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Various rainfall-runoff models are based on the development of unit hydrographs, loss rate functions, and routing criteria. With models of this type, characteristics used to define the unit hydrograph, loss rate, and routing criteria need to be modified to predict runoff that would occur because of future development within a watershed. Certain aspects of this problem, particularly changes in peak flow and lag time due to urbanization, have been treated previously. It was the aim of this note to present additional information regarding the modification of unit hydrograph characteristics due to increased urbanization and to introduce techniques which can be utilized in a practical solution. Relationships presented in this paper can be used as a guide to compute the regional unit hydrograph parameters: TC (the time in hours from the end of effective rainfall to the inflection point on the recession limb of the hydrograph) and R (the ratio in hours of the discharge at the inflection point on the recession limb of the hydrograph to the rate of change of discharge at that point), for existing and predicted values of imperviousness. Modified expressions, such as those developed, are applicable for all values of I (the percentage of impervious surface within a watershed) and the ratio of existing to future impervious surface.

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# DIRECT RUNOFF HYDROGRAPH PARAMETERS VERSUS URBANIZATION

By David L. Gundlach,[1] A.M. ASCE

## INTRODUCTION

Various rainfall-runoff models are based on the development of unit hydrographs, loss rate functions, and routing criteria. With models of this type, characteristics used to define the unit hydrograph, loss rate, and routing criteria need to be modified to predict runoff that would occur because of future development within a watershed. Certain aspects of this problem, particularly changes in peak flow and lag time due to urbanization, have been treated previously (1,2,4,5,6). It is the aim of this note to present additional information regarding the modification of unit hydrograph characteristics due to increased urbanization and to introduce techniques which can be utilized in a practical solution.

## EFFECTS OF URBANIZATION

A multiple regression analysis based on 15 flood hydrograph reconstitutions in the vicinity of Philadelphia, utilized in the preliminary report, "Metropolitan Chester Creek Basin, Pennsylvania," Department of the Army, Philadelphia District, Corps of Engineers, January 1976, resulted in the following expressions (see Table 1):

$$(TC + R) = 19.46\, I^{-0.40} \left(\frac{\mathrm{DA}}{S}\right)^{0.24} \qquad (1)$$

$$(TC) = 12.98\, I^{-0.42} \left(\frac{\mathrm{DA}}{S}\right)^{0.27} \qquad (2)$$

Eqs. 1 and 2 relate the direct runoff hydrograph parameters, $TC$ and $R$ to physiographic characteristics of the drainage basin, in which $TC$ = the time from the end of effective rainfall to the inflection point on the recession limb of the hydrograph, in hours; $R$ = the ratio of the discharge at the inflection point on the recession limb of the hydrograph to the rate of change of discharge at that point, in hours; $I$ = the percentage of impervious surface within a watershed

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(a measure of urbanization); DA = drainage area, in square miles; and $S$ = the average channel slope between the points 10% and 90% of the distance upstream from the gage or outflow point to the watershed boundary, in feet per mile. Although the correlation was improved in subsequent work when specific physiographic and meteorological characteristics were combined (4), the information outlined in Table 1 is sufficient to illustrate the following techniques.

**TABLE 1.—Results of Multiple Regression Analysis in Which Direct Runoff Hydrograph Characteristics, *TC* + *R* and *TC*, are Related to Physiographic Characteristics of Drainage Basin**

| Equation number (1) | Standard error of estimate (2) | Correlation coefficient, $\bar{R}$ (3) | Coefficient of determination, $\bar{R}^2$ (4) |
|---|---|---|---|
| 1 | 0.080 | 0.939 | 0.882 |
| 2 | 0.083 | 0.945 | 0.893 |

