Estimating Runoff Peak Rates from Flat, High-Water-Table Watersheds

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ABSTRACT

SIX methods of estimating stormwater runoff peak discharge are evaluated as to their performance on watersheds of Florida's flatwoods resource area. Characteristics of flatwoods watersheds include extremely flat relief, sandy soils, dynamic shallow water tables, and scattered wetlands. Data collected by the U.S. Geological Survey and South Florida Water Management District from five small (8 to 1450 ha) agricultural watersheds (improved and unimproved pasture) served as the basis of evaluation. Runoff peak rate estimation techniques ranged in approach from empirical formulas to an overland flow simulation model. Among the established methods examined, best results were achieved using the overland flow technique. Three of the six peak rate estimation methods (the SCS graphical method, the CREAMS hydrologic model equation, and the SCS triangular hydrograph method) were modified to improve their performance on flatwoods watersheds.

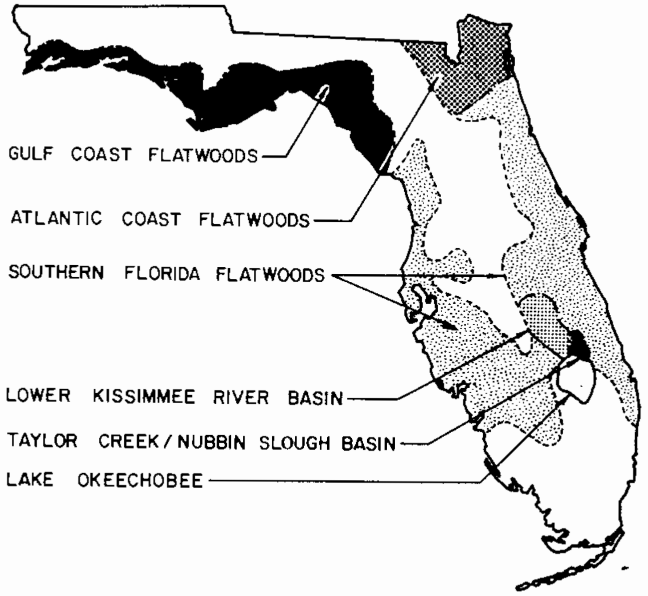

Fig. 1—General classification and distribution of flatwoods soils in Florida (Brady, 1974) and study area location.

INTRODUCTION

Many techniques have been developed to estimate stormwater peak discharge rates from small watersheds. However, problems arise when these methods are applied to the unusual hydrologic conditions found in Florida's flatwoods resource area (Fig. 1). Watersheds of this area typically have very flat slopes, extremely permeable sandy soils, high water tables, and wetlands scattered throughout their basins. Such characteristics are unlike those of watersheds which served as models for the development of most peak runoff rate prediction methods. The problems introduced by these watershed conditions are often compounded when the methods are called upon to predict peak runoff rates resulting from rainfall events for which they were not intended, i.e., frequent, instead of extreme (design), events.

There are no studies which document the accuracy of standard peak runoff rate prediction techniques as applied to Florida's flatwoods watersheds under a range of rainfall events. The objective of this study was to evaluate six techniques for estimating peak runoff rates as applied to Florida's flatwoods watersheds under small to moderate rainfall events. Additionally, three of the techniques were modified to better reflect observed data.

Approximately one third of Florida is classified as having flatwoods type soils. These are of the Spodosol order, characterized by amorphous materials (organic matter, aluminum and iron oxides) in subsurface horizons. Hydraulic conductivity of the spodic horizon is considerably less than that of the upper horizon, ranging between 1.5 and 15 cm/h. Despite the high hydraulic conductivities of the upper horizons of these soils (>16 cm/h), drainage is poor unless augmented by extensive ditching. Soil Conservation Service (SCS) hydrologic classification is A/D or B/D, the exact class determined by the effectiveness of drainage improvements at lowering the water table. Without extensive ditching and diking, the extremely low watershed slopes (<0.5%) make delineation of watershed boundaries a difficult task. Drainage patterns and watershed boundaries can, in fact, shift depending upon rainfall patterns, runoff magnitude and wind direction.

Hydrologic data from five watersheds ranging in size from 8 to 1450 ha located within the Lower Kissimmee River and Taylor Creek-Nubbin Slough Basins (Fig. 1) were collected between 1979 and 1983 by the U.S. Geological Survey and South Florida Water Management District. Land use in the two basins is dominated by improved and unimproved beef and dairy pasture. Natural vegetation on the study watersheds consists primarily of wet prairie grasslands interspersed with strands of pine-palmetto woodlands. In the depressional areas, wetlands species predominate. Selected watershed characteristics are summarized in Table 1. Detailed site and data descriptions are presented by Capece et al. (1986).

