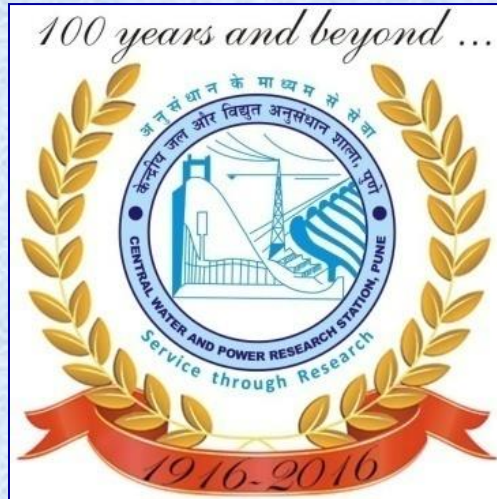


# Development of Flood Hydrograph for the Tributaries of River Sutlej Using Synthetic Unit Hydrograph Approach



**Technical Session**  
**Parallel Session – PW5**  
**Session Theme**  
**Extreme Events and their Management**

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# Outline of the Presentation

- Introduction
- Methodology
  - ❖ Extreme Value Analysis of rainfall (EVA) using Extreme Value Type-1 (EV1), 2-parameter Log Normal (LN2) and Generalized Extreme Value (GEV) probability distributions.
  - ❖ Estimation of peak flood discharge using Synthetic Unit Hydrograph approach (SUH) and development of flood hydrograph.
- Study area and data used
- Results and Discussion
- Recommendation

# Introduction

- Development of flood hydrograph for a given return period is considered as main aspect in hydrological studies for planning and design of hydraulic structures.
- For this purpose, information on peak flows and the distribution of flow with time (i.e. hydrograph) is necessarily needed in hydrologic design to estimate the runoff volume.
- For ungauged catchments, stream flow data is not usually available other than rainfall and therefore the estimated 24-hour maximum rainfall is used to compute the hourly distributed rainfall, which is used as an important input for estimation of peak flood discharge (PFD) as also to derive the flood hydrograph.
- Also, for ungauged catchments with catchment area more than 25 km<sup>2</sup>, in absence of stream flow data, Synthetic Unit Hydrograph (SUH) approach is considered as one of the effective tools for estimation of PFD.

# Methodology

## EVA of Rainfall Using Probability Distributions

Distribution	CDF	Quantile estimator
LN2 ( $\mu(y), \sigma(y)$ )	$F(y) = \Phi\left(\frac{y - \mu(y)}{\sigma(y)}\right)$	$x(T) = \exp(\mu(y) + K(T)\sigma(y))$
EV1 ( $\xi, \alpha$ )	$F(x) = e^{-e^{-\frac{x-\xi}{\alpha}}}, \alpha > 0$	$x(T) = \xi + \alpha[-\ln(-\ln(1 - (1/T)))]$
GEV ( $\xi, \alpha, \beta$ )	$F(x) = e^{-\left(1 - \frac{\beta(x-\xi)}{\alpha}\right)^{1/\beta}}, \alpha > 0, \beta > 0$	$x(T) = \xi + \frac{\alpha[1 - (-\ln(1 - (1/T)))^\beta]}{\beta}$

$\xi$  : Location parameter

$\alpha$  : Scale parameter

$\beta$  : Shape parameter

T	Return period (in year)
F(x)	CDF of variable x (i.e., Annual 1-day maximum rainfall)
K(T)	Frequency factor of a return period (T) corresponding to the Coefficient of Skewness ( $C_s$ ), say $C_s=0.0$ for N2 and LN2
x(T)	Estimated extreme rainfall for a return period (T)
G(...)	Incomplete gamma integral
$\phi(\dots)$	CDF of standard normal distribution
$\mu(x)$	Average of observed data (x)
$\sigma(x)$	Standard deviation of observed data (x)
$\mu(\ln(x))$	Average of log-transformed (i.e. $\ln(x)$ ) series of observed data

