TECHNICAL REPORT

MODIFICATIONS ON THE "SOIL CONSERVATION SERVICE METHOD" FOR THE ESTIMATION OF DESIGN FLOODS ON VERY SMALL CATCHMENTS IN THE ARID WESTERN PART OF THE UNITED STATES OF AMERICA

by

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ABSTRACT

Modifications are necessary on the so-called "Soil Conservation Method" for the estimation of runoff rates on ungaged catchments to make it applicable to very small catchments in the arid western part of the United States of America. First, a modification was made in the equation for peak rates of runoff to bring the equation in line with sound theoretical analysis. Second, it was shown that the rainfall occurring in a storm with 30-minute duration is more applicable to the region under consideration than the 6-hour storms used in the unmodified Soil Conservation Method. Third, an expression was found for the optimum storm duration suitable to calculations of peak rates of runoff on any small catchment. This optimum duration was found to be a function of the time-of-concentration of the catchment, the runoff curve number applicable to the catchment and the rainfall intensity during the storm. By means of the electronic digital computer, 1536 solutions of combinations of the three independent variables enabled the derivation of a simple approximate equation for the optimum storm duration in terms of only the time of concentration. This equation was shown to give results for the optimum storm duration with acceptable accuracy.

These modifications were found to be an improvement on the unmodified Soil Conservation Service Method when results were compared with historical data on four small catchments in the arid region of the Western part of the United States. In these comparisons the unmodified Soil Conservation Method, the Modified Soil Conservation Method described in this report, and a new generalized modification by the United States Department of Agriculture, Soil Conservation Service, on the Soil Conservation Method

were used. The Modified Soil Conservation Method of this report seems to be best suitable to the region under consideration.

Finally, the procedure to be followed when the Modified Soil Conservation Method of this report is used, is described together with the design charts necessary for the calculations.

ACKNOWLEDGMENTS

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LIST OF SYMBOLS

Symbol	Definition	Units
A	Area of catchment	sq. miles
C	Runoff curve number	
D	Storm duration	hours
D_o	Optimum storm duration	hours
d	Potential maximum retention	inches
H	A constant which equals $\frac{T_r}{T_p}$	
H_B	Total fall over the catchment	feet
I	Rainfall intensity	in. per hour
I_a	Initial abstraction	inches
L	Lag time	hours
L_B	Length of the longest drainage channel	miles
P	Total storm rainfall	inches
P_{30}	Maximum rainfall over 30 consecutive minutes in a storm	inches
P_D	Maximum rainfall amount over D consecutive hours in a storm	inches
Q	Total volume of runoff	inches
q_i	Peak rate of runoff	in. per hour
q_p	Peak rate of runoff	cubic ft. per second
q_u	Unit peak rate of runoff	cubic feet per second per square mile
T_b	Base length of triangular hydrograph	hours
T_c	Time of concentration	hours
T_p	Time to peak in triangular hydrograph	hours
T_r	Recession time in triangular hydrograph	hours
Z	Peak reduction factor	

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I. INTRODUCTION

A noteworthy contribution was made to applied hydrology by the Soil Conservation Service, United States Department of Agriculture, through publishing their method for the estimation of rates of runoff on small ungaged rural catchments, in the National Engineering Handbook[1]. Backed by extensive research on hydrological soil groups[2] and soil cover complexes, this method has become one of the most popular and powerful methods available for the estimation of runoff rates in rural areas[3,4]. However, in a recent study[5] doubt was cast on the applicability of this method to catchments with areas smaller than 40 square miles. On these catchments the Soil Conservation Method consistently underpredicts flood peaks.

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[1]National Engineering Handbook, Section 4, Supplement A, "Hydrology," U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 1957.

[2]National Engineering Handbook, Section 4, Hydrology, Part I-Watershed Planning, U. S. Department of Agriculture, Soil Conservation Service, Chapter 7, August, 1964, pp. 7.3 - 7.5.

[3]Hydrology for Use in Watershed Planning, Bureau of Land Management, United States Department of the Interior, BLM Manual, Release 7-5, May, 1966.

[4]Reich, B. M., "Soil Conservation Service Design Hydrographs," The Civil Engineer in South Africa, Vol. 4, No. 5, 1962, pp. 77-87.

[5]Hiemstra, L. A. V. and B. M. Reich, "Engineering Judgment and Small Area Flood Peaks," Hydrology Paper No. 19, Colorado State University, Fort Collins, Colorado, April, 1967.

Realizing this limitation on the applicability of their method the Soil Conservation Service recently modified the method for application to catchments smaller than 2000 acres[6]. This modification was designed to have general applicability regardless of meteorological or hydrological differences. Even better results can be expected if modifications are made with the objective of applicability to hydrological homogeneous regions. Such modification for the arid western part of the United States of America is the objective of this study.

To avoid confusion, the unmodified Soil Conservation Method will be denoted by the SCS-method, the new modification on the SCS-method by the Soil-Conservation Service will be called the Kent-method after the author of Reference No. 6, and the modified method described in this report will be called the modified SCS-method.

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[6]United States Department of Agriculture, Soil Conservation Service, "A Method for Estimating Volume and Rate of Runoff in Small Watersheds," SCS-TP-149, January 1968.

II. THE SOIL CONSERVATION SERVICE METHOD

An equation expressing the flood peak in terms of the total volume of runoff and other factors can be obtained by approximating hydrograph shapes by triangles. Such triangles were standardized by the Soil Conservation Service, U. S. Department of Agriculture[1], as shown in Fig. 1.

In Fig. 1, the total volume of runoff, or the area of the triangular hydrograph can be denoted by Q and

$$Q = \frac{1}{2}(q_i T_b) \tag{1}$$

in which q_i represents the peak rate of runoff and T_b the base length of the triangle.

The lag, as defined in Fig. 1, has been found[1] from many observations to be

$$L = 0.6\ T_c \tag{2}$$

where T_c represents the time of concentration for the catchment under consideration.

From Eq. (1) and Fig. 1

$$q_i = \frac{2Q}{T_p + T_r}$$

Let

$$T_r = HT_p$$

then

$$q_i = \frac{2Q}{(1+H)T_p} \tag{3}$$

Converting from inches per hour to cfs by introducing drainage area A in square miles and assuming $H = 1.67$, the peak rate of runoff

