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EFFECT OF RAINFALL EXCESS CALCULATIONS ON MODELED HYDROGRAPH ACCURACY AND UNIT-HYDROGRAPH PARAMETERS[1]

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ABSTRACT: Two methods of computing rainfall excess in the U.S. Army Corps of Engineers' flood hydrograph package (HEC-1), the Initial and Uniform method and the Exponential method, are compared to evaluate the effects on modeled hydrograph accuracy. Two computed unit-hydrograph parameters, time of concentration and storage coefficient, were also compared. Rainfall and runoff data from 209 storms in 32 gaged basins in Illinois were used to calibrate the HEC-1 model. Three hydrograph characteristics – sum of incremental flows, peak discharge, and time of peak discharge – were used to evaluate modeled hydrograph accuracy. Mean percent error for each basin and hydrograph characteristic was computed. An evaluation of the mean errors indicates that, although some bias in modeled hydrograph accuracy is evident, rainfall excess computed using either method results in a computed hydrograph accuracy that is within generally accepted limits. Application of a linear-regression model shows no significant differences in computed values of unit-hydrograph parameters.
(KEY TERMS: hydrologic models; infiltration; rainfall-runoff relationships; unit hydrographs.)

INTRODUCTION

Estimated values of rainfall excess are often used as input to models of surface runoff. Rainfall excess is defined as the difference between total rainfall and that lost to abstractions such as depression storage, interception, evaporation, and infiltration (Chow, 1964). There are many methods for estimating the volume, and distribution in time, of rainfall excess from rainfall data. Infiltration equations, such as those developed by Horton (1940), Philip (1957), Holtan (1961), and others, are commonly used for estimating rainfall excess. The effects of different methods of estimating rainfall excess on the accuracy with which surface runoff is modeled have been the subject of recent investigations. Singh and Buapeng (1977) compared the use of the ϕ-index and the equations of Horton, Kostyakov, and Philip to estimate rainfall-excess for use as input to a rainfall-runoff model. They concluded that rainfall excess was most closely estimated using the Horton equation and that the ϕ-index grossly misrepresented rainfall excess. Foroud and Broughton (1981) developed a technique which adequately estimated rainfall excess using an exponential-loss function defined by parameters expressed as curvilinear functions of the antecedent precipitation index. Kumar and Jain (1982) calibrated a Soil Conservation Service infiltration model which satisfactorily described the distribution of rainfall losses.

The U.S. Army Corps of Engineers' flood hydrograph package (HEC-1) is a computer program used to model surface runoff (U.S. Army Corps of Engineers, 1981). It provides four methods for computing estimates of rainfall excess. Two of these, the Initial and Uniform Loss-Rate (a modified infiltration index method) and the Exponential Loss-Rate, were used to estimate rainfall excess for 209 storms in 32 gaged basins in Illinois. These estimates of rainfall excess were input to the HEC-1 program. Calibrated model results were used to evaluate the differences in (1) observed (input) and computed (calibrated output) hydrograph shape, and (2) computed values of unit-hydrograph parameters due to the choice of method of estimating rainfall excess.

This paper presents an overview of the HEC-1 model, a discussion of the two methods used to estimate rainfall excess, and a summary of statistical techniques used to compare the differences in computed values of unit-hydrograph parameters and the accuracy of modeled hydrographs due to the application of each method.

Basins were chosen to provide a representative sample based on drainage area, geographic distribution within the State of Illinois, and availability of sufficient streamflow and rainfall data for model calibration. Drainage areas ranged from a maximum of 319 square miles to a minimum of 1.45 square miles. The average and median drainage areas were 91.8 and 45.0 square miles, respectively. Streamflow records from gaging stations located in Figure 1 were used to provide runoff data for model calibration. Hourly and daily rainfall data from rain gages in the vicinity of the gaged basins were used to construct a hyetograph for each of the 209 storms. Hourly rainfall data were used to define temporal distribution of modeled rainfall. In order to satisfy the requirement of

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HEC-1 program that input rainfall represent basin average conditions, daily rainfall data were used to weight measured rainfall at each rain gage. These data were obtained from National Oceanic and Atmospheric Administration publications "Hourly Precipitation Data" and "Climatological Data." The estimated values of rainfall excess computed by the HEC-1 program were transformed into discharge hydrographs through the application of instantaneous unit hydrographs for each basin. The computed hydrographs were compared to observed hydrographs for the same rainfall. Some of the data used for comparison were obtained from Graf, *et al.* (1982a).

