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GUIDELINES FOR CALIBRATION AND APPLICATION OF STORM ADDENDUM. D--ETC(U)
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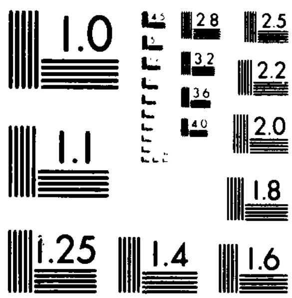

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Addendum to HEC Training Document No. 8
Guidelines for Calibration and Application of STORM

DESCRIPTION OF SCS METHOD OF RUNOFF DETERMINATION AS PROGRAMMED IN STORM

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DESCRIPTION OF SCS METHOD OF RUNOFF DETERMINATION AS PROGRAMMED IN STORM

Introduction

The purpose of this write-up is to provide documentation of the way STORM computes the quantity of runoff using what is referred to as the "SCS Method." The current STORM Users Manual (August 1977) does not describe this option of runoff determination in sufficient detail.

Acknowledgment: Portions of Art Pabst's STORM lecture notes, prepared for the 1978 Urban Hydrology training course, will be used to illustrate some definitions and concepts.

SCS Method

STORM contains a runoff procedure derived from the SCS Curve Number technique but modified to operate continuously at STORM's fixed 1-hour time interval. Curve numbers are not used in STORM; the SCS runoff equation is

$$Q = \frac{(P - IA)^2}{P - IA + S} \qquad (1)$$

where

Q = accumulated runoff

P = accumulated precipitation

IA = initial abstraction

S = soil moisture capacity

This equation is graphed in Figure 1 for various values of S and assuming IA = 0.2S.

