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DISTRIBUTED HYDROLOGICAL MODEL FOR DESIGN FLOOD REVIEW OF PROJECTS IN TEESTA BASIN

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ABSTRACT
Teesta Basin has been planned as a cascade for hydro-power development. Various projects are at different stages of planning and execution ranging from conceptualization to already operational. The hydrological studies for these projects had been done at different points of time by different agencies. It is seen that some inconsistencies have crept in for the values of design flood between upstream and downstream projects. Therefore, a necessity was felt to study the design flood of all the projects in the cascade in an integrated and consistent manner. In recent years, advances in Geographic Information Systems (GIS) have opened many opportunities for enhancing hydrologic modeling of basins in an integrated manner. The ability to perform spatial analysis for the development of distributed hydrologic parameters not only saves time and effort, but also improves accuracy over traditional lumped methods. Hydrologic modeling has evolved to represent the basin in more detail than the traditional lumped approach where hydrologic parameters are averaged over the basin. In the study presented in this paper a distributed hydrological model has been developed for design flood review study of projects in Teesta basin in an integrated manner. All the physiographic parameters required to develop unit hydrographs for different sub-catchments of distributed model has been estimated by GIS processing of STRM DEM. In the absence of a long term data availability and predominant orographic conditions in the area, the design storm for each sub catchment of distributed hydrological model has been finalized by taking characteristic maximum one day rainfall depth for different topographical regions. The design flood for different projects has been estimated using hydro meteorological approach and a distributed hydrological model set up on HEC-HMS.

1.0 INTRODUCTION

The Teestariver originates from TsoLhamo in North Sikkim at an elevation of 5,330 m (17,487 ft) above sea level in the Himalaya. The Teestariver is then fed by rivulets which arise in the Thangu, Yumthang and Donkia-La ranges. The river then flows past the town of Rangpowhere it forms the border between Sikkim and West Bengal up to Teesta Bazaar. Just before the Teesta Bridge, which joins Kalimpong with Darjeeling, the river is met by its main tributary, the Rangeet River. At this point, it changes course southwards flowing into West Bengal. The river hits the plains at Sevoke, at a distance of 22 Km from Siliguri, where it is spanned by the Coronation Bridge which links the north-east States to the rest of India. The river then courses its way to Jalpaiguri and then to Rangpur District of Bangladesh, before finally merging with the mighty Brahmaputra at Fulchori.The Teesta Basin has been planned as a cascade hydro-power development. Various projects are at different stages of planning and execution ranging from conceptualization to already operational. The hydrological studies for these projects have been done at different points of time by different agencies The design floods have been studied at different times for same project depending upon the availability of additional data and the methodology in vogue. It is seen that some inconsistencies have crept in for the evaluated values of design flood between upstream and downstream projects. Therefore, a necessity was felt to study the design flood of all the projects in the cascade in a uniform and consistent way. Design flood for Projects on the Lachen, Lachung and uptothe Teesta stage VI have been reviewed. As per BIS code 11223 - Guide lines for fixing of spillway capacity and BIS Code IS:6966 (Part1) 1989 – Hydraulic design of Barrage and Weirs, all these projects qualify for PMF as design flood, except Teesta stage VI which qualifies for SPF as design flood. For design flood estimation in an integrated manner,the entire catchment of the Teesta river uptothe Teesta-VI HE project site has been sub divided into eight sub-catchments as shown in Fig.1. With this sub-division of the catchments the distributed hydrological model for design flood estimation at different project sites has been prepared using HEC-HMS.