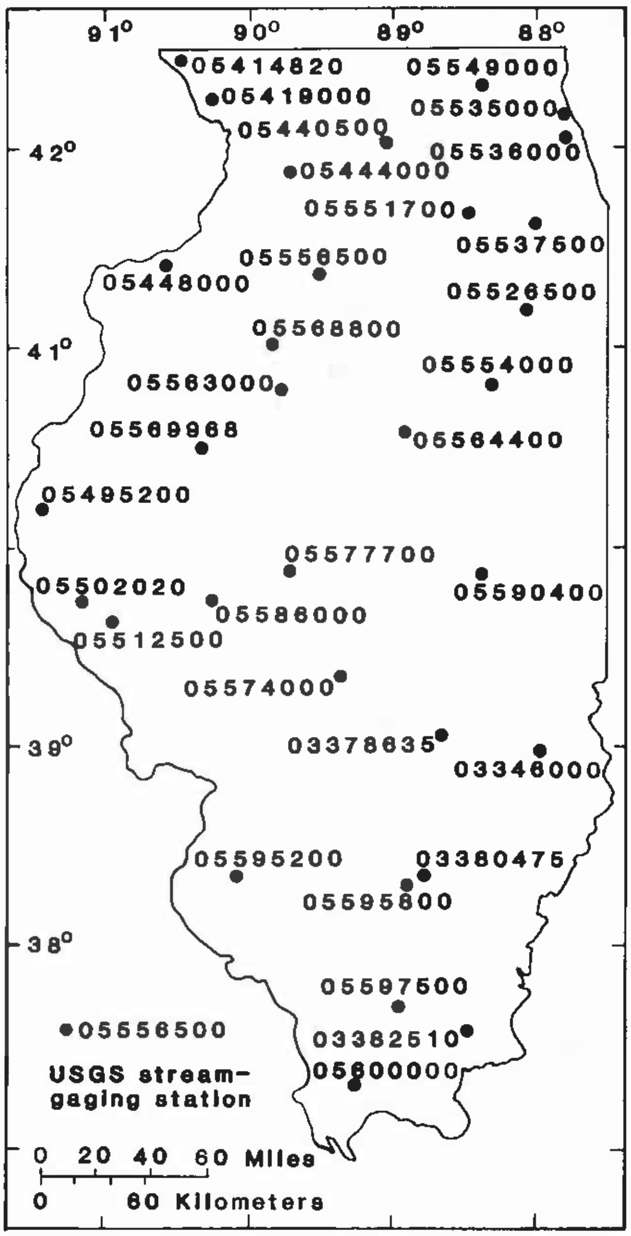

Figure 1. Location of U.S. Geological Survey Stream-Gaging Stations Used in this Investitation.

MODEL DESCRIPTION

The subprograms in the HEC-1 Flood Hydrograph Package model different aspects of the rainfall-runoff process. The general model assumes homogeneity of basin characteristics and of basin response to rainfall. Processes such as infiltration and rainfall are considered to be evenly distributed in space and are modeled as basin averaged values. Components of the subprograms are derived from mathematical expressions representing natural processes. These can be grouped into four categories: (1) rainfall, (2) abstraction processes, (3) transformation of rainfall excess into basin outflow, and (4) baseflow. For a complete explanation of the model, the HEC-1 Users Manual (U.S. Army Corps of Engineers, 1981) should be consulted.

A hyetograph is used as input to all runoff calculations. The hyetograph can be constructed from rainfall data from one or more rain gages. If several rain gages are used the model user can assign spatial and temporal weightings to each gage. This allows total rainfall on a basin to be computed as a weighted average value.

Rainfall not contributing to runoff is considered lost or abstracted from the modeled system. Abstractions occur when rainfall is lost to interception, depression storage, evaporation, and infiltration. The difference between total rainfall and that amount abstracted from the modeled system is considered rainfall excess. Four methods for estimating rainfall excess are available in HEC-1: (1) Initial and Uniform Loss-Rate, (2) Exponential Loss-Rate, (3) Soil Conservation Service Curve Number, and (4) Holtan Loss-Rate.

