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Derivation of unit hydrograph by using rainfall and runoff data for a small watershed

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ABSTRACT : Runoff is the drainage of precipitation from a catchment, which flows out through its natural drainage system. After the occurrence of infiltration and other losses from the precipitation (rainfall), the excess rainfall flows out through the small natural channel on the land surface to the main drainage channel of the small watershed. A plot of the stream discharge against the elapsed time, gives the flow hydrograph. A hydrograph of the stream flow in the drainage channel of a small watershed, measured at its outlet, is the response of the watershed to its input of precipitation on a continuous basis, with respect to the time of occurrence of the storm but a unit hydrograph is the hydrograph of direct runoff resulting from one unit (generally 1 cm) of effective rainfall generated uniformly over the basin at a uniform rate during a specified period of time (Sherman, 1932). In black box analysis approach, little consideration is given initially to the conceptual characteristic of the unit hydrograph Inspite of mathematical and statistical techniques were employed to determine appropriate numeral values of unit hydrograph ordinates or co-efficient of a functional series representing the unit hydrograph. The derivative of a unit hydrograph from a simple hydrograph consists of dividing the ordinates of the direct runoff hydrograph results from the multiperiod storm. Unit hydrograph are derived from rainfall and stream flow records of complex flood hydrograph using techniques such as Collions iterative solution (Collions, 1939), system of progressive ordinates (Linseley *et al.*, 1958) and Fourier transformation (Levi and Valdas, 1964). In this study, Collions method is used for derivation of unit hydrograph from complex flood is utilized to derive the unit hydrograph from single-peaked runoff hydrograph of kothuwatari watershed (27.93 km^2) was chosen for the study. For the analysis of storm events of the above watershed of Sept. 18, 1991, Sept. 1991, Nov. 2-3, 1993, July 4, 1994, July 18, 1999, Sept. 15, 1996. August 23-24, 1994 was considered and found average percentage absolute deviation of the above storm events with respect to computed and observed flow volumes was 8.433 and 8.355, respectively. Here our study was confined to develop representative unit hydrograph for the kothuwatari watershed by the Collions method.

KEY WORDS : Unit hydrograph, Collions method, Precipitation effective rainfall, Iterative solution

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Several rainfall-runoff events of Kothuwatari watershed which is the sub-catchment of upper Damodar Valley was selected for the derivation of unit hydrograph. In this study, Collions method was used for the derivation of unit hydrograph from the complex flood is used to derive the unit hydrograph from single-peaked runoff hydrograph and studied about computed and observed flow volumes of different storm events but for prediction set overall average values were found as 0.010, 0.010, 0.041, 0.169, 0.932 and 0.931, respectively as shown in Table-1 and Table-2. While considering prediction events of July 28, 1994, Octo 12-13, 1994 and July 16, 1995 the average percentage absolute deviation of the storm events was found to be 5.340 as shown in Table 1. The relative square error, integral square error and co-efficient of efficiency of the above mentioned events for calibration set, by Collions method the average values were found to be 0.006, 0.006, 0.026, 0.099, 0.954 and 0.953, respectively. Present study was confined to compare the computed and observed direct runoff hydrograph of the various storm events of small watershed and test the performance of the model by qualitative and quantitative evaluation approach under this study Collion (1993) approach was used for successive approximation for the derivation of

unit hydrograph from complex storm events based on trail and error approach.

METHODOLOGY

The aim of this study was to develop a representative unit hydrograph of Kothuwatari watershed which is situated in Hazaribagh distrcit of Jharkhand state and it forms a part of the Tilaiya dam sub-catchment of the upper Damodar Valley. Kothuwatari watershed is almost rectangular in shape, has a length of 7.50 km and mean width of 3.60 km. The total area of the watershed is 27.93 km^2. The average slope of the watershed varies from 1 to 5% and most of the soils are predominately red-loamy because of the presence of high percentage of iron oxide. The watershed area drains from the south-east to north direction directly or through its tributaries. Soils are generally acidic in nature with a pH range of 5.50 to 6.50. The Kothuwatari watershed has nearly 54% of the area under agriculture, 26% under forest and the remaining 20% mainly as waste land, community land and under habitation.