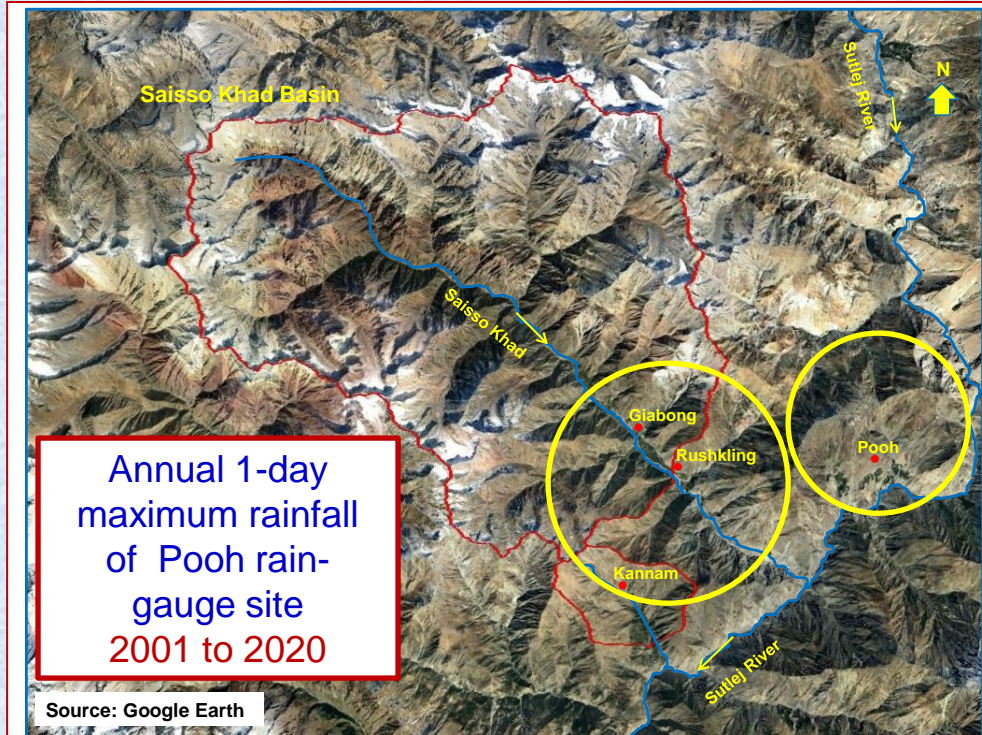
# Methodology

## Goodness-of-Fit and Diagnostic Tests

Goodness-of-Fit (GoF) Tests		Diagnostic Tests	
$\chi^2 = \sum_{j=1}^{NC} \frac{(O_j(x) - E_j(x))^2}{E_j(x)}$		$KS = \text{Max}_{i=1}^N  F_e(x(i)) - F_c(x(i)) $	
		$CC = \frac{\sum_{i=1}^N (x(i) - \mu(x))(z(i) - \mu(z))}{\sqrt{\sum_{i=1}^N (x(i) - \mu(x))^2 \sum_{i=1}^N (z(i) - \mu(z))^2}}$	
		$RMSE = \left( \frac{1}{N} \sum_{i=1}^N (x(i) - z(i))^2 \right)^{1/2}$	
$\chi^2$ : Chi-Square		<b>CC</b> : Correlation Coefficient	
<b>KS</b> : Kolmogrov-Smirnov		<b>RMSE</b> : Root Mean Squared Error	
$O_j(x)$	Observed frequency value of x for j <sup>th</sup> class		
$E_j(x)$	Expected frequency value of x for j <sup>th</sup> class		
NC	Number of frequency classes		
$F_e(x(i))$	Empirical CDF of x(i) of i <sup>th</sup> sample [ <b><math>F_e(x(i))=r/(N+1)</math></b> ]		
r	Rank assigned to a sample values arranged in ascending order (i.e., $x(1)<x(2)<.....x(N)$ )		
$F_c(x(i))$	Computed CDF of x(i) of i <sup>th</sup> sample.		
x(i)	Observed value of x of i <sup>th</sup> sample		
$\mu(x)$	Average of observed values		
z(i)	Predicted value of i <sup>th</sup> sample		
$\mu(z)$	Average of predicted values		
N	Total number of samples		

- If the computed values of **GoF** tests statistic by the distribution are lesser than its theoretical values at the desired level of significance (either 5% or 1%) then the distribution is considered to be acceptable for EVA at that level.
- Method with high **CC** (say, **CC>0.9**) and minimum **RMSE** is adjudged as best method for estimation of rainfall.