$$q_p = \frac{484\ AQ}{T_p} = \frac{484\ AQ}{\frac{D}{2} + L} \tag{4}$$

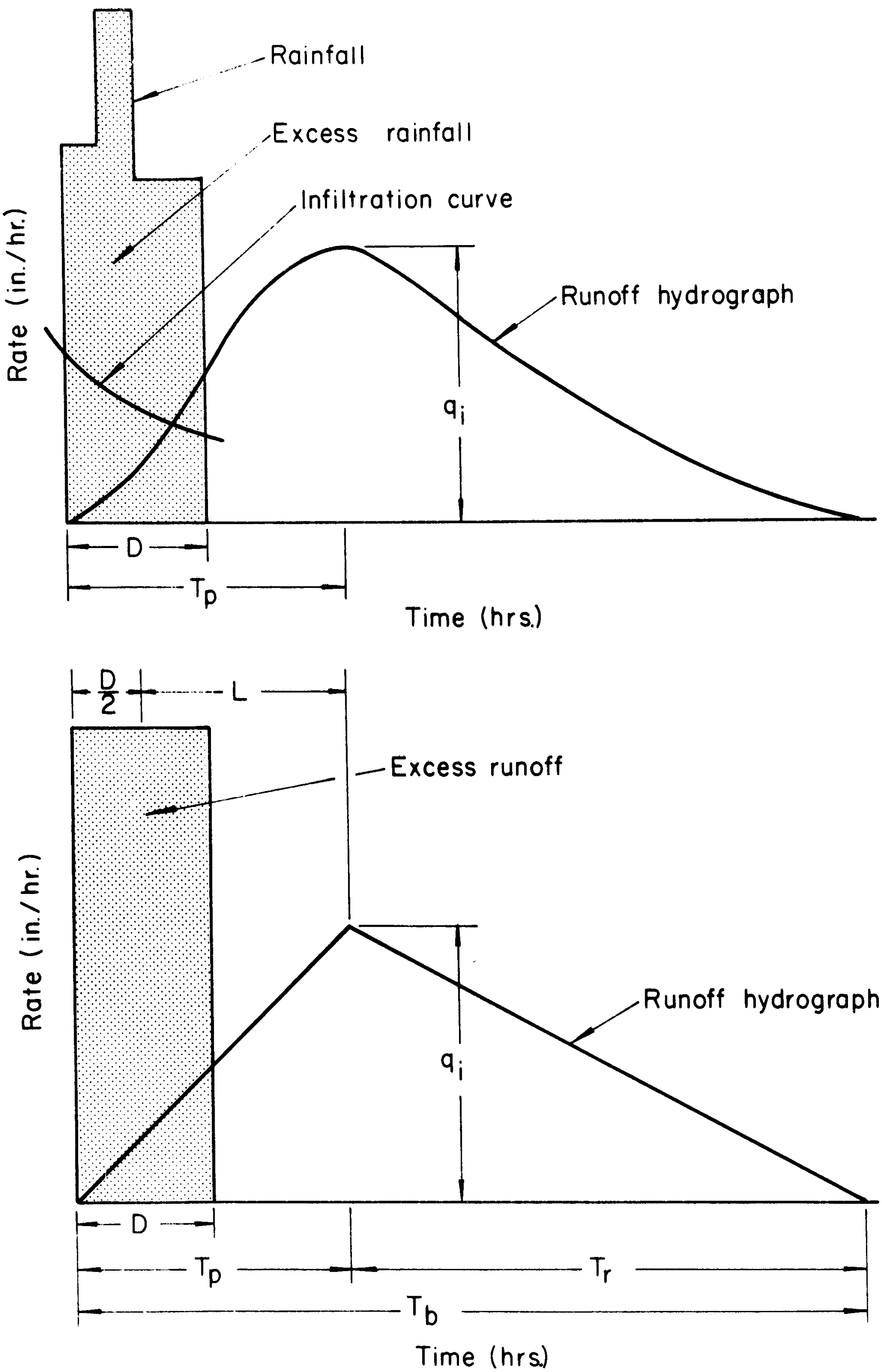

Fig. 1 Development of a triangular hydrograph

and substitution from Eq. (2) for L

$$q_p = \frac{484\ AQ}{\frac{D}{2} + 0.6T_c} \qquad (5)$$

In Eq. (5), A is known, there exist methods to obtain T_c and it remains to find relationships for Q and D in terms of variables which can be measured or estimated.

The Soil Conservation Service developed a relation between the total storm rainfall P and Q in terms of runoff curves for different soil-cover complexes[1]. The relation between P and Q is determined by starting from a certain initial abstraction (I_a), a potential maximum retention (d) and an assumption that the ratio of actual retention ($P-I_a-Q$) to potential maximum retention (d) equals the ratio of actual runoff (Q) to potential maximum runoff ($P-I_a$), or

$$\frac{P-I_a-Q}{d} = \frac{Q}{P-I_a}$$

from which follows

$$Q = \frac{(P-I_a)^2}{(P-I_a)+d} \qquad (6)$$

The initial abstraction I_a is, on the basis of practical experience, set by the SCS as equal to 20% of the maximum retention d. The value of d is related to the runoff curve number according to

$$C = \frac{1000}{10+d} \qquad (7)$$

Substituting $I_a = 0.2d$ into Eq. (6) results in

$$Q = \frac{(P-0.2d)^2}{P+0.8d}$$

and substitution for d from Eq. (7) results in

$$Q = \frac{(PC + 2C-200)^2}{C(PC-8C+800)} \qquad (8)$$

Using this relation between P and Q and with P and C known, it is possible to solve for the peak rate of runoff, using Eq. (5) on any problem catchment.

From historical records on experimental catchments, the relationship shown in Eq. (8) was further verified by the SCS for a variety of soil-cover complexes.

For design floods with fixed return periods, the method was further standardized on a storm duration of six hours.

Standard procedures for the application of the method are fully explained in the manuals of the agencies using this method[1,3].

III. MODIFICATION OF THE EQUATION FOR PEAK RATES OF RUNOFF

A general equation for peak rates of runoff was given by Chow[8] as

$$q_p = \frac{1.008\ ZAQ}{D} \tag{9}$$

where q_p is in inches per hour, and Q in inches. Z represents a "peak reduction factor" that specifies the effective fraction of the total catchment area contributing to the peak rate of runoff for a storm of given duration. Therefore, Z varies between zero and unity. In general, Z isan empirical function of the ratio D/L. This function may be determined either empirically by solving Eq. (9) for a large number of values of Z, using recorded flood data, or directly from the assumptions of unit hydrograph theory, or by a combination of the two methods[9].

If unit hydrograph theory is used, and the lag, L, is assumed constant, then Z must become equal to unity when D becomes equal to 2L. This is because unit hydrograph theory assumes that Z becomes equal to unity when the peak rate of runoff and the end of the storm coincide. If only L is assumed constant, the above restriction does not hold. It also follows that if L is assumed constant and Z does not become equal to unity at D = 2L, then unit hydrograph theory is not assumed. Chow's generalized Z function was based on both unit hydrograph theory and the assumption of constant L. It was specified only graphically, without an equation,and was intended for application mainly within the state of Illinois.

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[8]Chow, Ven T., "Hydrologic Design of Culverts." Journal of the Hydraulics Division, ASCE, Vol. 88, No. HY2, Proc. Paper 3071, March 1962, pp. 39-55.

[9]Merkle, John G., "Discussion of 'Tacitly Maximized Small Watershed Flood Estimates' by Reich and Hiemstra." Journal of the Hydraulics Division, ASCE, Vol. 92, No. HY4, July, 1966, pp. 148-154.