The rainfall-runoff events of Kothuwatari watershed were analysed for the year 1991 to 1996 of various storm events for the derivation of unit hydrograph. The effective rainfall for the rainfall-runoff events were determined by f-index method. The direct runoff hydrographs were thus derived by deducting the base flow from the total storm hydrogrph in this analysis. The rainfall and runoff analysis of the storm event of Aug. 23-24, 1994, have been shown in Fig.A. The direct runoff hydrograph ordinates the base flow from the total storm hydrograph ordinates using the following relationship:

$$QD_t = Q_{Tt} - Q_{Bt} \quad (1)$$

where

QD_t= Direct runoff hydrograph ordinates at time 't' in m^3/sec.

Q_{Tt}= Total runoff hydrograph ordinates at time 't' in m^3/sec.

Q_{Bt}= Base flow ordinates at time 't' in m^3/sec.

The unit hydrograph theory assumes that the watershed is linear and since invariant *i.e.* the direct runoff is derived from the effective rainfall by a linear operation. The unit hydrograph represent to a particular duration of effective rainfall and has a unit volume. Collions (1993) suggested that a variation of the trial and error approach in which the most recent estimate of unit hydrograph is applied to all rainfall parameter except the maximum one, the resulting estimated runoff was substarcted from the actual runoff to give runoff due to the maximum ordinate alone and this was used to update the precious estimation of unit hydrograph.

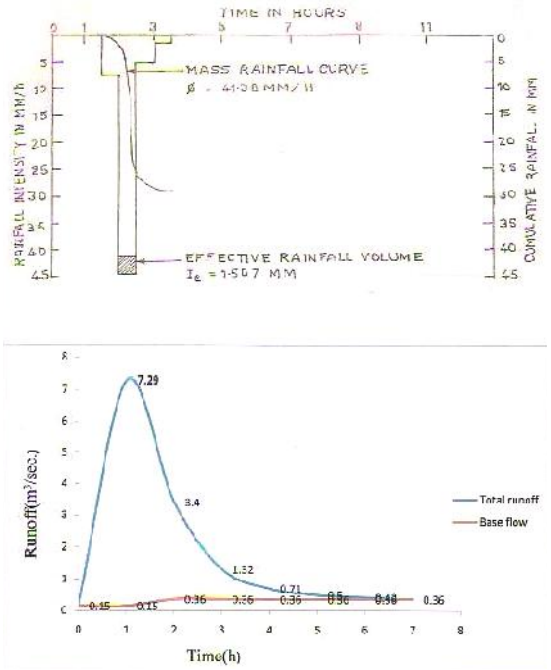

Fig. A : Rainfall and runoff analysis of the rainfall runoff event of August 23-24 1994

RESULTS AND DISCUSSION

The representative 0.5h unit hydrograph for the Kothuwatari watershed was developed by plotting the unit hydrograph derived for the rainfall-runoff events of calibration set. The average of peak ordinates and their time of flow were computed. The best fit average unit hydrograph judged visually was drawn through the average peak and confirming to the shape of unit hydrograph. The ordinates of representative unit hydrograph developed by the Collions methods is given in

Table 1 : Representative 0.5hr unit hydrograph ordinates for Kothuwatari watershed derived by Collions methods

Time (hr)	Unit hydrograph ordinates (m^3/sec)
0.0	0.000
0.5	23.233
1.0	40.698
1.5	42.634
2.0	21.975
2.5	13.944
3.0	7.852
3.5	4.759
4.0	3.312
4.5	2.051
5.0	1.493
5.5	0.856
6.0	0.697
6.5	0.584
7.0	0.465
7.5	0.000

Table 1.

