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Determination of weighting factor x, for Chaukhutia watershed of Ramganga reservoir

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ABSTRACT

The present paper outlines a strategy for computation of weighting factor (x) to compute the peak discharge for a given rainfall runoff event in a basin. The time invariant instantaneous unit hydrograph (IUH) was converted into unit hydrograph (UH) for each storm event. The peak and time to peak of runoff discharge are estimated for different storms of the basin by convolution of UH with rainfall excess (Re). The relative weights of the storm characteristics and basin parameters are also used in the prediction of peak. The Chaukhutia watershed of Ramganga reservoir catchment was selected to check the predicted results with respect to observed direct runoff hybrographs (DRHs). The theory provided excellent agreement for the basin (452 km2) area at the x value 0.30.

The need for accurate estimates of watershed runoff has grown rapidly during the past decades along with the acceleration of watershed management programmes for conservations, development and beneficial use of natural water resources. Prediction of runoff is also essential for accurate design of various components of water harvesting and hydraulic structures. The peak discharge of DRH is directly proportional to the IUH peak discharge. General expressions for the instantaneous unit hydrograph (IUH) have been derived as function of routing time area histogram (TAH) of a basin. The one most important parameter, weighting factor x, is the backbone of the Muskingum routing equation to rout the TAH. The parameters other than x of Muskingum routing equation such as storage coefficient and routing interval (Δt)are constant. So the study was conducted to determine the most appropriate value of x, for an accurate estimation of peak flow rate.

The IUH model attempts to establish a relationship between effective rainfall of a storm and the resulting DRH for a given basin. The major objective of this study was to determine the most suitable value of x for the Chaukhutia watershed of Ramganga river to compute the most accurate design discharge for the structures.

STUDY AREA

The study area of Chaukhutia Watershed is a sub catchment of Ramganga river, which is located on Ranikhet Karanpryag state highway and lies between 29° 46' 15" to 30° 6' N latitude and 79° 12' 15" to 79° 31' N longitude

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in the Chamoli district of Uttaranchal. The watershed area has been broadly categorized into forest (19.87%), cultivated lands (27.28%), pasture (42.76%) and miscellaneous lands (10.05%). The watershed has a hilly terrain with irregular slopes varying from relatively flat in narrow belts situated on either side of Ramganga river in valley to quite steep towards ridges. On the basis of slopes, the land of watershed may be classified in valley, moderate and steep hills. The soils are mostly derived from micamuscovite, sandstone and biotite parent materials.

MATERIAL AND METHODS

Data collection

For hydrological analysis the data of watershed characteristics, rating curves, stage hydrographs and corresponding rainfall records were collected from the Divisional Forest Office, Ranikhet. The twenty single peaked runoff hydrographs from the years 1976-85 were considered.

Mathematical Models of Rainfall-Runoff Process

Conceptual models of IUHs of rainfall-runoff transformation by routing time area histogram (TAH) (Clark, 1945) through a series of linear reservoirs and channels utilizing Muskingum method was derived for Chaukhutia watershed. The IUH and UH technique for hydrologic system modeling is based on the assumption of lumped linear time-invariant watershed system.

Clark (1945) method for developing an IUH involves the application of an instantaneously applied unit depth of effective rainfall over the watershed. The use of Clark method requires three parameters namely storage coefficient K, time of concentration Tc, and time area histogram (TAH).

The parameter K (1.314 h) was computed by the Wilson (1969) method, however the other parameter Tc is determined by Kirpitch (1940) formula. The computed value of Tc of the watershed was 4.52 hours, however for the construction of TAH it was taken as 5 hour.

For the development of TAH the channel distance scale of the catchment was divided into 10 equal sub-areas by isochronal having an equal time interval of 0.5 h. To assist in drawing isochrones, the longest watercourse was chosen and its profile plotted as elevation v/s distance from the outlet. By using the channel distance scale, the elevations of the intersections of the isochrones with the main-channel were estimated and transferred on the topographic map along the mainstream. The inter-isochrone areas A1, A2 .....A10 were measured by planimeter and were used to construct the travel TAH.