The rainfall excess hyetograph is transformed into basin outflow, which is a discharge hydrograph. The instantaneous-unit-hydrograph method, with linear storage, was used to transform rainfall excess into basin outflow (Clark, 1945). The instantaneous-unit-hydrograph method is based on two assumptions. First, the unit hydrograph is characteristic for a basin and is not storm-dependent. Second, runoff due to rainfall excess from different computation intervals can be linearly superposed. The Clark method requires values or estimates of two parameters, time of concentration (TC) and storage coefficient (R), and a time-area curve, to define the instantaneous unit hydrograph. Time of concentration is intended to represent the time required for a drop of rain falling on the most remote part of the drainage basin to reach the outlet or point of discharge on the stream. The storage coefficient is a proportionality constant between storage and discharge at the outflow point of a basin, and is considered a time characteristic of a basin, indicative of channel storage capacity. The time-area curve defines the cumulative area contributing runoff to the basin outlet over time, and serves as a means of translating runoff from incremental subareas to the basin outlet. TC and R may be supplied by the user or determined by the model using a nonlinear optimization algorithm. The time-area curve may be developed by the user or be derived by the model using a generalized time-area relation.

The base-flow component of total flow is computed separately from surface runoff and is treated as an exponential decay from a specified discharge. Both the discharge at which baseflow becomes dominant and the rate of exponential decay can be adjusted by the user.

RAINFALL-EXCESS ESTIMATIONS

Two methods of estimating rainfall excess were chosen for comparison. Graf, *et al.* (1982a), applied the Exponential Loss-Rate method to rainfall data from 98 gaged basins in Illinois. In this investigation, the Initial and Uniform Loss-Rate method was applied to rainfall data from 32 gaged basins, also studied by Graf, *et al.* (1982a).

The Initial and Uniform Loss-Rate method is similar to methods using infiltration indices to compute rainfall excess (Linsley, *et al.*, 1982). Two variables, STRTL and CNSTL, must be input by the user or derived from the programs default optimization scheme. All rainfall, to the depth specified by STRTL, the initial loss, is considered lost to abstractions. This initial loss can be thought of as that amount of rainfall needed to satisfy soil moisture deficiency. Thereafter, rainfall is lost at a rate specified by CNSTL, a constant loss-rate. An application of this method is shown in Figure 2.

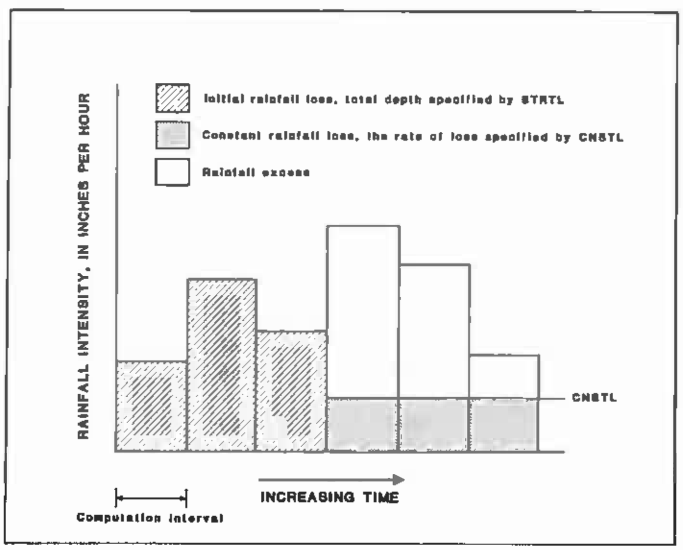

Figure 2. Application of Initial and Uniform Loss-Rate Method.

The Exponential Loss-Rate method is characterized by four variables, ERAIN, RTIOL, STRKR, and DLTKR. These variables define a relationship between rate of rainfall loss, rainfall intensity, and accumulated losses. The rainfall excess hyetograph is computed by subtracting the calculated losses from the observed rainfall for each computation interval. The rate of potential rainfall loss, ALOSS, is obtained by multiplying a loss-rate coefficient by an exponential function of precipitation as defined below and shown in Figure 3:

$$\text{ALOSS} = (\text{AK} + \text{DLTK})\ \text{PRCP}^{\text{ERAIN}} \tag{1}$$

where:

$$\text{AK} = \text{STRKR}/(\text{RTIOL}^{0.1\ \text{CUML}}),\ \text{and} \tag{2}$$

$$\text{DLTK} = 0.2\ \text{DLTKR}\ [1 - (\text{CUML}/\text{DLTKR})]^2 \quad \text{for CUML} \leqslant \text{DLTKR}. \tag{3}$$