# Study Area and Data Used



**Catchment map of study area with locations of ungauged catchments**

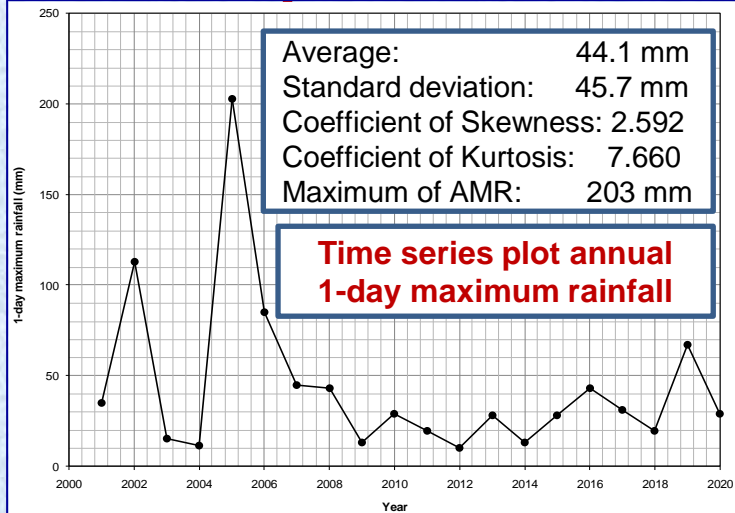
- Sulej is an ancient river that comprises the longest of the five tributaries of river Indus.
- It enters India near Shipki La Pass from where it traverses through the many Himalayan valleys before it merges with river Beas in Punjab that in turn merges with Chenab in Pakistan before landing into Indus.
- Sulej river rises on the north slope of the Himalayas in Lake Langa in south-western Tibet, at an elevation above 15,000 feet (4,600 meters).

Sl. No.	Location	Geographical coordinates		Catchment area (km <sup>2</sup> )
		Longitude (E)	Latitude (N)	
1	<b>Saisso Khad between</b>			
	Giabong Village	78° 26' 19.28"	31° 46' 48.20"	434.0
	Rushkling Village	78° 27' 49.34"	31° 45' 37.68"	61.91
2	<b>Kannam Nallah</b>	78° 26' 36.72"	31° 41' 12.24"	27.78

# Results and Discussion

## (Extreme Value Analysis of Rainfall)

Theoretical and computed values of  $\chi^2$  and KS statistic using LN2, EV1 and GEV distributions