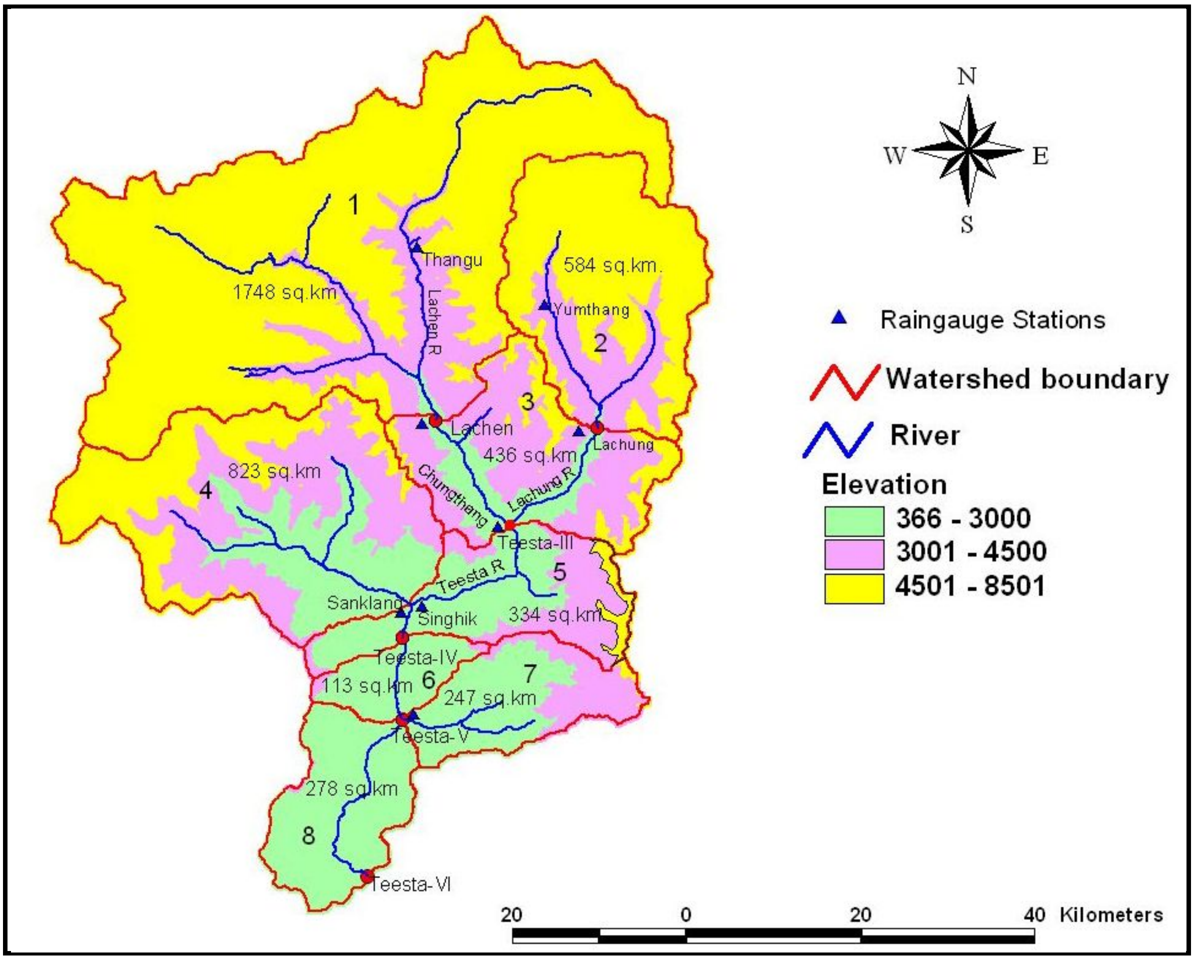

Fig.1: Catchment Area Plan of Teesta Basin up to Teesta HEP Stage-VI

2.0 DESIGN STORM

One day maximum rainfall depth recorded at various stations as obtained from IMD are given in Table- 1.

Table-1: One day maximum rainfall depth recorded at various stations

Raingauge Station	1-day maximum rainfall in mm	Date
Lachung	216	13.10.1973
Lachen	134	03.08.1992
Thangu	53	19.9.2000
Yumthung	62	26.09.1972
Chungthang	191.8	12.3.1983
Dikchu	400.8	25.8.1969
Singhik	504.2	12.5.1981
Sanklang	133.2	04.07.1996
Kurseong	501.7	11.6.1950

It is seen that overlap period of data availability at various stations is very small and it is difficult to identify a storm covering the entire basin in a largely orographic area. As such, the different extreme depths have been assumed as per characteristics of different portions of sub-catchments under extreme conditions. Average depths for each catchment have been worked out using weighted average of the different portions of these catchments.Further information considered for deciding the depths for various sub-catchments is as under:

- The only long term data available in the area is for Chungthang for which IMD has worked out a 500 year point rainfall of 250mm.