AK is the loss-rate coefficient at the beginning of each computation interval. STRKR is the initial value of the loss-rate coefficient. RTIOL is the rate of exponential decrease of the loss-rate coefficient with accumulated rainfall loss. CUML is the accumulated rainfall loss obtained by summing rainfall losses for each computation interval. DLTK is the incremental increase in the rainfall loss coefficient, AK, which occurs until DLTKR inches of loss is accumulated. The variable DLTKR can be considered a function of antecedent soil moisture conditions. PRCP is the amount of basin-average rainfall available during each computation interval. ERAIN is a dimensionless exponent related to storm variability on a regional basis.

The variables ERAIN, RTIOL, STRKR, and DLTKR must be input by the user or generated by the HEC-1 program.

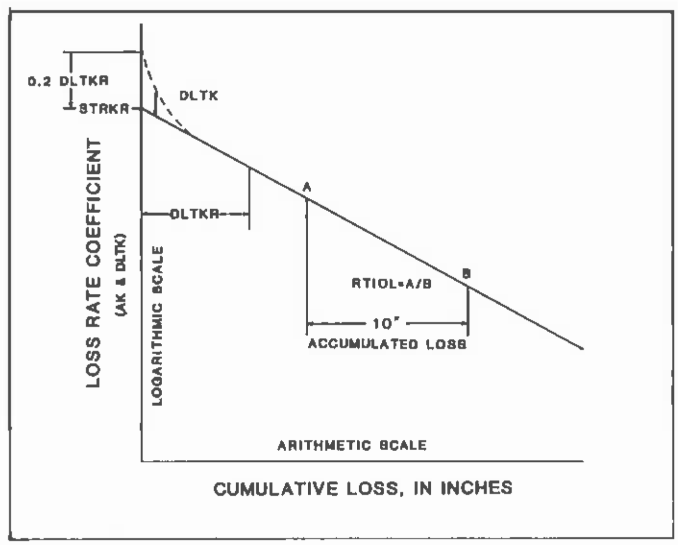

Figure 3. Exponential Loss-Rate Function (from U.S. Army Corps of Engineers, 1981).

COMPARISON OF RAINFALL-EXCESS ESTIMATING METHODS

Discharge hydrographs and unit-hydrograph parameters compared in this investigation were generated using the parameter calibration option of the HEC-1 model. Drainage area and a time-area curve for each basin, rainfall data, observed discharge hydrographs, and values for base flow variables for each rainfall-runoff event were supplied as input to the model. Rainfall data were chosen to best fit the limitations imposed by the lack of soil-moisture recovery schemes in the two rainfall excess estimating methods. Rainfall of short duration and moderate to high intensity was considered optimum. Four to seven rainstorms were chosen for modeling runoff at each of the 32 basins. This provided 209 rainfall-runoff events for model calibration. Two runs were made for each event, one each for the Initial and Uniform, and Exponential Loss-Rate methods. The variables STRTL and CNSTL of the Initial and Uniform Loss-Rate, and ERAIN, RTIOL, STRKR, and DLTKR of the Exponential Loss-Rate, as well as the unit-hydrograph parameters, time of concentration, TC, and storage coefficient, R, were initialized and optimized by the HEC-1 program. For each run, model output consisted of (1) optimized values of TC and R, (2) optimized values for each of the variables used in the rainfall excess estimating equations, and (3) a computed outflow discharge hydrograph. Values of TC and R are listed in Table 1.

Accuracy of modeled hydrographs was evaluated using three hydrograph characteristics: sum of incremental flow, V (ft^3/s), peak discharge, Q_p (ft^3/s), and time of peak discharge, T_p (hours). The sum of incremental flows, V, is the summation of discharges at the beginning of each computation interval used during modeling and is indicative of the total volume of flow. Three sets of V, Q_p, and T_p were available for comparison, one set for the 209 observed hydrographs, and one set each for the corresponding computed hydrographs developed using the two methods of estimating

TABLE 1. Unit-Hydrograph Parameters Computed Using Two Methods of Estimating Rainfall Excess.