It is possible to get an equation for Z by considering Eqs. (3) and (9)[10]. Equation (3) can be rewritten as

$$q_p = \frac{2 \times 1.008 \times A \times Q}{(1+H)(\frac{D}{2} + L)}$$

$$= \frac{2 \times 1.008 \times A \times Q \times D}{(1+H)(\frac{D}{2} + L)D} \qquad (10)$$

Comparing Eqs. (9) and (10)

$$Z = \frac{2D}{(1+H)(\frac{D}{2} + L)} \qquad (11)$$

Assuming unit hydrograph theory and a constant L

$$Z = 1 \quad \text{when } D = 2L \qquad (12)$$

which is only possible with $H = 1$.

In Eq. (5), it was assumed that $H = 1.67$; however, from the analysis above it seems reasonable to substitute for $H = 1$ in Eq. (3) in which case the modified equation for peak rates of runoff in cfs becomes

$$q_p = \frac{645\ AQ}{\frac{D}{2} + 0.6T_c} \qquad (13)$$

for $D << L$ and

$$q_p = \frac{645\ AQ}{D} \qquad (13a)$$

for $D \geq 2L$.

However, for the purpose of study only the optimum D for a peak runoff rate will be considered. This optimum D is always smaller than 2L for the situations encountered and therefore Eq. (13) should suffice.

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[10] Sangal, B. P., "Discussion of Paper No. 70 'Purpose and Performance of Peak Predictions' by Reich and Hiemstra." Vol. 2 of the Proceedings of the International Hydrology Symposium, Fort Collins, Colorado, U.S.A., September 6-8, 1967, pp. 378-381.

IV. GENERAL EQUATION FOR PEAK RATE OF RUNOFF

Combining Eq. (8) and Eq. (13), the general equation for peak rates of runoff is

$$q_p = \frac{1290A(PC + 2C - 200)^2}{C(D + 1.2T_c)(PC-8C+800)} \tag{14}$$

In Eq. (14) one problem remains, namely, to select a rainfall duration, D, for any problem catchment which would result in the desired peak rate of runoff. If it is possible to derive an equation which gives the relationships between the quantity of rainfall, P, and the storm D, substitution of this relationship in Eq. (14) would result in an equation which can be differentiated with regard to D and the optimum D for any problem catchment can thus be found.

Talbot first derived such a relationship in 1891[11] for durations from 1 to 2 hours. Later Bernard[12] derived formulas applicable to rainfalls of longer duration. Jennings[13] applied the same type of equation to durations from 5 minutes to 2 hours, Reich and Hiemstra[14] used the Jennings ratios on South African storms and recently Bell[15] found that the ratios apply also to other parts of the world.

[11] Williams, G. R., "Hydrology." Chapter IV in Engineering Hydraulics, edited by Hunter Rouse, John Wiley and Sons, N.Y., 1950, 4th Printing 1964, pp. 269-272.

[12] Bernard, Merrill M., "Formulas for Rainfall Intensities of Long Duration." Trans. ASCE, Vol. 96, 1932, pp. 592-606.

[13] Jennings, A. H., "Maximum Recorded United States Point Rainfall for 5-Minutes to 24-Hours at 296 First Order Stations." Technical Paper No. 2, U.S. Weather Bureau, Washington, D.C., 1963, 56 pp.

[14] Reich, Brian M. and Lourens A. V. Hiemstra, "Tacitly Maximized Small Watershed Flood Estimates." Journal of the Hydraulics Division, ASCE, Vol. 91. No. HY3, Proc. Paper 4339, May 1965, pp. 217-245 and Vol. 92, HY4, July, 1966.

[15] Bell, Frederick C., "Extreme Rainfall of a Short Duration." Technical Report prepared for the Bureau of Land Management, U. S. Department of the Interior under Contract No. 14-11-008-0590-62, Colorado State University, Civil Engineering Department, June, 1967, 32 pp.

This similarity between intensity-duration ratios for various localities can be explained by the fact that high-intensity short-duration storms from which most of the data are obtained are of the convective type. The physical laws governing the rainfall-producing characteristics of such storms are the same everywhere.

4.1 Index duration

With this constant relationship between extreme rainfall amounts for durations from five minutes to two hours a decision on an index duration is necessary to simplify calculations for rainfall amounts for any design storm of the convective thunderstorm type. Two approaches to derive a realistic index duration are possible, namely, through a study of watershed response under storms of different durations or through a study of the durations of storms which actually occurred in the region under study. The first approach was followed by Reich[16] where different storm durations were used in a regression analysis with peak rate of runoff as dependent variable. The 30-minute maximum rainfall amounts were found to be the most significant. The second approach was used by Hiemstra[17] where a frequency distribution of the durations of 388 observed thunderstorms were derived. The modal value of this distribution was 40-minutes.

With the results of the above mentioned studies in mind, it was decided to use an index duration of 30 minutes.

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[16] Reich, B. M., "Design Hydrographs for Very Small Watersheds from Rainfall." Civil Engineering Section, Colorado State University, Fort Collins, Colorado, CER62BMR41, 1962, 57 pp.

[17] Hiemstra, Lourens A. V., "Frequencies of Runoff for Small Basins." Ph.D. Dissertation, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, March, 1968, 134 pp.

4.2 Rainfall amount for any duration smaller than six hours

If the index duration is 30-minutes, the relation between rainfall extremes for 5, 10, 15, 45, 60-minutes and 2 hours are on the average 0.37, 0.57, 0.72, 1.15, 1.26 and 1.57 times the 30-minute extreme. For extrapolation of these ratios to the 6-hour duration, as part of this study, and using data published by the Weather Bureau[18], it was found that the six-hour amount is on the average 1.99 times the 30-minute extreme.

By plotting the reciprocal of intensity against duration, using the 30-minute extreme amount equal to 1 inch, the straight line on Fig. 2 was obtained. Rewriting the equation of this straight line, results in an equation of the Talbot type

$$K = \frac{P_{30}}{.584D + .175} \tag{15}$$

where I represents the extreme rainfall intensity in inches per hour, P_{30} the extreme rainfall amount for a 30-minute duration, and D the duration under consideration in hours.

From Eq. (15) the rainfall amount P_D for any duration is

$$P_D = \frac{D\ P_{30}}{.584D + .175} \tag{16}$$

From Fig. 2 it can be seen that Eq. (16) is subject to errors for durations longer than about two hours. For a duration of four hours the error is approximately 10% of the correct amount, which is still acceptable, but for longer durations the error becomes too large. As this study is limited to catchments smaller than 40 square miles, a limit on the durations to be used of four hours is still realistic. If an optimum storm

[18]Hershfield, D. M., "Rainfall Frequency Atlas of the United States for Durations from 30-Minutes to 24-Hours and Return Periods from 1 to 100 Years." Technical Paper No. 40, U. S. Weather Bureau, Washington, D.C., 1961, 115 pp.