To obtain the rainfall depth for area above 3000m contour (most of the area above Lachen and Lachung), a point depth of 250mm for 500 year return period of Chungthang was corrected in the normal ratio of annual normal rainfall at Lachen RG and Chungthang RG (taken as 1890 mm and 2500mm). This depth works out to be about 190mm and can be taken as characteristic depth for the area above the contour of 3000m for all sub catchmnetsof Teesta basin. However, 216 mm depth has been observed at Lachung and therefore, depth of 210 mm has been taken as characteristic depth for this area.

The maximum one day rainfall observed at Chungthang is of the order of 200mm. At Lachung the maximum observed rainfall is 216 mm although the length of data is not very long. The elevations of Lachen and Lachung are comparable and the length of data at Lachen is also not very long. Therefore, in the absence of long term data at Lachen and Lachung, 500 year return period rainfall computed at Chungthang (250 mm) is taken as characteristic maximum one day depth in the catchment between Lachen and Lachung to Chungthang for the area below El 3000m.

In the absence of long term data, for assessment of the characteristic maximum one day depth in the catchments between Chungthang to Sanklang, Sanklang to Dickchu, andDickchu to Teesta HEP VI Site for the area below 3000m elevation, the rainfall at Dickchu can be considered along with that at Singhik. The observed maximum one day rainfall at Dickchu is 400.8 mm (25.8.1969) whereas the same at Singhik is 504mm (12.5.1981). However, both the rain gauges appear to be in orographic regions and use of these values for entire region may lead to overestimation of design depths. The annual observed rainfall at Singhik and Dickchu are of the order of 3134mm and 3364mm respectively whereas the same at Chungthang is of the order of 2828mm. Increasing the 500 year return period rainfall computed at Chungthang (250 mm) (taken as 1 day SPS for corresponding region) in normal ratio for Dickchu (as the annual rainfall at Dickchu is more than that of Singhik) , the 1 day SPS in this region can be estimated as 300mm. Leaving the highest observed rainfalls at Dickchu and Singhik, the next highest observed rainfall at Dickchu is 210 mm whereas that at Singhik is 311mm. Therefore, a depth of about 300mm has been treated as characteristic one day depth for the area uptoDickchu and 350mm (an increase of 50mm as the elevations are decreasing, similar to the increase of 50mm from Chungthang to Dickchu) for Dickchu to Teesta HEP VI. The depths thus arrived for different topographical regions are given in Table-2.

Table-2: Characteristic maximum one day rainfall depth for different topographical regions

1-day Depth for areas above El 3000m	210mm
1-day Depth for areas below El 3000m between Lachen and LachunguptoChungthang	250mm
1-day Depth for areas below EL 3000m for Chungthang to Sankalang and Sanklang to Dickchu	300mm
1-day Depth for areas below EL 3000m for Dickchu to Teesta VI	350mm

The average 1 day areal SPS depth and corresponding 24 hr areal SPS and PMP depths arrived for different sub-catchments and project catchments are given in Table-3. For arriving at 24 hour values, the necessary clock hour correction has been applied. Further, for estimating 24 hr areal PMP, a MAF of 1.35 has been applied.

Table-3 : Average 1 day areal depth arrived for different sub-catchments

(All figures in mm)

Sub Catchments	Rainfall in area <3000m elevation	Rainfall in area >3000m elevation	Weighted 1 day areal SPS	24 hr areal SPS	24 hr areal PMP
Sub catchments approach					
Lachen	250	210	212	244	329
Lachung	250	210	212	244	329
Teesta III S.C.	250	210	222	255	345
Teesta IV S.C.1	300	210	250	285	388
Teesta IV S.C.2	300	210	267	302	410
Teesta V S.C.1	300	210	270	305	415
Teesta V S.C.2	300	210	295	330	449