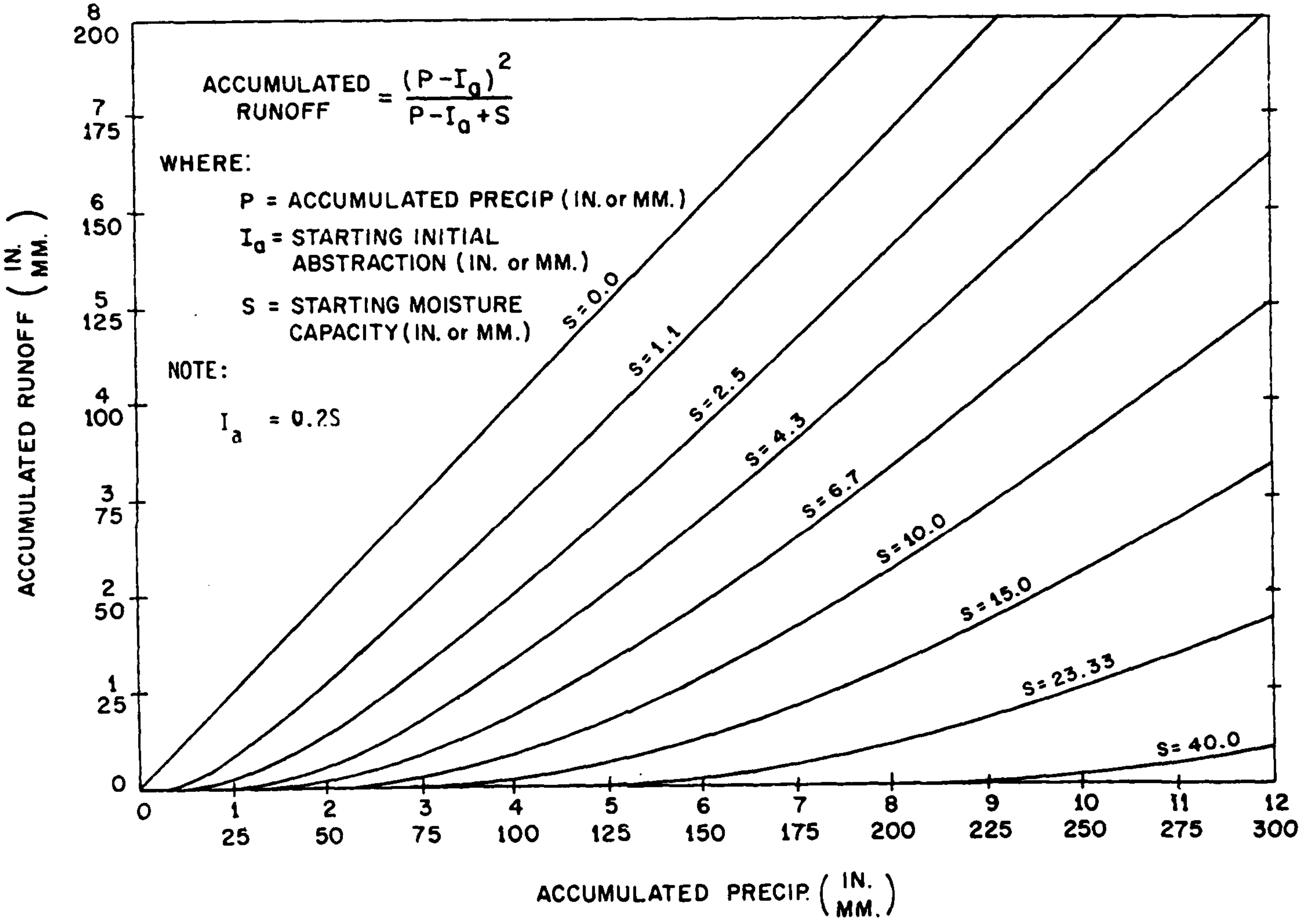


Figure 1. SCS RUNOFF PROCEDURE

IA represents all initial losses (interception, depression storage) that occur prior to the time when runoff begins. Figure 2 illustrates the conceptual storages, IA and S.

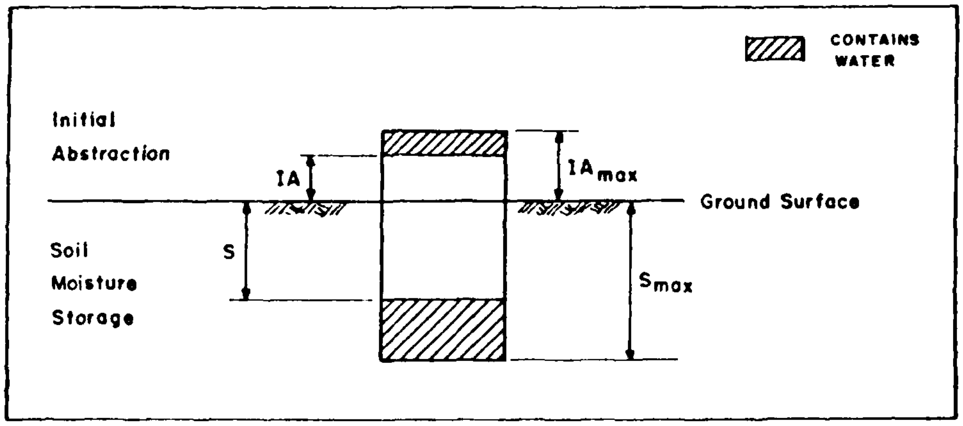


Figure 2

Conceptual Storages

The original SCS Curve Number technique was intended to compute <u>total</u> storm runoff volume. When the procedure was programmed in STORM the assumption was made that the SCS runoff equation could also be used to represent cumulative runoff during a storm event.

Input Parameters

The user must specify values for the following parameters.

Card-Field	Variable	Description
E5-2	DEPR	Maximum initial abstraction capacity (IA)
E5-3	ACTIA	Starting value of IA
E5-5	SMAX	Maximum soil moisture capacity (S)
E5-4	SACT	Starting value of S
E5-6	RATEIN	Maximum percolation rate
E5-7	PERCMX	Maximum deep percolation rate
E4-6	EPRC	Exponent in deep percolation equation
E4-5	EERC	Exponent in evapotranspiration equation

Runoff Calculation During a Storm Event

Once precipitation begins, the current values of IA and S (call them IA* and S*) are fixed and used in equation (1) throughout the storm event to compute cumulative runoff. For example, the cumulative runoff at the end of the previous hour would be

$$Q_{t-1} = \frac{(P_{t-1} - IA^*)^2}{P_{t-1} - IA^* + S^*}$$

and at the end of the current hour

$$Q_t = \frac{(P_t - IA^*)^2}{P_t - IA^* + S^*}$$

The incremental runoff for the current hour, ΔQ_t, would then be computed as

$$\Delta Q_t = Q_t - Q_{t-1}$$

Meanwhile a separate accounting of the actual changing values of IA and S continues to take place (as described in the next section) but is not used in the current storm. When precipitation stops, the updated IA and S become starting conditions for the recovery functions which operate during dry periods.

