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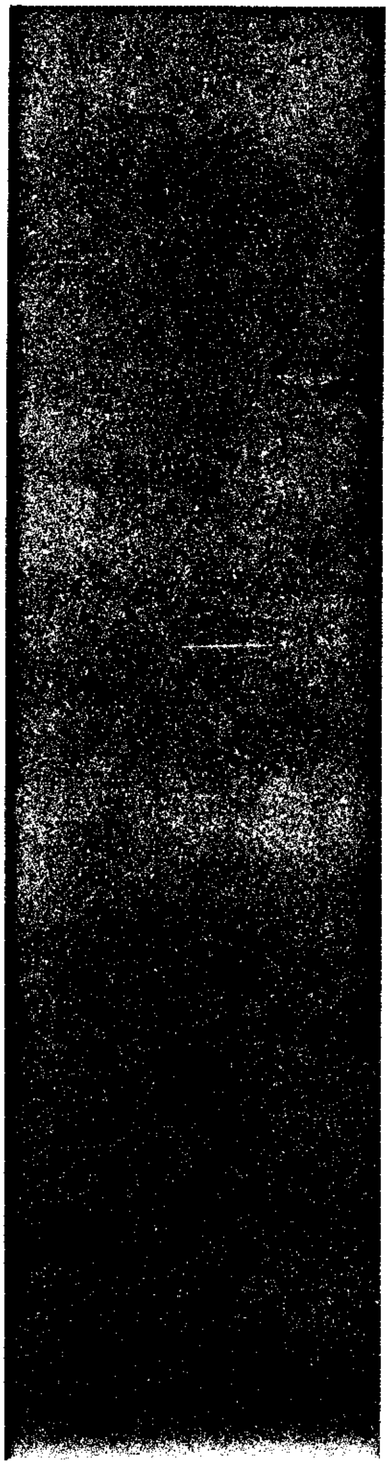

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A MODIFIED S.C.S. RUNOFF HYDROGRAPH METHOD

by

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Abstract. The well-known S.C.S. runoff hydrograph approach is modified for use in county jurisdictional flood control design criteria. Four modifications of the S.C.S. hydrograph approach are included: (1) incorporation of local precipitation-depth-frequency data into the S.C.S. 24-hour storm pattern; (2) incorporation of depth-area adjustment factors to modify point precipitation values for areal affects; (3) use of a maximum loss rate rather than the S.C.S. incremental loss rate; (4) use of a low loss rate such that the runoff hydrograph total volume approximately equals the S.C.S. 24-hour storm runoff volume.

The resulting modified S.C.S. 24-hour storm pattern was found to better meet the objectives of a design critical storm pattern than using a storm pattern of record. Namely, stormflow facilities would be subjected to precipitation-depths of the desired return frequency and the stormflow peak runoff would be based upon a maximum loss rate representing a near saturated soil infiltration rate rather than the current S.C.S. incremental loss rate.

The modified S.C.S. runoff hydrograph model is straightforward to use and is easily programmable on currently available microcomputers.

Introduction

Associated with every subdivision of land and subsequent urbanization is the need to predict storm runoff quantities such as peak flow rates and runoff volumes. With this information, the subdivision can be planned to safely accomodate flood flows through the subdivision such that individual property holdings are protected from damage resulting with a flood flow of a specified return frequency. In order to coordinate such hydrologic planning, municipal agencies generally develop drainage study criteria which standardizes procedures and methods to be used by engineers in the prediction of flood flow quantities. These standards usually incorporate a methodology for computing peak runoff rates from small watersheds (e.g., the Rational Method), and a runoff hydrograph methodology for use in studies of larger watersheds (e.g., larger than one square mile) and watershed systems which require the use of hydrographs to test the system with an anticipated time distribution of runoff volume.