The relative performance of the model has been tested by regenerating the direct runoff hydrographs for the seven storms events *viz*., Sept. 18, 1991, Sept. 22, 1991, Nov. 2-3, 1993, July 4, 1994, July 18, 1994, Sept. 15, 1996 and Aug. 23-24, 1994 which shows the response function of the watershed, *i.e.* UH (Table 2). The model performance has also been tested by predicting the direct runoff hydrographs for the storm events which were not utilized at all for the estimation of model parameters. The quantitative performance of the model used for regeneration and prediction of direct runoff hydrographs was tested by visual comparisons between the concentration segments, crest segments, recession segments etc. of the computed and observed direct runoff hydrographs of the same storm events for validating the equivalence between the watershed and model. The prediction was verified and validated though comparison of the computed and observed direct runoff hydrographs visually for the verification events of July 28, 1994, Oct. 12-13, 1994 and July 16, 1995. The overall features representing the shape of the direct runoff hydrograph computed from the model were found to be very similar to those observed ones which also showed the goodness of fit in the shape between the predicted and observed direct runoff hydrographs. Percentage absolute deviation in peak flow rates, time to peak and base, and volumes were estimated for judging the quantitative performance of the model. The percentage absolute deviation in peak flow rate varied from 5.32 to 28.12 per cent for Collions methods for the storm events considered for regeneration purpose and from 3.38 to 26.93 per cent under this method for the storm events considered for prediction purposes. The co-efficient of efficiency of the model describes the degree of association between the observed and estimated flows. The values of the co-efficient of efficiency for the events considered for regeneration and prediction purposes varied from 0.913 to 1.00 and 0.866 to 0.984, respectively. Higher values of the co-efficient of efficiency for all the events indicate fare degree of goodness of fit between the computed and observed direct runoff hydrographs. Its is evident the HU model simulates the flow values almost nearer to the observed ones. The details finding of observed and computed flow volumes, percentage absolute deviation, relative square error, integral square error and co-efficient of efficiency of the mathematical model by Collions methods of various storm events was delineated in Table 2 and 3, respectively.

Table 2: Observed and computed flow volumes and percentage absolute deviation of different shown events

Date of storm	Direct runoff volumes		
	Observed (m^3)	Computed (m^3) by Collions method	Percentage Absolute deviation by Collions method
Calibration set			
Sept. 18, 1991	12492.00	12859.20	0.778
Sept. 22, 1991	33192.00	33546.60	1.068
Nov. 2-3, 1993	57465.00	55656.00	3.148
July 4, 1994	14221.80	20295.00	42.70
July 18, 1994	28137.60	26802.00	4.747
Sept. 15, 1996	158250.60	160403.00	1.360
August 23-24, 1994	43992.00	41689.80	5.233
Avg. values			8.433
Prediction set			
July 28, 1994	37004.40	37461.60	1.236
Oct. 12-13, 1994	203209.20	193062.60	4.993
July 16, 1995	12655.80	12720.60	0.512
Avg. values			2.247
Overall Avg. Values			5.340

Table 3 : Relative square error, integral square error and coefficient of efficiency of the mathematical model

Date of storm	Relative square error	Integral square error	Coefficient of efficiency
Regeneration set			
Avg. values of all seven storm events	0.006	0.026	0.954
Prediction set			
Avg. Values of three storm events	0.013	0.055	0.909
Over all avg. values	0.010	0.041	0.932

Conclusion:

The study concludes the derivation of representation unit hydrograph for the estimation of runoff hydrograph for the Kothuwatari watershed by Collions method and also evaluatation and comparison the performance of the mathematical model for the storm events from 1991 to 1996. The models were evaluated based on visual inspection and also based on statistical analysis such as correlation co-efficient, integral square error, relative square error and percentage absolute deviation in estimated peak. The representative 0.5 h unit hydrograph ordinates at an interval of 0.5h, derived by Collions method was found 0.000, 23.233, 40.698, 42.634, 21.975, 13.944, 7.852, 4.759, 3.312, 2.051, 1.493, 0.856, 0.697, 0.584, 0.465, 0.000 at zero to 7.5 hours.

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