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Letter to the editor

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SYNTHETIC HYETOGRAPH FOR ESTIMATION OF DESIGN FLOODS DURING ABSENCE OF SELF RECORDING RAINGAUGE DATA — A UNIT HYDROGRAPH APPROACH

The estimation of design storm depth with its temporal distribution is a basic input for estimation of design floods. The methods for estimation of design storm depth are well established (WMO 1969). But there is no standard method for estimation of temporal distribution of design storm, particularly that of high magnitude. The main difficulty is the inadequate knowledge of physical processes responsible for rainstorm of high magnitude and their temporal variation. Also self recording raingauge (SRRG) network as well as SRRG data are poor in many countries. Hence, the statistical methods available cannot be effectively applied. Because of sparse network, available single SRRG station has to be taken as representative of the catchment. But this assumption is also doubtful. In order to avoid the difficulties due to inadequate SRRG data, in this article a method has been suggested to work out ordinates of synthetic hyetograph without using SRRG data. The basic input used here is the ordinates of design unit hydrograph.

2. *Theory and assumptions* — The unit hydrograph is a popular rainfall-runoff model. The unit hydrograph derivation requires SRRG data of short duration rainstorms and corresponding flood hydrograph. Even without SRRG data, methods are available for computation of synthetic unit hydrograph. From the unit hydrograph ordinates (U) and effective rainfall (P), the direct surface runoff (Q) is derived by:

$$Q_1 = U_1P_1 + 0.0 + 0.0 + \cdots\cdots$$
$$Q_2 = U_2P_1 + U_1P_2 + 0.0 + \cdots\cdots$$
$$Q_N = U_NP_1 + U_{N-1}P_2 + U_{N-2}P_3 + \cdots\cdots \quad (1)$$

or in matrix form it can be represented as :

$$(Q) = (U) \times (P)$$

If direct surface runoff ordinates (Q) are estimated by a suitable model, the effective rain depth ordinates (P) in chronological order can be derived by solving equation :

$$(P) = (U^TU)^{-1} \times (U^T) \times (Q) \quad (2)$$

Hence, the temporal distribution of design storm can be worked out by finding a suitable model for ordinated (Q) of design flood hydrograph.

The available SRRG data of heavy rainstorms reveal that these rainstorms are nearly uniformly distributed in time. Therefore, flood hydrograph resulted from such storms can be expected to be near to unit hydrograph with rainstorm depth as unit rain and some suitable unit duration. In other words, the peak discharge value due to non-uniformly distributed rainstorms in time can be represented by uniformly distributed rain of shorter duration. Hence, the basic assumption of the suggested method is that unit hydrograph of duration shorter than the design storm duration can be used as analog for design flood. The assumption is valid for the rainstorms of high magnitude like standard project storm or probable maximum precipitation.

3. *Scheme of computation*

(*a*) From the available design unit hydrograph develop unit hydrograph of various durations (like 1 hr, 2-hr, ..., up to design storm duration).

(*b*) Each of these unit hydrograph is represented in non-dimensional term. Discharge ordinates are represented as percentage of peak discharge value and time as percentage of total flood duration of that unit hydrograph.

(*c*) Measure the area under the curve of each such hydrograph. This area represents total volume of direct/ runoff (V) due to unit rain over the catchment. Find the volume of flood (V_1) represented by the unit area of the curve.

(*d*) The total time on x-axis represents the total duration of direct surface runoff due to design storm of given duration. This is equal to the base of unit hydrograph of design storm duration. Find the time represented by unit length on x-axis (T_1).

(*e*) Find the discharge represented by unit length on y-axis, $Q_1 = (V_1 / T_1)$.

(*f*) From the scales Q_1 and T_1 estimate design flood hydrograph ordinates (Q) for each unit hydrograph. Solve Eqn. (2) in each case to obtain effective rain depth ordinates (P).

(*g*) The suitable analog from these non-dimensional unit hydrographs is decided by trial and error method. The suitable analog will give all the ordinates of synthetic hyetograph (P) positive and critical. In nature these cannot be negative effective rain.