TABLE 1. WATERSHED CHARACTERISTICS AND MODEL PARAMETERS

Parameter	Site				
	Armstrong	Peavine	SEZ Dairy	Bass W.	Bass E.
Drainage area, ha	1450	730	290	65	8.0
Channel slope, %	0.030	0.015	0.021	0.10	0.021
Overland slope, %	0.15	0.15	0.080	0.12	0.10
Drainage density, km/km^2	0.66	0.98	4.3	24	13
Ponds and marsh, %	13	23	7.0	0	0
Channel length, m	6800	3050	3600	910	150
Length/width ratio	3.5	2.1	4.8	1.1	0.3
Slope factor – F_s	0.30	0.23	0.25	0.29	0.47
Pond factor – F_p	0.56	0.51	0.61	1.0	1.10
SCS curve number – CN_{II}	82	84	81	80	80

METHODS

Six runoff peak rate estimation techniques often applied to the Florida flatwoods are presented below. The techniques are presented beginning with the very empirical and progressing through to the more theoretical approaches.

Cypress Creek Formula

The Cypress Creek Formula was developed to aid in the design of drainage systems for small agricultural watersheds (Stephens and Mills, 1965). This formula estimates a maximum 24-h-average discharge using the following equation:

$$q_p = C(M^{5/6}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

where
q_p = maximum 24-h-average discharge rate, m^3/s
M = watershed area, ha
C = a coefficient based upon topography and rainfall

Speir et al. (1969) analyzed this formula as applied to the Taylor Creek Basin and arrived at:

$$C = 0.00045 + 0.00016(R_e) \quad \ldots\ldots\ldots\ldots\ldots [2]$$

where
R_e = 24-h rainfall excess, mm

Stephens and Mills (1965) present a curve relating instantaneous peak to the average 24-h rate as a function of drainage area. An expression equivalent to the Stephens and Mills curve is:

$$r = 3.04 - 0.43(\log M) \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

where
r = instantaneous peak/maximum 24-h-average rate

CREAMS Equation

The algorithm used in the CREAMS hydrologic model (Knisel, 1980) to estimate peak daily flow is:

$$q_p = 0.217(DA^{0.70})(CS^{0.159})(LW^{-0.187})(0.0394Q)^{0.836(DA^{0.0166})} \quad \ldots\ldots\ldots\ldots [4]$$

where
q_p = peak runoff rate, m^3/s
DA = drainage area, ha
CS = main channel slope, %
LW = watershed length to width ratio
Q = daily runoff volume, mm

This empirical formula was developed with data from 304 storms occurring on 56 watersheds in 14 states which did not include Florida (Smith and Williams, 1980).

SCS Graphical Method

The Soil Conservation Service (USDA-SCS, 1980) published an interim peak discharge curve for Florida. An equivalent curve is shown in Fig. 2. This graph represents simplified results from execution of the SCS TR-20 computer model and reports peak runoff rate in m^3/s/mm of runoff per km^2 as a function of time of concentration, T_c. The hydrograph parameter, T_c, is shown in Fig. 3 and defined as time from the end of rainfall excess to the inflection point of the hydrograph recession. The graphical method is described by the SCS as being applicable to homogeneous watersheds where channel routing is not required.

TR-55 (USDA-SCS, 1975) presents two techniques for estimating time of concentration. The simpler of the two

