MEMORANDUM

April 25, 1990

TO: **SJRWMD MSSW PERMIT APPLICANTS**

FROM **Hal Wilkening, P.E., Chief Engineer**
Department of Resource Management

RE: **PROCEDURE FOR SELECTION OF SCS PEAK RATE FACTORS FOR USE IN MSSW PERMIT APPLICATIONS**

1 INTRODUCTION

Sections 10.3 and 12.0 of the Management and Storage of Surface Waters (MSSW) applicants handbook provides methodologies for calculating peak discharge in order to meet the peak discharge criteria in Section 10.3 of the applicants handbook. The handbook explains that peak discharge estimates should be make using a District approved hydrograph method. One of the approved methods is the SCS unit hydrograph, first documented in the National Engineering Handbook, Section 4 (Chapter 16) and later incorporated into the computer model described in TR-20 and TR-55. Many of the computer models currently used by design engineers are further refinements of the TR-20 model. District Technical Report SJ 85-5 (Suphunvorranop, 1985) provides a detailed review of the SCS methodologies and further guidance on its use for MSSW applications.

This memo provides additional guidance on the use of the SCS dimensionless unit hydrograph (DUH) methodology, specifically, selection of the peak rate factor, K'. The memo presents a brief review of the SCS unit hydrograph, some of the limitations in the use of the standard K' value of 484, a summary of pertinent research and literature, and recommended guidelines for estimating peak rate factors.

This information will be incorporated into the methodology section of the Applicants Handbook in the near future. In the interim, applicants should use the information in this memo in preparation of MSSW applications.

2 DISCUSSION

2.1 Review of SCS Unit Hydrograph Methodology

Hydrograph theory was advanced in 1932 by Sherman. He defined the unit hydrograph (UH) as "basin outflow resulting from one inch of direct runoff generated uniformly over the drainage area at a uniform rainfall rate during a specified period of rainfall duration". The unit hydrograph procedure assumes that discharge at any time is proportional to the volume of runoff and that time factors affecting hydrograph shape are constant. The following assumptions from Chow (1964) need to be considered when working with unit hydrographs:

1. The effective rainfall is uniformly distributed within the duration of specified period of time,
2. The effective rainfall is uniformly distributed throughout the whole area of the drainage basin,
3. the base or time duration of the hydrograph of direct runoff due to an effective rainfall of unit duration is constant,

4. the ordinates of the direct runoff hydrographs of a common base time are directly proportional to the total amount of direct runoff represented by each hydrograph.

5. for a given drainage basin, the hydrograph of runoff due to a given period of runoff reflects all the combined physical characteristics of the basin.

The dimensionless unit hydrograph used by the Soil Conservation Service (SCS) was developed by Victor Mockus. It was derived from a large number of unit hydrographs from watersheds varying widely in size and geographical locations throughout the United States. Unit hydrographs were normalized by division of runoff values by the peak runoff values and time by the time to peak. The dimensionless curvilinear hydrograph corresponds closely with the triangular hydrograph as shown in Figure 1. Similarities include 37.5% of the total volume under the rising leg of the hydrograph, time base of the triangular hydrograph is 2.67 time units and the recession is 1.67 time units. The peak rate equation as described below is derived from the relationship of the triangular hydrograph.

$$q_p = \frac{KQ}{T_p} \qquad \text{Equation 1}$$

$$K = \frac{2}{1+\frac{T_r}{T_p}} \qquad \text{Equation 2}$$

where;

q_p = peak rate in inches/hour,
Q = total volume under the unit hydrograph in inches,
K = hydrograph shape factor,
T_p = time to peak in hours,
T_r = time of rise in hours.

After conversion from inches to cubic feet per second and including the drainage area in square miles, the equation is as follows:

$$q_p = \frac{K'AQ}{T_p} \qquad \text{Equation 3}$$

The constant K' is referred to as the 'peak rate factor' for the unit hydrograph. For the dimensionless triangular unit hydrograph, $T_r = 1.67T_p$. Therefore, after substitution into the appropriate equation, K' is equal to 484. See Technical Publication SJ 85-5 and USDA-SCS (1972) for more detailed information and background on the SCS unit hydrograph method.

