha = 1 - \frac{T}{T_p} + \log_e \frac{T}{T_p}$
8. Since q_p & T_p is known, value of q for various Time are calculated.
9. q(in units of per time) are converted to IUH after dividing the values by **0.36**
10. IUH so calculated using the Gamma function is Gamma Instantaneous Unit Hydrograph (GUIH)
11. GIUH can be converted to 1-hour Gamma Unit Hydrograph (GUH) by lagging and averaging the GUIH by 1 hour.

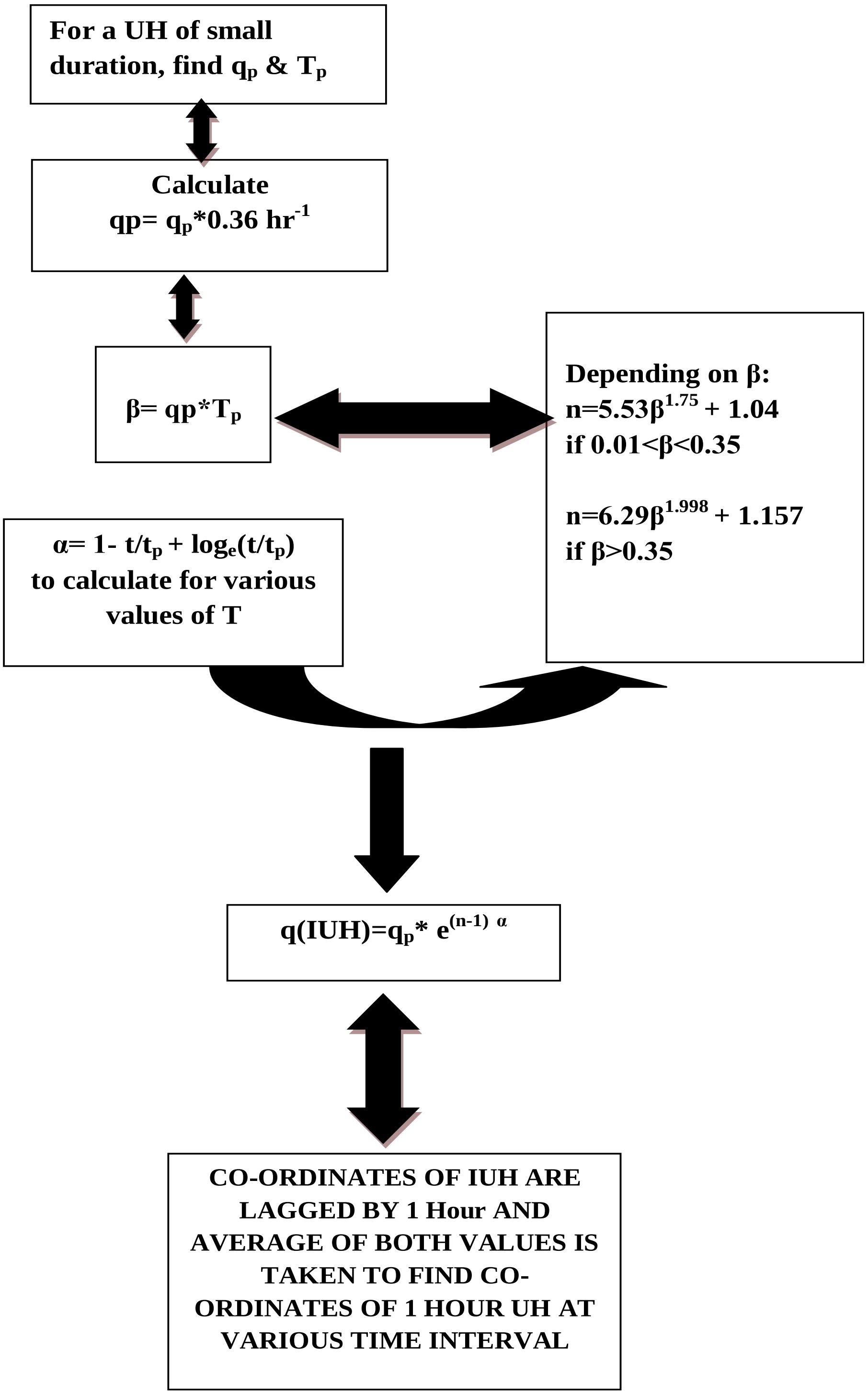


Figure 6.2 Flowchart for Developing Gamma Hydrograph

CHAPTER 7

COMAPRISON OF VARIOUS METHODS FOR DEVEOPING UNIT HYDROGRAPH

ANALYSIS OF SUB-BASIN (SITE NUM 519) OF CHAMBAL SUBZONE 1(b) FOR UNIT HYDROGRAPH:

7.1 REPRESENTATIVE UNIT HYDROGRAPH (DATA PROVIDED IN CWC REPORT)

Q_p= 395 m^3/sec L=89.77 Km

T_b= 40 hours S=1.22 m/Km

T_p= 10.50 hours

W_{50}= 7.50 hours

W_{75}= 4 hours

WR_{50}= 3.73 hours

WR_{75}= 2 hours

7.2 CENTRAL WATER COMMISSION’S SYNTHETIC UNIT HYDROGRAPH

1. $T_P = 0.339(L / S^{0.5})^{0.826}$ **r^2=0.958**
2. $q_p = 1.251(t_p)^{-0.610}$ **r^2=0.817**
3. $W_{50} = 2.215(q_p)^{-1.034}$ **r^2=0.984**
4. $W_{75} = 1.191(q_p)^{-.1.057}$ **r^2=0.968**
5. $WR_{50} = 0.834(q_p)^{-1.077}$ **r^2=0.948**
6. $WR_{75} = 0.502(q_p)^{-1.065}$ **r^2=0.932**
7. $T_b = 6.662(t_p)^{0.613}$ **r^2=0.877**
8. $T_m = t_p + t_r/2$

   Values of various UH parameters for site 519 are:

   Q_p= 425m^3/sec

   T_p= 12.82 hours

   T_b= 31.82 hours

   W_{50}= 8.78 hours

   WR_{50}= 3.50 hours

   W_{75}= 4.86 hours

   WR_{75}= 2.07 hours

7.3 MULTIPLE NON-LINEAR REGRESSION MODELING CONSIDERING ALL 18 SUBZONES

$$T_P =.573\ L^{0.32} q_p^{-0.25} S^{-0.43} A^{.19},$$

$$Q_P =.920\ T_P^{-0..73} A^{1.27} L^{-0.31} S^{0.08}$$

$$T_b = 5.508\ Q_p^{-0.69} T_p^{0.132} A^{.76} S^{0.093},$$

$$\mathrm{W}_{50} = 3.03\ \mathrm{T_P^{0.06} S^{0.005} A^{-0.02} q_p^{-1.11} L^{-0.09}}$$

$$\mathrm{W}_{75} = 1.267\ \mathrm{T_P^{-0.105} S^{-0.03} A^{0.027} q_p^{-1.14} L^{-0.026}}$$

$$\mathrm{WR}_{50} = 0.75\ \mathrm{T_P}^{0.146\mathrm{A}^{-0.114}\mathrm{q_p}^{-0.78}\mathrm{L}^{0.252}} \mathrm{S}^{-0.162},$$

$$\mathrm{WR}_{75} = 0.28\ \mathrm{T_P^{-0.242} S^{-0.237} A^{-0.066} q_p^{-0.869} L^{0.475}}$$

Values of various UH parameters for Chambal river (site 519) are:

Q_p= 484 m^3/sec

T_p= 12.76 hours

T_b= 33.57 hours

W_{50}= 8.35 hours

W_{75}= 5.18 hours

WR_{50}= 4 hours

WR_{75}= 3 hours

7.4 GAMMA UNIT HYDROGRAPH USING GAMMA DISTRIBUTION FUNCTION

T_P=10.5 Hours, Q_p=400.75 m^3/sec, A=1613.6 Km^2, q_p=0.25 m^3/sec/ Km^2

qp=q_p/E.R.=0.25*0.36=0.09 $hour^{-1}$

β=0.09*10.5=.95

since β>0.35, n=6.29*.95^1.998+.95=6.77

α=1-(T/9.5)+$\log_e$(T/9.5), **q/qp=**$e^{(n-1)\alpha}$

$$q=0.25e^{5.77\alpha}\ \&\ \alpha = 1 - \frac{T}{10.5} + log_e(\frac{T}{10.5})$$

For various values of **T,** α can be found which is used to find q for various time intervals. The value of q can be converted to IUH in units of Discharge per unit area and IUH can be converted to 1 hour UH by lagging it by 1 hour and taking the average of both the values. These values can be multiplied by area of sub-basin (for **site 519**, Area=1613.6 Km^2) to find the co-ordinates of the Unit Hydrograph.

7.5 CALCULATION OF UH PARAMETERS FOR SITE 519

Table 7.1: Representative Unit Hydrograph

Point	Time (hours)	X	Discharge (m^3/sec)	Y
1		0		0
2	T_p-WR_{50}	6.75	0.5Q_p	200.15
3	T_p-WR_{75}	8.5	0.75Q_p	300.225
4	**T_p**	**10.5**	**Q_p**	**400.3**
5	T_p+(W_{75}-WR_{75})	12	0.75Q_p	300.225
6	Tp+(W_{50}-WR_{50})	14.47	0.5Q_p	200.15
7	T_b	40		0

Table 7.2: Synthetic UH by CWC method

Point	Time (hours)	X	Discharge (m^3/sec)	Y
1		0		0
2	T_p-WR_{50}	9.32	0.5Q_p	212.5
3	T_p-WR_{75}	10.75	0.75Q_p	318.75
4	**T_p**	**12.82**	**Q_p**	**425**
5	T_p+(W_{75}-WR_{75})	15.61	0.75Q_p	318.75
6	Tp+(W_{50}-WR_{50})	18.1	0.5Q_p	212.5
7	T_b	31.83		0

Table 7.3: Mutiple Non Linear Regression

Multiple Non Linear Regression				
Point	**Time (hours)**	**X**	**Discharge(m^3/sec)**	**Y**
1		0		0
2	T_p-WR_{50}	8.76	0.5Q_p	242
3	T_p-WR_{75}	10.13	0.75Q_p	363
4	**T_p**	**12.76**	**Q_p**	**484**
5	T_p+(W_{75}-WR_{75})	15.31	0.75Q_p	363
6	Tp+(W_{50}-WR_{50})	17.11	0.5Q_p	242
7	T_b	33.57		0

Table 7.4: Gamma Hydrograph Method

T	**T_p**	**q_p**	**qp (hr^{-1})**	**B**	**n**	**K**	**IUH (hr^{-1})**	**q ($m^3/sec/km^2$)**	**Q FOR 1 hr IUH**
0	10.5	0.25	0.09	.95	6.77	1.82	0.00	0.00	0.00
1							0.00	0.00	0.05
2							0.00	0.00	1.55
3							0.00	0.01	10.5
4							0.01	0.03	36.34
5							0.03	0.07	84.57
6							0.04	0.12	151.86
7							0.06	0.16	227.61
8							0.07	0.20	298.87
9							0.08	0.23	354.85
10							0.09	0.24	389.29
11							**0.09**	**0.25**	**400.75**
12							0.09	0.24	391.53
13							0.08	0.22	366.18
14							0.07	0.19	330
15							0.06	0.16	288.11
16							0.05	0.14	244.68
17							0.04	0.11	202.85
18							0.03	0.09	164.62
19							0.03	0.05	131.08
20							0.02	0.04	102.61
21							0.02	0.02	79.12
22							0.01	0.01	60.16
23							0.01	0.00	45.18
24							0.01	0.00	33.54
25							0.00	0.00	24.64
26							0.00	0.00	17.92
27							0.00	0.00	12.92
28							0.00	0.00	9.24
29							0.00	0.00	6.55
30							0.00	0.00	4.62

