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Derivation of 6-hour unitgraphs for Barakar (D. V. C.) and Yamuna catchments for flood forecasting

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ABSTRACT. In this paper, series of unit hydrographs were derived assuming a 6-hr unit period for the *Barakar* and *Yamuna* catchments. The best fit unit hydrograph is selected mainly by the least square's method. Several important relationships to apply the method for operational use were also derived. These relationships are in the form of API initial loss relationships and the inter-relationship of rainfall intensity, loss rate and API.

Although the results are based upon a small sample, it has been possible to derive the above relationships. At the end a correction diagram is also given to enable the user to correct the time of occurrence as well as the magnitude of the flood peak.

1. Introduction

The derivation of three hourly unit hydrographs and their application to flood forecasting has been discussed by Rao *et al.* (1974 a, b). In these studies, it is implied that the rainfall data will become available at three hourly intervals. In a given flood situation, it is possible that this may impose strain on the data transmission system and in a worst case, a flood forecaster has to issue a flood forecast with many compromises. For this reason, it is necessary to have alternate methods ready to enable the issue of flood forecasts with whatever data that becomes available. For instance, if the data are not forthcoming, one has to even think of 6 or 12-hr unit hydrographs. With this objective in view, the present study has been attempted. There are inherent limitations, particularly with regard to the time and areal distribution of rainfall. In spite of these, a method would still be needed in flood situations where there can be simultaneous breakdowns of any well placed arrangements.

2. Analysis of data

In the earlier studies (*loc.cit.*) the procedure adopted is to derive the unit hydrographs from the selected storms for *Barakar* (D.V.C.) and *Yamuna* catchments, taking the self recording (S.R.) rainfall data and discharge data for 3-hr time periods. In the present study, the time period has been taken as 6 hours both in the S.R. rainfall data and discharge data while deriving the unitgraphs in the *Barakar* and *Yamuna* catchments. The essential aspects of unit hydrograph theory have been explained by Dhar (1973) and no repetition is made.

The application of unitgraph to flood forecasting has been given in detail in the Macleay Flood Forecasting (Bur. Met. Rep. Australia 1963) and in the Elements of River Forecasting (Richards *et al.* 1969).

The unitgraph, as it is applied to flood forecasting, is based on the assumption that a linear relationship exists between the excess rainfall, unit hydrograph and the reproduced hydrograph in each unit period within a storm. In the present case the unit period chosen is 6 hr. The direct runoff is related to excess rainfall, once the unit period chosen and gross areal rainfall of the catchment determined. A series of equations which are well known are expressed in the form:

$$Q_1 = U_1 P_1$$
$$Q_2 = U_1 P_2 + U_2 P_1$$
$$Q_3 = U_1 P_3 + U_2 P_2 + U_3 P_1 \text{ etc and so on.}$$

where P is the excess rainfall during the chosen unit period, Q is the discharge ordinate of the direct runoff hydrograph, and U is the unitgraph ordinate. These sets of equations, which are so defined assuming linearity condition, are solved by the least square approach in this case to produce the ordinates of unitgraph for each given storm and for a certain condition of initial loss and continuing loss. The method of

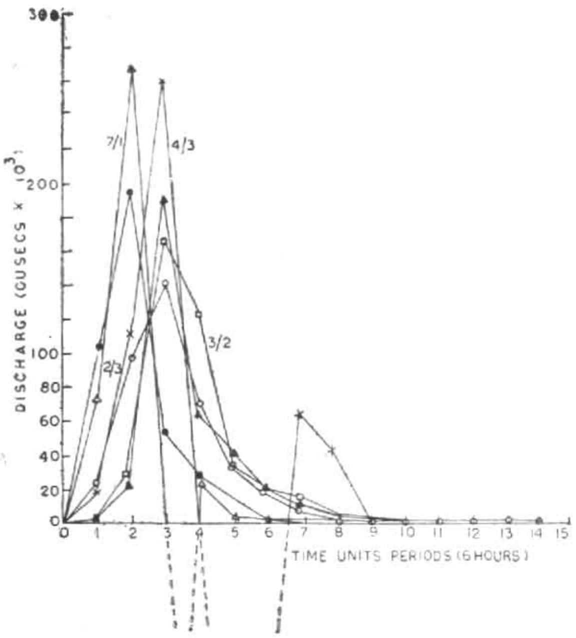

Fig. 1(a). *Barakar* river upto Palganj (6-hr) individual unitgraphs

analysis carried out is the same as by Rao *et al.* (1974).

