

AN ALTERNATE APPROACH FOR ESTIMATING SCS UNIT
HYDROGRAPH PEAK RATE FACTORS (PRFS) IN SOUTHWEST FLORIDA

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ABSTRACT

This paper presents an alternate method for determining a consistent dimensionless unit hydrograph based upon stream flow and rainfall dates collected by the U S Geological Survey and the Palmer Ranch Developer. An average dimensionless unit hydrograph using peak rate factors 256, 284 and 323 overestimates peak discharges unless the time of concentration/time-to- peak is adjusted. A method is presented whereby unit hydrographs are synthesized using a two parameter gamma function. An equation for peak rate factor is provided for the Southwest Florida watersheds. This equation involves two combinations of watershed area, and percentage imperviousness. The equation is based on an analysis of nearly 63 storm events from 15 urban watersheds in Southwest Florida.

INTRODUCTION

Synthetic unit hydrograph methods are popular and play an important role in urban stonnwater drainage design. These methods are simple, requiring only an easy determination of watershed and land use characteristics. Therefore, these methods serve as useful tools to simulate runoff from unged watershed, design, rainfall events and watersheds undergoing land use change.

Several most popular computer simulation models such as HEC-1 (USACE 1985), SWMM (EPA SWMM 1994), and TR-20 (SCS 1973) are available for developing either peak discharge rate, volume or a runoff hydrograph. Because the parameters used in the equations are empirical, the model is limited to physiolographic, climatic, and land use conditions. Therefore, model should be evaluated with the local data.

Relative to Southwest Florida, two unit hydrograph models have been widely used, when the SCS hydrologic design method is considered. In these models, no calibrated data was considered. Therefore the need clearly exists for such a modeling process.

This paper presents a method of estimating the peak rate factor for a dimensionless unit hydrograph in an unged watershed using the SCS unit hydrograph method.

BASIS FOR STUDY

To develop a synthetic unit hydrograph, several techniques are available. The most popular method used is the Soil Conservation Service (SCS) curvilinear unit hydrograph. This method is based on the assumption that the same unit hydrograph shape applies to all watersheds; only the scale differs. The unit hydrograph is dimensionless with axis of q/q_p and t/t_p , in which q equals the discharge rate at any time t , and q_p equal the peak discharge at time t_p ; thus, the peak of the dimensionless unit hydrograph is dimensionalized by multiplying the time values by the estimated time-to-peak, and the discharge ordinates by the peak discharge which is given by

$$DAR$$
$$q_p = \frac{DAR}{t_p}$$

(1)

in which q_p = the peak discharge in c.f.s.; A = the drainage area in square miles; R = runoff depth in inches and t_p = the time to peak and D = peak rate factor, which has units of hours- cubic feet per second per square mile per inch. The peak rate factor D equals 484 results from the conversion of square miles to acres and the assumption that 37.5 percent of the runoff volume occurs under the rising limb of the hydrograph. The SCS indicates that D can vary from 300-600 with a value of 300 in very flat, swampy country and a value of 600 in steep terrain. However, no specific value of D for watershed has been proposed. A study by Woodward et. at. (1980) suggested a value of 284 for the Delmarva Peninsula. The University of Florida (1986) has found that a peak rate factor of 75-100 is appropriate for flatwoods watersheds.

Because the peak discharge computed with Eq. I is linearly related to D , Southwest Florida has widely accepted D equals to 256 and 323. This created some questions on the applicability of the above values for low flat

sloped areas in the southwest watersheds. This concern emphasizes the need for a accurate, systematic method for determining the peak rate factor and dimensionless unit hydrograph for ungaged watersheds where the above peak rate factors in the SCS dimensionless unit hydrograph is considered to be inappropriate.

PROCEDURE- FOR ESTIMATING PEAK RATE FACTOR

Recent research has demonstrated that the hydrologic and geomorphologic approaches to defining watershed hydrologic response functions are convergence and may be expressed through the gamma function (Rosso 1984). The parallel between the geomorphologic and hydrologic approaches has led to the development of a geomorphologic based method for estimating unit hydrograph shape and scale parameters and is represented by the Nash model (1959).

$$Q(t) = \frac{1}{I(n)Kn} t^{n-1} e^{-Vt/k} \quad (2)$$

Where $Q(t)$ is the unit hydrograph ordinate at time t ; K and n are the scale and shape parameters, respectively; and $I(n)$ is the gamma function.

Wu (1963) related K to n and t_p by equating the **first** derivative of Eq. 2 to zero.

$$K = \frac{t_p}{n-1} \quad (3)$$

After substituting Eq. 3 into Eq. 2, to remove K , Wu (1963) suggested the following equation

$$Q = Q_p \left[\frac{t}{t_p} e^{-(1 - t/t_p)} \right] \quad (4)$$

Where, Q is the unit hydrograph ordinate, in c.f.s, Q_p and t_p are the peak discharge rate in c.f.s. and time to peak in hours, respectively, and n is a shape parameter. This is the form of the two-parameter gamma function used in this paper.

Meadows and Blandford (1983) developed a relationship between Q_p and n using a peak rate factor (PRF) concept. They developed the following equation by substituting Eq.3 into Eq. 2.

$$Q_p = \frac{(n-1)n}{(n-1)!e^{(n-1)}} \quad (5)$$

Where B is a peak and is rate factor a function of the shape parameter n .

$$Q_p = \frac{B}{t_p} \quad (6)$$

For Q_p in cfs. and t_p in hours, Eq. 6 can be expressed as
(645.33 B) A

$$Q_p = \frac{(645.33 B) A}{t_p} \quad (7)$$

or

$$Q_p = (\text{PRF}) \frac{A}{t_p} \quad (8)$$

Where A is the watershed area in square **miles** and PRF is the unit hydrograph peak rate factor.