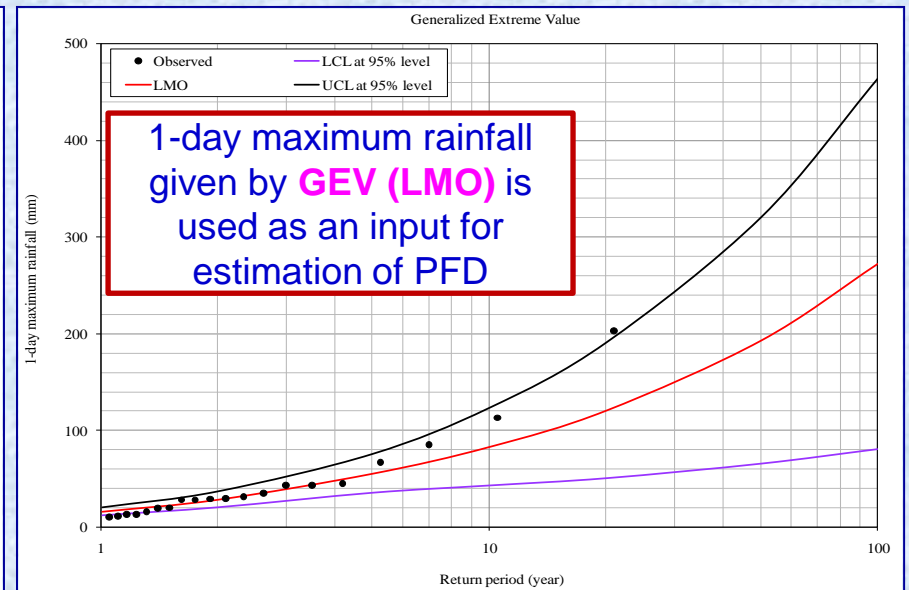
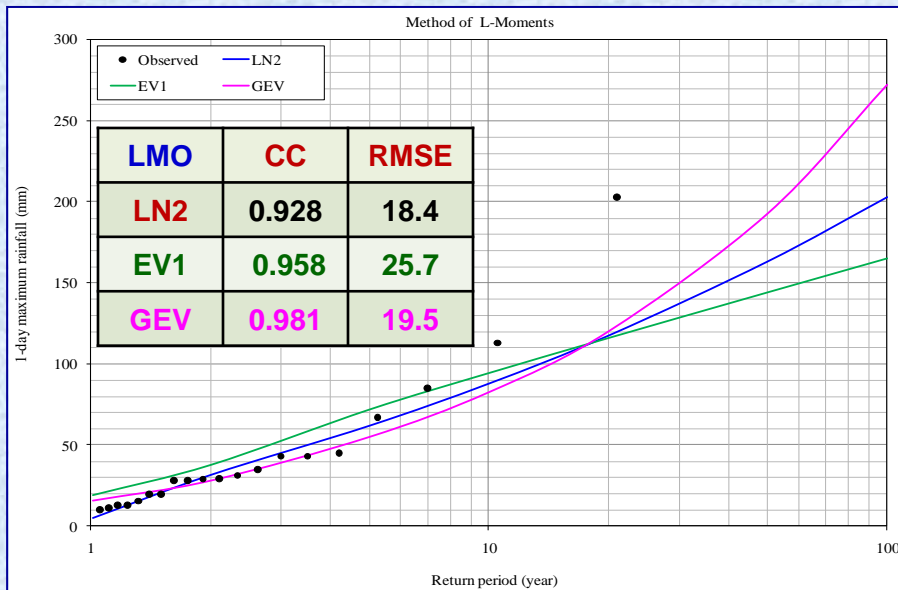
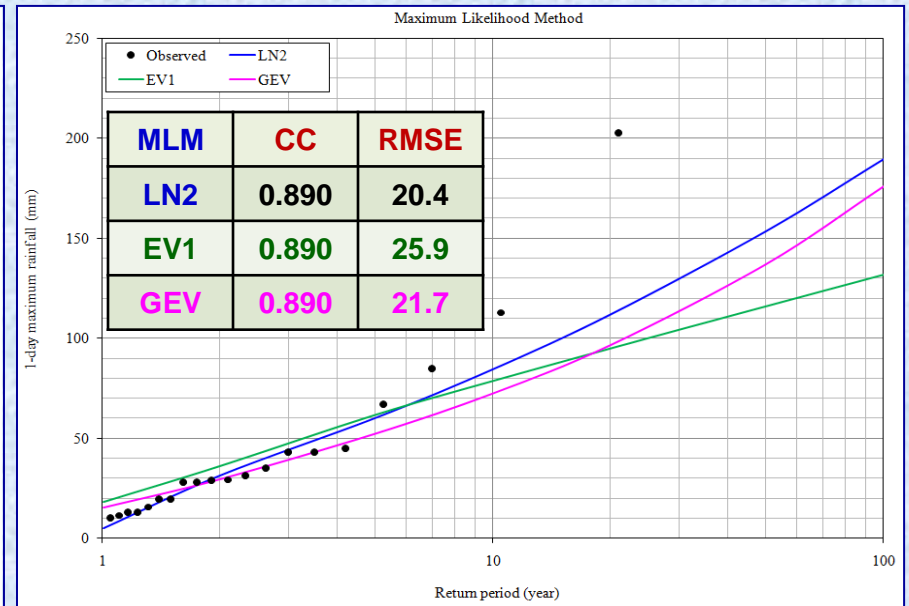
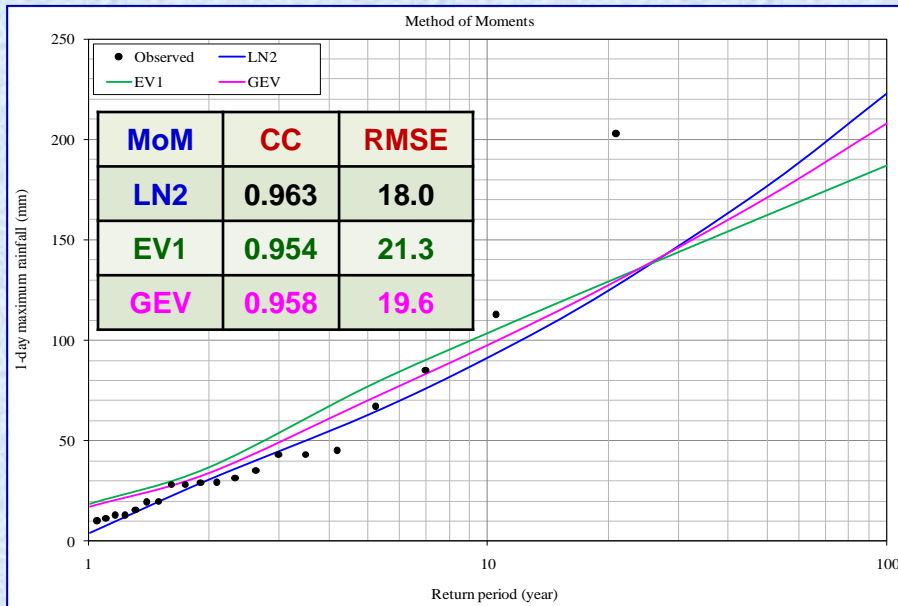