In the unitgraph analysis the rainfall is taken such that it represents the average catchment rainfall in both area and in time. The areal rainfall is obtained by averaging the 24-hr rainfall of the various raingauge stations within the catchment. An examination of the available S. R. rainfall data in the catchment is made and 6 hourly rainfall distribution at the above stations are obtained. From the general synoptic situation, the movement of the storms etc, it will be possible to select a particular rainfall distribution out of the above. This is so chosen that it represents approximately the time distribution of rainfall with reference to the whole catchment. However, if the S.R. rainfall data in the catchment was adequate, the best procedure would be to get the average of the 6 hourly values at all the S.R. raingauge stations. In the absence of adequate network, the above procedure has become necessary. Care is taken that both the average catchment rainfall and representative S.R. rainfall data refer to the same period of time.

The ratio of the catchment average rainfall and the total S.R. rainfall data of the station gives, what is known as, the distribution factor. This distribution factor is multiplied with each unit period of S.R. rainfall data, to get the simulated average temporal rainfall distribution. Values of average temporal rainfall distribution are fed in IBM-360/44 computer to get unitgraphs. A copy of the derivations given by the computer for each catchment under study is given in Table [1(a) and 1(b)]. The individual unitgraphs from every storm can be seen in Figs. 1(a) and 1(b).

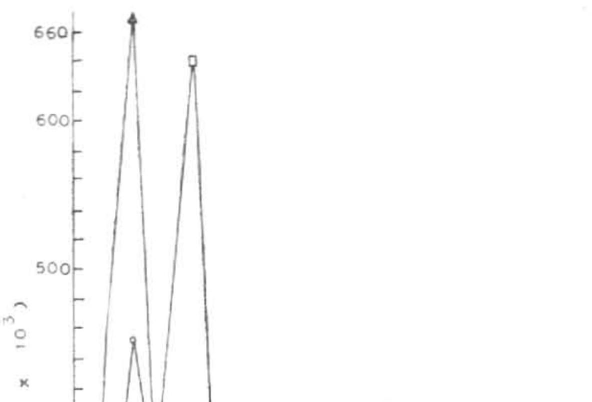

Fig. 1(b). *Yamuna* river upto Kalanur (6-hr) individual unit graphs

3. Results of six-hour unitgraphs for Barakar and Yamuna

From the individual unitgraphs, an average unitgraph has been derived by averaging the various response functions of each individual unitgraphs. In this connection, a number of combinations were tried for the storms selected for averaging and the storm selected for application. The combination which gave the best results has been selected as the operationally adopted average unitgraph and the graphs of these

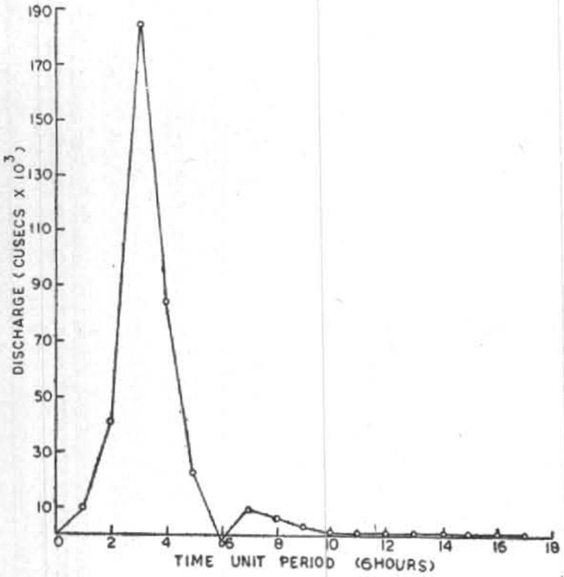

Fig. 2(a). *Barakar* river (upto Palgan; Average unitgraph (Computer produced)