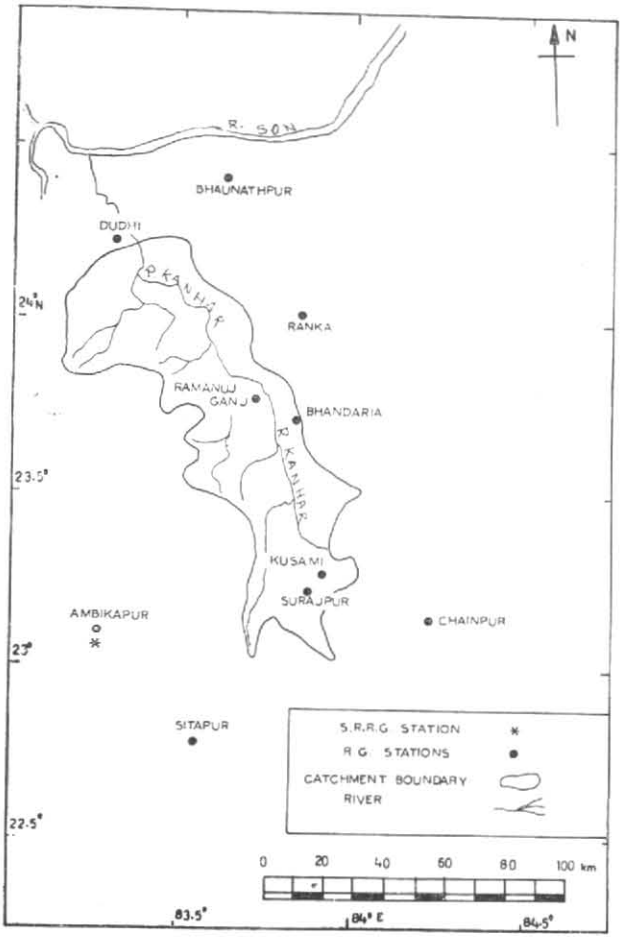

Fig. 1. Kanhar catchment up to dam site (Dudhi)

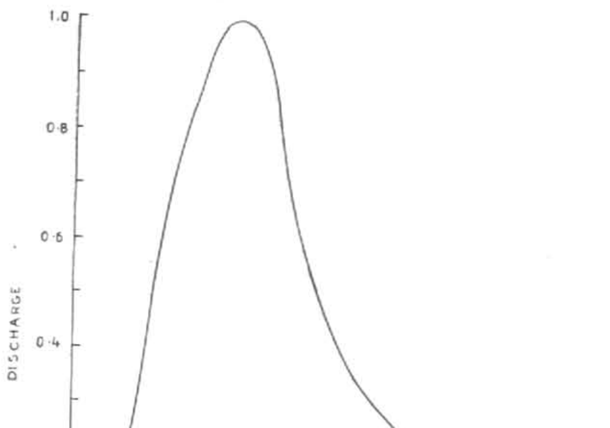

Fig. 2. Non-dimensional hydrograph of 18 hours

TABLE 1

Ordinates in cumecs for 1 cm of effective rain

Time (hr)	3-hr unit hydrograph	18-hr unit hydrograph	24-hr analogous flood hydrograph
0	0	0	0
3	120.00	20.00	14.45
6	300.00	70.00	52.93
9	670.00	181.67	134.9
12	880.00	328.33	257.7
15	599.8	428.29	368.4
18	380.00	491.63	426.3
21	300.00	521.64	472.0
24	245.50	512.56	481.6
27	200.00	434.23	457.5
30	180.00	317.56	375.6
33	150.00	242.60	284.1
36	130.00	200.93	226.4
39	110.00	169.27	185.4
42	90.00	143.35	161.4
45	70.00	121.70	139.7
48	49.90	100.02	118.0
51	30.10	80.03	101.1
54	20.00	61.70	81.8
57	0.0	43.35	65.0
60		28.35	50.6
63		16.67	33.8
66		8.35	24.0
69		3.33	14.4
72		0.0	7.22
75			2.33
78			0.0