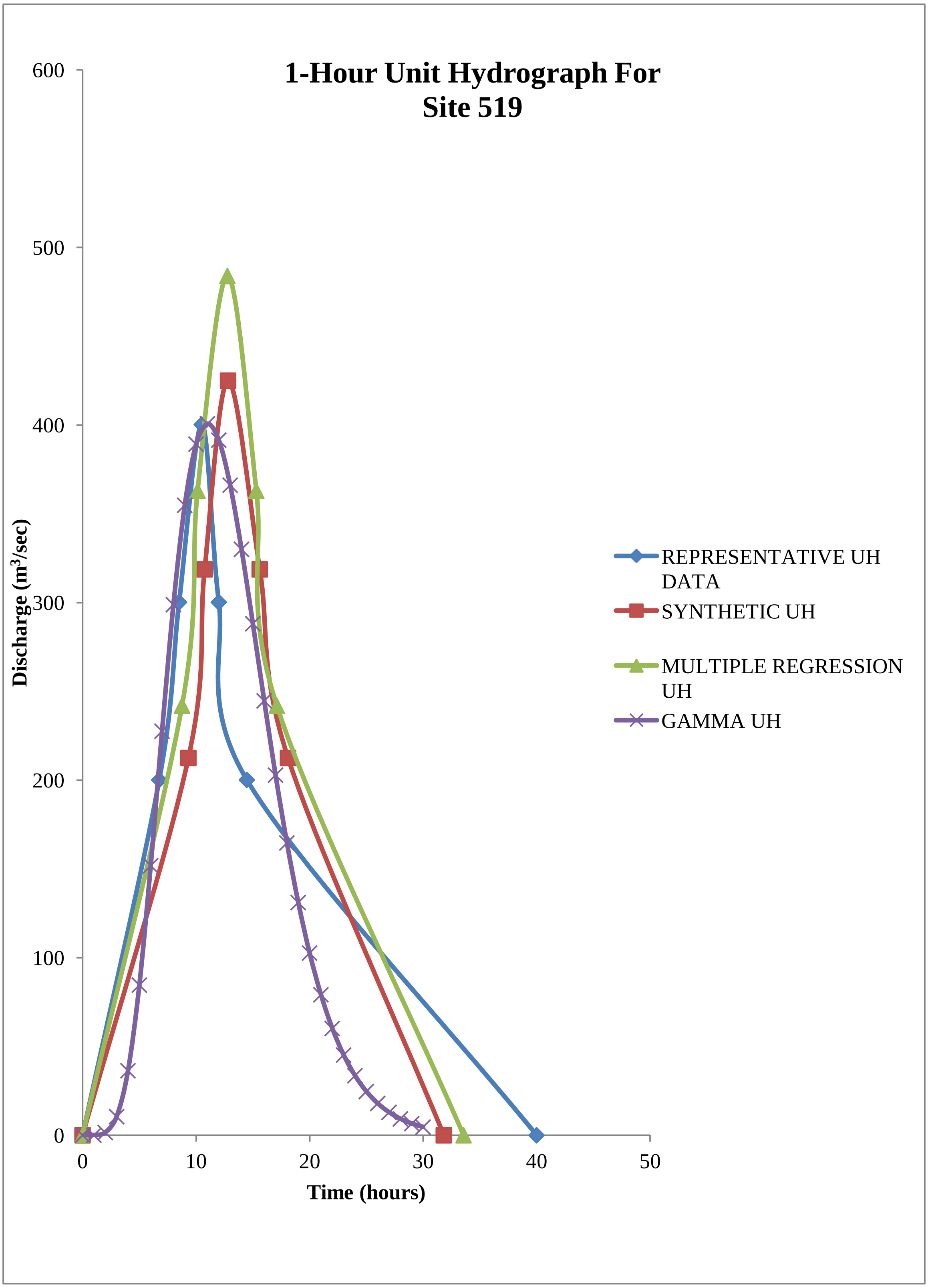


Figure 7.1: Comparison of various SUH methods and Gamma Hydrograph for site 519

7.6 CONCLUSIONS

1. Peak of discharge of Gamma Unit Hydrograph is nearest to the Representative Unit Hydrograph value as compared to any other regression method used.

2. Regression method used by CWC has lesser correlation coefficient than the multiple non linear regression method used.

3. Shape of the Gamma Unit Hydrograph is bell shaped which is generally the cases which need not to be predicted and depends on well known Gamma distribution function.

4. Area of the Gamma distribution function is always unity. Thus area of Unit Hydrograph is equal to area of the catchment. In all other methods, unit hydrograph has to be fitted with hit and trial to get area equal to area of the catchment through the "SEVEN" known points.

5. In gamma hydrograph method unit hydrograph can be made with help of only 2 parameters, **q_p and T_p** as compared to all other methods which require q_p, T_p, W_{50}, WR_{50}, W_{75} and WR_{75} to draw the Unit Hydrograph.

6. Gamma Hydrograph method requires lesser calculation as compared to any other regression method and is very simple in approach.

7. Gamma Hydrograph method is more accurate compared to any other methods discussed here.

8. For finding the most suitable method, various probability distribution functions can be studied and compared with gamma function.

CHAPTER - 8

FLOODS

8.1 INTRODUCTION

Flood is a very unusual high rise in the depth of water in a river or a stream. It even overflows that portion of landmass which is generally found dry. The banks of the river are over flown and mass destruction of nearby area takes place. There is a heavy destruction in form of life, property and economy of the region. Hydraulic structures prevent water from overflowing the nearby areas. Various structures constructed for these purposes are reservoirs, levees etc. Emergency measures are also employed if these hydraulic structures fail. Flood generally takes place when a hydraulic structure fails o if a large earthquake took place inside water or nearby area. When the structure fails the water from the rivers comes to land with a very high speed and inundates the entire area. Tsunami that took place in Indian Ocean took about 2.5 lacks lives.

For safe design and safety of the place, accurate flood estimation for an area is of prime importance. Over estimation of flood will lead to high loss of economy and under estimation will lead to construction of a structure which will not be able to control H.F.L of the river and will not be able to control flood for the region.

For construction of flood control structures, flood estimation is required to be done. Various agencies have given guidelines for design of small, medium and large hydraulic structures. As per C.W.C, a minimum of 50 year return flood is required and as per IS 11223-1985, for construction of small dam 100 year return flood is required. For construction of larger dams, flood having very high return flood like Standard Project Flood (S.P.F), Probable Maximum Flood (P.M.F) etc need to be calculated so that the risk of failure of the structure is minimized. Risk of failure means the structure will at least once in N years. Higher the return period, lower is the risk of failure of an hydraulic structure.

Various methods of Flood Peak estimation is in practice like Rational Method, SCS-CN etc. For calculation of peak of Flood Hydrograph in a particular area various empirical formulas have been derived by the researchers. If rainfall data for a large number of years is available for a region, flood frequency analysis by Gumbel’s Method, Log Pearson etc can be used for Flood Estimation of a required return period.

Application of all these methods is limited for particular fields and depends on the desired output, type of data available and the area on which studies are taken.