2.2 Sensitivity and Relevance of Peak Rate Factor, K'

The effect of K' values on the shape of triangular unit hydrographs is shown in Figure 2. Peak discharge is very sensitive to variation in K' values. With parameters A, Q, and time of concentration, t_c, held constant,

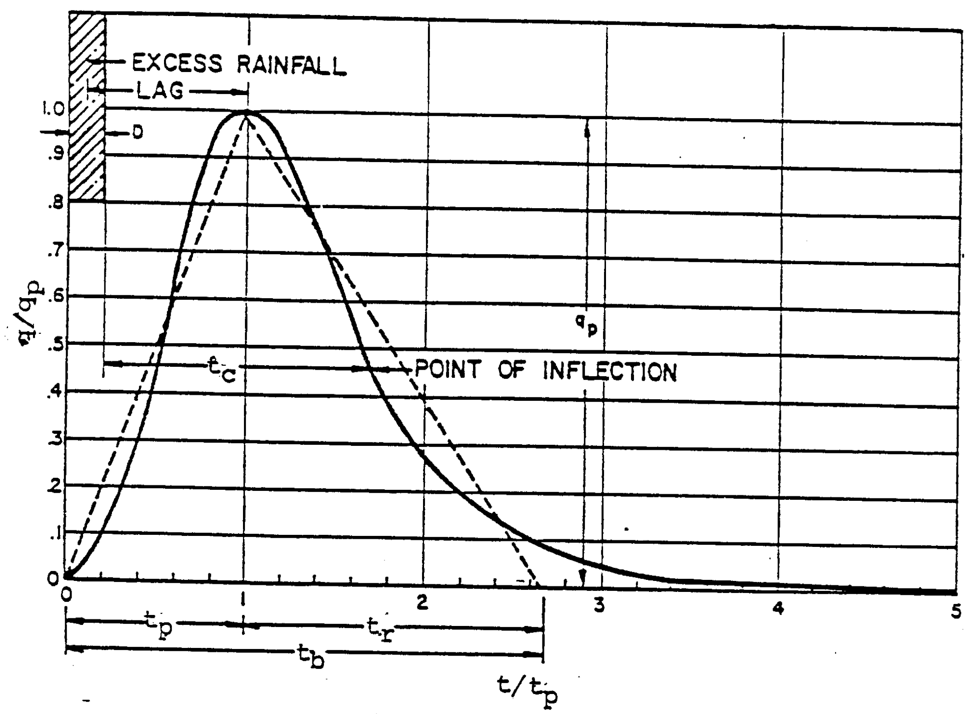

Figure 1.--SCS Dimensionless Curvilinear and Triangular Unit Hydrographs (SCS, 1972) from Technical Publication SJ85-5