Teesta VI S.C.	350	210	350	385	

3.0 PHYSIOGRAPHIC PARAMETERS AND UNIT HYDROGRAPHS

In the absence of availability of short term rainfall-runoff data, the Synthetic UG for the different sub-catchments have been developed based on the Sub zone 2(a) report of Central Water Commission and used for the present study. The physiographic parameters required to work out the unit hydrograph for a project catchment are rainfedcatchment area, longest stream length from the farthest point on the catchment boundary to catchment outlet (L), length along longest stream from a point near centre of gravity of catchment to catchment outlet (Lc), equivalent stream slope (S). Area above elevation of 4500m (approximately 15000 ft) has been considered under permanent snow and the same has been considered as snowfed area.

The physiographic parameters of all the eight sub catchments have been estimated by GIS processing of SRTMDigital Elevation Model. The physiographic parameters and unit hydrograph parameters for different sub catchments are given in Table-4. The unit hydrographs of different sub catchments are given in Table-5.

Table-4: Physiographic and SUG parameters for distributed hydrological model

Sub-catchments and their corresponding polygon no. (shown in bracket) as per Fig.1	Snowfed catch-ment area (sq.km)	Rainfed catch-ment area (sq.km)	**Physiographic parameters**			**UG parameters**		
			Longest flow path (L) (km)	Centroidal flow path (L_C) (km)	Equiv stream slope (S) (m/km)	Peak discharge (Q_P) (cumec)	Time to peak (t_P) (hrs)	Base width (T_B) (hrs)
Lachen (1)	1465	285	33.9	11.2	63.3	311	3	12
Lachung (2)	434	150	24.5	9	70.95	214	2	8
Teesta-III IC (3)	79	351	28.2	12.8	84.45	440	3	12
Teesta-IV SB1 (4)	258	566	38.4	15.5	68.44	530	4	12
Teesta-IV SB2 (5)	22	310	35	12	76.42	350	3	12
Teesta-V SB1 (6)	5	242	32.4	16.2	110.12	290	3	12
Teesta-V SB2 (7)	0	113	20.5	5.4	136	250	2	8
Teesta-VI (8)	0	278	30.6	11.4	39	258	3	12

Table-5: Unit Hydrographs (UGs) for Distributed Hydrological Model

Time (hour)	**Lachen**	**Lachung**	**Teesta-III IC**	**Teesta-IV SB1**	**Teesta-IV SB2**	**Teesta-V SB1**	**Teesta-V SB2**	**Teesta-VI IC**
	Discharge (cumec)	Discharge (cumec)	Discharge (cumec)	Discharge (cumec)	Discharge (cumec)	Discharge (cumec)	Discharge (cumec)	Discharge (cumec)
0	0	0	0	0	0	0	0	0
1	48	78	66	37	42	24	35	52
2	140	**214**	164	114	158	82	**250**	120
3	**311**	88	**440**	250	**350**	**290**	19	**258**
4	160	24	210	**530**	175	145	4	158
5	72	7	52	312	60	64	3	82
6	31	4	18	160	29	29	2	44
7	14	2	8	80	18	16	1	24
8	7	0	6	46	12	10	0	16
9	5		5	26	9	6	0	11
10	3		4	12	5	4	35	5
11	1		2	5	3	2	250	2
12	0		0	0	0	0	19	0

4.0 DISTRIBUTED HYDROLOGICAL MODEL SET UP FOR DESIGN FLOOD STUDY

The design flood for different projects has been estimated by settinga distributed hydrological model on HEC-HMS. The HEC-HMS model set up is given in Fig.2, where OtLachen, OtLachung, Ot T-III, Ot T-IV, Ot T-V and Ot T-VI is the location of Lachen, Lachung, Teesta-III, Teesta-IV, Teesta-V and Teesta-VI projects respectively.