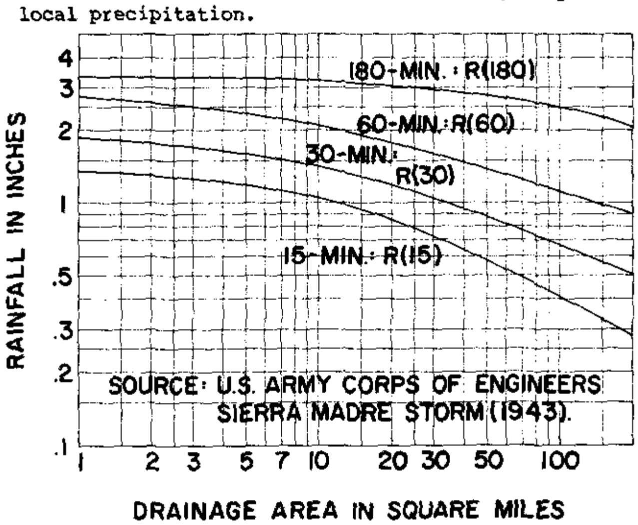
Development of the drainage criteria is usually accomplished at the county government agency level. Generally, this agency (e.g., flood control department) is also charged with review and coordination of flood control engineering from both the private and public sectors. The flood control standards are published in the form of a Hydrology Manual which is usually adopted county-wide for use in the planning of drainage facilities within city as well as county jurisdictional limits. Some major requirements of the hydrology methods are uniformity of results and the applicability to various watershed configurations and conditions. Due to the principal goal of providing for public protection, the hydrology methods must necessarily produce results which provide a high level of confidence in flood protection for the current public needs as well as the anticipated future needs as the watershed condition changes due to development.

The major objective of this paper is to report on the current results of two Southern California county flood control agencies (Counties of San Bernardino, and Orange) in the evaluation and subsequent modification of the well known S.C.S. (U.S. Soil Conservation Service) runoff hydrograph procedure.[27] The modified S.C.S. method is found to accommodate several of the concerns which are generally associated with applying a rainfall based hydrology method (such as the S.C.S. hydrograph method) in estimating floodflow characteristics for ungaged watersheds. The main concerns are to address the selection of a design rainfall storm pattern of a specific return frequency, the manner of computing effective rainfall, and the utilization of a unit hydrograph in estimating runoff quantities. Although the synthetic unit hydrograph procedure has several theoretical shortcomings, [3,7,10] the method is still widely used throughout the world and is particularly used throughout Southern California. The modified S.C.S. approach includes the S.C.S. 24-hour critical storm pattern modified to represent local peak rainfall intensities of the desired return frequency and adjusted for areal affects by precipitation depth-area reduction factors. Additionally, the S.C.S. single-unit hydrograph is expanded to include four classes of unit hydrographs developed by the Los Angeles District of the U.S. Army Corps of Engineers for watersheds classified as Valley, Foothill, Mountain, or Desert. Finally, the S.C.S. curve number (CN) approach for estimating watershed losses is modified so that the resulting 24-hour storm runoff hydrograph volume approximately equals the S.C.S.

CN predicted 24-hour volume with a maximum soil loss rate (ϕ-index) utilized during the peak design storm intensities.

Critical Storm Pattern

The use of a critical (or design) storm pattern for testing watershed response is well known and several approaches have been advanced.[11,15,16,25,26,27] There are major advantages and disadvantages in a design storm pattern approach.[30] Some major advantages of a critical storm pattern approach is its simplicity and uniformity of results as well as the concept's wide use in rainfall-based hydrology methods. In the Southern California watersheds, the U.S. Army Corps of Engineers (U.S.A.C.E.) utilize a critical storm of record such as the Sierra Madre Thunderstorm of *1943 (Fig. 1)*. This type of approach, however, was found to result in peak storm rainfall intensities that exceeded the return frequency of local precipitation.



HYETOGRAPH COMPUTATION

UNIT PERIOD	AMOUNT
1	.07 (R(180)-R(60))
2	.05 (R(180)-R(60))
3	.11 (R(180)-R(60))
4	.05 (R(180)-R(60))
5	.20 (R(180)-R(60))
6	.22 (R(180)-R(60))
7	.14 (R(180)-R(60))
8	.16 (R(180)-R(60))
9	.48 (R(60)-R(30))
10	.52 (R(60)-R(30))
11	1.00 (R(15))
12	1.00 (R(30)-R(15))

UNIT PERIOD = 15 MINUTES

FIGURE 1. LOCAL PROJECT STORM DEPTH-AREA-DURATION CURVES.