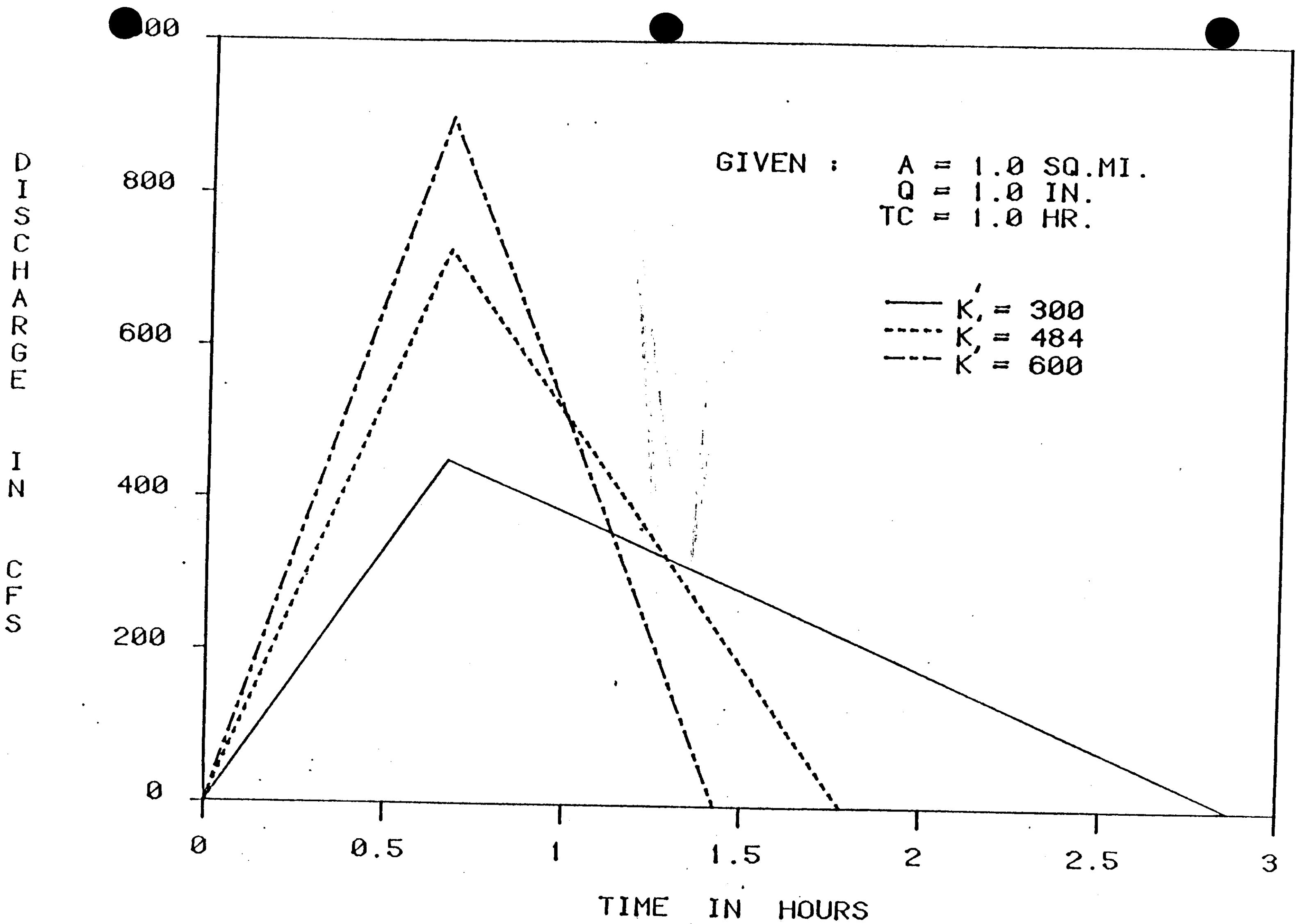

Figure 2.--Sensitivity of Triangular Unit Hydrograph to K' from Technical Publication SJ85-5

q_p increases and the time base, t_b, decreases as K' increases, or vice versa. It should be noted that the t_p of the unit hydrograph is not a function of K' and therefore is not affected by changing in K' values. An example of the effect of K' values on a typical runoff hydrograph is shown in Figure 3.

Peak rate factor is used to represent the effect of watershed storage on hydrograph shape. High values represent little storage to no storage characterized by steep slopes and low values represent watersheds with significant ponding effects due to very little to no slope and areas of significant surface storage.

Selection and adjustments K' should be based on the extent of natural surface storage and not watershed slope, because the effect of slope on hydrograph shape is accounted for when t_c is calculated.

As natural areas undergo land development and other urbanization, K' values will increase as the amount of storage within the watershed is eliminated.

2.3 Limitations of SCS Unit Hydrograph Method

Although the SCS methodology is often used with a constant $K'$of 484, the variation of the peak rate factor has been documented from below 100 to 600 and is discussed in other publications addressed below. Common practice, until recently, has been to use the standard peak rate factor of 484 for all MSSW applications, regardless of watershed conditions. When applied to areas with little slope and substantial surface storage, such as pine flatwoods, the peak discharge will be significantly over-estimated. In this case, control structures, could be designed with a discharge capacity greater than the actual pre-development condition.

2.4 Summary of Research on K'

Different peak rate factors have been determined for several different areas that are similar to soil type and slope conditions exhibited in the District. The following table gives the range of values by different researchers working on peak rate factor determination.