Station No.	Time of Concentration (in hours) (TC)		Storage Coefficient (in hours) (R)		(TC + R)		R/(TC + R)	
	Exponential Loss Rate	Initial and Uniform Loss Rate	Exponential Loss Rate	Initial and Uniform Loss Rate	Exponential Loss Rate	Initial and Uniform Loss Rate	Exponential Loss Rate	Initial and Uniform Loss Rate
03346000	60.0	55.8	19.1	18.8	79.1	74.6	0.24	0.25
03378635	27.9	27.0	12.0	13.0	39.9	40.0	0.30	0.32
03380475	31.5	31.0	12.6	13.8	44.1	44.8	0.29	0.31
03382510	7.4	7.5	5.8	5.8	13.2	13.3	0.44	0.44
05414820	4.5	4.6	2.0	1.9	6.5	6.5	0.31	0.29
05419000	14.0	13.5	10.8	10.5	24.8	24.0	0.44	0.44
05440500	12.0	11.6	9.2	9.6	21.2	21.2	0.43	0.45
05444000	8.2	8.4	17.4	14.7	25.6	23.1	0.68	0.64
05448000	7.2	6.6	3.0	3.9	10.2	10.5	0.29	0.37
05495200	0.3	0.4	0.9	0.7	1.2	1.1	0.75	0.64
05502020	4.1	3.6	1.9	2.2	6.0	5.8	0.32	0.38
05512500	3.2	2.0	1.7	2.3	4.9	4.3	0.35	0.54
05526500	6.2	5.8	10.0	13.0	16.2	18.8	0.62	0.69
05535000	3.4	2.9	14.5	17.6	17.9	20.5	0.81	0.86
05536000	13.3	12.8	25.3	22.0	38.6	34.8	0.66	0.63
05537500	4.1	3.7	8.3	12.6	12.4	16.3	0.67	0.78
05549000	8.3	6.8	10.0	12.7	18.3	19.5	0.55	0.65
05551700	60.3	52.6	30.0	52.0	90.3	104.6	0.33	0.50
05554000	13.2	13.0	22.0	23.4	35.2	36.4	0.62	0.64
05556500	7.4	7.2	18.4	14.8	25.8	22.0	0.71	0.67
05563000	5.0	3.6	3.0	4.1	8.0	7.7	0.38	0.53
05564400	26.2	24.6	5.6	6.0	31.8	30.6	0.18	0.20
05568800	18.6	13.8	11.0	10.3	29.6	24.1	0.37	0.43
05569968	4.8	3.6	2.5	2.9	7.3	6.5	0.34	0.45
05574000	2.5	1.7	2.5	2.5	5.0	4.2	0.50	0.60
05577700	1.2	0.9	0.8	0.7	2.0	1.6	0.40	0.44
05586000	12.1	10.8	6.6	10.6	18.7	21.4	0.35	0.49
05590400	13.6	12.7	11.5	9.8	25.1	22.5	0.46	0.44
05595200	11.0	10.9	9.5	9.5	20.5	20.4	0.46	0.47
05595800	8.8	7.2	3.7	4.5	12.5	11.7	0.30	0.38
05597500	15.7	14.0	11.8	11.6	27.5	25.6	0.43	0.45
05600000	7.2	6.2	4.3	5.5	11.5	11.7	0.37	0.47

rainfall excess. Accuracy of a computed hydrograph was defined by the percent differences, hereafter referred to as errors, in V, Q_p, and T_p. The errors in V, Q_p, and T_p were calculated using the equation:

$$PD(Y) = [(Y_o - Y_x) \div Y_o] \times 100,$$

where PD(Y) is the error for hydrograph characteristic V, Q_p, or T_p; Y_o is the value of V, Q_p, or T_p for the observed hydrograph; and Y_x is the value of V, Q_p, or T_p for the hydrograph computed using either method of estimating rainfall excess. The mean and standard deviation of the errors in V, Q_p, and T_p at each basin were computed for all rainfall-runoff events modeled at that basin. Values of the mean and standard deviation of the errors for each method and basin are listed in Table 2 and Table 3, respectively.

In order to determine the overall accuracy with which either method reproduced observed hydrographs, the total mean and standard deviation of all basin mean percent errors were computed. These values are shown at the bottom of Table 2.