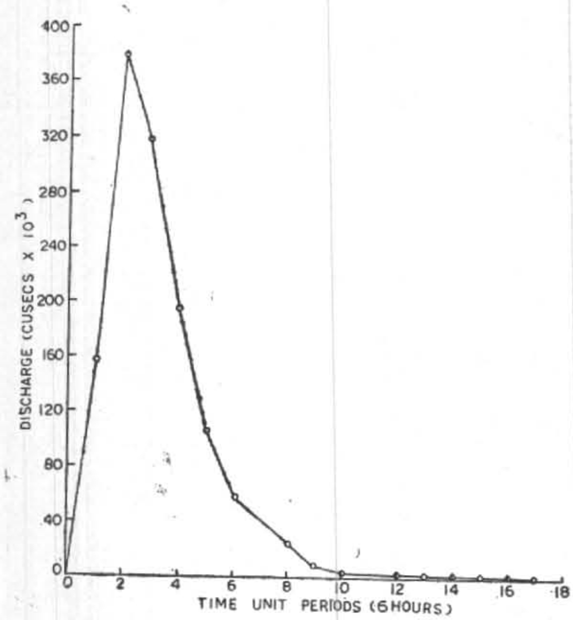

Fig. 2(b). *Yamuna* river upto Kalanur. Average unit graph (Computer produced)

adopted average unitgraphs for *Barakar* (D.V.C.) and *Yamuna* are presented in Figs. 2(a) and 2(b). The ordinates of the average unitgraphs for these catchments are given in Table 2.

Table 3[(a) and (b)] shows the peaks of observed hydrograph and predicted hydrograph with their times of difference of all the storms for both the catchments. The graphs based on these tables are by plotting the observed peaks and

TABLE 1

Sample derivation of unitgraph

Period	Rain (inch) Gross	Rain (inch) Excess	Observed hydrograph	Reproduced hydrograph	Unitgraph
(a) *Barakar* river at Paiganj for 6-hr storm 2/2					
1	1·18	0·0	0	0·0	6020·9
2	0·51	0·0	0	0·0	62092·9
3	1·16	0·531	1000	3200·1	169375·3
4	1·85	1.122	40800	39757·8	79245·9
5			159200	159693·4	37428·1
6			232400	232165·9	22110·2
7			108700	108810·4	8120·7
8			53800	53747·6	1084·6
9			29100	29124·8	543·9
10			9700	9688·2	353·9
11			1500	1505·6	196·1
12			800	797·4	149·4
13			500	501·1	113·6
14			300	299·4	86 2
(b) *Yamuna* river at Kalanur for 6-hr storm 4/2					
1	0·0	0·0	0	0·0	138112·4
2	0·26	0·0	0	0·0	225424·9
3	0·04	0·0	0	0·0	257147·9
4	0·28	0·0	0	0·0	193674·9
5	1·02	0·0	29000	0·0	126999·9
6	0·83	0·630	87000	86999·9	71437·9
7	0·12	0·0	142000	141999·9	34925·0
8	0·04	0·0	162000	161999·9	11112·5
9			122000	121999·9	7143·7
10			80000	79999·9	3968·7
11			45000	45000·0	3175·0
12			22000	22000·0	2540·0
13			7000	7000·0	2032·0
14			4500	4500·0	1625·6
15			2500	2500·0	1300·5

For (a) *Barakar* river

Excess rain=1·65 inch, Loss rate=0·728 inches/3hr, Initial loss=1·69 inches, Recession constant=0·760, Unitgraph terms=11 Squares fit=$0·62\times10^7$