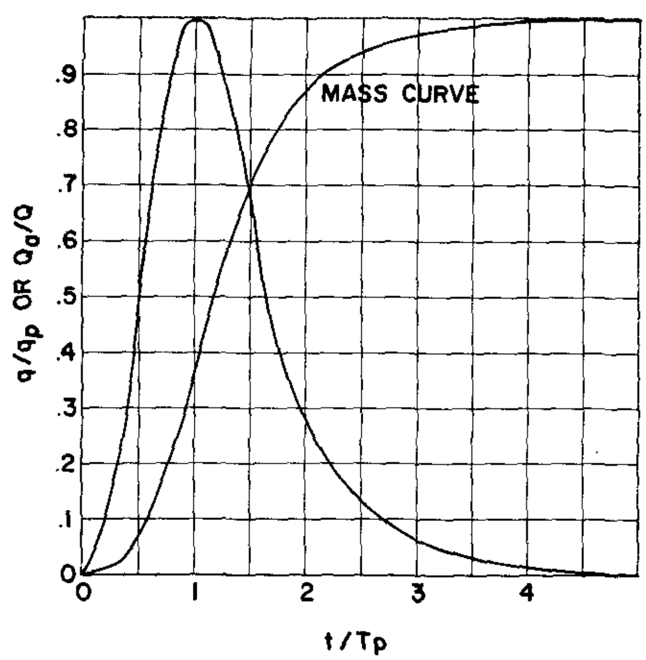
It can generally be assumed for design study purposes that the critical duration of rainfall is approximately the time of concentration (Tc) to the study facility. Using a storm pattern of record which results in a precipitation depth (for duration of Tc) exceeding the desired return frequency could result in an overly conservative design. Likewise, the storm pattern may subject the study point to a rainfall depth of less than the desired return frequency for a duration equal to the Tc.

Consequently, the historic storm pattern needed modification in order to subject the watershed to *the desired return frequency precipitation* depth for a duration equal to the Tc. Using the historic critical storm pattern, the peak intensities are identified and reduced (where necessary) to equal the intensities associated with the desired return frequency. The excess rainfall is then distributed to the neighboring rainfall periods and the comparisons repeated until the entire storm pattern was scanned. The resulting storm pattern is a composite hyetograph composed of nested peak rainfall depths (for each major interior duration) analogous to the well known S.C.S. 24-hour storm pattern.

The S.C.S 24-hour storm patterns are based on the generalized rainfall depth-duration-frequency relationships published by the U.S. Weather Service. The two S.C.S. storm patterns (Type I and Type II) are composite hyetographs composed of nested peak rainfall depths as averaged over the entire United States. Consequently, modifying the S.C.S. storm pattern to represent local rainfall depth-duration-frequency data will result in a storm pattern which subjects a watershed study point to a rainfall depth corresponding to a duration equal to the Tc.

Unit-Hydrograph

The time distribution of runoff accumulation at the point of concentration is approximated for a unit period by the well known unit-hydrograph convolution approach. The S.C.S. runoff hydrograph method uses a single unit-hydrograph (Fig. 2) to be used for all watersheds. The Los Angeles U.S.A.C.E. determined four unit-



q = DISCHARGE AT TIME t
q_p = PEAK DISCHARGE.
Q_a = ACCUMULATED VOLUME AT TIME t.
Q = TOTAL VOLUME.
t = A SELECTED TIME.
T = TIME FROM BEGINNING OF RISE TO THE PEAK.

FIGURE 2. S.C.S. DIMENSIONLESS UNIT HYDROGRAPH AND MASS CURVE.

TERMINOLOGY	
L =	LENGTH OF LONGEST WATERCOURSE.
L_{ca} =	LENGTH ALONG LONGEST WATERCOURSE, MEASURED UPSTREAM TO POINT OPPOSITE CENTER OF AREA.
S =	OVER-ALL SLOPE OF LONGEST WATERCOURSE BETWEEN HEADWATER AND COLLECTION POINT.
LAG =	ELAPSED TIME FROM BEGINNING OF UNIT PRECIPITATION TO INSTANT THAT SUMMATION HYDROGRAPH REACHES 50% OF ULTIMATE DISCHARGE.
$\bar{n}$ =	VISUALLY ESTIMATED MEAN OF THE n (MANNING'S FORMULA) VALUES OF ALL THE CHANNELS WITHIN AN AREA.

GUIDE FOR ESTIMATING BASIN FACTOR($\bar{n}$)

$\bar{n}$=0.050: DRAINAGE AREA IS QUITE RUGGED, WITH SHARP RIDGES AND NARROW, STEEP CANYONS THROUGH WHICH WATERCOURSES MEANDER AROUND SHARP BENDS, OVER LARGE BOULDERS, AND CONSIDERABLE DEBRIS OBSTRUCTION. THE GROUND COVER, EXCLUDING SMALL AREAS OF ROCK OUTCROPS, INCLUDES MANY TREES AND CONSIDERABLE UNDERBRUSH, NO DRAINAGE IMPROVEMENTS EXIST IN THE AREA.