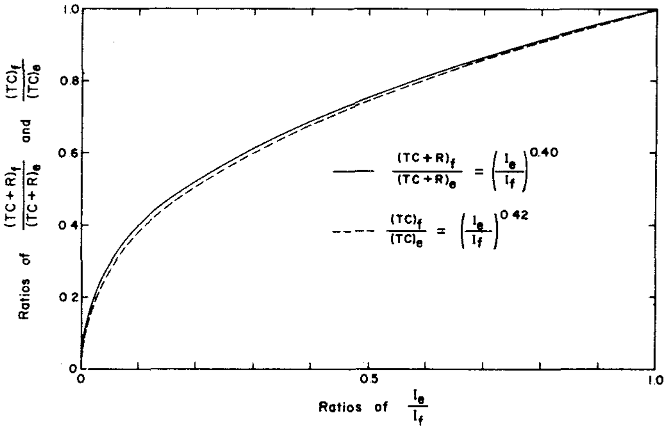

**FIG. 1.—Effects of Changes in Imperviousness on Characteristics (*TC* + *R*) and (*TC*)**

If development is predicted within one of the drainage basins in the study area and if drainage area and slope remain relatively constant with time, then it follows from Eqs. 1 and 2 that

$$\frac{(TC+R)_f}{(TC+R)_e} = \left(\frac{I_e}{I_f}\right)^{0.40} \qquad (3)$$

and

$$\frac{(TC)_f}{(TC)_e} = \left(\frac{I_e}{I_f}\right)^{0.42} \qquad (4)$$

in which subscripts $e$ and $f$ refer to existing and future conditions, respectively. A graph of the left-hand terms of Eqs. 3 and 4 versus the change in imperviousness, $I$, is shown in Fig. 1. As indicated by the curves and indirectly by the Tracor Report (6), Eqs. 1 and 2 are significantly limited in range, particularly for practical application. Consider as first approximations the following two examples.

**Example 1.**—It is predicted that a pristine area, $I_e = 0\%$, will be developed to such an extent that at some time in the future it will be considered 100% impervious. In cases such as this where $I_e = 0\%$ initially the ratio $(I_e/I_f) = 0$ regardless of the value of $I_f$, and from Fig. 1 or Eq. 4, $(TC)_f = 0$. The preceding results are impractical even for very small values of $(TC)_e$.

**TABLE 2.—Results of Multiple Regression Analysis in Which $K = 1.0 + 0.30\ I$**

| Equation number (1) | Standard error of estimate (2) | Correlation coefficient, $\bar{R}$ (3) | Coefficient of determination, $\bar{R}^2$ (4) |
|---|---|---|---|
| 8 | 0.082 | 0.937 | 0.878 |
| 9 | 0.081 | 0.948 | 0.898 |

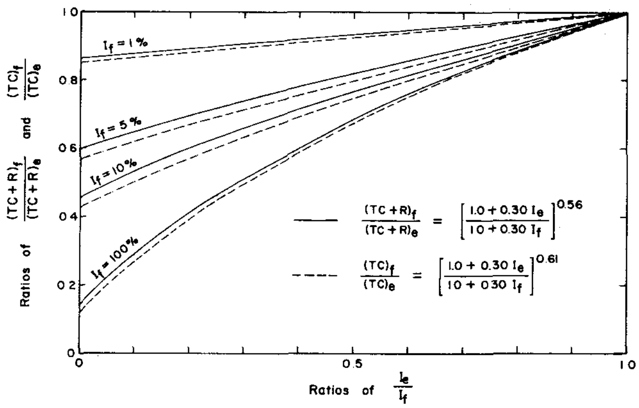

**FIG. 2.—Effects of Changes in Imperviousness on $(TC + R)$ and $(TC)$ where $K = 1.0 + 0.30\ I$**

A reasonable estimate of $(TC)_f/(TC)_e$ for a condition similar to the preceding can be developed from the following formula proposed by Kerby (3):

$$t^{2.14} = \frac{2}{3}\frac{Ln}{\sqrt{S}} \quad \text{. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (5)}$$

in which $t$ = the time of concentration for overland flow within a catchment area, in minutes; $L$ = the length of flow, in feet; $S$ = the slope of the surface, in feet per foot; and $n$ = a retardance coefficient. In a situation where a dense grass covered surface will be completely paved, then

$$\frac{(t)_f}{(t)_e} = \left(\frac{n_f}{n_e}\right)^{0.47} \quad \text{. . . . . . . . . . . . . . . . . . . . . . . . . . . . (6)}$$

or $$\frac{(t)_f}{(t)_e} = 0.18 \quad \text{. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (7)}$$

in which $n_f$ and $n_e$ are 0.02 and 0.80, respectively.