Moisture Accounting During a Storm Event

Let ΔP_t be the amount of precipitation (rainfall or snowmelt) occurring in hour t and ΔQ_t be the amount of runoff for the same time interval. (ΔQ_t would be computed as described in the previous section.) During a storm the following moisture accounting takes place:

- IA is decreased by ΔP_t, $0 \le IA \le IA_{max}$
- S is decreased by $\left[\Delta P_t - \Delta Q_t - IA^*\right]$, and

  increased by $\left[PERCMX \left(\frac{S_{max} - S_{t-1}}{S_{max}}\right)^{EPRC}\right]$, $0 \le S \le S_{max}$

Available initial abstraction storage (IA) is decreased by the amount of precipitation until there is no IA storage left. Soil moisture capacity (S) is decreased by infiltration; i.e., the difference between precipitation and the sum of runoff (ΔQ_t) plus initial abstraction storage at the start of the storm (IA*). Simultaneously, S is being increased by deep percolation at the maximum rate (PERCMX) adjusted by a ratio ($(S_{max} - S_{t-1})/S_{max}$) that reflects current status (wet or dry) of soil moisture. An exponent (EPRC) is available to reflect nonlinearity in the deep percolation equation.

Figure 3 illustrates the change in IA and S during a storm. Figure 4 shows the variation in deep percolation adjustment ratio with selected integer exponents (EPRC).