Rational Method is used for calculation of Peak Flood in a region of very small size having Area < 50 Km^2. This method is commonly used in Australia for flood estimation in small rivers.

$$Q_p = C*A*i; \quad \text{for } t \geq t_c$$

If intensity of rainfall of a required Return Period is known, Peak Discharge can be calculated for a very small catchment.

Various Empirical Formulas have been derived by researchers for calculation of Peak of Flood. They are applicable for a particular region.

Dickens: $Q_p = C_D\, A^{\frac{3}{4}}$

Ryves: $Q_p = C_D\, A^{\frac{3}{4}}$

Inglis: $Q_p = \frac{124\, A}{\sqrt{A+10.4}}$

Unit Hydrograph Method can be applied to catchments having size less than 5000 Km^2. This method assumed that the response of rainfall to the catchment is linear i.e volume of water collected is proportional to peak discharge. Unit Hydrograph drawn for a region can be used for predicting Flood of required return period if rainfall for required duration is known.

Flood Frequency Studies is a Probabilistic Method and can be applied if Rainfall-Runoff data is available for a long time. Gumbel’s Method r Log Pearson Method can be used to predict peak of flood. This method has disadvantage that for prediction of flood of very large return period, extrapolation of coefficients is required to be done which should be avoided when flood estimations are carried out.

For flood estimation of Ungauged catchments, flood estimation cannot be done by these methods as adequate rainfall data is not available. In such cases, regional methodology is used. Geomorphology of region is related with Hydrograph data calculated using the available data for the region. If rainfall data of past 2-3 flood events is available, using these methods a very reliable Hydrograph for the region can be developed. Various Synthetic Unit Hydrograph or Probability Distribution Function based Unit Hydrograph comes handy in such situations.

Synthetic Unit Hydrograph has been used for flood estimation in ungauged catchments. This Hydrograph is developed using geomorphology of the region instead of rainfall parameters. Various methods like Clark’s, Nash, and Snyder etc are available and each method has its own limitations.

Single variable regression method has been very commonly used. In this UH parameters are correlated with a derived parameter involving various Geomorphologic parameters. Non linear function can be used to fit the best curve in the dispersed data. The equation so developed can be applied to a homogenous region and is applicable within the boundary of this homogenous region.

Multiple regression method can also be used as a tool by which accuracy of the work can be improved. Various variables are related to particular flood parameter and regression equation for a known Confidence Interval can be developed using MATLAB or SPSS.

Probability Distribution Functions are now increasingly used for flood estimation works in small catchments. Various functions commonly in use are Gamma, Chi-Square etc. These functions have advantage that shape of the function is known and area under these curves is always UNITY. In SUH method after calculation of various parameters Unit Hydrograph is required to be fitted through those calculated coordinates. This problem is removed in these PDF's. These functions generally require lesser parameters which are generally available so these methods can be applied in most of the situations.

Gamma function can be used for flood estimation of ungauged catchments. The hydrograph developed using this function is I.U.H. This function requires two parameters q_p & T_p for calculation of ordinates of the IUH. This 0 hour UH developed ca be used for developing flood hydrograph using various rainfall and areal data for the region.

For gamma distribution function: $q\ (t) = \frac{e^{\frac{-t}{k}} * (\frac{t}{k})^{n-1}}{k * \Gamma(n)}$

Here n & k are shape and scae parameters of the function and q(t) is the IUH.

The parameters of this function are dependent on only two flood parameters , q_p (peak discharge per unit area per unit effective rainfall) and Time to peak of the hydrograph.

The unit hydrograph is developed for the region . The Unit Hydrograph can be converted to required return period flood for the region. For a given return period rainfall for a given storm duration is calculated. Unit hydrograph values near to peak are multiplied to hourly point rainfall. These when added gives direct runoff. Base flow when added to Direct Runoff gives peak of the flood hydrograph. Similar procedure can be applied to obtain the flood hydrograph. Thus both shape and peak of the hydrograph are known using this method.

8.2 FLOOD ESTIMATION FOR CHAMBAL RIVER(SITE 519) USING GAMMA HYDROGRAPH

OBTAINING 1-Hour UNIT HYDROGRAPH

Table 8.1: 1- Hour Unit Hydrograph

T	**T_p**	**q_p**	**qp (hr^{-1})**	**B**	**N**	**K**	**IUH (hr^{-1})**	**q (m^3/sec/km^2)**	**Q FOR 1hr IUH**
0	10.5	0.25	0.09	.95	6.77	1.82	0.00	0.00	0.00
1							0.00	0.00	0.05
2							0.00	0.00	1.55
3							0.00	0.01	10.5
4							0.01	0.03	36.34
5							0.03	0.07	84.57
6							0.04	0.12	151.86
7							0.06	0.16	227.61
8							0.07	0.20	298.87
9							0.08	0.23	354.85
10							0.09	0.24	389.29
11							**0.09**	**0.25**	**400.75**
12							0.09	0.24	391.53
13							0.08	0.22	366.18
14							0.07	0.19	330
15							0.06	0.16	288.11
16							0.05	0.14	244.68
17							0.04	0.11	202.85
18							0.03	0.09	164.62
19							0.03	0.05	131.08
20							0.02	0.04	102.61
21							0.02	0.02	79.12
22							0.01	0.01	60.16
23							0.01	0.00	45.18
24							0.01	0.00	33.54
25							0.00	0.00	24.64
26							0.00	0.00	17.92
27							0.00	0.00	12.92
28							0.00	0.00	9.24
29							0.00	0.00	6.55
30							0.00	0.00	4.62

8.2.2 Storm Duration (Td)

T_d=1.1*T_p **(**for Chambal Subzone**)**

T_d=11.55 hours taking **12** hours

8.2.3 Reduction Factors

1. For Duration: for T_d= 12 hours, R.F.=0.8

2. For Area: Area =1613.6Km^2, R.F.=0.76

8.2.4 24 Hour Rainfall having Return Period 50-Year

From Plate 9 available in flood estimation report, for site 519

rainfall= 24cm

8.2.5 Point Rainfall

P.R.= 24*0.8*0.76**=14.59 cm**

8.2.6 Calculation of Flood Peak For 50-Year Return Flood

T_d is divided into 1 hour duration rainfall, since % rainfall in each hour is known from Report, Effective Rainfall (column 6) can be found. Direct Runoff is found for Peak calculation in such a way that highest value of E.R. is multiplied with highest value of 1-Hour UH ordinate. These values are added and base flow is added to that value to find peak of 50-Year Return flood.