If the model reproduced observed hydrographs accurately, the expected value of the mean of errors of V, Q, and T for an infinite number of basins would equal zero. Since the

TABLE 2. Mean Percent Error Between Observed and Computed Total Volume of Flow (V), Peak Discahrge (Q_p), and Time of Peak Discharge (T_p).

Station No.	Total Volume of Flow (V)		Peak Discharge (Q_p)		Time of Peak Discharge (T_p)	
	Initial and Uniform Method	Exponential Method	Initial and Uniform Method	Exponential Method	Initial and Uniform Method	Exponential Method
03346000	−2.0	−5.5	4.1	6.2	−3.5	−7.6
03378635	7.0	7.4	−11.7	−10.0	−7.9	−7.6
03380475	1.2	−0.1	2.2	0.2	−0.1	−0.1
03382510	8.8	4.0	−12.1	−5.2	−0.2	−0.2
05414820	−12.9	−26.3	6.9	−4.2	−1.4	0.1
05419000	2.2	−3.0	−10.4	−9.6	−0.1	−0.1
05440500	4.7	−1.6	−1.2	1.4	−0.7	−0.7
05444000	7.8	0.1	−4.2	−3.1	−2.4	−2.4
05448000	2.5	−3.1	−0.1	−0.7	1.6	1.6
05495200	5.9	−3.8	−3.6	−5.3	9.1	10.2
05502020	3.4	−0.2	−3.4	−2.2	1.2	0.0
05512500	−8.8	−5.6	1.1	−1.2	−1.4	−2.6
05526500	−4.4	1.9	−1.2	4.7	−6.0	−6.0
05535000	15.5	19.0	−7.3	−10.1	−0.1	0.0
05536000	19.7	8.2	−5.5	−1.1	−11.9	−10.6
05537500	1.8	8.3	−12.0	−27.3	−1.1	−1.1
05549000	19.3	18.4	−10.7	−20.0	4.9	−0.5
05551700	−7.0	2.1	−1.3	−5.1	−0.4	0.0
05554000	3.7	4.6	−0.7	−1.9	−0.3	0.7
05556500	6.6	−9.3	1.6	0.9	−2.7	−3.1
05563000	−6.7	−1.5	−4.2	3.3	0.0	−0.1
05564400	0.4	−2.0	−7.0	−1.5	−2.6	−2.5
05568800	6.2	−3.7	−2.5	−0.7	−3.9	−5.2
05569968	2.8	−4.2	−5.6	−2.5	0.5	0.9
05574000	0.5	−2.1	−5.5	1.7	−0.9	−5.0
05577700	−0.5	−0.2	−0.4	−4.2	−0.5	−1.0
05586000	3.0	8.9	−3.9	−9.0	−0.3	0.0
05590400	6.4	2.9	−4.7	−3.2	0.0	0.0
05595200	0.6	−0.2	−2.6	−1.6	0.6	−0.7
05595800	2.5	−3.7	0.2	−5.3	0.3	0.2
05597500	4.1	0.8	−4.2	−2.4	−0.6	−0.6
05600000	4.2	1.5	−2.0	−4.3	−1.0	−1.7
Mean	3.1	0.4	3.5	−3.9	−1.0	−1.4
Standard Deviation	7.0	7.9	4.6	6.6	3.5	3.6

TABLE 3. Standard Deviation of Percent Error Between Observed and Computed Total Volume of Vlow (V), Peak Discharge (Q_p), and Time of Peak Discharge (T_p).