For (b) *Yamuna* river

Excess rain=0·63 inch, Loss rate=0·197 inches/3 hr, Initial loss=1·50 inches, Recession constant=0·800, Unitgraph terms=10, Squares fit=0·0

TABLE 2

Ordinates of average unitgraph

Periods	Barakar river (DVC)	Yamuna river
1	9092·7	157050·1
2	39263·5	377719·6
3	183390·6	316371·7
4	84229·2	191494·3
5	22039·7	103936·2
6	—1509·8	58559·5
7	10397·8	42236·4
8	6491·5	25160·6
9	2640·4	6220·8
10	278·5	2166·0
11	—204·6	1624·5
12	414·3	1218·4
13	279·0	913·8
14	209·3	685·3
15	156·9	514·0
16	117·7	385·5

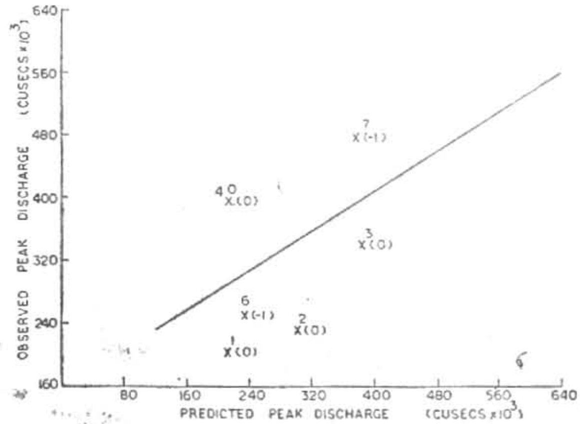

Fig. 3(a). *Barakar* river upto Palganj

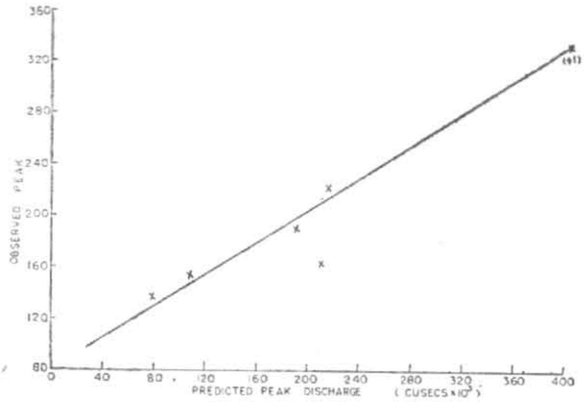

Fig. 3(b). *Yamuna* river upto Kalanur

Peak trend diagrams

Nos. on top refer to storm number and Nos. in brackets—Sime difference in unit periods of 6-hr between predicted & observed peaks. Plus sign indicates predicted and observed peaks whereas negative sign to predicted peak after observed.

TABLE 3

Predicted and observed peaks and their times of occurrence

Storm No.	Observed peak (cusecs)	Time and date of observed peak	Predicted peak (cusecs)	Time and date of predicted peak	Time difference (units 6 hr)	Difference	Percentage
			(a) *Barakar* river upto Palganj				
1	202800	9 A.M., 19 Aug 67	194942	9 A.M., 19 Aug 67	0—	—7858	—3·9
2	232400	3 A.M., 24 Sep 65	303244	3 A.M., 24 Sep 65	0+	—70344	+30·5
3	347000	3 A.M., 24 Oct 63	386520	3 A.M., 24 Oct 63	0+	+39520	+11·4
4	396000	9 A.M., 3 Oct 63	214905	9 A.M., 3 Oct 63	0—	—181095	—45·7
6	251800	9 P.M., 29 Aug 60	236311	3 A.M., 30 Aug 60	—1—	—15489	—6·1
7	479000	9 A.M., 2 Oct 59	371557	3 P.M., 2 Oct 59	—1—	—107443	—22·4
			(b) *Yamuna* river upto Kalanur				
1	330000	3 A.M., 7 Aug '71	407860	9 P.M., 6 Sep 71	+1+	+7786	+23·6
3	187000	3 P.M., 7 Jul '71	192258	3 P.M., 7 Jul 71	0+	+5258	+2·8
4	162000	3 A.M., 7 Aug '69	212573	9 P.M., 6 Aug 69	+1+	+50573	+31·2
5	153000	9 P.M., 18 Jul '68	107308	9 A.M., 19 Jul 68	—2—	—45692	—29·9
7	250000	3 A.M., 28 Aug '67	218611	3 A.M., 28 Aug 67	0—	—31389	—12·6
8	136000	9 A.M., 13 Sep '70	79617	9 P.M., 12 Sep 70	+2—	—56383	—41·5