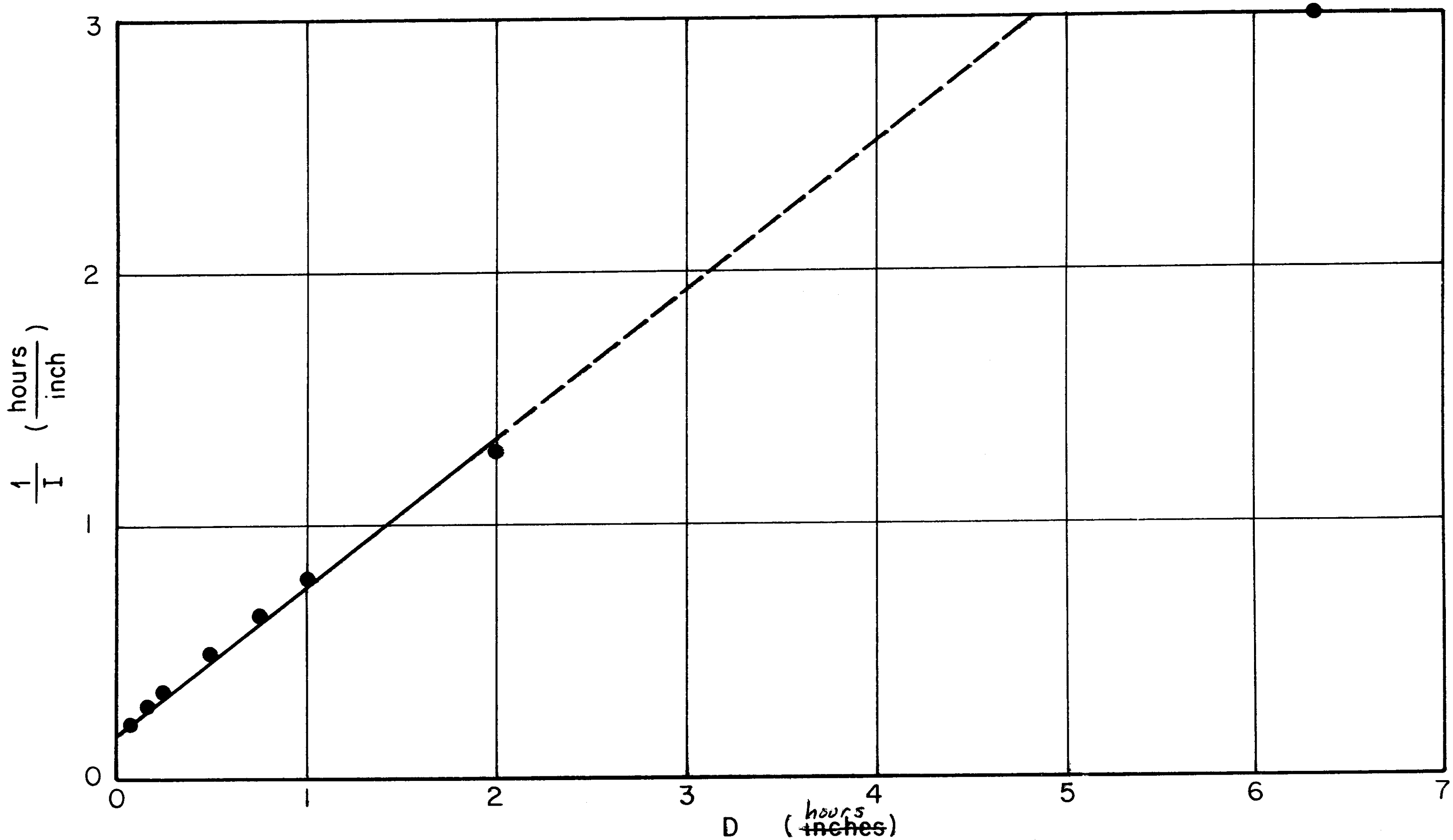

Fig. 2 The relation between the reciprocal of extreme rainfall intensity and storm duration

duration of more than four hours is encountered, the results obtained with this modified SCS-method may give excessively high peak runoff rates.

4.3 Optimum storm duration

It is now possible to rewrite the general equation for peak rates of runoff in terms of the catchment area, storm duration, time of concentration, runoff curve number and the 30-minute rainfall extremes. Substituting P_D from Eq. (16) for P in Eq. (14) results in

$$q_p = \frac{1290A[CDP_{30}+2C(.584D + .175) - 200(.584D+.175)]^2}{C(.584D+.175)(D+1.2T_c)[CDP_{30}-8C(.584D+.175)+800(.584D+.175)]}$$

or

$$q_p = \frac{u}{V} \tag{17}$$

where

$$\begin{aligned} u = 1290A[&D^2(C^2P_{30}^2 + 2.336C^2P_{30} - 233.6\ CP_{30} + 1.364C^2 \\ &- 272.844C + 13642.24) + D(.7C^2P_{30} - 70CP_{30} + .818C^2 \\ &- 163.52C + 8176) + C(.123C - 24.5) + 1225] \end{aligned}$$

and

$$\begin{aligned} V = &D^3(.584C^2P_{30} - 2.728C^2 + 272.845C) + \\ &D^2(80.124C^2 + .701C^2P_{30}T_c - 3.274C^2T_c \\ &+ 327.414CT_c + .175C^2P_{30} + 81.76C) \\ &+ D(96.15)C^2T_c + 24.255C^2 + .21C^2P_{30}T_c \\ &+ 98.112CT_c) + 29.106 \end{aligned}$$