Station No.	Total Volume of Flow (V)		Peak Discharge (Q_p)		Time of Peak Discharge (T_p)	
	Initial and Uniform Method	Exponential Method	Initial and Uniform Method	Exponential Method	Initial and Uniform Method	Exponential Method
03346000	5.9	6.2	10.7	8.1	15.2	14.5
03378635	27.7	12.4	43.1	20.5	31.8	31.0
03380475	2.8	0.2	13.8	16.2	11.6	11.6
03382510	19.6	20.5	21.2	20.0	3.7	3.7
05414820	10.8	22.6	6.8	14.9	6.5	6.7
05419000	15.7	14.5	29.5	11.2	3.3	3.3
05440500	4.9	17.6	13.0	22.8	12.2	12.2
05444000	9.6	0.2	23.0	22.4	14.2	12.8
05448000	8.4	12.4	15.2	10.9	6.4	6.4
05495200	4.8	7.2	7.7	15.8	18.7	25.4
05502020	19.0	17.9	19.3	12.2	10.7	12.1
05512500	37.6	26.3	31.2	18.8	12.1	12.7
05526500	13.7	13.2	24.5	9.7	22.6	22.6
05535000	6.4	16.7	38.6	48.7	4.4	7.3
05536000	9.8	22.3	30.2	27.8	41.5	36.3
05537500	11.5	8.3	29.3	36.7	12.5	12.4
05549000	18.7	7.6	35.8	14.8	12.2	1.4
05551700	19.6	6.1	30.6	19.2	6.7	7.2
05554000	2.2	7.0	15.4	24.0	6.6	6.0
05556500	6.6	28.4	23.7	11.8	23.9	19.7
05563000	11.1	22.9	25.0	9.0	11.6	9.3
05564400	10.4	22.6	23.9	5.7	18.8	18.4
05568800	4.6	19.5	31.9	24.5	15.9	23.7
05569968	12.1	14.5	20.5	14.7	8.3	8.9
05574000	1.3	7.7	14.9	15.5	9.0	7.3
05577700	3.0	1.4	24.5	14.0	15.0	9.0
05586000	6.6	13.0	19.3	13.9	6.5	6.8
05590400	4.8	4.3	9.1	10.6	7.7	7.7
05595200	20.2	12.1	19.3	10.2	13.8	11.0
05595800	7.7	18.0	16.4	5.3	9.1	10.6
05597500	2.5	4.8	12.3	14.6	7.2	7.2
05600000	2.9	11.2	8.9	2.8	10.4	10.2
Mean	10.7	13.1	21.5	16.5	12.8	12.4
Standard Deviation	8.2	7.7	9.3	9.2	8.1	8.0

mean of errors of V, Q, and T for the sample (the 32 basins) do not equal zero, it is necessary to determine whether this is due to statistical sampling fluctuations or is an indication of a significant bias. A t-test was used to aid in making this distinction (Neter and Wasserman, 1974).

The test results indicate that there is a significant bias (at a 0.05 level of significance) in computed V using the Initial and Uniform method, in computed Q_p using either method, and in computed T_p for the Exponential method. The total mean errors of V for hydrographs computed using the Exponential method and the total mean errors of T_p for hydrographs computed using the Initial and Uniform method were not significantly different from zero. (Although these errors could not be distinguished from zero using the t-test, this is not proof that they equal zero.)

The three hydrograph characteristics were further tested to determine whether the absolute values of mean errors of V, Q_p, and T_p for either method were greater than, or equal to, 5 percent. The statistical tests are described by Neter and Wasserman (1974, pp. 12-14). The criterion of 5 percent was chosen as an acceptable range for absolute value of mean errors in V, Q_p, and T_p. The hypothesis tested was that mean errors in V, Q_p, and T_p are greater than, or equal to, 5 percent. This hypothesis was rejected at the 0.05 level of significance for the absolute value of all mean errors except those for V from the Initial and Uniform method and Q_p from the Exponential method. The criterion was then changed to test the hypothesis that the absolute value of mean errors was greater than, or equal to, 6 percent. This hypothesis was rejected at the 0.05 level of significance, regardless of the method employed to estimate rainfall excess.

Results of these tests indicate that although there may be statistically significant bias in V and Q_p for hydrographs computed using the Initial and Uniform method and in Q_p and T_p for hydrographs computed using the Exponential method, the mean errors of V, Q_p, and T_p are, nonetheless, within limits that are generally acceptable in hydrology.

Differences in values of the unit hydrograph parameters TC and R computed using the two methods of estimating rainfall excess were evaluated using a linear regression technique. Two composite variables, (TC + R) and R/(TC + R), are introduced in the HEC-1 model because of interdependency of TC and R (U.S. Army Corps of Engineers, 1973, pp. 5-23; Graf, *et al.*, 1982b). In the model, optimum values of the composite variables are found and individual values of TC and R are computed from those optimum values. Since the model uses the composite variables in its optimization scheme, regression analyses were performed using these variables.