Table 8.2: Peak of 50- Year Return Flood

Duration	**Cumulative Distribution in Duration**	**Rainfall till Duration**	**Increment**	**Loss Rate**	**Rain-fall**	**UH Ordinates**	**Direct Runoff**
1	0.37	5.39	5.39	0.17	5.23	400.75	2095.538
2	0.54	7.88	2.48		2.31	391.53	904.696
3	0.67	9.78	1.89		1.73	389.29	672.291
4	0.76	11.09	1.31		1.14	366.18	418.646
5	0.84	12.26	1.17		0.99	354.85	353.910
6	0.88	12.84	0.58		0.41	330.01	136.52
7	0.92	13.42	0.58		0.41	298.87	123.637
8	0.94	13.71	0.29		0.12	288.11	35.104
9	0.96	14	0.29		0.12	244.69	29.81
10	0.97	14.15	0.14		-0.024	227.61	-5.480
11	.98	14.30	0.14		-0.024	202.85	-4.884
12	1	14.59	0.29		0.12	164.62	20.056
						Direct Runoff	**4779.853**

BASE FLOW= $q_p \times$ Area

where q_p=$(.207 \times A^{-.290})$ [for subzone 1(b)]=39.22 m^3/sec

PEAK OF 50 YEAR RETURN FLOOD=D.R.H. + BASE FLOW

=4819.072 m^3/sec

8.2.7 Calculation Of Co-Ordinates Of 50 Year Return Flood

Effective Rainfall calculated are multiplied with all ordinates of Unit Hydrograph each lagged by 1 hour by each previous value. The values are added to find the co-ordinates of Direct Runoff Hydrograph. Base flow is added to these ordinates to find the co-ordinates of 50-year return flood.

Table 8.3 Ordinates of Flood Hydrograph

T(Hr)	D.R.H.	Base-Flow	F.H.
0	0.00	39.22	39.22
1	0.25		39.47
2	8.20		47.42
3	58.56		97.78218
4	217.02		256.2483
5	546.17		585.3939
6	1065.85		1105.076
7	1739.82		1779.043
8	2488.48		2527.706
9	3213.67		3252.887
10	3824.04		3863.259
11	4253.84		4293.062
12	4471.43		4510.656
13	4478.77		4517.991
14	4304.048		4343.268
15	3990.67		4029.889
16	3586.563		3625.783
17	3136.39		3175.616
18	2677.12		2716.34
19	2236.26		2275.484
20	1832.09		1871.312
21	1474.84		1514.06
22	1168.45		1207.67
23	912.31		951.53
24	702.85		742.07
25	534.84		574.06
26	402.39		441.61
27	299.56		338.78
28	220.84		260.06
29	161.33		200.55
30	116.85		156.07
31	83.97		123.19
32	59.89		99.11
33	39.10		78.32
34	22.79		62.01
35	13.48		52.70
36	7.64		46.86
37	3.99		43.21
38	1.90		41.12
39	0.99		40.21
40	0.54		39.76
41	0.31		39.53
42	0.25		39.47
43	0.11		39.33
44	0		39.22

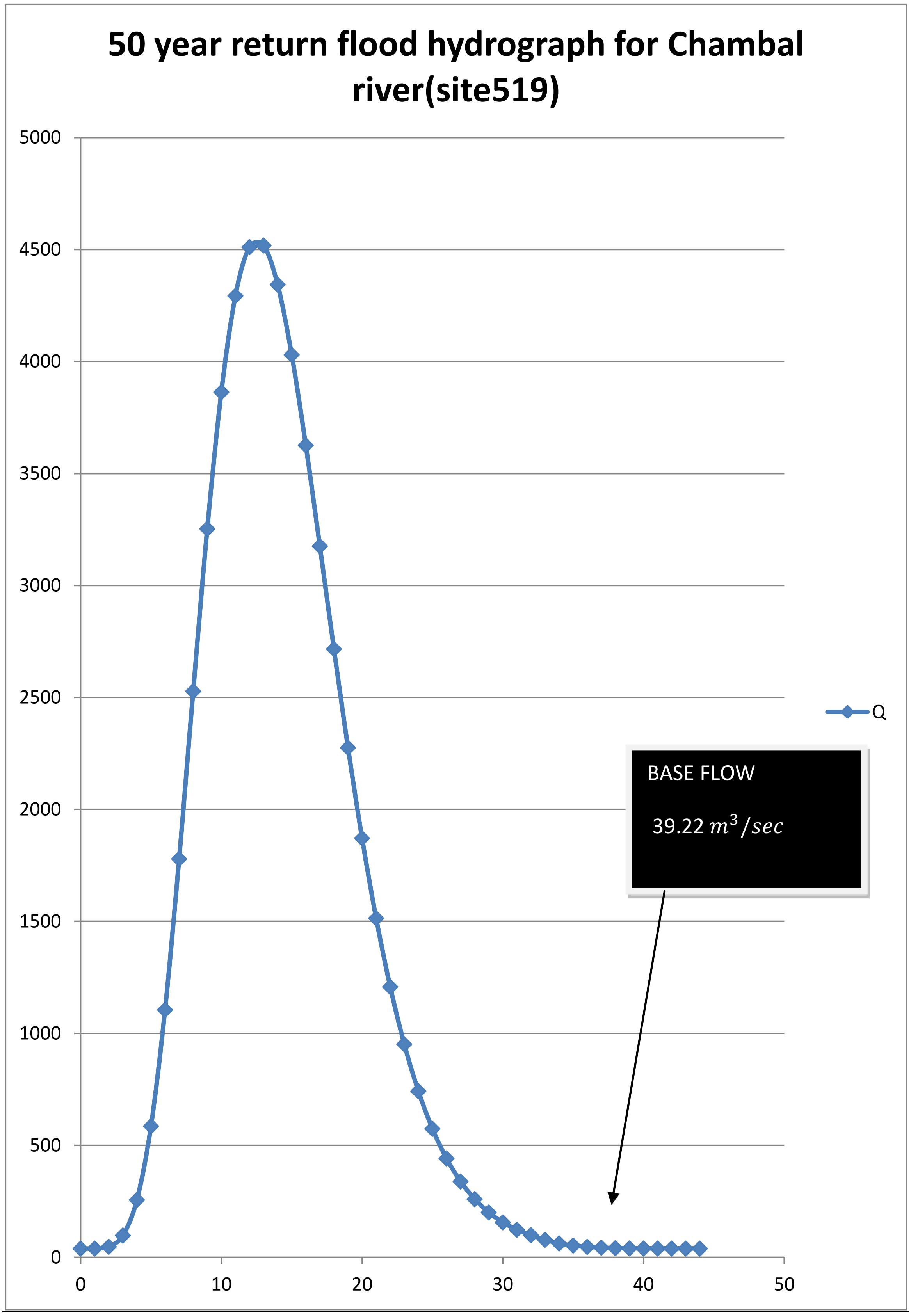


Figure 8.1: 50 – year Return Flood- Flood Hydrograph for (site 519) Chambal River