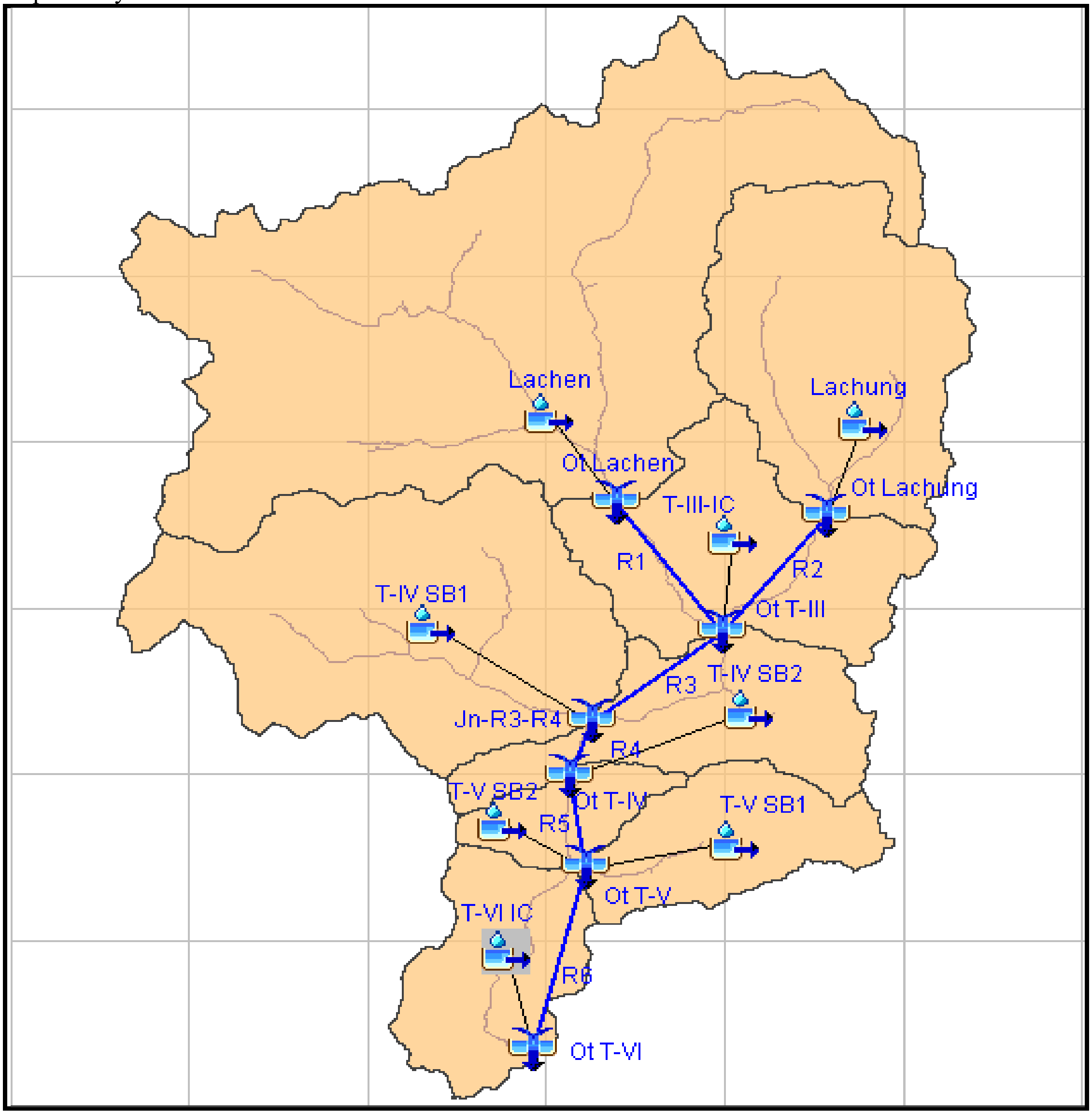

Fig.2: HEC-HMS model set up for design flood study

5.0 CHANNEL ROUTING

The Channel routing of flood hydrographs through river reaches R1, R2, R3, R4, R5 and R6 has been carried out using Muskingumrouting method. For the stability of Muskingum routing the limiting value of Δt (time interval of flood hydrograph) should be such that $\Delta t > 2KX$, hence, for stability of Muskingum routing algorithm the channel routing has been carried out using stepped routing where the routing reach has been divided in to sub reaches based on the stability criteria. The Muskingum routing parameters adopted are given in Table-6.