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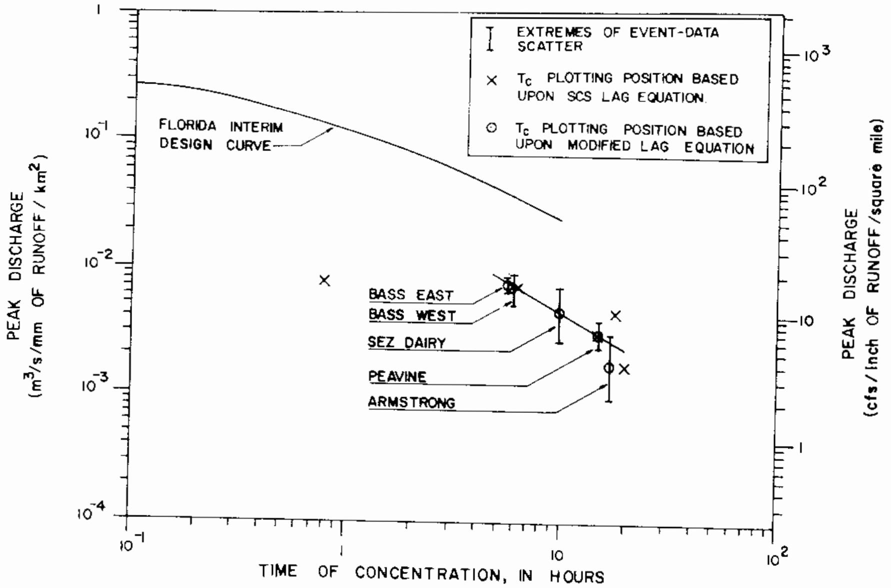

Fig. 2—Comparison of the SCS graphical method design curve to plots of the average peaks for each site against estimates for time of concentration. These estimates are based on equation [5] and watershed lags calculated by the SCS standard method (equation [6]) and by the modified method (equation [13]).

techniques relates time of concentration to a watershed time lag parameter:

$$T_c = 1.67(L) \quad \ldots\ldots\ldots\ldots [5]$$

where

L = watershed lag (time from rainfall excess center of mass to peak rate of runoff) in hours

Watershed lag can be estimated by the formula:

$$L = \frac{\ell^{0.8}\,(S+1)^{0.7}}{734.8\,Y^{0.5}} \quad \ldots\ldots\ldots\ldots [6]$$

where

ℓ = hydraulic length of watershed, m

S = SCS watershed storage parameter from the curve number method (USDA-SCS, 1980)

Y = average watershed land slope, %

The alternate SCS method for estimating T_c relies upon the calculation of watershed total travel time. For a natural watershed this includes overland and channel flow times. However, Mierau (1981) points out that determination of flow paths and velocities is not an easy task on flatwoods watersheds due to their extremely flat slopes.

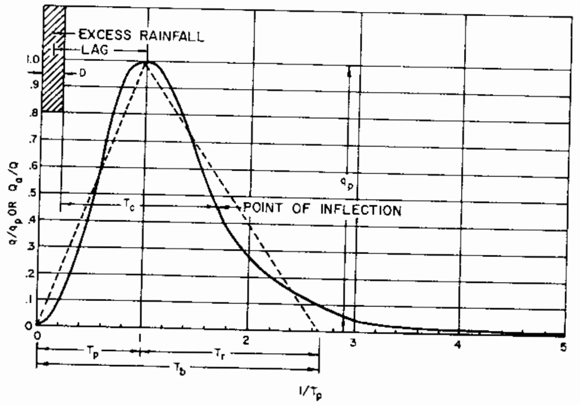

Fig. 3—SCS triangular unit hydrograph approximation and time parameter interpretations (USDA-SCS, 1972).

SCS Chart Method

The SCS Chart Method is comparable to the graphical method. However, instead of calculating the watershed lag directly, general slope and length considerations are internal to the chart. For Florida flatwoods conditions, the appropriate chart is that of the Florida interim rainfall distribution and flat watershed slopes (USDA-SCS, 1980). The chart-derived peak discharge is modified with tabulated adjustment factors for specific watershed slope and the distribution and extent of swamps and ponds within the drainage basin (USDA-SCS, 1980):

$$q_p = q_p{}'\,(F_s)(F_p) \quad \ldots\ldots\ldots\ldots [7]$$

where

q_p = peak discharge in m^3/s per mm of runoff

q_p' = peak discharge from the Florida Interim Report (USDA-SCS, 1980), m^3/s

F_s = slope adjustment factor

F_p = swamps and ponds adjustment factor

SCS Triangular Hydrograph Method

The SCS triangular hydrograph approach to estimating stormwater peak discharge utilizes a triangular approximation of a runoff unit hydrograph (Fig. 3). Synthetic hydrographs of this shape can be created using watershed and storm characteristics to estimate time parameters of the triangular hydrograph. The basic relationship of the triangle can be written as:

$$q_p = \frac{(K)\,(A)\,(Q)}{T_p} \quad \ldots\ldots\ldots\ldots [8]$$

where

q_p = peak runoff rate, m^3/s

A = area, ha

Q = rainfall excess depth, mm

T_p = time to peak, h

K = hydrograph shape and unit conversion factor

Synthesis of an SCS triangular hydrograph requires the estimation of two parameters (K and T_p). The standard estimate for K (0.0021) describes a hydrograph whose recession is 1.67 times as long as its time to peak. Mockus (USDA-SCS, 1972) notes that this K value has been known to vary from 0.0026 in steep terrain to 0.0013 in flat swampy country. For the Delmarva peninsula, which includes Delaware and parts of Maryland, Welle et al. (1980) concluded that a value of 0.0011 is more appropriate. The watersheds examined were 12 to 155 km^2 in area with sandy soils and slopes in the range of 2%. The U.S. Army Corps of Engineers (1955) studied records from several large watersheds in Central and South Florida (the entire Kissimmee River Basin being one) and determined an appropriate time factor for use in a similar peak discharge equation. Miller and Einhouse (1984) translated this factor into the SCS form, arriving at a value of 0.0012 for K. The other time parameter in equation [8], T_p, is defined as:

$$T_p = L + \frac{\Delta D}{2} \quad \ldots\ldots\ldots\ldots [9]$$

where

L = watershed time lag

ΔD = rainfall excess duration

Given a triangular unit hydrograph tailored to a specific watershed and rainfall excess duration, a composite storm hydrograph can be developed by superposition of a series of unit hydrographs taken over ΔD time increments within a storm event. Kent (1973) described this convolution procedure which allows the construction of complex hydrographs in addition to single event hydrographs.

Application of the SCS triangular hydrograph technique involved first applying the method as presented in the SCS NEH-4 and second, modifying the technique to better fit the observed data. The SCS triangular hydrograph method described herein includes a change in the implementation as presented by USDA-SCS (1972). Instead of applying the SCS runoff volume equation to each increment of rainfall, all rainfall not appearing as runoff was extracted from the beginning of the storm. This is considered more appropriate since total soil storage, not infiltration rate, appears to be the limiting factor for runoff from flatwoods areas. The SCS estimates for K (0.0021 normally and 0.0013 for flat, swampy areas) and time to peak (from the lag method) were used to evaluate the standard approach. The watershed storage factor used by the lag formula (equation [6]) was calculated by two approaches. The two resulting lag estimates are referred to as "SCS-Fixed" and "SCS-Variable". Storage determined at the median condition curve number, CN_{II}, gave a fixed watershed lag, while S determined as a direct function of antecedent depth to the water table allowed the lag to vary with watershed wetness (Fig. 4). The relationship between the storage factor and curve number as presented by Mockus (USDA-SCS, 1972) is:

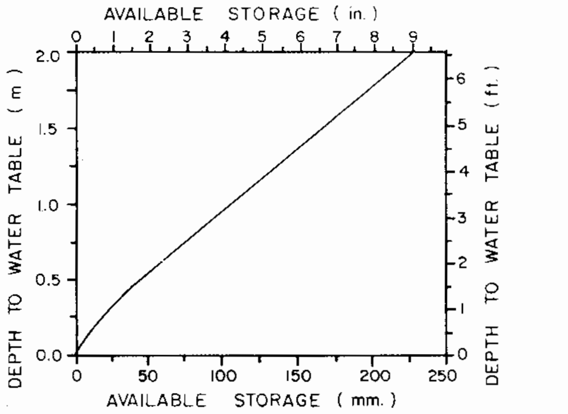

Fig. 4—Soil profile moisture storage capacity as a function of depth to the water table (Capece et al., 1986).

$$S = \frac{25400}{CN_{II}} - 254 \quad \ldots\ldots\ldots\ldots [10]$$

where

S = watershed storage factor, mm

CN_{II} = SCS curve number at antecedent moisture condition II

SFWMD Model

The South Florida Water Management District (SFWMD) publishes a graphical technique to determine peak discharges for watersheds within their jurisdiction. The peak discharge graphs in the District Regulatory Manual IV (SFWMD, 1983) originate from output of an overland flow computer model as constructed by Higgins (1976) and implemented by SFWMD (1979).

This program employs Manning's form of the overland flow momentum equation combined with an assumed retention depth and models the watershed as a single uniform inclined plane. Evaluation of the stormwater routing component independent of the total volume calculations required that the infiltration portion of the SFWMD overland flow model be modified. Specifically, the minimum infiltration rate used by the Horton equation component of the model was reduced from 2.54 to 0 mm/h. Taken over the entire time-base of an event hydrograph, the 2.54 mm/h value results in significant runoff volume errors. To remove errors attributable to runoff volume determination for a given event, the infiltration process was halted once the cumulative infiltration equaled the difference between observed rainfall magnitude and observed runoff.