8.3 RESULTS

1. q_p AND T_p FOR 1-HOUR UH DEVELOPED BY SUH(CWC) METHOD AND GAMMA HYDROGRAPH METHOD

Analysis of correlation between q_p and T_p for the Gamma Hydrograph and CWC method results shows that Gamma Hydrograph results have higher correlation than that of CWC results. Graphs are shown below:

From CWC Report**:** **$q_p = 1.251(t_p)^{-0.610}$, r=.810**

From the results obtained by drawing Gamma Hydrograph and Correlating q_p and T_p using Power function we get, **$q_p = 1.372(t_p)^{-0.646}$, r=.830**

Table 8.4: Comparison of UH results for SUH and GUH method for subzone 1(b)

S.NO.	BRIDGE SITE	AREA	1 hour UH data by CWC Report		1 hr UH by G.I.U.H.	
		In KM^2	q_p	T_p	q_p	T_p
1	94	2297.33	0.18	22.5	0.139	23
2	519	1617.6	0.29	10.5	0.248	11
3	72	662.81	0.33	8.5	0.277	9
4	283	587.63	0.44	5.5	0.542	6
5	198	419.13	0.49	4.5	0.715	5
6	221	361.05	0.58	3.5	0.731	4
7	272	349.13	0.58	3.5	0.638	4
8	140	274.33	0.58	3.5	0.962	4
9	437	237.14	0.58	3.5	0.55	4
10	39	145.45	0.71	2.5	0.594	3
11	51	140.43	0.71	2.5	0.549	3
12	44	108.78	0.71	2.5	0.77	3
13	495	66.3	0.49	4.5	0.486	5
14	406	47.44	0.97	1.5	0.982	2
15	1	44.75	0.97	1.5	1.074	2
16	306	43.77	0.97	1.5	0.447	2
17	118	41.44	0.97	1.5	0.701	2
18	35	39.52	0.71	2.5	0.713	3
19	77	26.18	0.97	1.5	0.71	2

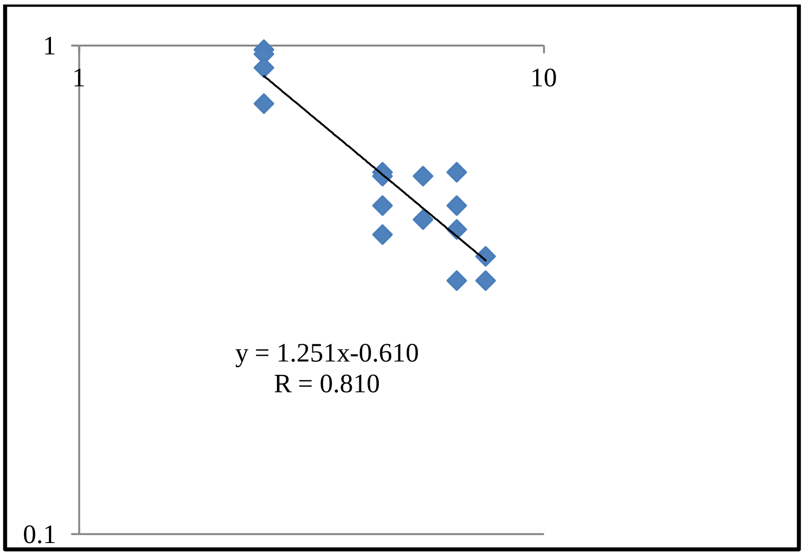


Figure 8.2 : q_p vs T_p as per CWC's S.U.H Method

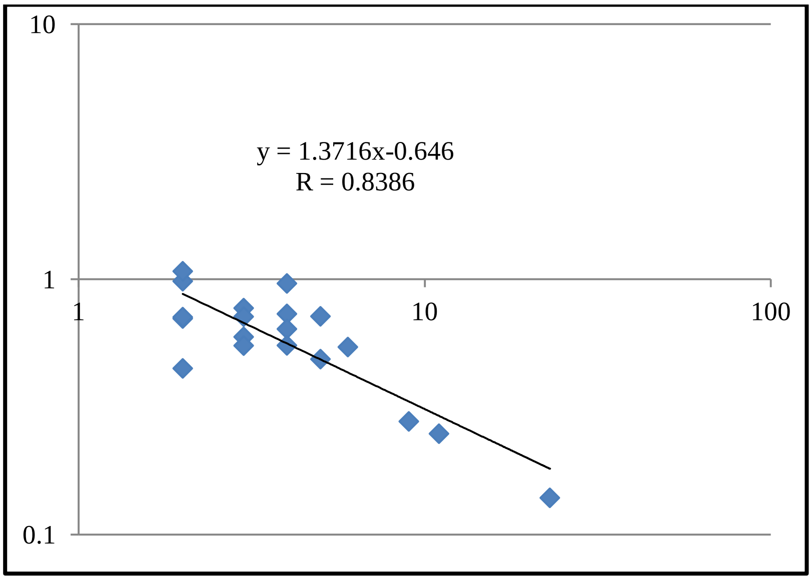


Figure 8.3: q_p vs T_p as per Gamma Hydrograph

2. Q_P FOR 50 YEAR RETURN FLOOD BY SUH & GAMMA HYDROGRAPH METHOD

Table 8.5: Q_p for 50 year return flood by GUH & SUH METHOD used by CWC, India

S. No.	BRIDGE SITE	AREA in KM2	Q_p OF 50-Year R.F.by CWC	Qp OF 50-Year R.F.by GUH
1	94	2297.33	9364.78	6066.15
2	519	1617.6	4805.01	4819.07
3	72	662.81	3309.13	2679.94
4	283	587.63	3282.41	3742.72
5	198	419.13	1669.41	2226.16
6	221	361.05	2102.97	2628.36
7	272	349.13	1954.89	2247.91
8	140	274.33	1752.17	2261.2
9	437	237.14	1620.29	1538.74
10	39	145.45	983.31	886.97
11	51	140.43	1019.23	859.5
12	44	108.78	834.63	947.66
13	495	66.3	425.24	400.67
14	406	47.44	486.15	478.93
15	1	44.75	553.09	563.04
16	306	43.77	384.27	177.01
17	118	41.44	472.06	215.05
18	35	39.52	418.58	414.41
19	77	26.18	200.25	139.22