Routing of flow of the watershed

GT McCarthy *et al.* (1934-35) in connection with studies of the Muskingum conservancy district Flood control project of the U.S. Army Corp of Engineers developed a variable discharge storage relationship method, which involves the concept of wedge and prism storage. The total storage is, therefore expressed by the relationship.

$$S = K\,[x\,I + (1-x)\,Q] \qquad \ldots (1)$$

Equation (1) gives a linear relationship and is known as the Muskingum routing equation. In a channel reach for routing interval ($\Delta t = 0.5$) in the Muskingum equation, the change in the storage is sum of wedge and prism storage, which is given by the equation:

$$S_2 - S_1 = K [x(I_1-I_2) + (1-x) (Q_2-Q_1)] \quad ... (2)$$

The continuity eq. for the channel reach is expressed as:

$$S_2-S_1 = [\{I_1+I_2\}/2-\{Q_2+Q_1\}/2]\Delta t \quad ...(3)$$

Equation (2) and (3) gives the following Muskingum routing equation:

$$Q_2 = C_o I_2 + C_1 I_1 + C_2 Q_1 \quad ...(4)$$

Where C_o, C_1 and C_2 are determined by the following eqs:

$$C_o = \frac{-Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t} \quad ... (5)$$

$$C_1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t} \quad ... (6)$$

$$C_2 = \frac{K\text{-}Kx\text{-}0.5\Delta t}{K\text{-}Kx\text{+}0.5\Delta t} \quad ... (7)$$

and

$$Co + C_1 + C_2 = 1 \quad ... (8)$$

Routing of flow through series of linear reservoirs and channels

The reservoir routing provides methods for evaluating modifying effects of flow passing through reservoirs. The effective rainfall first undergoes pure translation and then attenuation. The translation achieved by routing TAH and the attenuation achieved by routing the linear reservoirs which is hypothetically available at the watershed outlet. A linear reservoir is a fictitious reservoir in which the storage S, is directly proportional to the out flow Q as:

$$S= KQ \quad ... (9)$$

The IUH was obtained by the Eq. (4) and C_o, C_1, C_2 are computed by putting x =0 (for reservoir routing) in equations 5, 6 & 7. The channel storage is function of inflow and out flow both. In case of channel storage, outing coefficients were determined by the Eq. 5, 6 & 7 respectively for various values of x = 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5.

With the assumption of a uniform distribution of effective rainfall in TAH method during the time interval (Dt, I_1, = I_2 = I. The IUH for different value of (x = 0.0 to 0.5) considered in the study can be written with the help Eq. (4).

For x = 0.0

$$Q_2 = 0.322I + 0.678Q_1 \quad ... (10)$$

For x = 0.05

$$Q_2 = 0.336I + 0.664Q_1 \quad ... (11)$$

For x = 0.30

$$Q_2 =0.429I +0.571Q_1 \quad ..(12)$$

For x = 0.5

$$Q_2 = 0.554I + 0.446Q_1 \quad ... (16)$$

The IUH ordinates of the watershed are shown in Fig. 1

The average IUH ordinates were converted into UH. The UH was convoluted to get the DRHs ordinates for various values of x with Re.

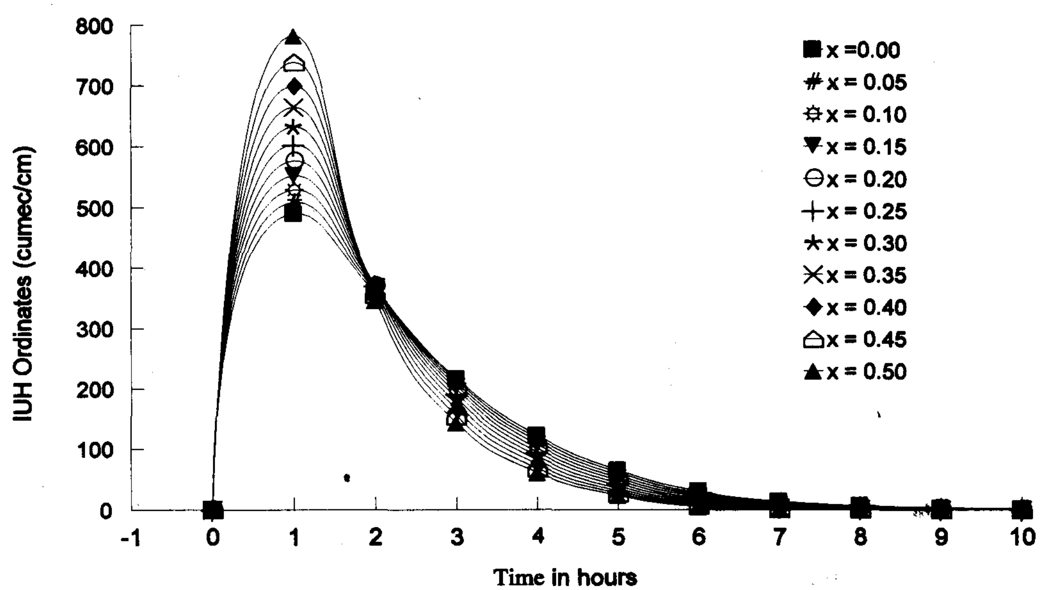

Fig. 1 Instantaneous unit hydrographs Chaukhutia watershed

RESULT AND DISCUSSION

The ordinates of IUHs for the watershed were developed by routing TAH through series linear reservoirs and channels. The average IUHs and UH ordinates are shown in Fig. 1 & 2.