**Example 2.**—If only a small amount of development is predicted, $0\% < I_f \leq 5\%$, for a relatively pristine drainage area, then, in most cases, it is reasonable to assume that development may have little or no effect on the time of concentration. Under these circumstances $(TC)_f/(TC)_e$ should be equal to or nearly equal to 1.

First approximations such as given in Examples 1 and 2 were used to modify the regression expressions (Eqs. 1 and 2) as originally developed. In this case various transformations were tested until one of the general forms, $K = C_1 + C_2 I$, proved applicable. The constants, $C_1$ and $C_2$, were varied until the initial approximations were reasonably satisfied and an optimum degree of correlation obtained. The modified relationships (see Table 2) are

$$(TC + R) = 17.01\, K^{-0.56} \left(\frac{\text{DA}}{S}\right)^{0.24} \quad \text{(8)}$$

$$(TC) = 11.54\, K^{-0.61} \left(\frac{\text{DA}}{S}\right)^{0.27} \quad \text{(9)}$$

in which $K = 1.0 + 0.30\, I$ (10)

The results are shown in Fig. 2 and can readily be compared with previous results. The ratios, future to existing, of $TC + R$ and $TC$ now become

$$\frac{(TC + R)_f}{(TC + R)_e} = \left(\frac{1.0 + 0.30\, I_e}{1.0 + 0.30\, I_f}\right)^{0.56} \quad \text{(11)}$$

and $$\frac{(TC)_f}{(TC)_e} = \left(\frac{1.0 + 0.30\, I_e}{1.0 + 0.30\, I_f}\right)^{0.61} \quad \text{(12)}$$

From Fig. 2 it is apparent that $(TC + R)_f/(TC + R)_e \approx (TC)_f/(TC)_e$ such that a practical method of relating $TC$ and $R$ exists for a particular study area. From Eqs. 8 and 9

$$\frac{TC}{TC + R} = \frac{11.54\, K^{-0.61} \left(\dfrac{\text{DA}}{S}\right)^{0.27}}{17.01\, K^{-0.56} \left(\dfrac{\text{DA}}{S}\right)^{0.24}} \quad \text{(13)}$$

or $$\frac{TC}{TC + R} = 0.68\, K^{-0.05} \left(\frac{\text{DA}}{S}\right)^{0.03} \quad \text{(14)}$$

For practical purposes, Eq. 14 becomes

$$\frac{TC}{TC + R} \approx 0.68 \quad \text{(15)}$$

A similar analysis yields

$$\frac{R}{TC + R} \approx 0.32 \quad \text{(16)}$$

## SUMMARY AND CONCLUSIONS

Relationships presented in this paper can be used as a guide to compute the regional unit hydrograph parameters, $TC$ and $R$, for existing and predicted values of imperviousness. Modified expressions, such as those developed, are applicable for all values of $I$ and $I_e/I_f$.

## APPENDIX.—REFERENCES

1. Carter, R. W., "Magnitude and Frequency of Floods in Suburban Areas," *Professional Paper 424-B*, United States Geological Survey, Washington D.C., 1961, pp. B9-B11.
2. Hollis, G. E., "The Effect of Urbanization on Floods of Different Recurrence Interval," *Water Resources Research*, Vol. 11, No. 3, June, 1975, pp. 431-435.
3. Kerby, W. S., "Time of Concentration for Overland Flow," *Civil Engineering*, ASCE, Vol. 29, No. 3, Mar., 1959, p. 174.
4. Rao, R. A., and Delleur, J. W., "Instantaneous Unit Hydrographs, Peak Discharges and Time Lags in Urban Basins," *Hydrological Sciences—Bulletin—des Sciences Hydrologiques*, Vol. XIX, No. 2, June, 1974, pp. 185-198.
5. Stankowski, S. J., "Magnitude and Frequency of Floods in New Jersey with Effects of Urbanization," *Special Report 38*, United States Geological Survey and New Jersey Department of Environmental Protection, Division of Water Resources, 1974.
6. "Statistical Analysis of Hydrograph Characteristics for Small Urban Watersheds," *Tracor Project 077-014, Document Number T73-AU-9559-U*, Office of Water Resources Research, United States Department of the Interior, Washington, D.C., Oct., 1973.

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