8.4CONCLUSIONS

1. The Unit Hydrograph results have shown that for all the subzones, Gamma Hydrograph results are about 5% lower than the actual values provided in the report but are very near to actual values as compared to Synthetic Unit Hydrograph method used by CWC whose peak value is very less compared to the observed values for the bridge site.

2. The coefficient of correlation between q_p & T_p for the 1-hour Unit Hydrograph for the results of Gamma Hydrograph(0.929) is higher as compared to the correlation coefficient for the formula developed by non linear regression method used by CWC(0.858) in flood estimation report between q_p & T_p

3. There is high variation between the values of peak of 50-Year return flood between the results calculated by Gamma Hydrograph Method and the results available in CWC reports.

4. The flood formula developed by relating peak of 50 year return flood with A, L, L_C, S, R_f by both CWC results and Gamma Hydrograph has very high multiple correlation coefficient (>0.97, nearly unity)

By CWC: $Q_p = 2.315\ A^{0.918}\ L^{-0.415}\ S^{0.279}\ R_f^{1.010}$ r=0.97

By GUH: $Q_p = 17.20\ A^{1.04}\ L^{-0.519}\ S^{0.186}\ R_f^{0.072}$ r=0.96

REFERENCES

1. Ajward, M. H., & Muzik, I. (1999). A spatial hydrology model for flood estimation. Bridges. Vol. 10(40430), 188.
2. Aksoy, H., & Bayazit, M. (2000). A model for daily flows of intermittent streams. Hydrological Processes. Vol. 14, No. 10, pp:1725-1744
3. Al- Mashidani, G., Lal, P. B., & Mujda, M. F. (1978). A simple version of Gumbel’s method for flood estimaion. Hydrological Sciences Journal. Vol. 23 No. 3, 373-380.
4. Aron, G., and White, E.L. (1982). Fitting a Gamma distribution over a synthetic unit hydrograph. Water Resources Bull. Vol. 18, No. 1, pp. 95-98.
5. Aziz, K., Rahman, A., Fang, G., Haddad, K., & Shreshtha, S. (2010). Design Flood estimation for ungauged catchments: Application of Artificial Neutral Networks for Eastern Australia. In World Environment and Water Resources Congress, ASCE , Providence, Rhodes Island, USA.
6. Basu, B. and Srinivas, V . (2013). A relook at Ohio Watershed Regions for Homogeneity in Flood Frequency Analysis. World Environmetal and Water Resources Congress. pp. 2271-2280.
7. Bhaskar, N. R., Parida, B. P., & Nayak, A. K. (1997).Flood estimation for ungauged catchments using GIUH. Journal of water resources planning and management. Vol. 10 no. 6, pp:228-238.
8. Bhunya, P. K., Ghosh, N. C., Mishra, S. K., Ojha, C. S., & Berndtsson, R. 2005. Hybrid model for derivation of synthetic unit hydrograph. Journal of Hydrologic Engineering, Vol. 10 No. 6, pp:458-467
9. Bhunya, P. K., Mishhra, S. K., & Berndtsson, R. (2003). Simlified two parameter gamma distribution for derivation of synthetic unit hydrograph. Journal of Hydrologic Engineering, Vol. 8 No. 4, pp:226-230
10. Bhunya, P. K., Panda, S. N., & Goel, M. K. (2011). Syntheticunit hydrograph methods: a critical review. Open Hydrology Journal. Vol. 5, pp:1-8
11. Brandes, D., & Kucz, D. A. (2007). Effect of recurring Large Floods on Estimated Base Flood Elevations along the Delaware River. In World Environmetal and Water Resources Congress. pp: 1-7.
12. Burn, D. H., Zrinji, Z., & Kowalchuk, M. (1997). Regionalisation of catchments for regional flood frequency analysis. Journal of Hydrologic Engineering, Vol. 2 No. 2, pp:76-82
13. Central Water Commission India 2002. Flood estimation report for Chambal Subzone 1(b) a method based on unit hydrograph principles. Design Office Rep. No. 3/1980. Hydrology of small catchments Directorate, CWC, New Delhi, India.
14. Chen, L. C., Bradley, A. A., & McCollum, J. R. (2008). A regional Probablistic Appoach for Estimating Flood Probabilities. In World Environmetal and Water Resources Congress. pp: 1-10.
15. Chowdhary, J. U., & Stedinger, J. R. (1991). Confidence interval for design floods with estiimated skew coefficient. Journal of Hydraulic Engineering, Vol. 117 No. 7, pp:811-831.