$\bar{n}$=0.030: DRAINAGE AREA IS GENERALLY ROLLING, WITH ROUNDED RIDGES AND MODERATE SIDE SLOPES. WATERCOURSES MEANDER IN FAIRLY STRAIGHT, UNIMPROVED CHANNELS WITH SOME BOULDERS AND LODGED DEBRIS. GROUND COVER INCLUDES SCATTERED BRUSH AND GRASSES. NO DRAINAGE IMPROVEMENTS EXIST IN THE AREA.

$\bar{n}$=0.015: DRAINAGE AREA HAS FAIRLY UNIFORM, GENTLE SLOPES WITH MOST WATERCOURSES EITHER IMPROVED OR ALONG PAVED STREETS. GROUND COVER CONSISTS OF SOME GRASSES WITH APPRECIABLE AREAS DEVELOPED TO THE EXTENT THAT A LARGE PERCENTAGE OF THE AREA IS IMPERVIOUS.

REFERENCE: BIBLIOGRAPHY ITEM NO. 26.

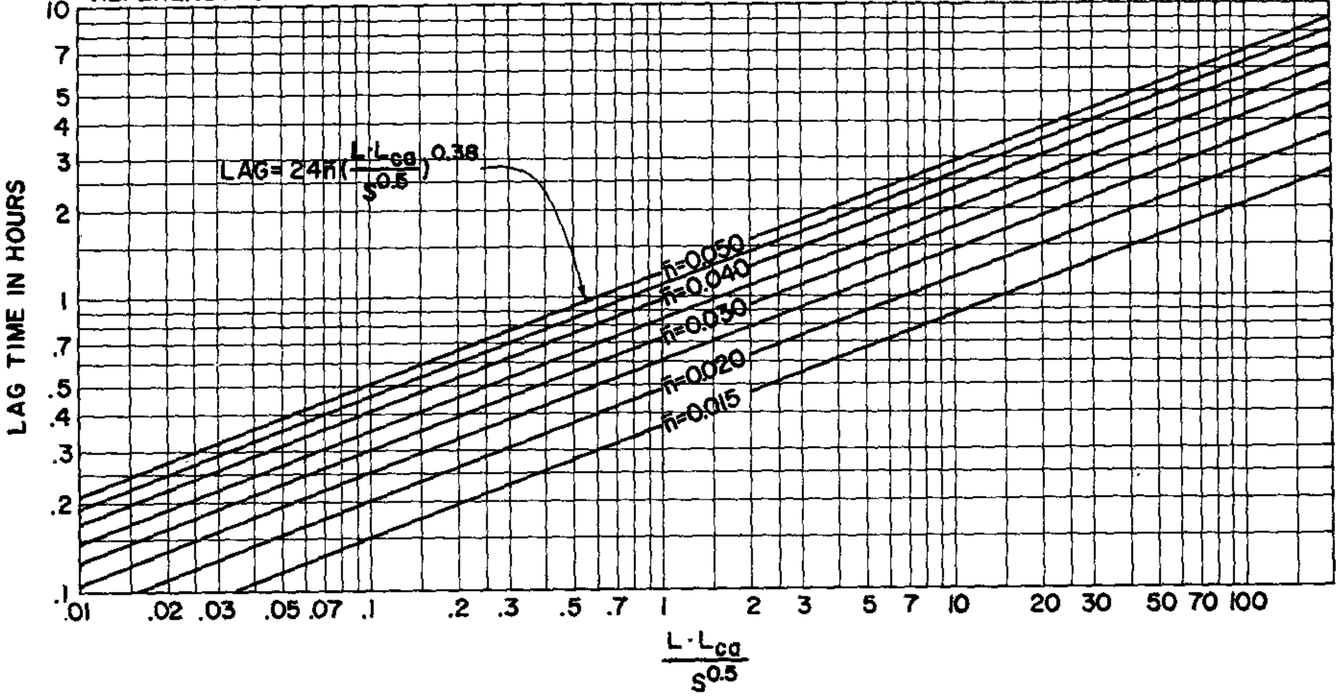


FIGURE 3. LAG RELATIONSHIPS FOR SOUTHERN CALIFORNIA.

hydrograph distributions based on the general type of watershed basin (e.g., Valley, Foothill, Mountain, or Desert). These curves were determined by duplicating runoff hydrographs from major floodflows in Southern California. Consequently, the four local unit-hydrographs are substituted into the convolution procedure in order to better represent local floodflow accumulation patterns. The unit hydrographs are functions of the usual watershed Lag function which, in turn, is a function of watershed geometry and a characteristic basin $\bar{n}$ factor (Fig. 3).