Differentiating Eq. (17) and setting the result equal to zero results in

$$\frac{dq_p}{dD} = \frac{V\frac{du}{dD} - u\frac{dv}{dD}}{V^2} = 0$$

or

$$V\frac{du}{dD} = u\frac{dv}{dD} = 0$$

Hence

$$A[D^4(-.0006C^4P_{30}^3 + .0014C^4P_{30}^2 + .0056C^4P_{30} + .4481C^4P_{30}T_c$$

$$+ .0037C^4 - .1364C^3P_{30}^2 - 1.1153C^3P_{30} - 1.1165C^3 + 55.7697C^2P_{30}$$

$$+ 111.6602C^2 - 4722.2170C) + D^3(-.0008C^4P_{30}^3 - .0008C^4P_{30}^2$$

$$+ .0037C^4P_{30} + .0045C^4 + .2452C^3P_{30}^2 - .1910C^3P_{30}$$

$$- 1.1155C^3 - .1635C^2P_{30}^2 - 9.9315C^2P_{30} + 305.9356C^2P_{30}T_c$$

$$+ 89.0010C^2 + 38.1983CP_{30} - 2186.1669C - 2230.7791)$$

$$+ D^2(.0001C^4P_{30}^3 + .0002C^4P_{30}^3T_c + .0241C^4P_{30}^2 + .0962C^4P_{30}^2T_c - .2215C^4P_{30}T_c$$

$$+ .1338C^4T_c + .0315C^4 + .0123C^3P_{30}^2 + .0982C^3P_{30}^2T_c$$

$$+ .0715C^3P_{30} - 22.6325C^3P_{30}T_c - 26.9033C^3T_c + 6.2497C^3$$

$$- 9.4147C^2P_{30} - 2.8665C^2P_{30}T_c + 1365.2391C^2T_c$$

$$- 307.6249C^2 + 11.4464CP_{30} - 1338.4694CT_c - 307.4968C$$

$$- 1336.9395)$$

$$+ D(.0582C^4P_{30}^2T_c - .0170C^4P_{30} + .1358C^4P_{30}T_c$$

$$+ .1041C^4T_c - .0197C^4 + .0086C^3P_{30}$$

$$- 13.5640C^3P_{30}T_c - 16.1237C^3T_c + 3.9261C^3$$

$$- .4288C^2P_{30} + 5.1504C^2P_{30}T_c + 818.2067C^2T_c$$

$$- 196.3239C^2 - 802.1653CT_c + 4.0062C + .0170P_{30}$$

$$- 200.3120) + C^4 (.0203P_{30}T_c - .0118T_c - .0030)$$

$$+ C^3 (-2.0323P_{30}T_c - 2.4158T_c + .5942)$$

$$+ C^2(-7.1251P_{30}T_c + 122.5907T_c) - 120.1872CT_c] = 0$$

This is an equation of the form

$$K_1D^4 + K_2D^3 + K_3D^2 + K_4D + K_5 = 0 \tag{19}$$

where $K_1 \ldots K_5$ represents constants for previously assigned values of C, P_{30}, and T_c. Using numerical methods, Eq. (19) can easily be solved on the digital computer for any combination of C, P_{30}, T_c. Newton's method[19] was used to obtain 1536 solutions for different combinations of the three independent variables. Table 1 shows some typical results and Fig. 3 shows a summary of all the results, from which it can be seen that simply assuming the optimum storm duration

$$D_o = .75\ T_c \tag{20}$$

should not result in serious errors.

In this simplification only the real roots of Eq. (19) with values closest to the value of T_c were used. In most cases this D-value should also result in the highest flood peak, because for longer durations the

[19] Stanton, Ralph G., "Numerical Methods for Science and Engineering." Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 1961, pp. 84-98.

TABLE 1 OPTIMUM STORM DURATIONS WITH P_{30} AND C VARYING BUT WITH T_c CONSTANT AND EQUAL TO 0.75 HOURS

C	P_{30}	D_o
50	.25	.474
	.50	.693
	.75	.850
	1.00	.918
	1.25	.918
	1.50	.884
	1.75	.837
	2.00	.789
	2.25	.744
	2.50	.703
	2.75	.668
	3.00	.637
	3.25	.610
	3.50	.586
	3.75	.566
	4.00	.547
60	.25	.576
	.50	.779
	.75	.883
	1.00	.883
	1.25	.849
	1.50	.800
	1.75	.752
	2.00	.707
	2.25	.668
	2.50	.634
	2.75	.605
	3.00	.579
	3.25	.557
	3.50	.538
	3.75	.521
	4.00	.505
70	.25	.634
	.50	.790
	.75	.833
	1.00	.814
	1.25	.772
	1.50	.727
	1.75	.684
	2.00	.646
	2.25	.613
	2.50	.585
	2.75	.561
	3.00	.540
	3.25	.521
70	3.50	.505
	3.75	.491
	4.00	.478
80	.25	.651
	.50	.762
	.75	.778
	1.00	.750
	1.25	.710
	1.50	.670
	1.75	.634
	2.00	.602
	2.25	.574
	2.50	.551
	2.75	.530
	3.00	.512
	3.25	.496
	3.50	.482
	3.75	.470
	4.00	.458
90	.25	.644
	.50	.724
	.75	.726
	1.00	.698
	1.25	.663
	1.50	.628
	1.75	.597
	2.00	.570
	2.25	.546
	2.50	.525
	2.75	.508
	3.00	.492
	3.25	.478
	3.50	.466
	3.75	.455
	4.00	.445

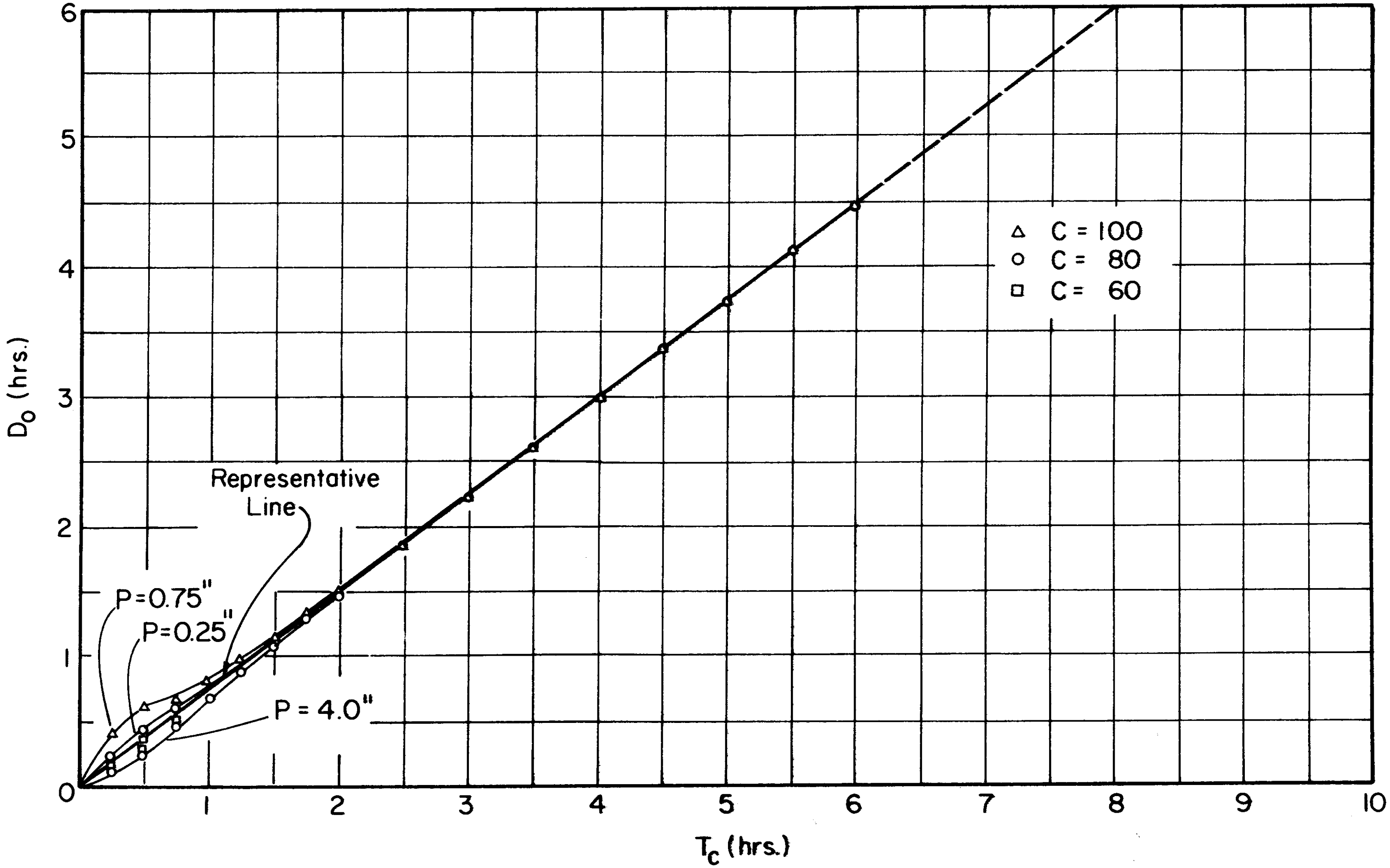

Fig. 3 Optimum storm durations in terms of the time-of-concentration

rainfall intensity decreases as shown by the plotted points on Fig. 2. For a given C, a lower rainfall intensity must result in a lower flood peak, regardless of D, hence the smallest real root for D from Eq. (19) is the correct value to maximize the flood peak.