EVALUATION RESULTS

Evaluation results for the methods described above, with the exception of the SCS graphical method, are presented as percent error of estimate:

$$e = 100\,(\frac{q_p{}' - q_p}{q_p}) \quad \ldots\ldots\ldots\ldots [11]$$

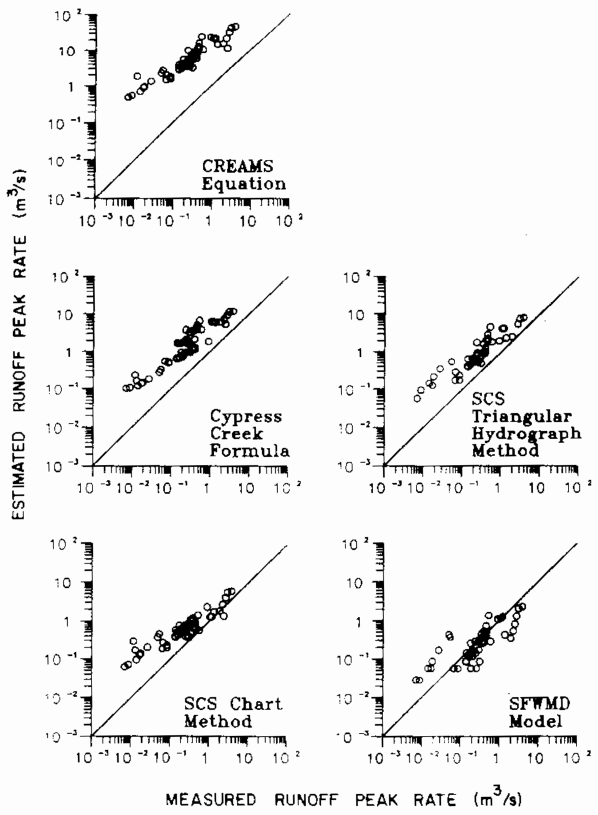

Fig. 5—Comparisons of estimated and measured runoff peak rates.

TABLE 2. RUNOFF PEAK RATE ESTIMATION ERRORS, IN PERCENT, FOR VARIOUS IMPLEMENTATIONS OF THE SCS UNIT HYDROGRAPH PARAMETERS

K	Lag method	Geometric mean error, %	Average error, %
0.0021	SCS-Fixed	430	540
0.0021	SCS-Variable	550	720
0.0013	SCS-Fixed	240	330
0.0013	SCS-Variable	310	450
0.00043	SCS-Fixed	33	73
0.00043	Mod-Fixed	24	45
0.00043	SCS-Variable	73	120
0.00043	Mod-Variable	85	150
0.00037	SCS-Variable	62	96
0.00037	Mod-Variable	64	120
0.00033	SCS-Fixed	29	35
0.00033	Mod-Fixed	13	13

where

e = percent error of estimate
q_p' = predicted peak runoff rate, m³/s
q_p = measured peak runoff rate, m³/s

Fifty-five events having both measured rainfall and runoff equal to or exceeding 18 and 13 mm, respectively, served as the basis for evaluation. Comparisons of measured and estimated runoff peak rates for each method are presented in Fig. 5.

In evaluating the SCS triangular hydrograph method, 10 of the original 55 storm events could not be included in the analysis due to incomplete rainfall data. Table 2 presents results from application of two recommended SCS K factors (0.0013 and 0.0021) and two methods of calculating time to peak (fixed and variable estimates from equation [6] and [9]). Reported results are based upon the SFWMD (1979) assumed rainfall time-distribution since this distribution, measured distributions, and the USDA-SCS Type II distribution (Kent, 1973) yield very similar results. Best peak estimates were obtained using a K of 0.0013 and the fixed lag estimates for each watershed. However, this method (referred to as the SCS unit hydrograph method in Table 3) still tended to overpredict discharge peaks by about 200%.