Rainfall Abstractions

The S.C.S. method utilizes the curve number (C-- approach[27] which relates 24-hour storm r f (Q) to 24-hour storm rainfall (P). Various ta..es have been prepared (Table 1) which provide CN values for various development types and cover complexes. The S.C.S. incremental runoff computation has been criticized by several authors[6,12,13], for resulting infiltration rates being a function of rainfall intensity during the variable intensity critical storm pattern. For high intensity rainfall, the S.C.S. loss rate can far exceed the more commonly accepted loss rates for an urbanized soil complex.

The S.C.S. method can be modified to include a maximum loss rate (ϕ-index) during the peak intensity rainfalls by utilizing a simple loss rate function, f, defined by

$$f = f^*(I), \; f^* \leq f_m$$

where f_m is the defined maximum loss rate (usually the saturated infiltration rate for the severe design storm pattern) and $f^*(I) = kI$ where I is the rainfall intensity and k is a constant chosen

TABLE 1. Runoff Curve Numbers for Hydrologic Soil-Cover Complexes.
(AMC II, Ia = 0.2 S)

Land Use Description/Treatment/Hydrologic Condition			Hydrologic Soil Group			
Residential:1/			A	B	C	D
Average lot size	Average % Impervious2/					
1/8 acre or less	65		77	85	90	92
1/4 acre	38		61	75	83	87
1/3 acre	30		57	72	81	86
1/2 acre	25		54	70	80	85
1 acre	20		51	68	79	84
Paved parking lots, roofs, driveways, etc.3/			98	98	98	98
Streets and roads:						
paved with curbs and storm sewers3/			98	98	98	98
gravel			76	85	89	91
dirt			72	82	87	89
Commercial and business areas (85% impervious)			89	92	94	95
Industrial districts (72% impervious)			81	88	91	93
Open Spaces, lawns, parks, golf courses, cemeteries, etc.						
good condition: grass cover on 75% or more of the area			39	61	74	80
fair condition: grass cover on 50% to 75% of the area			49	69	79	84
Fallow	Straight row	---	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured & terraced	Poor	66	74	80	82
	Contoured & terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured & terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded	Straight row	Poor	66	77	85	89
legumes4/	Straight row	Good	58	72	81	85
or	Contoured	Poor	64	75	83	85
rotation	Contoured	Good	55	69	78	83
meadow	Contoured & terraced	Poor	63	73	80	83
	Contoured & terraced	Good	51	67	76	80
Pasture		Poor	68	79	86	89
or range		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods or		Poor	45	66	77	83
Forest Land		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		---	59	74	82	86

1/Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

2/The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

3/In some warmer climates of the country a curve number of 95 may be used.

4/Close-drilled or broadcast.