Method	$\chi^2$			KS				
	Theoretical value at 5% level	Computed value			Theoretical value at 5% level	Computed value		
		LN2	EV1	GEV		LN2	EV1	GEV
MoM	5.991	1.5	1.4	1.5	0.204	0.088	0.090	0.092
MLM	5.991	15.0	13.0	10.0	0.204	0.184	0.183	0.182
LMO	3.841	4.5	3.2	1.5	0.204	0.146	0.132	0.114

Return period (year)	1-day maximum rainfall (mm)									24-hour maximum rainfall (mm) GEV_LMO
	LN2			EV1			GEV			
	MoM	MLM	LMO	MoM	MLM	LMO	MoM	MLM	LMO	
2	30.6	31.4	31.4	36.6	36.2	37.7	33.6	29.7	28.2	32.4
5	62.8	60.2	61.7	76.9	61.8	71.8	69.8	52.4	55.1	63.4
10	91.4	84.6	87.7	103.6	78.8	94.4	97.5	72.5	82.7	95.1
20	124.7	112.0	117.3	129.3	95.1	116.0	127.3	96.7	120.3	138.3
25	136.5	121.5	127.7	137.4	100.3	122.9	137.4	105.5	135.1	155.4
50	176.8	153.5	162.8	162.4	116.2	144.1	171.0	137.1	192.5	221.4
75	203.1	174.1	181.6	177.0	125.4	156.3	192.2	158.8	235.8	271.2
100	223.1	189.5	202.5	187.3	132.0	165.0	208.1	175.9	271.9	312.7