Method performance was analyzed as a split-plot experiment considering watershed sites as primary experimental units, rainfall events within sites as sub-units and runoff estimation methods as treatments. Analysis of variance was accomplished using the Statistical Analysis System General Linear Model procedure (SAS, 1985). Method-site interaction proved to be significant at the 5% level requiring site-by-site comparison of the methods as shown in Fig. 6. Much of the apparent interaction is due to the SCS chart method and the SFWMD model. Errors associated with the modified methods were not significantly related to site. Table 3 reports geometric and arithmetic mean percent errors of estimate. Geometric means are based upon logs of percent error of estimate absolute values and provide a measure of error magnitude. Also reported in Table 3 are average percent errors which reflect a method's tendency toward over or underprediction. Of the original (unmodified) methods examined, the SFWMD overland flow model performed best, while the CREAMS equation yielded estimates which were least accurate. The arithmetic mean error of the SFWMD method was not significantly different from zero at the 5% level.

Fig. 2 presents the SCS graphical method interim design peak estimation curve developed for Florida by

TABLE 3. GEOMETRIC MEAN AND ARITHMETIC AVERAGE RUNOFF PEAK RATE ESTIMATION ERRORS, IN PERCENT, FOR EVENTS HAVING MEASURED RAINFALL AND RUNOFF EQUAL TO OR EXCEEDING 18 mm AND 13 mm, RESPECTIVELY

Percent error	CREAMS equation	Cypress Creek Formula	SCS unit hydrograph method	SCS chart method	SFWMD model	Modified unit hydrograph method	Modified CREAMS equation
Geometric	2200 (A)*	490 (B)	240 (C)	120 (D)	36 (E)	13	17
Arithmetic	2700 (A)	600 (B)	330 (C)	260 (C)	48† (D)	13	−3

*Methods corresponding to a common letter (A-E) are not significantly different at the 5% level as determined by Duncan's multiple range test (SAS, 1985) performed on original methods.
†Not significantly different from zero at the 5% level.

the SCS. Most observed hydrograph time of concentration values were out of the SCS curve range, making anything except a subjective evaluation of the technique impossible. Where T_c calculated values (using equations [5] and [6]) were within range of the curve, significant overpredictions resulted.

METHOD MODIFICATIONS AND RESULTS

As a result of the above evaluations, three of the methods (the CREAMS equation, the SCS triangular hydrograph method and the SCS graphical method) were modified as described below to better reflect observed data.

CREAMS Equation

The standard CREAMS equation (equation [4]) was least accurate of all methods examined in this study. It consistently overpredicted by one or more orders of magnitude. A regression of the CREAMS model formulation against measured data yielded a modified version of equation [4]:

$$q_p = 0.0075(DA^{1.06})(CS^{0.77})(LW^{0.389})(0.0394Q)^{2.64(DA^{-0.20})} \quad \ldots\ldots [12]$$

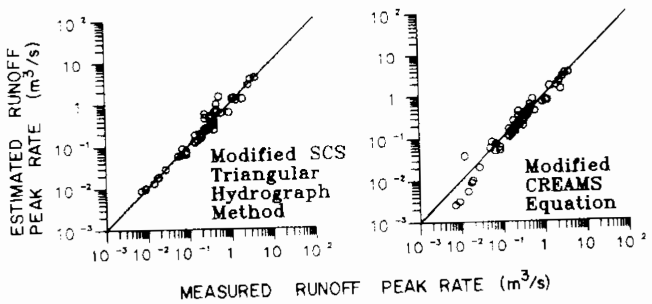

Fig. 7—Comparisons of estimated and measured runoff peak rates for modified methods.

The modified CREAMS results shown in Table 3 and Figs. 6 and 7 do not represent an independent evaluation of the modified CREAMS equation, but simply reflect the regression fit to the data. This equation resulted in a correlation coefficient of 0.96.

SCS Triangular Hydrograph Method

In modifying the triangular hydrograph method, an improved combination of hydrograph factor (K) and time to peak estimate was sought. The first step of the modification involved assembling several (5) time to peak estimates for each watershed. Two sets of estimates, as previously described, are the fixed and variable values from the lag method (equations [6] and [9]) referred to as "SCS-Fixed" and "SCS-Variable", respectively. Minimum measured times to peak served as the basis for a third set referred to as "MES-Fixed". The fourth set of estimates, referred to as "MOD-Fixed", is from an equation based upon minimum observed hydrograph times to peak plotted against watershed percent wetlands:

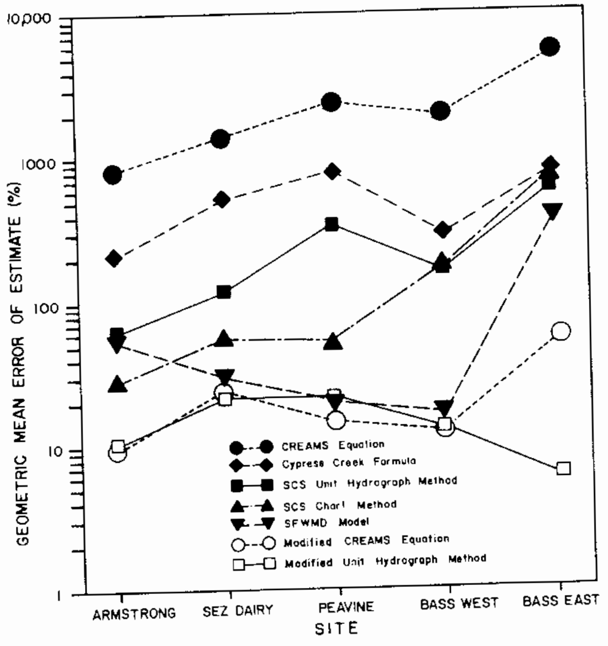

Fig. 6—Peak rate estimation errors illustrating method-site interactions.

$$L = 3.0 + 0.38(A^{0.11})(W+1)^{0.71} \quad \ldots\ldots\ldots\ldots [13]$$

where

L = watershed lag, h (MOD-Fixed)
A = drainage area, ha
W = percent wetlands

A fifth set of T_p values referred to as "MOD-Variable" result from a variable form of the same equation:

$$L = 3.0 + 0.38(A^{0.11})(W+1)^{0.71}(S+1)^{0.50} \quad \ldots\ldots [14]$$

where

L = watershed lag, h (MOD-Variable)
S = SCS watershed storage parameter

The last multiplicative term of this equation allows lag to vary over the same range as does the SCS variable lag (1 to 3 times the fixed estimate), but is not based on observed hydrographs. The variable term is similar to that used by the SCS (equation [6]) and was simply concatonated onto the modified lag equation (equation [13]). The variable storage parameter in this case is calculated as a direct function of antecedent depth to the water table (Fig. 4).

The second step of the evaluation was to determine best-fit K factors using various estimates of time to peak. A computer program searched out the K value which would yield the observed hydrograph peak for various rainfall time-distributions and time to peak estimates.

TABLE 4. RESULTS FOR SCS UNIT HYDROGRAPH K FACTOR OPTIMIZATION USING SFWMD DESIGN RAINFALL TIME-DISTRIBUTION. $\overline{K}$ VALUES REPRESENT AN AVERAGE FOR ALL SITES AND s VALUES REPRESENT STANDARD DEVIATIONS ASSOCIATED WITH K VALUES

Lag method	Runoff ⩾ 13 mm		Runoff < 13 mm	
	$10^4\,\overline{K}$	$10^4 s$	$10^4\,\overline{K}$	$10^4 s$
MOD Fixed*	3.1	0.56	3.7	1.3
MES Fixed†	4.1	2.5	5.3	2.8
SCS Fixed‡	3.8	2.3	4.6	3.5
MOD Variable §	3.7	1.3	5.3	1.8
SCS Variable‖	3.6	2.7	4.9	4.1

*as calculated from equation [13].

† minimum observed times to peak from hydrograph analysis.

‡as calculated from equation [6].

§as calculated from equation [14] using a variable storage parameter determined from antecedent depth to the water table (Fig. 4).

‖ as calculated from equation [6] and using the above variable storage parameter

For each event and parameter combination the program generated a K value referred to as optimum or best-fit.

As previously stated, the SFWMD design rainfall time-distribution yielded almost identical results to those derived from measured distributions. Factors for events less than 13 mm were 20 to 30% higher than factors for the class of larger events. Focusing in on the K determined using the SFWMD rainfall time-distribution and events greater than 13 mm, all were computed to be less than 0.00043. Even when using the SCS-Fixed lag estimates, results were significantly lower than the 0.0013 value recommended for flat, swampy areas. Values were also lower than the 0.0011 found to be appropriate for the Delmarva Peninsula (Welle et al., 1980). The Delmarva area, although having similar soil characteristics, still has slopes (2%) which are steeper than the flatwoods watersheds examined in this study.