predicted peaks against each other are presented in Figs. 3(a) and 3(b). These are known as Peak Trend Diagrams.

3·1. *A.P.I. initial loss relationship for 6-hr unit duration*

The Antecedent Precipitation Index (A.P.I.) is taken to represent adequately the status of the soil at the commencement of flood producing rainstorm. Initial loss is usually taken as that amount of rainfall which is lost to the soil and runoff starts only after fulfilling these initial losses. A linear relationship is expected to exist between the A.P.I. and initial loss on the one hand and curvilinear relationship between A.P.I. and continuing loss, which is that amount of water that continues to be lost to the soil after the surface runoff commences. The A.P.I. initial loss relationship for 6-hr duration is shown in Fig. 4(a) and the A.P.I. initial loss for 3-hr periods obtained by Rao *et al.* (1974) is shown in Fig. 4(b) for purpose of comparison.

3.2. *Explanation for negative values*

In a few cases the unitgraph ordinates were showing negative values. In the type of solution attempted here, *i.e.*, linear regression equation type, such negative values are possible. For example, let us find out the specific solution of U_5 in the following equation :

$$Q_5 = U_5 P_1 + U_4 P_2 + U_3 P_3 + U_2 P_4 + U_1 P_5$$

In the above equation except U_5 all others are known variables.

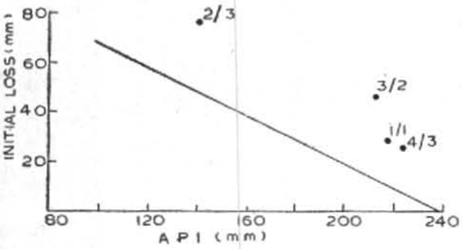

Fig. 4(a). *Barakar* river upto Palganj
(Based on 6-hrly data)

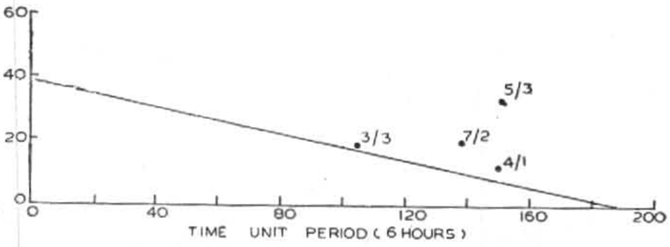

Fig. 4(b). *Yamuna* river upto Kalanur. API initial loss
(Based on 6-hrly data)

Therefore,

$$U_5 = \frac{Q_5 - (U_4P_2 + U_3P_3 + U_2P_4 + U_1P_5)}{P_1}$$

Let us replace the terms in the bracket by X. Then

$$U_5 = (Q_5 - X)/P_1$$

U_5 will be positive or negative depending on $Q_5 - X$. In turn it depends on the products of U_4P_2, U_3P_3 etc. In some cases, depending on a more skew distribution of rainfall, the products may be quite large, resulting in their accumulated totals being higher than the observed discharge, in this case Q_5. In actual practice, however, these negative values are simply ignored.

4. Conclusion

This study has highlighted the unitgraphs applicable for 6-hr unit periods for flood forecasting in *Barakar* and *Yamuna* catchments. This study would enable that for a certain river catchment, if short period observations (say 3 hourly values) are not available, it is possible to use this method of unitgraph analysis for a quick application for longer period observations (namely 6 hr) for flood forecasting.

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