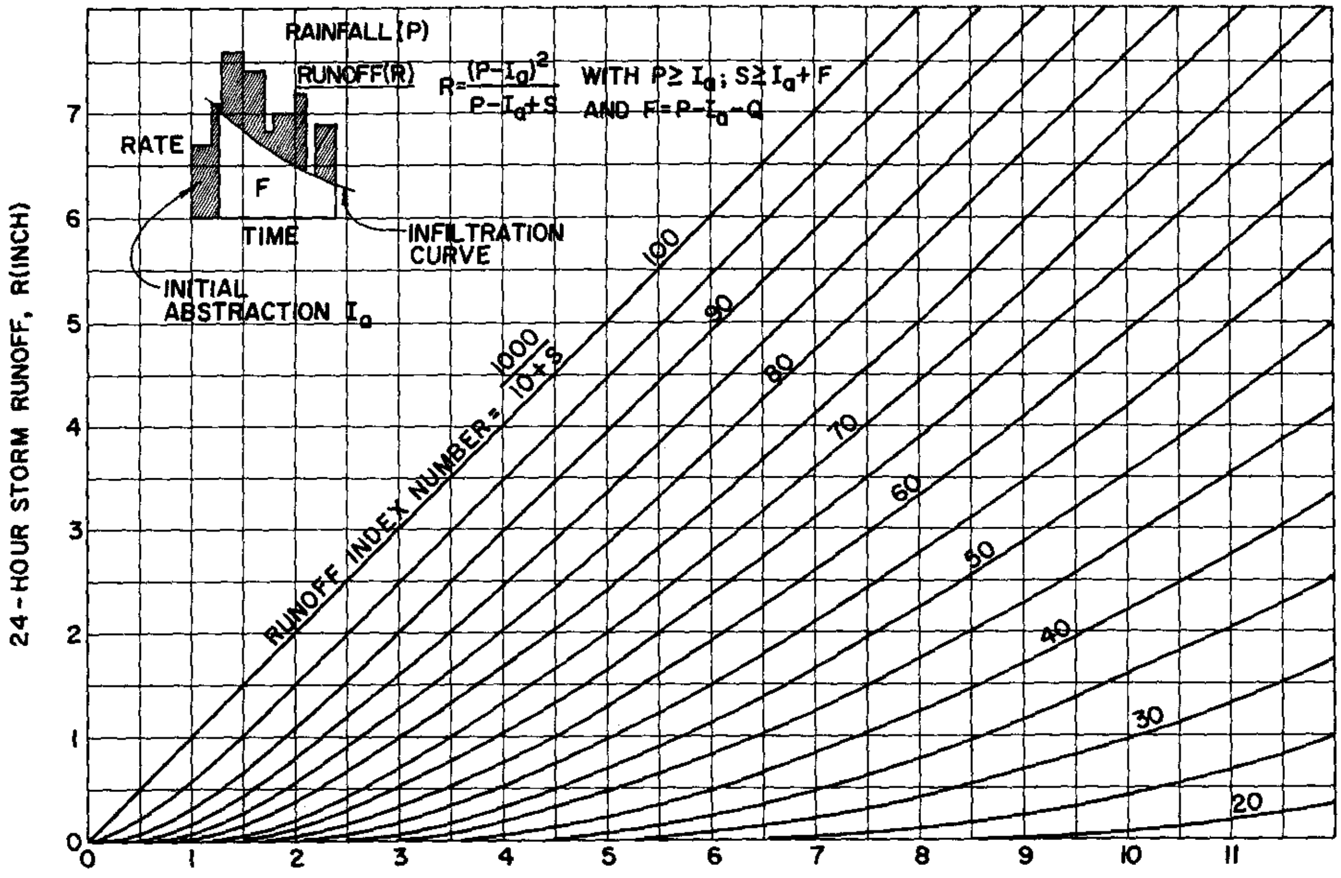


FIGURE 4. S.C.S. 24-HOUR STORM RAINFALL-RUNOFF RELATIONSHIPS.

such that the total runoff hydrograph volume equals the predicted S.C.S. 24-hour storm runoff volume (Fig. 4). The resulting design storm runoff hydrograph has the property that the single peak flow-rate is based on critical duration precipitation and a critical storm saturated loss rate, and the runoff volume equals the S.C.S. predicted 24-hour storm runoff volume. Consequently, a design storm time distribution of runoff volume is generated for various design applications.

The S.C.S. initial abstraction term (Ia) is also subject to criticism and has been recommended to be 1/4 to 1/2 of the S.C.S. recommended value.[5,9] In design storm considerations, it is considered that general rainfall during the previous 5 days satisfies this Ia term and, consequently, Ia is set to zero for study purposes.

Analysis of raingage and stream gage data for a heavily urbanized watershed in Orange County supports this approach. As shown in Fig. 5, the Santa Ana-Delhi Channel drainage area produced 60% yield from a 5-year frequency, 2-hour storm with AMC-I soil moisture on a 17.6 square mile watershed that is 90% developed. The development is approximately 60% single-family houses, 20% apartments ı 20% commercial with minor amounts in park, ıool and agriculture. Virtually all streets have curb and gutter and the storm drain network is fairly dense.