In order to arrive at the most appropriate value of x the model performance was evaluated qualitatively and quantitatively. The qualitative comparison is based on visual observation of peak reproduction. The quantitative comparison is based on certain statistical parameters of the observed and computed DRHs.

The observed, regenerated (the evnts which are used in model development) and predicted (the evnts which are not used in model development) DRHs are shown in Fig. 3, 4, 5 and 6. The regenerative performance of the models was evaluated on the basis of visual observation of rising, crest and recession segments and peak flow rates of predicted, regenerated with observed DRHs. From the Fig. 3, 4, 5 & 6, it is evident that the predicted and regenerated DRHs are closer to the observed DRHs at x = 0.3 and the peak increased with increase of x values(>0.3).

Beside the qualitative comparison of the observed, and regenerated DRHs certain efficiency, departure percentage and absolute relative error criteria in computed peaks were used for quantitative evaluation of the model performance.

Nash and Sutcliffe (1970) introduced the term coefficient efficiency to describe the degree of

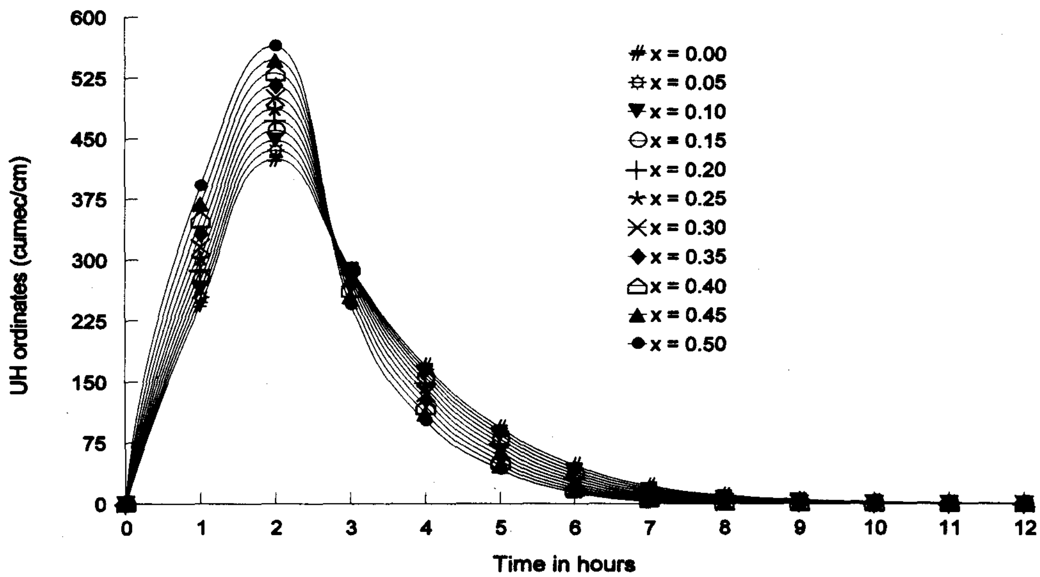

Fig. 2 One hour unit hydrographs for Chaukhutia watershed

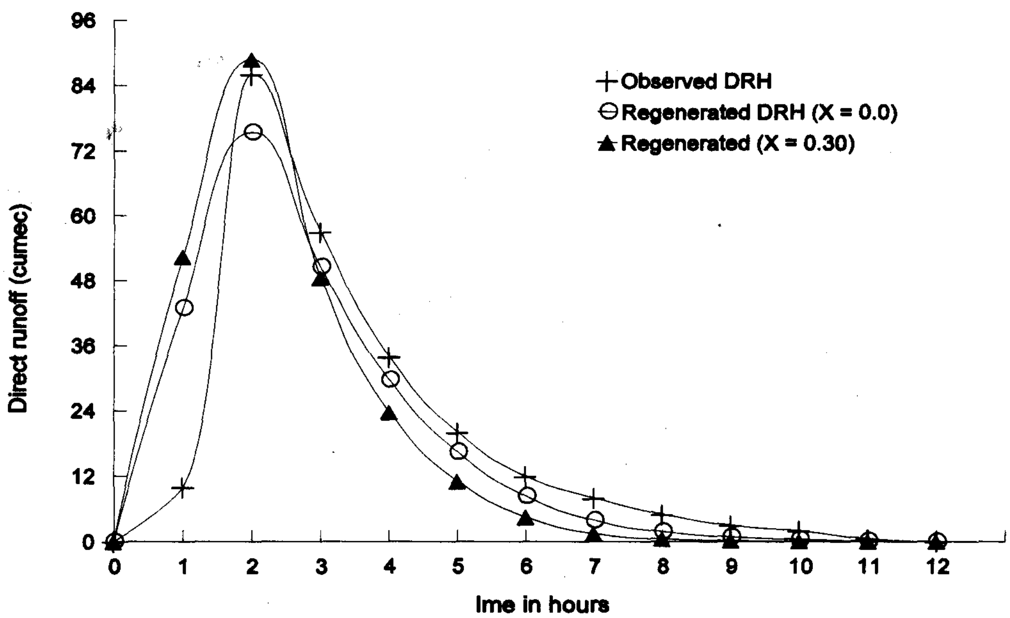

Fig. 3 Comparison of observed and regenerated direct runoff hydrographs for the storm events of September 5-6, 1983

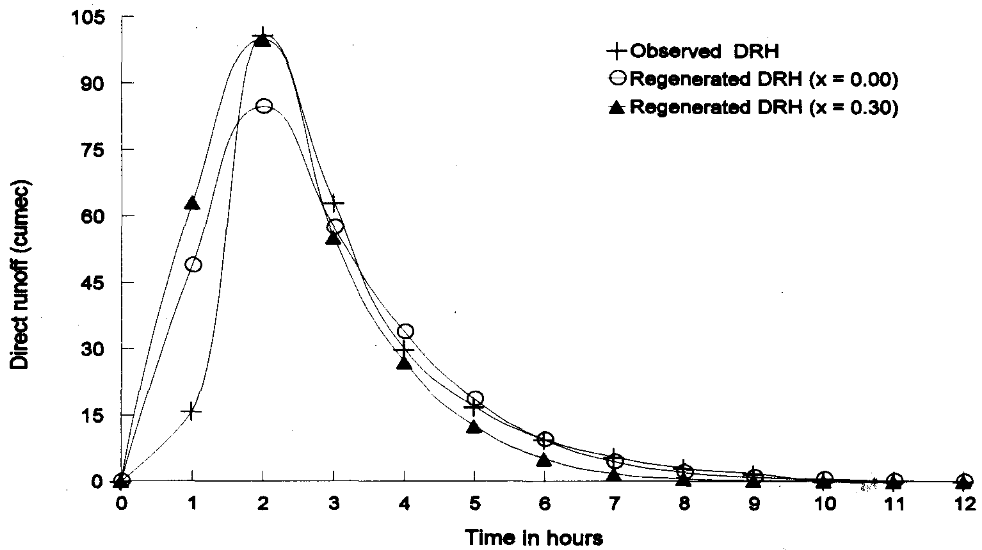

Fig. 4 Comparison of observed and regenerated direct runoff hydrographs for the storm events of August 18-19, 1984