From Eqs. 5 to 8, it appears that the PRF is a function of n . Table I shows the gamma function shape parameter relationships. While Fig. I shows unit hydrograph shape with different PRF values. Fig. I was constructed by plotting

the product of the hydrograph ordinates and t_p against dimensionless time. Neidrauer (undated) has also developed a general equation for curvilinear dimensionless unit hydrograph shape with a different PRF.

Analysis

By combining Eqs. 4 and 8 and the optimizing n value (when the estimated hydrograph ordinates were best fitted with the observed hydrograph ordinates by using a method of successive approximation (trial and error method), PRFs and t_p were computed for various storm events. The computed grouped data of PRFs were used to perform a non-linear regression analysis to establish a relationship between the PRF and the watershed parameters. Two main parameters - basin area and imperviousness were considered in the analysis. Since the effect of slope on the hydrograph shape is accounted for in calculating time of concentration, t_c , the effect, of slope was not considered in the regression analysis. It was assumed that i) a minimum of 5 percent impervious area was considered in the analysis, and ii) the storm event which produced a runoff volume between 0.94 inches and 1.07 inches was adopted as a unit hydrograph for the watershed under consideration. Based on the above technique, the following equation was obtained for Southwest Florida.

$$PRF = 60 \frac{Imp^{0.28}}{AO-15} \quad (9)$$

Where A is the watershed area in square miles and Imp is the imperviousness of the watershed. Meadows and Ramsey (1991) developed a relationship similar to EQ. 9.

To facilitate the designer, Table 2 summarizes the recommended design values of the PRF for the various imperviousness. Eq. 9 predicts more accurate value of the PRF for a given watershed characteristics.

The application of Eq. 9 is limited to watersheds with physical measures contained in statistical data base summarized in Table 3.

VERIFICATION

The proposed procedure (Eq. 9) for estimating a value for the peak rate factor for an ungaged watershed was tested using measured rainfall and runoff data. The data was provided by the U.S. Geological Survey and the Palmer Ranch Developer in Sarasota County. It included rainfall and streamflow data for between two and 17 events at 15 urban watersheds in Southwest Florida. The watersheds range in size from 0.14 square miles to 15.22 square mile, imperviousness from 0 to 85 percent, and slope from 0.03 to 0.89 percent.

Table 3 shows the watershed characteristics. Locations of the watershed are shown in Fig. 2.

Table 2. Recommended PRF

Imperviousness	PRF
Undeveloped	
for Slope 0.0% to 0.5%	75
for Slope 0.5% to 1.0%	100
10	115
20	130
30	140
40	150
50	170
60	190
70	205
80	225

Table 4 and Fig. 3 show the comparison between observed and estimated peak discharge rate. The results shown in Table 4 and Fig. 3 indicate that the mean PRF computed for watersheds with physical measures that fall within the watersheds contained in the statistical data showed good agreement with the values of PRF obtained from the analysis. Table 4 shows the comparison between observed and estimated peak discharge rates.

DISCUSSION

The SCS methods are some of the most widely used hydrologic design methods. The standard SCS peak rate factor of 484; peak rate factor of 284, resulted from Delmarva peninsula study; peak rate factors of 256 and 323 commonly used in the Southwest Florida may not be applicable for the flat terrains. Specific values can be derived for the watersheds within the Southwest Florida using the procedure outlined in this paper. For watersheds with significant amounts of storage, the PRF should be even less than the value computed from Eq. 9. Fig. 4 shows visual comparison of runoff hydrographs using the peak rate factors of 484, 323, 256 and 75 for a 25 year 24 hours storm event.

The procedure outlined in this paper for deriving the dimensionless unit hydrograph from topographic and land use data is a very reasonable method for estimating the SCS peak rate factor when the measured rainfall and runoff data are not available. The design should make the following additional assumptions, if the SCS method is going to be used for the design: a) the gamma distribution or Neidrauer method can be used to represent the shape and proportion of the design unit hydrograph; b) the shape and scale parameters of the design unit hydrograph are related to the time-to-peak; c) the shape parameter can be determined from the proportion of the area under rising limb; and d) the SCS relationship between time-to-peak and time of concentration is valid (i.e., $t_c = 1.5t_p$)

CONCLUSION

1.

The two-parameter gamma distribution can be used to accurately estimate the peak rate factor (PRF) and time-to-peak t_p parameters.

2.

The relationship derived in this study is intended for screening level analysis and is not intended to replace more complex analysis. EQ. 9 estimates runoff hydrograph more accurate than the peak rate factors of 256, 323 and 484 for peak flow rates when compared with observed data (**fig. 3**).

3. The PRF is a function of drainage area and imperviousness.

4. This study is based on the assumption that a single storm produces both peak flow rate and hydrograph volume of equivalent frequency.

5. The proposed method did not perform well in simulating peak multi hydrograph.

6. Further investigations may be warranted to: a) developing direct runoff hydrographs (alternative methods for the subtraction of surficial groundwater from the runoff hydrograph), b) fine tuning a best fit peak rate factor, c) verifying findings on other watersheds in Southwest Florida where continuous rainfall and discharge information is available; and d) developing improved techniques for determining basin times of concentration to assist in the generation of design hydrographs for ungauged watersheds.

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Table 1. Gamma Function Shape Parameter Relationships

Shape Parameter (n)	Peak Rate Factor (PRF)	Peak Factor B
<i>1.50</i>	156	0.2420
<i>2.00</i>	237	0.3679
<i>2.50</i>	298	0.4625
<i>3.00</i>	349	0.5413
<i>3.50</i>	393	0.6102
<i>4.00</i>	433	0.6721
<i>4.50</i>	470	0.7288
<i>5.00</i>	504	0.7815