RESEARCHER	AREA	PEAK RATE FACTOR
Corps of Engineers (1955)	Kissimmee River Basin	312
	Central & South Florida (avg)	256
Capece et al. (1987)	South Florida	80-100
Woodward et al. (1983)	Delmarva (De, Md, Va)	284

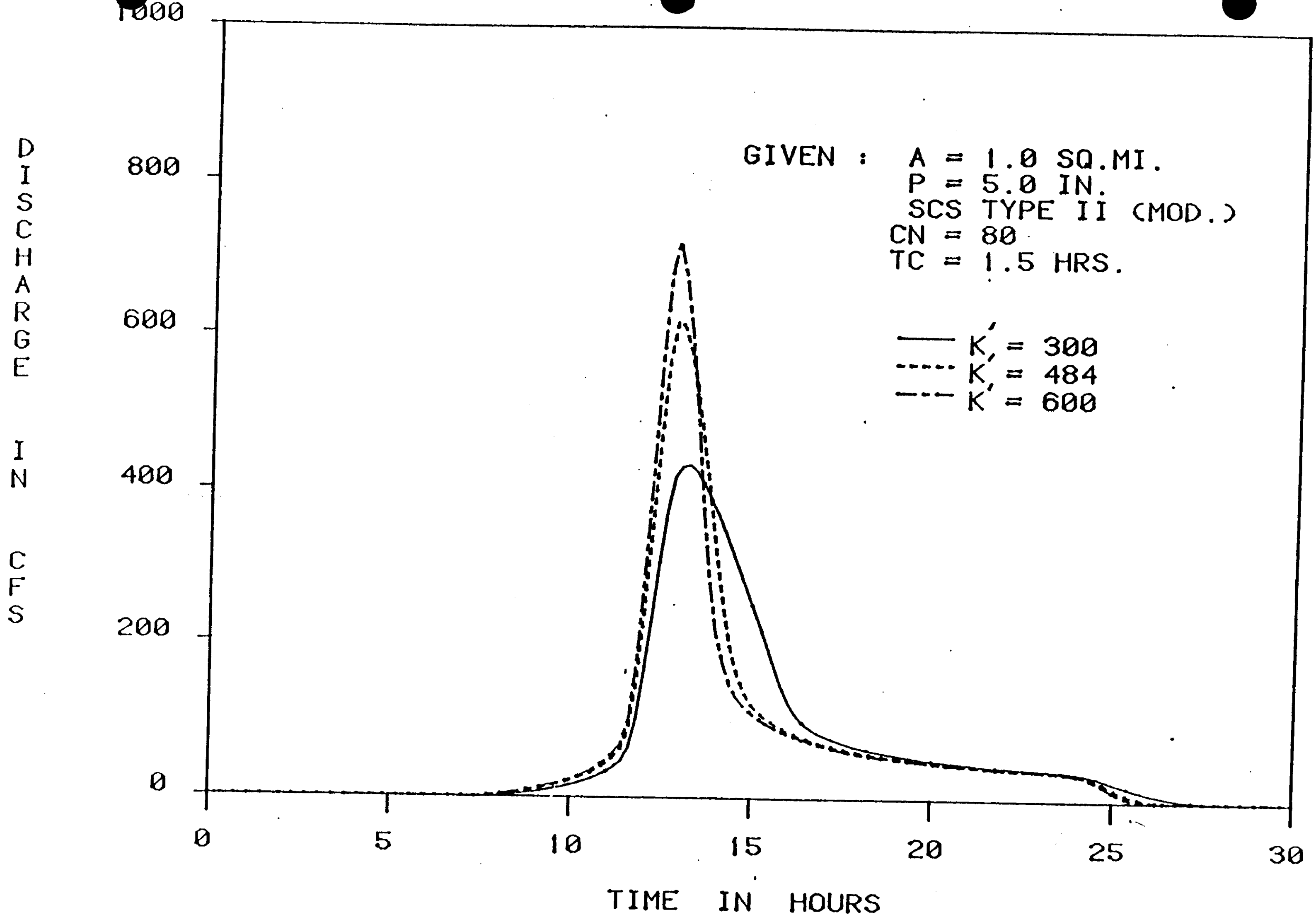

Figure 3.--Sensitivity of Runoff Hydrograph to K' from Technical Publication SJ85-5

2.4.1 Capece

Capece et al. studied different methods used to estimate peak runoff rates and volumes from flatwood watersheds in south Florida. All methods reviewed over-estimated runoff. In the case of using a peak rate factor of 300 to model runoff hydrographs from the 5 instrumented watersheds, the error was about 200%. In other words, the model results with K' of 300 significantly over-predicted the measured peak discharge. A possible limitation in the study results is the lack of storm events with rainfall depths corresponding to the type of larger design storm events often modelled for design of surface water management systems (i.e. 24 hour storm with 10 year or 25 year return periods).