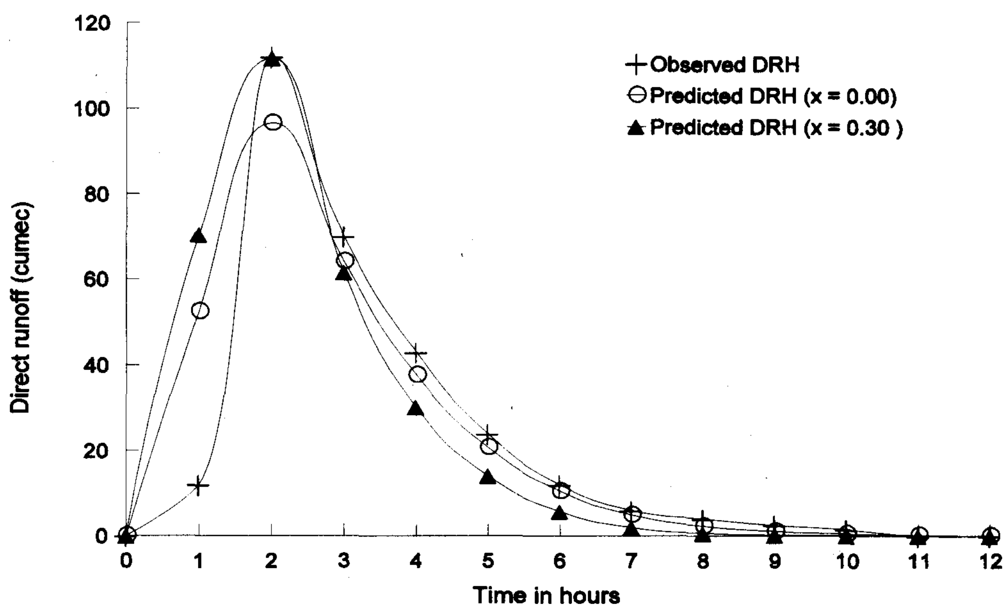

Fig. 5 Comparison of observed and predicted direct runoff hydrographs for the storm events of September 17-18, 1984

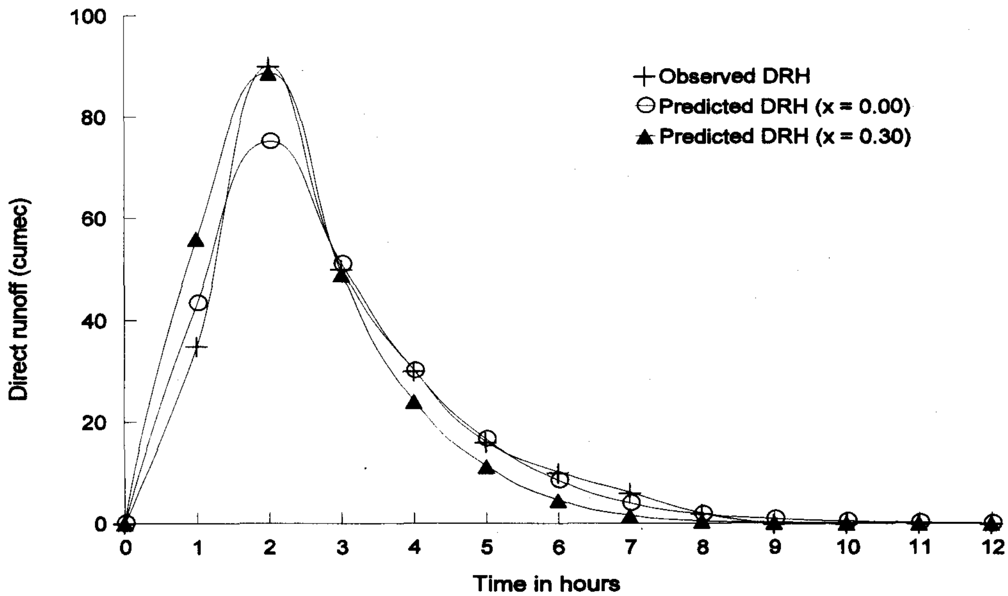

Fig. 6 Comparison of observed and predicted direct runoff hydrographs for the storm events of July 24-25, 1985

association between observed and computed flows. Chiew *et al.*, 1993 developed equation to compute efficiency. The average efficiency of the model at x = 0.3 is evaluated 0.734 which is satisfactory on the basis of qualitative comparison (Table 1).

The minimum value of departure percentage was 0.1837 for x = 0.30.The term departure percentage is defined as the percentage difference between computed from observed peak flow rates. Chen *et al.*, (1986) used term absolute relative error term in computed peak. It is a measure to obtain more suitable value of x and model performance. The minimum value of absolute relative error is necessary for accuracy of model performance, which was 3.73.

CONCLUSION

The DRHs for 20 storm events of model calibration and model verification sets were obtained by convolving the one-hour UHs with

Table:-1 Average values of models efficiency, departure percentage and absolute relative error in computed peaks for various values of x

	Weighting factor x					
	x = 0.00	x = 0.10	x = 0.20	x = 0.30	x = 0.40	x = 0.50
Efficiency	0.837	0.819	0.787	0.734	0.652	0.528
Departure %	-15.13	-10.47	-5.38	0.18	6.24	12.81
Abs relative error	15.13	10.47	5.63	3.73	6.49	12.81

corresponding effective rainfall values. The model performance was evaluated both quantitatively and qualitatively. The peak flow rates of the DRHs regenerated by routing through channels (x = 0.30) were in closer agreement with observed peak flow rates and in case of predicted DRHs also. According to quantitative comparison, the value of coefficient of efficiency (0.73), value of departure percentage (0.184) and value of absolute relative error (3.73) were minimum. On the basis of these results the value of x was best for Chaukhutia watershed of Ramganga river catchment of Kumaon region.

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