Table-6: Routing paramers used for distributed hydrological model

Reach	Length (km)	Muskingum 'K' (hrs)	Muskingum 'X'	Number of sub reaches
R1 (Lachen to Teesta-III)	17	2	0.2	2
R2 (Lachung to Teesta-III)	17	2	0.2	2
R3 (Teesta-III to Teesta-Tolong Chu confluence)	20	2.5	0.2	2
R4 (Teesta-Tolong Chu confluence to Teesta-IV)	4	0.5	0.2	1
R5 (Teesta-IV to Teesta-V)	11	1.2	0.2	1
R6 (Teesta-V to Teesta-VI)	25	2.5	0.2	2

6.0 BASE FLOW, LOSS RATE AND SNOWMELT CONTRIBUTION

In the absence of any reliable observed flood event, baseflows have been taken as per FER- 2a i.e. 0.05 cumecs/sq km of catchment area. Loss Rate has been taken as 2.4 mm per hour as per FER- 2a.Snowmelt contribution has been taken as per the formula (Ref: Guide to Hydrological Practices, WMO No.168-1994) given below:

$h = (0.30+0.012P)*T_{avg}+1.0$ mm

Where,

h- Daily snowmelt in mm

P- Daily rainfall in mm

T_{avg} -Mean daily temperature(^{0} C) taken as 3^0 C

7.0 CATCHMENT AREA, SPS AND PMP ADOPTED FOR DISTRIBUTED HYDROLOGICAL MODEL

The SPS and PMP adopted for different sub-catchment for distributed hydrological model is given in Table-7.

Table-7: SPS and PMP for distributed hydrological model

("CA" = "Catchment Area)

Sub-catchment	Total CA (km^2)	Snowfed CA (km^2)	Rainfed CA (km^2)	1-day areal SPS (mm)	24-hr areal SPS (mm)	MAF	1-day areal PMP (mm)	24-h areal PMP (mm)
Lachen	1750	1465	285	212	244	1.35	286	329
Lachung	584	434	150	212	244	1.35	286	329
Teesta-III IC	430	79	351	222	255	1.35	300	345
Teesta-IV SB1	824	258	566	250	285	1.35	338	388
Teesta-IV SB2	332	22	310	267	302	1.35	360	410
Teesta-V SB1	247	5	242	270	305	1.35	365	415
Teesta-V SB2	113	0	113	295	330	1.35	399	449
Teesta-VI	278	0	278	350	385			

8.0 DESIGN FLOOD FOR DIFFERENT PROJECTS FROM DISTRIBUTED HYDROLOGICAL MODEL

The estimated design flood at different locations from the distributed hydrological model is given in Table-8. The plot of flood hydrographs are given in **Annexure-I**.

Table-8: Design flood as per distributed hydrological model

Project	Total CA (km^2)	Snowfed CA (km^2)	Rainfed CA (km^2)	Design Flood as per distributed Hydrological model (cumec)	Remarks
Teesta-III	2764	1978	786	6685	PMF
Teesta-IV	3920	2258	1662	13000	PMF
Teesta-V	4280	2263	2017	14596	PMF
Teesta-VI	4558	2263	2295	11462*	SPF

*corresponding PMF for Tessta VI is15474 cumec

9.0 CONCLUSION

The distributed hydrological approachthrough a number of sub catchments represents the project catchment in more detail than the traditional lumped approach where hydrologic parameters are averaged over the entire catchment.By the present design flood estimate for different projects in an integrated manner using distributed hydrological approach, it is possible to eliminate theinconsistencies in the values of design flood between upstream and downstream reaches. The SRTM digital elevation model,remote sensing, GIS and hydrological modeling softwares are now available in public domain.The same can be used to estimate hydrological response of a watershed with improved accuracy.

Disclaimer: *The views expressed in the paper are purely personal and not necessarily the views of the organisation they belong to.*

REFERENCES:

1. Flood Estimation Report subzone-2(a), Central Water Commission
2. HEC-HMS 3.4 user manual
3. HEC-HMS reference manual
4. ILWIS 3.7 user manual
5. ESRI, arcView user manual