This final equation then completes the necessary modifications on the Soil Conservation Method for estimating runoff rates.

V. PROCEDURE FOR APPLYING THIS MODIFIED SOIL CONSERVATION METHOD

The same limitations as discussed in the Bureau of Land Management Manual[3] are also applicable to this Modified Method. The procedures listed in the Manual must be followed for the estimation of the time-of-concentration, T_c and for the runoff-curve-number, C. (More extensive lists of hydrological soil groups than the list in the Manual are available in References 2 and 7).

With the area of the problem catchment, A, in square miles, the time-of-concentration, T_c, in hours and the runoff-curve-number, C, known, the following procedure is necessary to derive the peak rate of runoff:

(a) From published charts in Reference 18, read off the 30-minute extreme rainfall amount for the desired return period.

(b) From Fig. 4, which is a graphical representation of Eqs. (16) and (20) read off the rainfall amount applicable to the problem catchment.

(c) Use the rainfall amount obtained in step (b) on Fig. 5 to obtain the total volume of runoff, Q. Figure 5 was transcribed from the Bureau of Land Management Manual, Reference 3.

(d) With Q known, read off the flood peak, q_u, in cfs per square mile from Fig. 6. Figure 6 is a graphical representation of Eqs. (13) and (2) with $A = 1$.

(e) Finally, multiply q_u by the area of the catchment to obtain the desired flood peak.

5.1 Example

As an example the flood peak with a 25-year return period on a catchment at Safford, Arizona, was estimated.

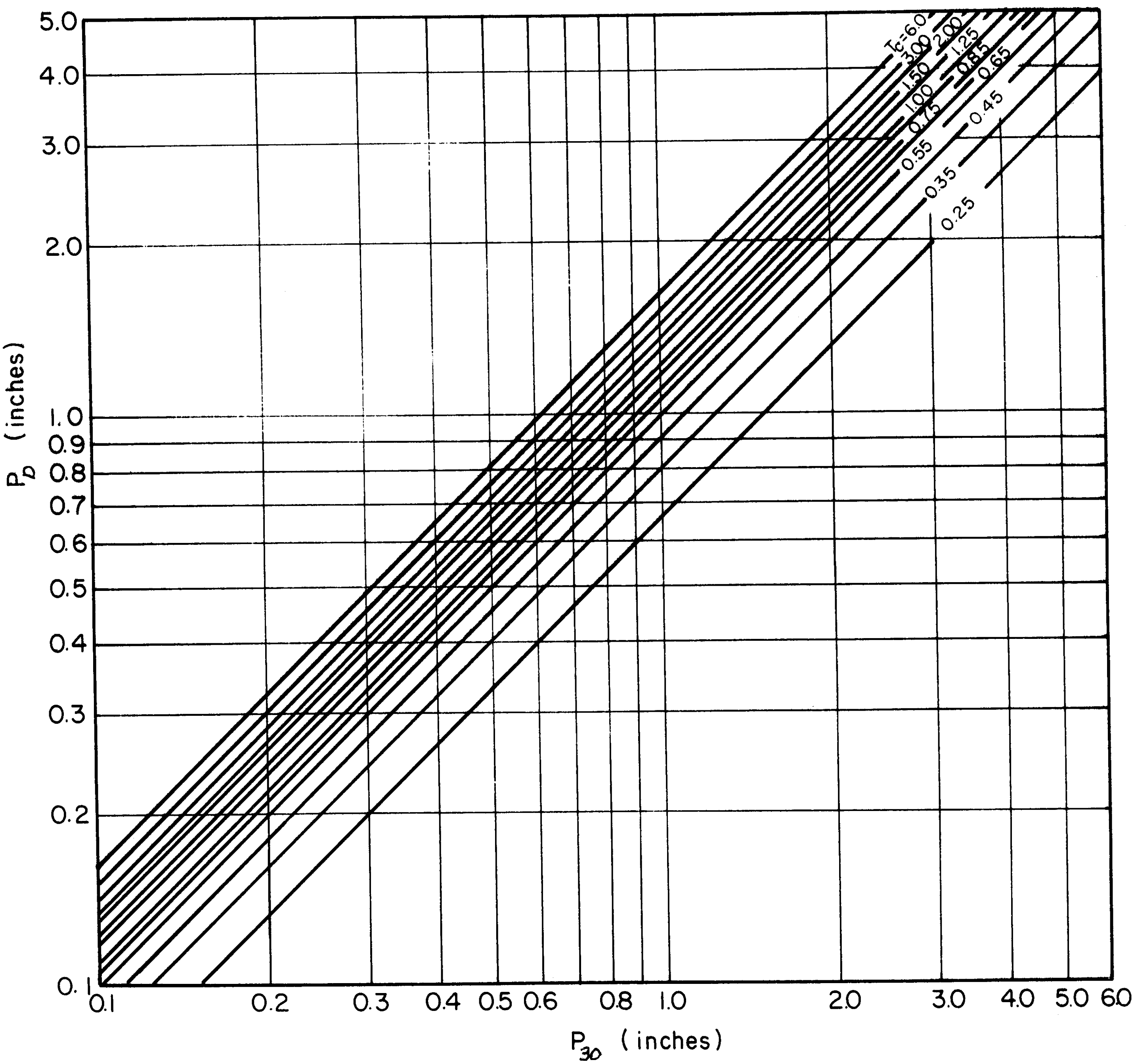

Fig. 4 Rainfall amounts for optimum storm durations from the 30-minute duration amount