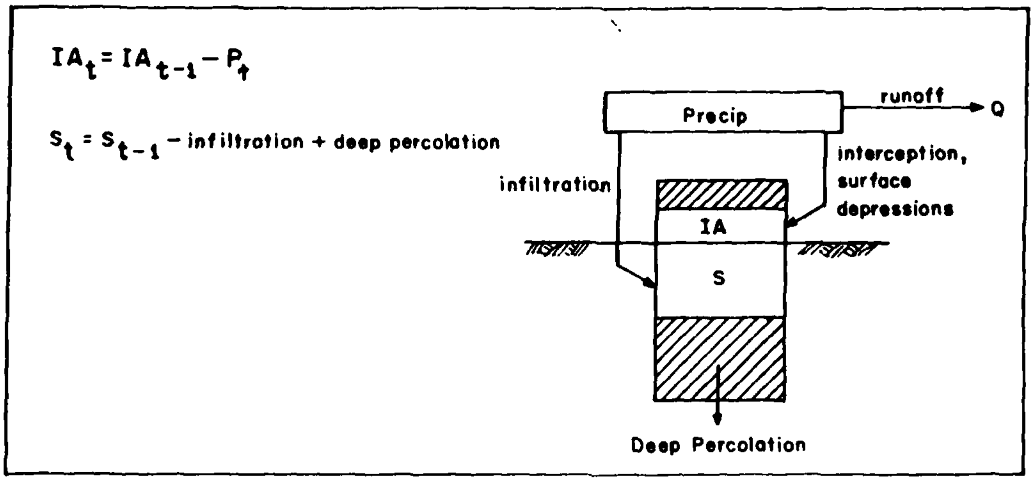


Figure 3

Moisture Accounting During Precipitation

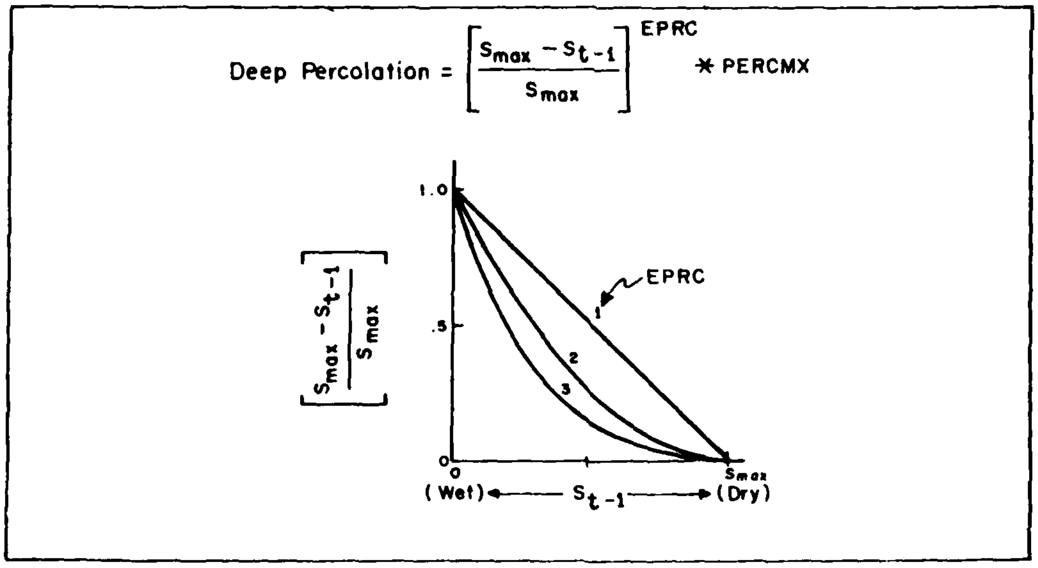


Figure 4

Deep Percolation Equation

Soil Moisture Accounting During Dry Periods

Initial abstraction storage recovers during dry periods through evapotranspiration to the atmosphere and percolation to the soil moisture zone. Evapotranspiration is removed at the potential rate (PET). Average daily values of pan evaporation (provided by the user as input) are considered equivalent to PET. Percolation of water from IA to S occurs at the maximum rate (RATEIN) modified by the relative amount of moisture present in the soil. The percolation equation is graphed in Figure 5.

$$\text{PERCOLATION} = \left[\frac{S_{t-1}}{S_{max}}\right] * \text{RATEIN}$$

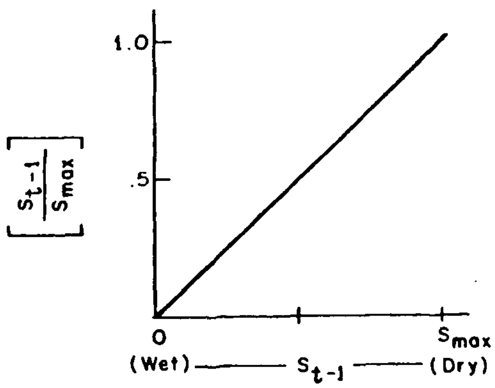


Figure 5

Percolation Equation

Change in soil moisture capacity (S) during dry periods is the result of (1) percolation from IA, (2) deep percolation, and (3) evapotranspiration. Percolation, as described above, adds water to soil moisture storage and thus decreases S. The deep percolation function is the same as was previously described for the water balance during a storm event. The evapotranspiration (ET) function is similar to the deep percolation function; both contain the relative soil moisture ratio raised to an exponent (Figure 4), but the ET formula has an additional constant term (0.7).

$$ET = (0.7) * \left[\left(\frac{S_{max} - S_{t-1}}{S_{max}} \right)^{EERC} \right] * PET$$

Soil moisture accounting for IA and S during dry periods is illustrated in Figure 6.

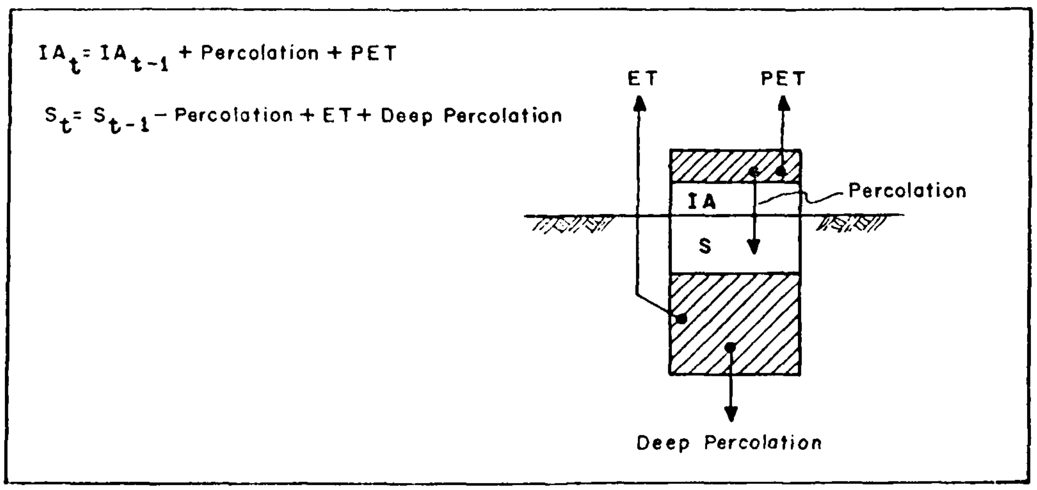
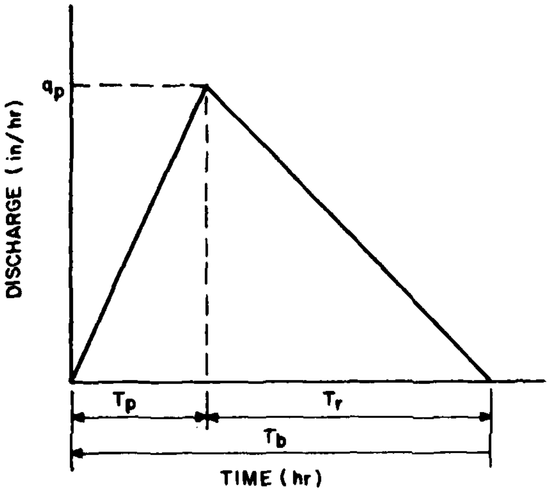