4. *Illustration* — In order to illustrate the method, the synthetic hyetograph ordinates of 24-hr duration design storm are worked out for Kanhar catchment in Uttar Pradesh (Fig. 1). The total area of the catchment up to dam site is 4590 sq. km. The ordinates of three-hour unit hydrograph for 1 cm of unit rain are available (CDD, U.P. 1980). From this unit hydrograph, ordinates of other unit durations 1-hr, 2-hr up to 24-hr are derived. All these unit hydrographs are plotted in non-dimensional terms. The scale used as 1 unit on x-axis represents 5% of total duration of direct surface runoff and 1 unit on y-axis represents 5% of peak discharge of that unit hydrograph. The scheme of computation for 18-hr unit hydrograph is given below as an example.

TABLE 2

The synthetic hyetograph ordinates of 24-hr design storm expressed in percentage as computed and in critical order

Time (hr)	Computed	Critical order
0–3	9.8	3.3
3–6	17.7	7.9
6–9	13.3	9.8
9–12	16.9	13.3
12–15	13.3	16.9
15–18	17.6	17.7
18–21	7.9	17.6
21–24	3.3	13.3

The total area under the 18-hr analog unit hydrograph curve (Fig. 2) is 135.7 units. This area represents the direct surface runoff volume.

$$V = 4590 \times 10^6 \times 10^{-2} = 4590 \times 10^4 \text{ cu.m}$$

Thus, unit area of the curve will represent runoff volume of:

$$V_1 = \frac{4590 \times 10^4}{135.7} = 338217.12 \text{ cu.m}$$

From the 24-hr unit hydrograph, the total duration of direct surface runoff due to 24-hr design storm can be computed. This total duration is 78 hr. Therefore, 1 unit on x-axis represents:

$$T_1 = 5\% \text{ of } 78 \text{ hr} = 14040 \text{ sec.}$$

and 1 unit on y-axis represents:

$$Q_1 = V_1/T_1 = 24.08 \text{ cumecs}$$

The ordinates on y-axis at 3-hr interval, that is, at points 0.038, 0.076, 0.115, ..., 1.0 on x-axis of the curve are measured. Each ordinate represents the analog flood hydrograph due to 24-hr design storm when multiplied by Q_1. The discharge ordinates of 3-hr unit hydrograph (U), 18-hr unit hydrograph and 24-hr analog flood hydrograph (Q) are given in Table 1. By solving Eqn. (2) the ordinates of synthetic hyetograph (P) at 3-hr interval are worked out in chronological order. The computation is to be repeated for each non-dimensional unit hydrograph to work out corresponding 24-hr flood hydrograph ordinates. The suitable analog should result all the hyetograph ordinates (P) positive and critical after solving Eqn. (2). Engineer may rearrange these ordinates so as to get critical design flood.

In this case 18-hr non-dimensional unit hydrograph was found to be suitable analog. The hyetograph ordinates in chronological as well as critical order worked out for 1 cm of effective rain are given in Table 2. Thus, with unit hydrograph as only input, synthetic time distribution of design storm can be worked out without SRRG data.

5. *Limitations* — This method has all the limitations of unit hydrograph theory. Also the time distribution so derived is applicable to design storm of high return periods or probable maximum storm as the assumptions made are well applicable to such rainstorms.

This method is just a substitute when SRRG data is not sufficient to derive temporal distribution of design storm. It should be kept in mind that perfect methodology can be derived only after taking into consideration the physical processes responsible for severe rainstorm, as input.

6. *Conclusions* — (*a*) The unit hydrograph theory can be extended effectively to compute ordinates of synthetic hyetograph of design storm.

(*b*) As the discharge is the integrated effect of spatial and temporal variation of rainstorm over the catchment, the time distribution derived by this method is representative of the whole catchment.

References

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