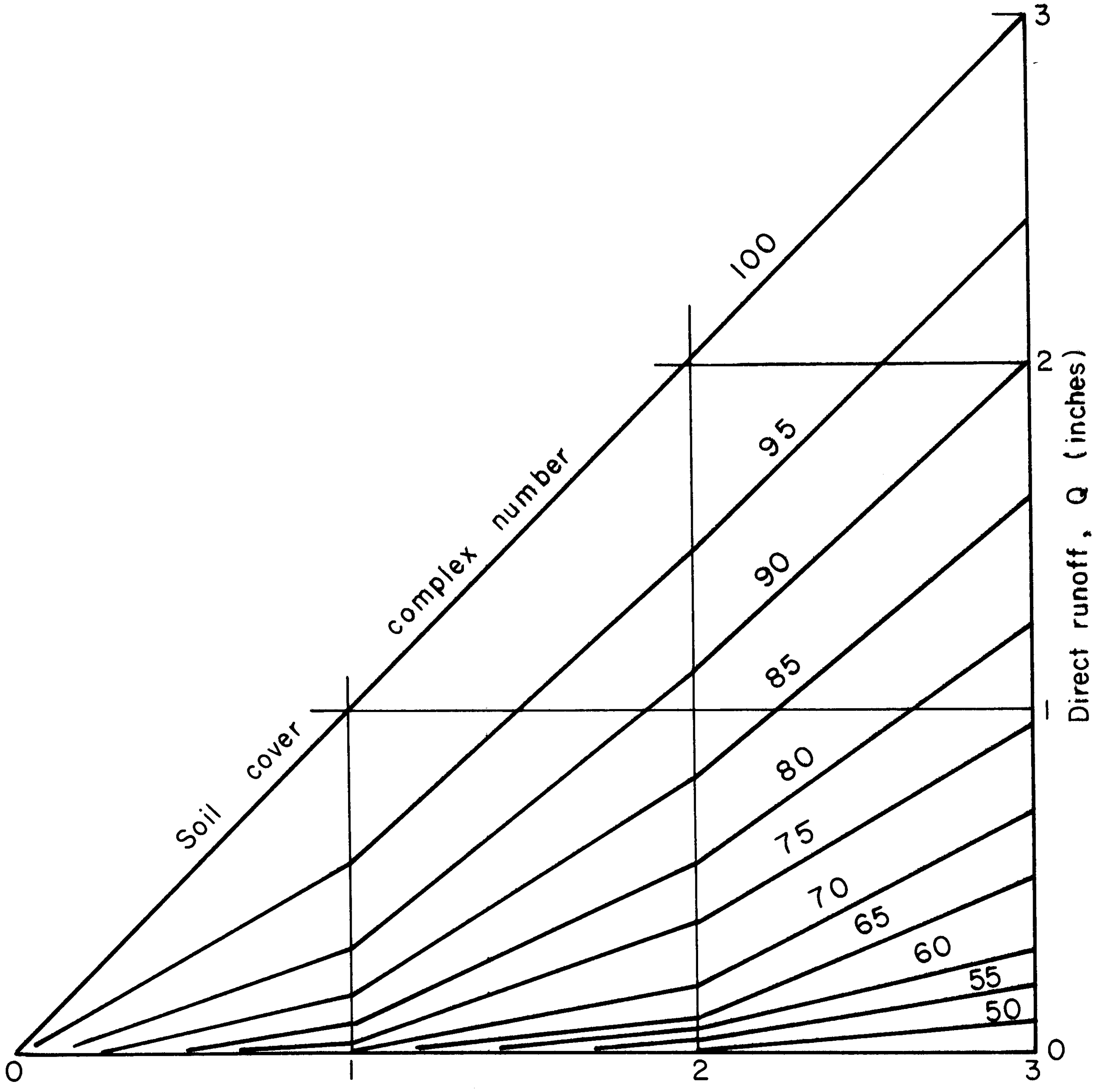

Fig. 5 (a) Direct runoff from rainfall (Reference 3)

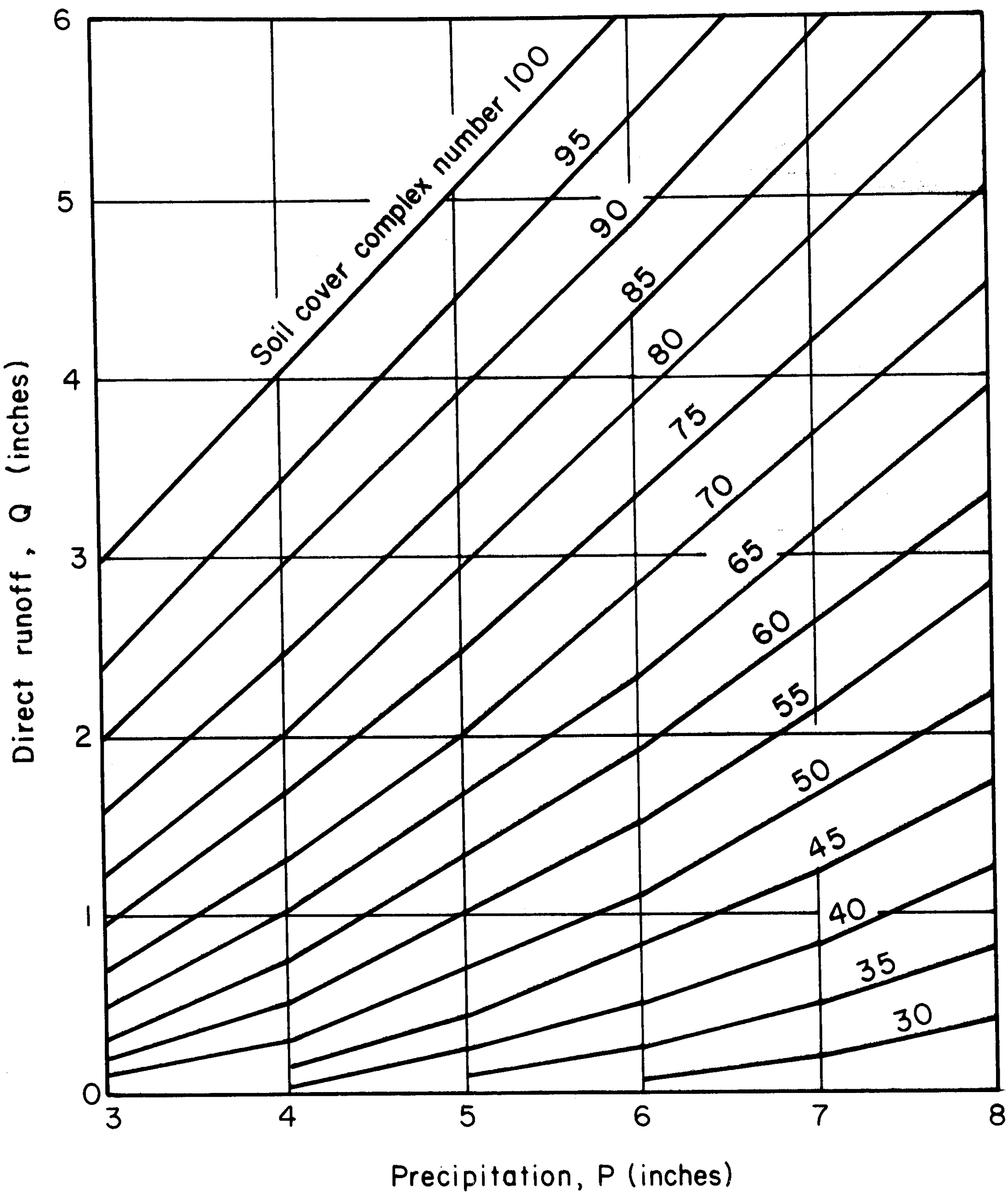

Fig. 5(b) Direct runoff from rainfall (Reference 3)