Figure 6

Moisture Accounting During Dry Periods

SCS Triangular Unit Hydrograph

Runoff transformation (from rainfall excess to subbasin runoff hydrograph) can be modeled by STORM using the SCS triangular unit hydrograph.



q_p = peak flow

T_p = time to peak

T_r = time of recession

T_b = time of base = T_p+T_r

Q = total volume

Peak Flow Rate Equation

$$Q = \frac{q_p T_p}{2} + \frac{q_p T_r}{2} = \frac{q_p}{2}(T_p+T_r)$$

$$q_p = \frac{2Q}{T_p+T_r} = \frac{2Q}{T_p(1 + T_r/T_p)}$$

let $K = \frac{2}{(1 + T_r/T_p)}$, then $q_p = \frac{KQ}{T_p}$ $\left\{ \begin{array}{l} q_p \text{ (in/hr)} \\ Q \text{ (in)} \\ T_p \text{ (hr)} \end{array} \right.$

or $q_p = 1.00833 \frac{KAQ}{T_p}$ $\left\{ \begin{array}{l} q_p \text{ (cfs)} \\ A \text{ (acres)} \end{array} \right.$

Unit Hydrograph Parameters

Ratio of time of recession to time to peak (T_r/T_p) and subbasin time of concentration (T_c) are the two unit hydrograph parameters that must be provided by the user to STORM.

Time of concentration (T_c) is defined as the time it takes runoff to travel from the hydraulically most distant part of the watershed to the point of reference. Lag (L) is the time from the center of mass of rainfall excess to the peak rate of runoff. T_c and L are related by an empirical equation.

$$L = 0.6\ T_c$$

Time to peak (T_p) and lag (L) are related by their respective definitions.

$$T_p = 1/2\ \Delta t + L$$

where Δt = time interval of unit excess rainfall (always 1 hour in STORM).

Substituting, this expression becomes

$$T_p = 0.5 + 0.6\ T_c$$

By specifying T_c (which defines T_p) and the ratio T_r/T_p (which determines K), and knowing the subbasin area (A) and unit hydrograph volume (Q = 1 inch), the peak discharge and shape of the unit hydrograph is set.

Although the parameters define a triangular unit hydrograph, STORM, working with a fixed 1-hour time period, computes the volume under the unit hydrograph in each time interval and does not deal with the actual ordinates of the unit graph. The sequence of 1 hour unit hydrograph volumes is then applied to the rainfall excess to determine the runoff volume hydrograph. An example is given below to demonstrate the unit hydrograph computations.

Example

Input to STORM: T_c = 20 min (0.33 hrs)