# Results and Discussion

## (Extreme Value Analysis of Rainfall)



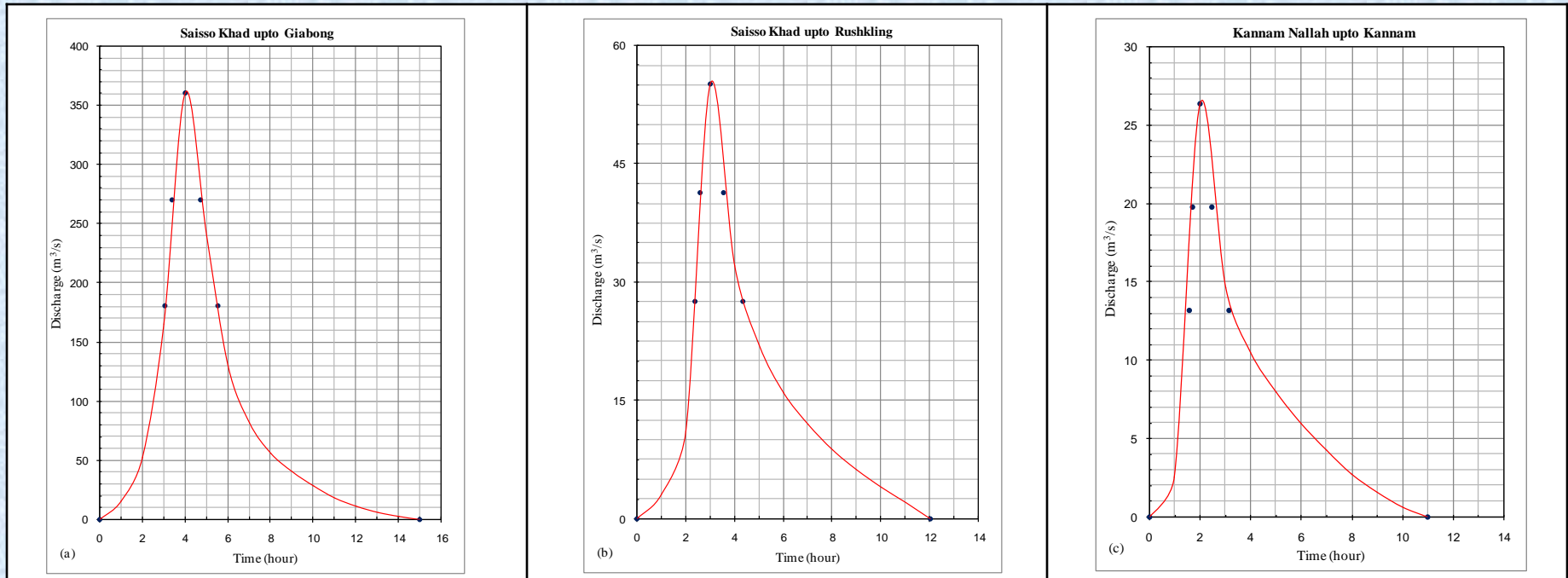
# Results and Discussion

## (SUH parameters of the catchments )

Sl. No.	SUH parameters	Unit	Name of the catchment		
			Saisso Khad up to Giabong	Saisso Khad between Giabong and Rushkling	Kannam Nallah up to Kannam
1	Catchment area (A)	km <sup>2</sup>	434.0	61.9	27.8
2	Length of longest main stream along river course (L)	km	35.5	16.4	8.5
3	Length of longest stream from centre of gravity (L <sub>c</sub> )	km	16.1	8.6	3.0
4	Equivalent stream slope (S)	m/km	48.5	144.6	242.8
5	Time to peak or basin lag (t <sub>p</sub> )	hour	3.67(≅ 3.50)	2.49(≅ 2.50)	1.75(≅ 1.50)
6	Peak flood (m <sup>3</sup> /s) of UH per unit area (q <sub>p</sub> )	km <sup>2</sup>	0.8	0.9	1.0
7	Width of UH at 50% of Q <sub>p</sub> (W <sub>50</sub> )	hour	2.5	2.0	1.6
8	Width of UH at 75% of Q <sub>p</sub> (W <sub>75</sub> )	hour	1.3	1.0	0.7
9	Width of the rising limb of the UH at 50% of Q <sub>p</sub> (WR <sub>50</sub> )	hour	1.0	0.6	0.4
10	Width of the rising limb of the UH at 75% of Q <sub>p</sub> (WR <sub>75</sub> )	hour	0.6	0.4	0.3
11	Time base of UH (T <sub>B</sub> )	hour	15.0	12.0	11.0
12	Time from the start of rise to peak of unit hydrograph (T <sub>m</sub> )	hour	4.0	3.0	2.0
13	Peak flood of UH (Q <sub>p</sub> )	m <sup>3</sup> /s	360.9	55.2	26.4