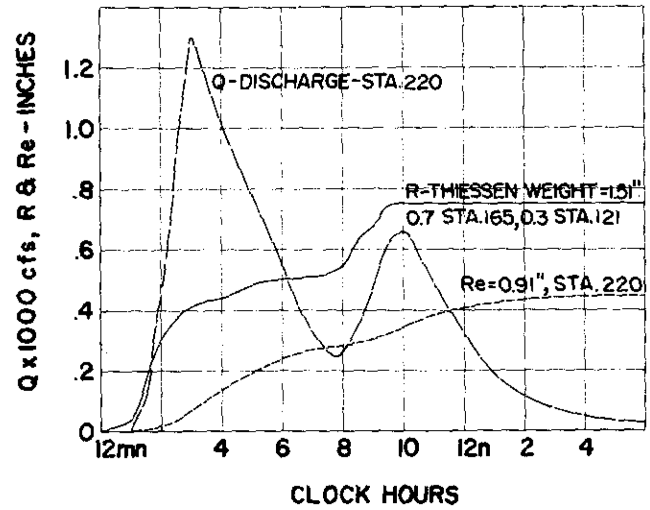


FIGURE 5. RAINFALL (R), DISCHARGE (Q,Re), SANTA ANA-DELHI CHANNEL, NOV. 30, 1982.

Depth-Area Relationships

The resulting 24-hour storm pattern can be directly applied towards estimating peak flow rates and runoff volumes of small watersheds where rainfall-runoff gauge records are inadequate for the development of statistical interpretations. As the watershed areas increases, however, studies indicate that the average areal point rainfall values used in the design storm pattern should be reduced. For example, the NOAA Atlas 2[21] includes point rainfall depth-area reduction relationships (Fig. 6) for 30-minute, 1-, 3-, 6-, and 24-hour average areal point rainfall values. Such depth-area curves can be used to estimate the reduction in average areal point rainfall values to account for the effects of watershed areal extent. The NOAA Atlas 2 depth-area curves, however, are an average of rainfall patterns throughout the United States and may be subject to modification due to local precipitation tendencies. In regions where rainfall data is inadequate or storm characteristics preclude reliable interpretation of rainfall intensity data to develop depth-area relationships, the NOAA Atlas 2 may be considered for study purposes.

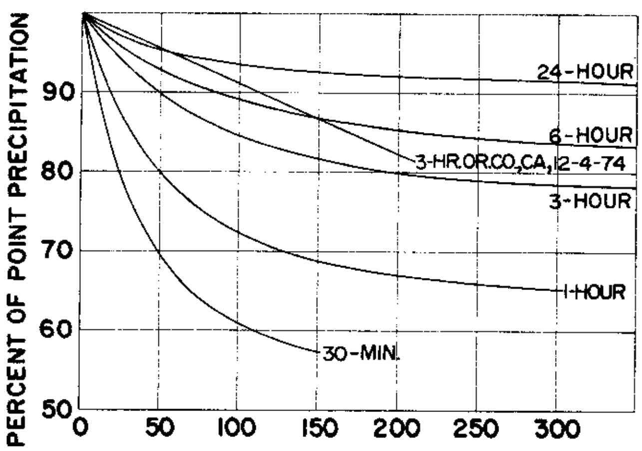


FIGURE 6. NOAA DEPTH-AREA-DURATION REDUCTION AND ORANGE CO.,CALIF.,STORM DEC. 4,1974.

The NOAA depth-area curves are especially useful in Orange County, California, which has characteristics typical of the Southern California coastal region, i.e., a relatively narrow, flat, coastal plain adjacent to steep mountain ridges typically rising 5,000 to 10,000 feet within 10 to 50 miles. Consequently, isohyetal patterns rarely have the intense centers required for depth-area-duration analysis that are not complicated by severe orographic effects and the absence of data over the nearby ocean. The need in Orange County is for methods applicable to catchments of 1 to 100 square miles in a coastal plain area. The NOAA curves permit appropriate reductions in point rainfall despite the inadequacy of local reduction values. An example of a depth-area analysis of a single 3-hour storm in Orange County (Dec. 4, 1974, approximately 100-year point depth) is shown on the NOAA depth-area curves in Figure 6.