$T_r/T_p = 2.43$

$$T_p = 0.5 + 0.6\ T_c = 0.70 \text{ hrs}$$

$$T_r = (2.43)(0.70) = 1.68 \text{ hrs}$$

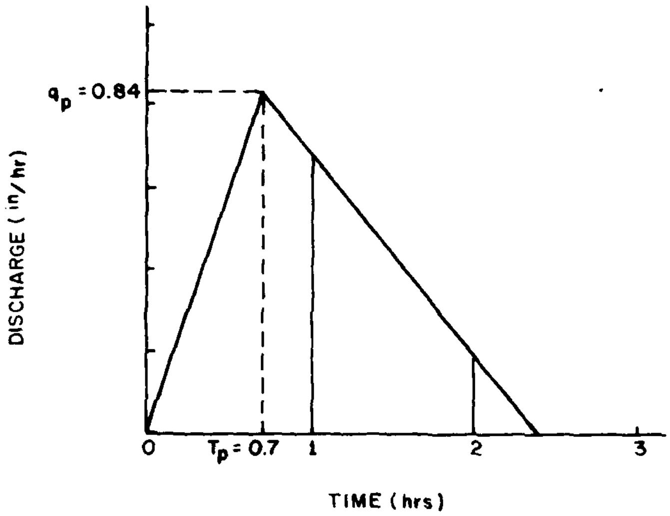
$$T_b = T_p + T_r = 2.38 \text{ hrs}$$

$$q_p = \frac{KQ}{T_p} \qquad K = \frac{2}{1 + T_r/T_p} = 0.59$$

$$Q = 1 \text{ in}$$

$$q_p = \frac{(0.59)(1)}{(0.70)} = 0.84 \text{ in/hr}$$

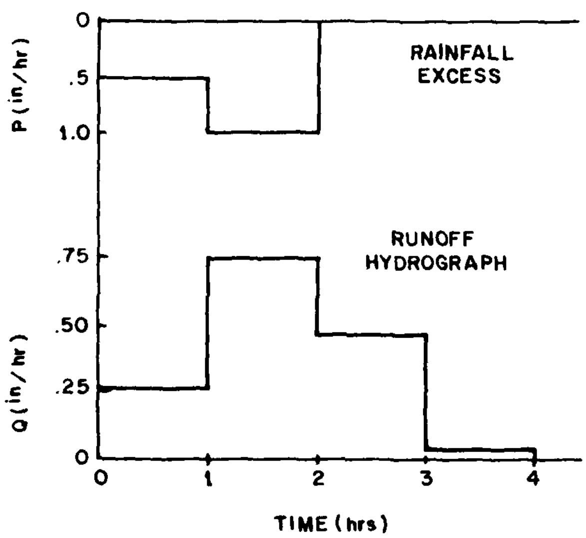
Unit Hydrograph



Volume Under Unit Graph

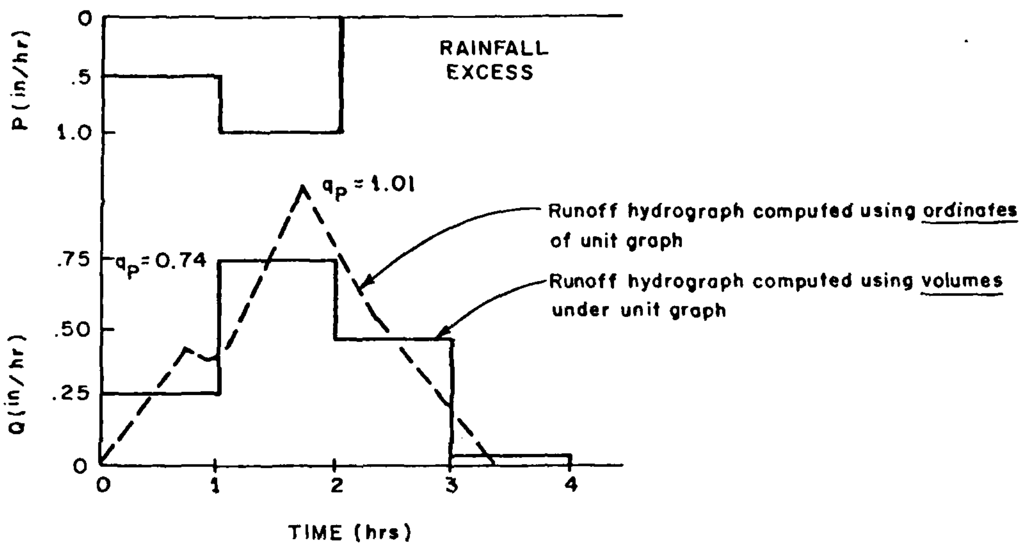
Hour	Volume
1	0.52
2	0.44
3	0.44
	1.00 inches

Computed Runoff Hydrograph



Hr.	Runoff Volume	
1	(.5)(.52)	= .26
2	(.5)(.44)+(1.0)(.52)	= .74
3	(.5)(.04)+(1.0)(.44)	= .46
4	(1.0)(.04)	= .04
		1.50 in

If instead of using volumes under the unit hydrograph in 1-hour intervals, STORM were able to compute (which it cannot) ordinates of the unit graph and apply them to the excess rainfall, the runoff hydrograph would be as shown below.



The difference in peaks between the ordinate derived and volume derived runoff hydrographs, 1.01 in/hr vs. 0.74 in/hr, demonstrates the reduction in peak discharge that can be expected from the way STORM applies the SCS triangular unit hydrograph.

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