2.4.2 Kissimmee River Study (Corps of Engineers)

The hydrograph analysis done by the Corps of Engineers for the Kissimmee River study was done in the General Design Memorandum about 1955. The 6 hour unit hydrographs were assumed to be a valid shape for developing the generalized shape characteristics for the Central Florida Region. These hydrographs were reduced to dimensionless unit hydrographs and plotted together to establish the general trend. A representative dimensionless graph was selected and checked for unity of volume. The area under the rising limb of this hydrograph was 24% of the total volume. Therefore, the K' used for the Kissimmee River Basin was 312.

Miller & Einhouse (1984) conducted a flood study and water quality investigation in the Little Econlockhatchee River Basin located in East Central Florida. The SCS Unit hydrograph method was used for all the watersheds in the basin. Reasonable results were obtained using a peak rate factor of 256. This value (256) was an average of peak rate factors determined for several measured runoff hydrographs from several basins (in addition to the Kissimmee) in central and southern Florida by the U.S. Army Corps of Engineers as part of the General Design Memorandum for Central and South Florida Flood Control Project (1955). The peak rate factors for the observed hydrographs were computed from lag time and peak flow based on the Snyder equation.

2.4.3 Coastal Plains Unit Hydrograph Studies

A hydrologic study was conducted by Woodard (1983) in the Delmarva Peninsula in the Atlantic Coast Flatwoods area. This area is characterized by local relief of a few feet to 10 feet with considerable surface storage in swales and swamps. Four small agricultural watershed were selected for which at least 10 years of stream flow data were available. The Snyder coefficient, C_p, was used as an indicator of whether the unit hydrograph for each flood graph was representative of floods in the Delmarva Peninsula. Seven of the 10 floods statistically met the criterion. The unit hydrographs were made dimensionless and averaged to obtain a unique dimensionless unit hydrograph with K' of 284.

2.5 Ongoing and Future Research Efforts

Campbell and Capece are working in cooperation with South Florida Water Management District to determine phosphorus loading from instrumented watersheds on pine flatwood areas in South Florida. The researchers expect that rainfall and runoff data collected from these instrumented watersheds will also allow for determination of SCS peak rate factors. The study is expected to collect data until September 1990. If there are insignificant events during that time period, the study period will probably be extended collect data until December. The time of completion depends on the number and size of rainfall events and hence adequate data before project completion.

SJRWMD is currently investigating alternatives for setting up long-term rainfall and runoff data collection stations on several small watersheds (10-100 acres) in conjunction with stormwater management studies, to validate and improve runoff modelling methodologies, including the SCS unit hydrograph.

3 RECOMMENDATIONS FOR USE OF SCS UNIT HYDROGRAPH

3.1 Other Peak Rate Methods

Although SCS unit hydrograph is easy to use, the designer must be aware of its limitations. Reasonable estimates of peak discharges from natural watersheds (i.e. undeveloped) can only be expected if peak rate factor is adjusted to account for local conditions. Given the limitations in the SCS method, the design engineer should be aware there are other acceptable methods for generating runoff hydrograph and peak discharge rates, which may be more appropriate in some cases, including Santa Barbara Unit Hydrograph and regression methods as described below.

3.1.1 Santa Barbara Unit Hydrograph

The Santa Barbara Unit Hydrograph (SBUH) was developed in the early 1970's by James M. Stubchaer, a flood control engineer for the Santa Barbara County Flood Control and Water Conservation District in California. This hydrograph method uses the percentage of pervious and hydraulically connected impervious areas to calculate the total runoff from small urban watersheds. Rainfall on or flowing across impervious portions is considered to be 100% runoff. Infiltration is calculated from an exponential decay curve of loss rate verses antecedent precipitation index. Typical infiltrations values range from 0.15-0.40 for urban areas. The total runoff from the impervious and pervious surfaces are routed through an imaginary linear reservoir with a time delay equal to the time of concentration to obtain the final hydrograph.

The use of SBUH should be limited to small urban watersheds. For watersheds with considerable surface storage the procedure may not give the accuracy that could be used for design of detention structures. The procedure is capable of sizing outflow structures such as weirs and culverts.