Two regression analyses were performed with data from all 32 basins. Values of the variable (TC + R) computed using the Exponential method, were regressed on values of the variable (TC + R) computed using the Initial and Uniform method. A second regression was then performed in which values of the other composite variable, R/(TC + R), computed using both methods of estimating rainfall excess were regressed on each other.

The general linear model used for comparing the two composite variables has the form

$$E[Y] = \hat{\beta}_0 + \hat{\beta}_1 x ,$$

where E[Y] is the estimated value of the dependent variable, x is the independent variable, and $\hat{\beta}_0$ and $\hat{\beta}_1$ are regression coefficients representing the intercept and slope of the regression line, respectively. Values of the regression coefficients $\hat{\beta}_0$ and $\hat{\beta}_1$ (the intercept and the slope), and their respective standard errors of estimate are shown in Table 4. Using a test described by Neter and Wasserman (1974, pp. 60-62), the intercepts were tested for equality to zero, and the slopes were tested for equality to 1. The intercepts for both regressions could not be distinguished from zero under the null hypothesis at the 0.05 level of significance. In addition, for the regression using values of R/(TC + R) computed using both methods, the slope could not be distinguished from 1 at the 0.05 level of significance. The slope of the regression for values of (TC + R) is significantly different from 1 at the 0.05 level of significance. However, at the 0.04 level of significance, the slope could not be distinguished from 1.

TABLE 4. Parameter Estimates and Their Respective Standard Errors of Estimate for (TC + R) and R/(TC + R) Regressions.

Parameter	Parameter Estimate	Standard Error of Estimate
REGRESSION OF VALUES OF (TC + R)		
$\hat{\beta}_0$ (intercept)	1.43	0.848
$\hat{\beta}_1$ (slope)	0.940	0.028
REGRESSION OF VALUES OF R/TC + R)		
$\hat{\beta}_0$ (intercept)	−0.034	0.411
$\hat{\beta}_1$ (slope)	0.973	0.080

Because the slope was not equal to 1 at the 0.05 level of significance, an influence statistic was used to identify possible outliers. The statistic used, Cook's D, measures the change to estimates of (TC + R) that results from deleting each observation (Cook, 1977, 1979). Values of (TC + R) for two basins, North Fork Embarras River near Oblong, Illinois, (0334600), and Blackberry Creek near Yorkville, Illinois (0551700), were identified as possible outliers. The regression for values of (TC + R) was recomputed without these two basins. The intercept could not be distinguished from zero and the slope could not be distinguished from 1 at the 0.05 level of significance.

Results of these tests suggest that values of the hydrograph parameters TC and R obtained when using the Initial and Uniform method of estimating rainfall excess, are not different from values of TC and R obtained when using the Exponential method. Differences in values of (TC + R) computed for Blackberry Creek and North Fork Embarras River are attributed in part to the subjectivity involved in the selection of basin-average values of TC and R, rather than to the method used to compute rainfall excess.

CONCLUSIONS

Two methods of computing rainfall excess – the Exponential method and the Initial and Uniform method – were compared for effects on modeled hydrograph accuracy and computed values of unit-hydrograph parameters. The U.S. Army Corps of Engineers' flood hydrograph package (HEC-1) was used with rainfall and runoff data from 209 storms in 32 basins in Illinois. Three hydrograph characteristics – total volume of flow, peak discharge, and time of peak discharge – were computed for each observed hydrograph and two hydrographs computed using the two methods of estimating rainfall excess. The mean percent error was computed for each basin and hydrograph characteristic to evaluate the accuracy of computed hydrographs.

A bias is evident in the value of some of the mean error measures. Although a bias is present, analysis of mean errors indicates that there is no difference in accuracy of modeled hydrographs using the two methods of estimating rainfall excess. The performance of the model using either method to compute rainfall excess can be considered equivalent when the acceptable modeling error is approximately ±5 percent.

A linear-regression model was used to evaluate differences in two unit-hydrograph parameters – time of concentration (TC) and storage coefficient (R). Two regression analyses were performed in which (1) values of (TC + R) computed using the Exponential method were regressed on values of (TC + R) computed using the Initial and Uniform method, and (2) values of R/(TC + R) computed using the Exponential method were regressed on values of R/(TC + R) computed using the Initial and Uniform method. Results of these analyses suggest that values of TC and R obtained when using the Initial and Uniform method are not significantly different from values of TC and R obtained when using the Exponential method.

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