# Results and Discussion

## (Derivation of SUH Parameters)



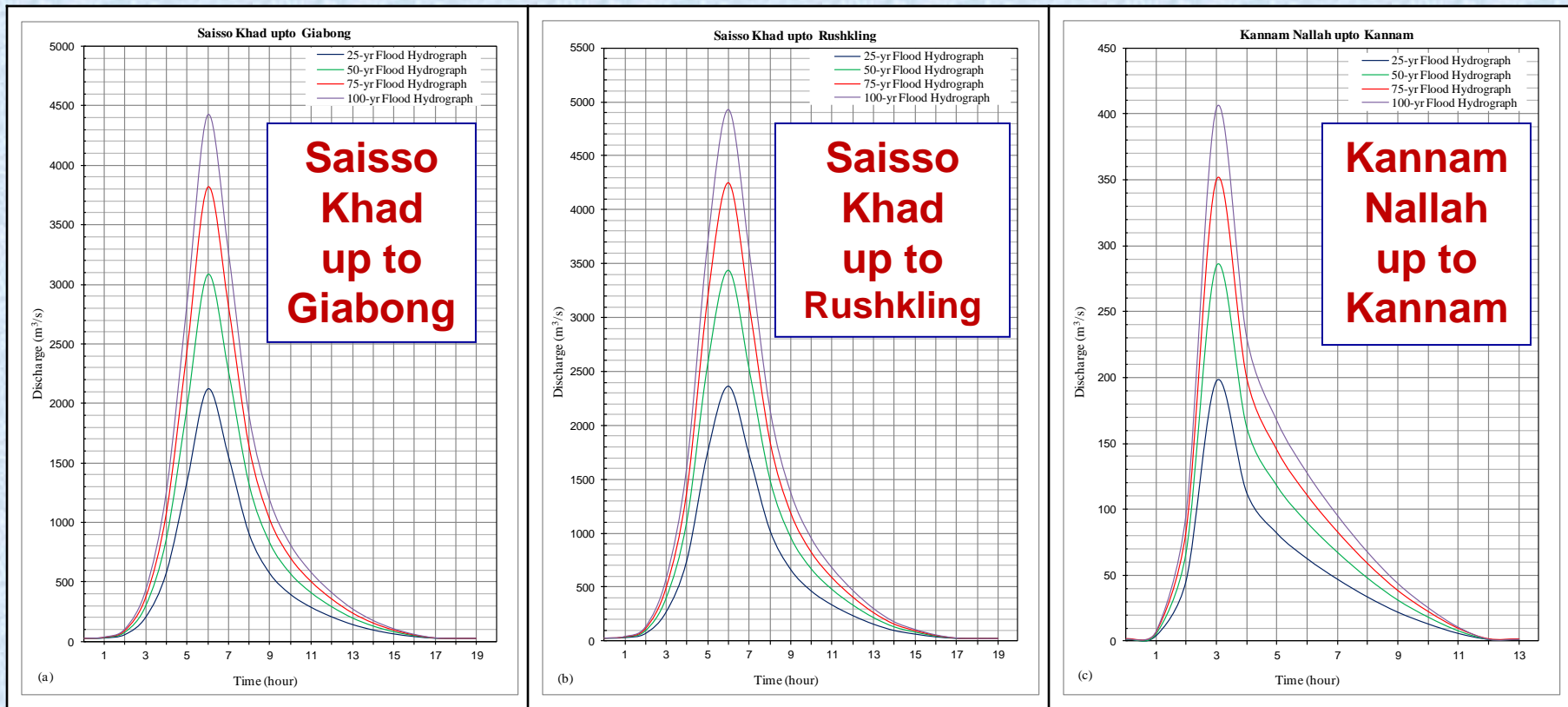
### Empirical equations used in determination of SUH parameters

$q_p = 1.048(t_p)^{-0.178}$	$W_{75} = 0.972(LL_c/S)^{0.124}$	$T_B = 7.845(t_p)^{0.453}$
$t_p = 2.498(LL_c/S)^{0.156}$	$WR_{50} = 0.189(W_{50})^{1.769}$	$Q_p = q_p * A$
$W_{50} = 1.954(LL_c/S)^{0.099}$	$WR_{75} = 0.419(W_{75})^{1.246}$	$T_m = t_p + 0.5$

**Source:** CWC flood estimation report for Western Himalayas-Zone 7 (1994)

# Results and Discussion

## Estimation of PFD using SUH Approach



Catchment	Peak Flood Discharge ( $m^3/s$ )			
	25-year	50-year	75-year	100-year
Saisso Khad up to Giabong	2117.6	3084.2	3813.4	4421.3
Saisso Khad up to Rushkling	2363.4	3439.1	4250.6	4927.1
Kannam Nallah up to Kannam	197.7	284.6	350.1	404.7

# Conclusions

- Goodness-of-Fit and diagnostic tests result confirmed the selection of **GEV (LMO)** distribution for rainfall estimation.
- From the fitted curves of the estimated rainfall, it was observed that about 80% of the observed annual 1-day maximum data are within the confidence limits of the estimated 1-day maximum rainfall by **GEV (LMO)**.
- 25-year, 50-year, 75-year and 100-year return period 24-hour maximum rainfall at Pooh site are 155.4 mm, 221.4 mm, 271.2 mm and 312.7 mm respectively.
- By using distributed rainfall and SUH parameters of the catchments, the peak flood discharge (**PFD**) of three ungauged catchments in the tributaries of river Sutlej viz., (i) Saisso khad upto Giabong (ii) Saisso khad between Giabong and Rushkling and (iii) Kannam Nallah up to Kannam village were computed; and are used to develop the flood hydrographs.

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# Recommendation

The estimated **peak flood discharge** by adopting **Synthetic Unit Hydrograph approach** of the following ungauged catchments in the tributaries of river Sutlej

- Saisso Khad up to Giabong
- Saisso Khad up to Rushkling
- Kannam Nallah up to Kannam

could be used for design of hydraulic structures, river protection works and development of integrated water resources management projects.

**THANK YOU**