3.1.2 Regression equations

There are a class of peak discharge estimation formulas of the form
$Q = CA^x$

where

Q = design peak discharge;
A = drainage area; and
C,x = regression coefficients.

This equation has been used successfully by Stephens and Mills (1965) to relate maximum daily discharges to instantaneous peak discharge rates for flatwoods watersheds in South Florida. The form of their equation is referred to as the 'Cypress Creek Formula'. This type of regression equation is useful when the equations and procedures can be validated for a specific area.

The hydrologic analysis of flood-peak flows has been shown to be dependent on contributing drainage area, lake area within the drainage area and the channel slope. Rao (1986) has shown that the regression model for the region covered by the SJRWMD is of the following form:

$$Q_T = C * AREA^{B_1} * SLOPE^{B_2} (LAKE + 3.0)^{B_3}$$

where:
Q_T = discharge for a recurrence interval of T years;
C = regression constant;
AREA = drainage area (square miles);
SLOPE = channel slope (feet/mile);
LAKE = lake area in percent;
B_1, B_2, B_3 are exponents of the regression.

Rao has presented the regression model coefficients and the correlation coefficients for the St. Johns River Water Management District. Regionalized models for the Nassau and St. Marys River, Middle St. Johns, and Oklawaha River were given as somewhat better estimates than the District model. Estimates of peak rates using these procedures should be used as alternative design values for comparison with other estimates.

Regression equations described above have been used for peak rate estimates for design of water management structure and conveyance systems. However, hydrograph methods, rather than regression equation, should be used to design retention/detention storage. Care and professional engineering/hydrologic judgement should be used when applying any procedure based on limited site specific data for complete design specifications. At least two procedures could be used to ensure a degree of accuracy of results.

3.2 Selection Peak Rate Factor, K'

Peak rate factor has been a subject of considerable controversy with designers and permitters in the state. Clearly, the peak rate factor should be considered as a constant for a particular basin but one that varies from one basin to another. Careful review of peak rate factor determination is essential. The SCS recommends (USDA-SCS 1980) that a peak rate factor of 284 be used for all cases in which the average land slope is less than 0.5 percent. Technical Publication SJ 85-5 recommends that peak rate factors be reduced to account for surface depressions.

Based on the clear evidence that the peak rate factor should be reduced substantially to reflect natural surface storage within most watersheds in the District, the following procedure should be followed by MSSW applicants (note that the following recommendations are a revision provided in Technical Publication SJ 85-5):

1. Determine an appropriate peak rate factor for pre-development conditions based on an assessment of the storage characteristics of the watershed. Table 1 provides acceptable *K′* values for three general categories of watershed characterized by significant, moderate, and little or no surface storage. These recommended *K′* values are based on the literature and research summarized in this memorandum. The table generally refers to the following characteristics of a watershed, all of which are indicative of the extent of surface storage which may be expected to further attenuate the runoff hydrograph in natural watersheds:

a. Slope. The average watershed slope is directly accounted for in the SCS unit hydrograph with Time of Concentration, T_c. However, the average slope of natural watersheds is highly interrelated with the surface storage potential. As slope decreases, runoff must pond deeper before overland flow occurs. Watershed slope was reported to be a primary factor in determination of low *K′* values for coastal watersheds in the Delmarva peninsula (Woodard, 1983). Based on this study, the SCS has recommended a *K′* of 284 for when the average slope of the watershed is 0.5% or less. (See attachment 1).

b. Drainage works. Pre-existing drainage works, such as ditches, may serve to reduce surface storage. The size, depth, and location of pre-existing ditches should be considered. If such works are widespread and judged to be effective, then the *K′* value will be higher than that expected under natural conditions.

c. Surface depressions. Surface storage is furthered increased when the watershed contains low lying depressional areas such as marshes, cypress heads, intermittent sloughs, lakes, ponds, and sink formations, which act to store significant runoff prior to overflowing and contributing to off-site runoff. The percentage of the watershed in depressional area should be carefully considered. *K′* should be further reduced to account for the significant surface storage that these areas will provide.

d. Landscape. Major ecological communities can be generally related to hydrologic conditions and indicative of surface storage. For example, Pine flatwoods, which is a predominant landscape within the District, is characterized by very flat slopes, limited drainage features, and surface ponding. Pine flatwoods should generally be modeled in natural conditions with a *K′* of 256 to 284.