16. Cleveland, T. G., He, X., Asquith, W. H., Fang, X., & Thompson, D. B. (2006). Instantaneous unit hydrograph evaluation for rainfall-runoff modlling of small watersheds in north and souh central Texas. Journal of irrigation and drainage engineering. Vol. 132 No. 5, pp:479-485.
17. Countryman, J., (2007). 500- Year flood – Can it be reliable estimated? World Environmetal and Water Resources Congress. pp: 1-10.
18. Croley, I. I., & Thomas, E. (1980). Gamma synthetic hydrographs. Journal of Hydrology, Vol. 47 No. 1, pp:41-52.
19. Gray, D. M. (1961). Synthetic unit hydrographs for small watersheds. Journal of the Hydraulics Division. Proceedinds of the American Society of Civil Engineers. HY, 4, pp:33-54
20. Haktanir, T., & Citakoglu, H (2014). Trend, independence, stationarity, and homogeneity tests on maximum rainfall series of standard durations recorded in Turkey. Jounal of Hydrologic Engineering.
21. Illorme, F. and Grrifis, V.2009. Providing a Physical Basis for statistical Homogeneity in Regional Frequency Analysis. World Environmetal and Water Resources Congress. pp: 70-81.
22. James, W. P., Winsor, P. W., & Williams, J. R. (1987). Synthetic unit hydrograph. Journal of water resources planning and management. Vol. 113 No. 1, pp:70-81.
23. Jeng, R. I., & coon, G. C. (2003). True form of onstantaneuos unit hydrograph of linear reservoirs. Journal of irrigation and drainage engineering. Vol. 129 No. 1, pp:11-17.
24. Jin, C. X. (1992). A deterministic gamma-type geomorphologic instantaneous unit hydrograph based on path types. Water resources research. Vol. 28 No. 2, pp:479-486
25. Kar, A. K., Goel, N. K., Lohani, A. K., & Roy, G. P. (2011). Application of clustering techniques using prioritized variables in regional flood frequency analysis- case study of Mahanadi Basin. Journal of Hydrologic Engineering. Vol.17 No. 1, pp:213-223
26. Lee, K. T., & Yen, B. C. (1997). Geomorphology and kinematic wave based hydrograph derivation. Journal of Hydraulic Engineering. Vol.123 No. 1, pp:73-80.
27. Lim, Y. H., & Voeller, D. L. (2009). Regional flood estimations in Red river using L moment based index flood and Bulletin 17B Procedures. Journal of Hydrologic Engineering. Vol.14 No. 9, pp:1002-1016.
28. Mair, A., & Fares, A. (2009). Assesing rainfall data homogeneity and estimating missing records in Makaha valley, O ‘ahu, Hawai ‘i. Journal of Hydrologic Engineering, Vol. 15 No. 1, pp:61-66.
29. Mishra, B. K., Takara, K., & Tachikawa, Y . (2009). Integrating the NRCS runoff curve number in delineation of hydrologic homogenous regions. Journal of Hydrologic Engineering, Vol. 14 No. 10, pp:1091-1097.
30. Nash, J. E. (1959). Systematic determination of unit hydrograph parameters. Journal of Geophisical Research. Vol.64 No.1, 111-115.
31. Pate, H., & Rahman, A. (2010). Design Flood Estimation using Monte Carlo Simulation and RORB Model: Stochastic Nature of RORB model parameters. In World Environmetal and Water Resources Congress. pp: 4692-4701.

32. Raiford, J., Aziz, N., and Khan, A.2006. Development of Depth-Duration-Frequency Relationships using homogenous regions concept. World Environmetal and Water Resources Congress. pp: 1-10.
33. Sahoo, B., Chatterjee, C., Raghuwanshi, N. S., Singh, R., & Kumar, R. (2006). Flood estimation by GIUH based Clark and Nash models. Journal of Hydrologic Engineering, Vol. 11 No. 6, pp:515-525.
34. Scawthorn, C., Blais, N., Seligson, H., Tate, E., Mifflin, E., Thomas, W., Murphy, J., and Jones, C. (2006). Hazus-MH flood loss estimation methodology. II. Damage and loss assesment. Natural Hazards Review. Vol. & no. 2, pp:72-81
35. Shi, P., Chen, X., Qu, S. M., Zhang, Z. C., & Ma, J. L. (2009). Regional Frequency Analysis oflow flow based on L moments: Case study in Karst area, Southwest China. . Journal of Hydrologic Engineering, Vol. 15 No. 5, pp:370-377.
36. Singh , R. D., Mishra, S. K., & Chowdhary , H. (2001) Regional flow duration models for large number of ungauged Himalayan catchments for planning microhydroprojects. Journal of Hydrologic Engineering, Vol. 6 No. 4, pp:310-316.
37. Singh, S. K. (1998). Reconstructing a synthetic unit hydrograph into a Gamma distribution. In proceeding of International conference onIntegrated water resources Management, Alexandria University, Egypt. pp. 104-110.
38. Singh, S. K. (2000). Transmuting synthetic unit hydrograph into a Gamma distribution. Journal of Hydrologic Engineering, Vol. 5 No. 4, pp:380-385.
39. Singh, S. K. (2005). Clark’s and Espey’s unit hydrographs vs the gamma unit hydrograph. Hydrologic sciences journal. Vol. 50 No. 6
40. Singh, S. K. (2007). Identifying representative parameters of IUH. Journal of irrigation and drainage engineering. Vol. 133 No. 6, pp:602-608..
41. Singh, S. K. (2007). Use of Gamma distribution/ Nash modelfurther simlplified for runoff modelling. Journal of Hydrologic Engineering, Vol. 12 No. 2, pp:222-224.
42. Singh, S. K. (2009). Time base as an invertible function of the parametrs of Gamma unit hydrograph. Journal of irrigation and drainage engineering. Vol. 135 No. 6, pp:802-805.
43. Singh, V. P., Aminian, H. (1986). An empirical relation between volume and peak of direct runoff. Journal of the American Water Resources Association. Vol 22, No. 5, pp 725-730
44. Sivakumar, B., Singh, V. P., Berndtsson, R., & Khan, S. K. (2013). Catchment classification framework in Hydrology: challenges and directions. Journal of Hydrologic Engineering
45. Sordo-Ward, A., Bianucci, P., Garrote, L., & Granados, A. (2014). How safe is hydrologic infrastructure design? Analysis of factors affecting extreme flood estimation. Journal of Hydrologic Engineering
46. Sun, N., Hall, M., Hong, B., & Zhang, L. (2012). Impact of SWMM Catchment Discretization: Case study in Syracuse, New York. Journal of Hydrologic Engineering. Vol. 19 No. 1, pp: 223-224.
47. Swamee, . K., Ojha, C. S. P., & Abbas, A. (1995). Mean annual flood estimmation. Journal of Water Resources Planning and Management. Vol. 121 No. 6, pp: 403-407.

48. Thandaveswara, B. S., & Sajikumar, N. (2000). Classification of river basins using artificial neutral network. Journal of Hydrologic Engineering. Vol. 5 No. 3, pp: 290-298.
49. Wall, D. J., Kibler, D. F., Newton, D. W., & Herrin, J. C. (1987). Flood Peak estimates from limited at site historic data. Journal of Hydraulic Engineering. Vol. 113 No. 9, pp: 1159-1174.
50. Zelelew, M. B., & Alfredsen, K. (2013). Use of Cokrigingic and Map Correlation to study Hydrological Response Patterns and Select Reference Stream Gauges for Ungauged catchments. Journal of Hydrologic Engineering. Vol. 19 No. 2, pp: 388-406.