Having isolated a range of factors between 0.00033 and 0.00043, the next step was to identify a technique for estimating lag which would result in a fairly consistent K for all sites. For both the modified and standard lag estimation techniques, no benefit (in terms of factor uniformity among sites) was derived from the use of a variable lag equation. For the fixed lag estimates, the modified method (equation [13]) produced the most consistent optimized K for all sites. Table 5 shows the site variability of the best-fit K factor for the modified-fixed lag case. The trend among sites was for an increasing K value with decreasing watershed percent wetlands. Also included in Table 5 are the best-fit K factors for the large runoff events associated with Hurricane David as well as the maximum and minimum best-fit K factors among all events within a site. Runoff from Hurricane David ranged between 64 and 132 mm, depending upon the specific site.

Incorporating results from the K and T_p analyses, the incremental triangular hydrograph method was re-applied to the data base and results are included in Table 2. The modified SCS triangular hydrograph method presented in Table 3 and Figs. 6 and 7 employs modified-fixed lag estimates and a K value of 0.00033.

SCS Graphical Method

Fig. 2 shows average peak discharge values (m^3/s per mm of runoff per km^2) for each site plotted against the SCS estimates of time of concentration from the lag method, equations [5] and [6]. This plotting showed little trend in the graph and also resulted in severe overestimates of peak discharge. The same peak values were also plotted against modified estimates of T_c from equations [5] and [13]. This plot produced a definite trend as shown by the subjectively fitted curve. The revised curve may be useful for predicting peaks from typical runoff events, however for design applications, the upper extremes of data scatter should be noted.

SUMMARY AND CONCLUSIONS

Results of this study demonstrate that more accurate estimates of runoff peak rates can be expected as models progress from the empirical to the more physically based. However when empirical models are tailored to specific watershed conditions, results may be comparable to or better than those from more complex models. As watershed conditions change or changes are anticipated, physically-based models can be expected to again become more reliable than empirical techniques.

With decreasing overall mean percent error of estimate, the established methods ranked from poorest to best are: CREAMS, 2200%; Cypress Creek Formula, 490%; SCS triangular hydrograph, 240%; SCS Chart, 120%; and SFWMD, 36%.

TABLE 5. RESULTS FOR SCS UNIT HYDROGRAPH K FACTOR OPTIMIZATION USING SFWMD ASSUMED RAINFALL TIME-DISTRIBUTION, RUNOFF EVENTS EQUAL TO OR EXCEEDING 13 mm, AND MODIFIED–FIXED LAG ESTIMATES. $\overline{K}$ VALUES REPRESENT AN AVERAGE OF ALL EVENTS FOR A SITE AND s VALUES REPRESENT STANDARD DEVIATIONS ASSOCIATED WITH $\overline{K}$ VALUES

Site	Number of events	Maximum* 10^4 K	Minimum† 10^4 K	$10^4\,\overline{K}$	$10^4 s$	David‡ 10^4 K
Armstrong	5	5.2	2.7	3.6	0.95	3.8
Peavine	13	3.3	1.2	2.3	0.60	2.9
SEZ Dairy	4	4.4	1.7	3.0	1.1	–
Bass West	16	4.6	2.6	3.8	0.52	5.2
Bass East	7	3.6	2.9	3.1	0.53	3.0
Average				3.1	0.56	

*Maximum optimized event K factor for all events within a site.

†Minimum optimized event K factor for all events within a site.

‡Based on available data for rainfall associated with Hurricane David (9-3-79).

As would be expected, fitting the CREAMS equation and SCS triangular hydrograph to the data significantly improved the performance of both methods resulting in 17 and 13% error of estimate, respectively. Of the two modified methods, the SCS method is more versatile and should be more transportable to other flatwoods watersheds. The SCS technique is better adapted to handling multiple-day (complex) events, whereas the CREAMS equation does not allow time-staggered superposition of hydrographs.

Evaluation of the SCS triangular hydrograph method demonstrated the need for improved algorithms for estimating time to peak. A simplified algorithm based upon data from the five study sites is presented, but its transportability has not been verified. Significant triangular hydrograph results also suggest that the SCS recommended hydrograph factor, 0.0013, is too high. Analysis indicates that a value less than 0.00043 is more appropriate for small runoff events from small Florida flatwoods watersheds. Results from the limited number of larger runoff events also suggest that when using the modified lag estimation equation, a factor less than 0.00065 would be more reasonable for design purposes. Also noteworthy were the almost identical peak rate estimates derived from measured rainfall time-distributions and the SCS and SFWMD design rainfall time-distributions. Discharge hydrographs from flatwoods watersheds were found to be much more attenuated and to produce much lower peaks than the watersheds which served as models in the original development of the techniques examined in this study.

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