The *K′* factors described in Table 1 should be used to estimate runoff hydrographs from natural basins using the SCS unit hydrograph unless the applicant can provide reasonable assurance, through other means, that watershed storage has been properly accounted for. An example of an acceptable alternative approach is the determination of *K′* based on a method proposed by McCuen and Bondelid (1983), in which a dimensionless unit hydrograph can be developed by computing the time-area curve for the watershed and using the proportion under the rising limb to compute the peak rate factor for the dimensionless unit hydrograph. The reader is referred to Technical Publication 85-5 for a summary of this method and McCuen and Bondelid (1983) for a more detailed discussion.

2. Determine a post-development peak rate factor based on the pre-development K', and the degree to which natural storage areas will be eliminated. Land development will generally result in a reduction of natural storage. As a result, the K' value should either increase or remain constant, but never decrease. In most cases, post-development conditions will include detention storage areas; this storage should be accounted for by routing the hydrograph based on a defined stage-storage-discharge relationship and should therefore not be considered in determining the K'. The most conservative approach is to use $K' = 484$ for post-development. However, in some cases where significant surface storage is maintained or replaced by swales, shallow natural depressions, lakes or wetlands, (which are not directly accounted for in routing calculations) K' may be reduced up to the same value used in pre-development.

3. K' Values should be considered basin specific (similar to area, CN, and t_c) and estimated for each hydrologic sub-basin for which a runoff hydrograph is generated.

Table 1. Recommended K' For Varied Site Conditions

SITE CONDITIONS	K'
Represents watersheds with very mild slopes, recommended by SCS for watersheds with average slope of 0.5% or less. Significant surface storage throughout the watershed. Limited on-site drainage ditches. Typical ecological communities include: North Florida flatwoods, South Florida flatwoods, freshwater marsh and ponds, swamp hardwoods, cabbage palm flatlands, cypress swamp, and similar vegetative communities.	256-284
Intermediate peak rate factor representing watersheds with moderate surface storage in some locations due to depressional areas, mild slopes and/or lack of existing drainage features. Typical ecological communities include: Oak Hammock, upland hardwood hammock, mixed hardwood and pine, and similar vegetative communities.	323-384
Standard peak rate factor developed for watersheds with little or no storage. Represents watersheds with moderate to steep slopes and/or significant drainage works. Typical ecological communities include: Long leaf pine - turkey oak hills, and similar vegetative communities.	484

3.3 Implementation of Recommendations

Peak rate factor, K', can be adjusted in almost every available computer model which uses the SCS unit hydrograph method, by one of the following methods:

1. Input selected K' value directly: Some computer models are currently available which allow the user to select any desired K' factor and the program will automatically compute the appropriate triangular or curvilinear unit hydrograph ordinates (both are acceptable). The user should confirm that the program correctly computes unit hydrographs; check to confirm the total volume is 1 " of runoff and that the ratio of volume under rising limb to total volume is correct for the desired peak rate factor.

2. Select one of several K' values: Several models currently allow the user to select from two or more specific K' values. This does not offer as much flexibility, but is generally sufficient. The user should specify the K' values which most closely represents the value given in Table 1.

3. Input unit hydrograph ordinates: Some computer models do not allow the user to select a K' factor; these models use the unit hydrograph for the standard K' of 484. These models, most notably TR-20, do allow the user to input the ordinates for an alternative unit hydrograph. In this case, the hydrograph ordinates for the appropriate peak rate factor may be included in the input file.

4. SCS TR-55: TR-55 is a tabular method based on the results of TR-20 model output. This method is commonly used to estimate peak discharge rates directly. The SCS has prepared an addendum to TR-55, included as attachment 1, to calculate peak discharge based on a K' of 284, instead of the standard 484.

The applicant should provide the model input file which documents the K' value (or unit hydrograph ordinates) that was used for each sub-basin unit that was modelled.

4 SUMMARY

The procedure for selection of SCS peak rate factor supplements and updates the MSSW applicants handbook, and SJRWMD Technical Publication SJ 85-5. This method should be used by MSSW applicants in demonstrating that the proposed surface water management system meets the peak discharge design criteria. These recommendations are based on the relevant literature and data available at this time and may be revised subsequent to completion of additional research.

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