Design Storm Pattern

The depth-area curves are used to reduce the average areal watershed point rainfall values for the corresponding durations. Since the curves do ɔt provide reduction factors for all durations, .n assumed relationship may be used to expand the depth-area factors. The approach used in this study is to plot the reduced point rainfall values for the 30-minute, 1-, 2-, 6-, and 24-hour dura-

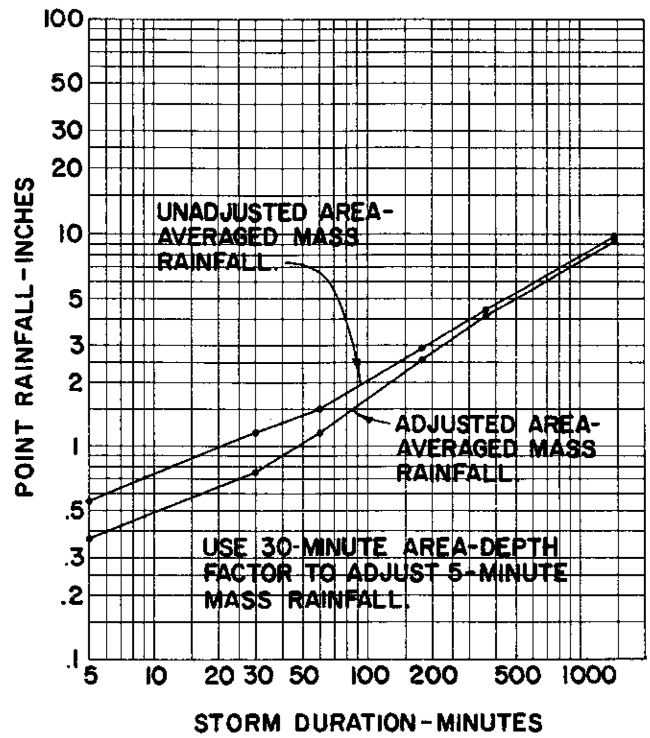


FIGURE 7. AREA-AVERAGED MASS RAINFALL PLOTTING SHEETS.

tions on log-log paper and assume straight-line interpolation (Fig. 7). Other relationships may be assumed, but a log-log plot is convenient in that usually both the adjusted and unadjusted point rainfall values plot as smooth curves which are easy to manipulate arithmetically. Unit rainfall values are determined from the resulting mass rainfall plot by successive subtractions of design storm mass-rainfall values, each offset by a selected unit period (e.g., 5 minutes, 10 minutes, etc.). The sequence of decreasing unit rainfall values are then rearranged to form a composite hyetograph analogous to the single peak S.C.S. 24-hour storm pattern. The resulting design storm pattern (1) provides a critical duration (Tc) for the watershed, (2) does not exceed any maximum rainfall intensity associated with the desired return frequency (such as can occur when using storm patterns of record), (3) provides for a critical rainfall depth as adjusted for the areal effects of the watershed size, (4) can be used for both small and large watersheds such as are studied by local city or county governmental agencies, (5) provides an easy to use uniform critical storm pattern for both peak flow rate and runoff volume studies, (6) is easily extendable to multiple day storms (by extending the mass rainfall log-log plot or using local rain-gage data).

The concept of a design storm composed of nested durations all with the same (say 100-year) return frequency depths has been criticized as being an excessively conservative storm pattern with an extremely low probability of occurence. On March 1, 1983 a storm struck Orange County, California where two recording rain gages five miles apart received the following depths that equalled or exceeded the 100-year return frequency for each station.

Table 2. March 1, 1983 Storm, Orange County, California.

dur. (min.)	Costa Mesa (in.)	Santa Ana (in.)
15	0.87	
30	1.38	1.12
60	1.81	1.72
120	2.24	2.25
180	2.76	2.65
360	3.60	4.06

The synthesis of local rain gage data which recorded this severe storm event indicates that the proposed design storm procedures will test a watershed against the demands of such a severe storm, but will not exceed the locally accepted reasonable engineering standards for public protection.

Conclusions

A modified S.C.S. runoff hydrograph approach is presented which was developed during the course of revising two Southern California County Flood Control agency hydrology manuals. The procedure modifies the well known S.C.S. method in order to accomodate criticisms that have surfaced in the recent literature. The modifications are straightforward to use in hand calculations and are readily programmable on microcomputers.[14] The procedure results in a runoff hydrograph that includes a 24-hour storm single peak time distribution of runoff which equals the S.C.S. predicted 24-hour storm runoff volume, and yet has a maximum peak infiltration rate analogous to the ϕ-index approach. Additionally, the S.C.S. storm pattern is modified to fit local rainfall data and provides for depth-area adjustment.

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