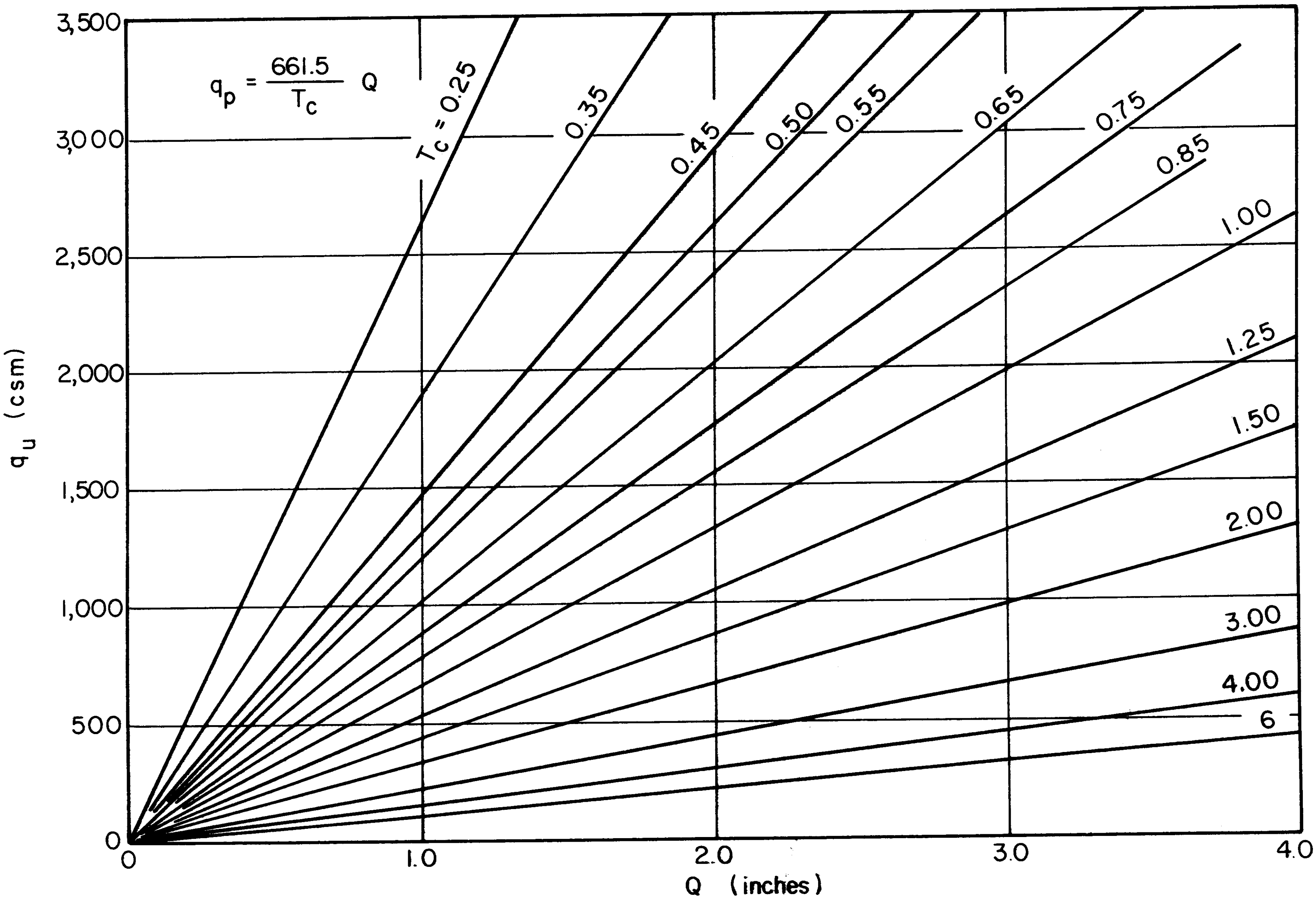

Fig. 6 Peak rates of runoff from total volumes of runoff

5.1.1 Catchment description

$$A = 723 \text{ acres} = \frac{723}{640} = 1.13 \text{ square miles}$$

Degrees latitude = 32^{o} 45'

Degrees longitude = 109^{o} 35'

Length of longest collector, L_B = 3.53 miles.

Fall over the catchment, H_B = 520 feet

Soils:	Hydrologic Soil Group
Signal (cliff) - 60%	C
Gilman - 19%	B
Luzend - 21%	D

Catchment Condition

80% of the area is bare. Short grasses (tobosa, curly mesquite, blue-black-side-oats grama, three-awn, triodia), shrubs (mesquite, snakeweed, acacia, soapweed, lycium, opuntia and baccharis) and forbs (crassina, indian wheat, filaree)

5.1.2 Estimation of T_c and C

(a) Catchment slope $= \frac{H_B}{L_B} = \frac{520}{3.53 \times 5280} = 2.8\%$

Apparent T_c = .81 hours

$$\text{Width} = \frac{A}{L_B} = \frac{723 \times 43560}{3.53 \times 5280} = 1690 \text{ feet}$$

Hence no correction and T_c = .81 hours

(b)

Soil	%	C	
Signal (cliff)	60	86	86 x 60 =5160
Gilman	19	79	79 x 19 1501
Luzena	21	95	95 x 21 = 1995
		SUM	= 8656

Assume C = 85

5.1.3 Estimation of q_p

(a) From Reference 18, P_{30} = 1.50 inches

(b) From Figure 3, p_D = 1.75 inches

(c) From Figure 4, Q = .65 inches

(d) From Figure 5, q_u = 475 cfs per square mile

(e) Finally, $q_p = A \times q_u = 475 \times 1.13 = 537$ cfs

VI. EVALUATION OF THE SUCCESS OF THE MODIFIED SOIL CONSERVATION METHOD

To evaluate the success of the modifications on the SCS-Method described in this report, the Modified SCS-Method was applied on four selected small catchments for which historical records were available. The results obtained with this Modified Method were compared to results obtained by using the unmodified SCS-Method as described in the Bureau of Land Management Manual[3]. On three of the selected catchments with areas smaller than 2000 acres, the Kent-Method for small areas was also applied. The results obtained by the three methods were then compared with the observed flood peaks on the catchments, as shown on Figure 7, 8, 9 and 10.

The best fit lines through the observed peaks were calculated according to the procedures explained by Kendall [20] and the 95% confidence limits by using Kaczmarek's Method[21].

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[20]Kendall, G. R., "Statistical Analysis of Extreme Values." First Canadian Hydrology Conference, Symposium on Spillway Design Floods, Ottawa, November 4-5, 1959, 26 pp.

[21]Kaczmarek, Z., "Efficiency of the Estimation of Floods with a given Return Period." International Association of Science Hydro. Publication No. 45, General Assembly of Toronto, Vol. III, 1957, pp. 144-159.

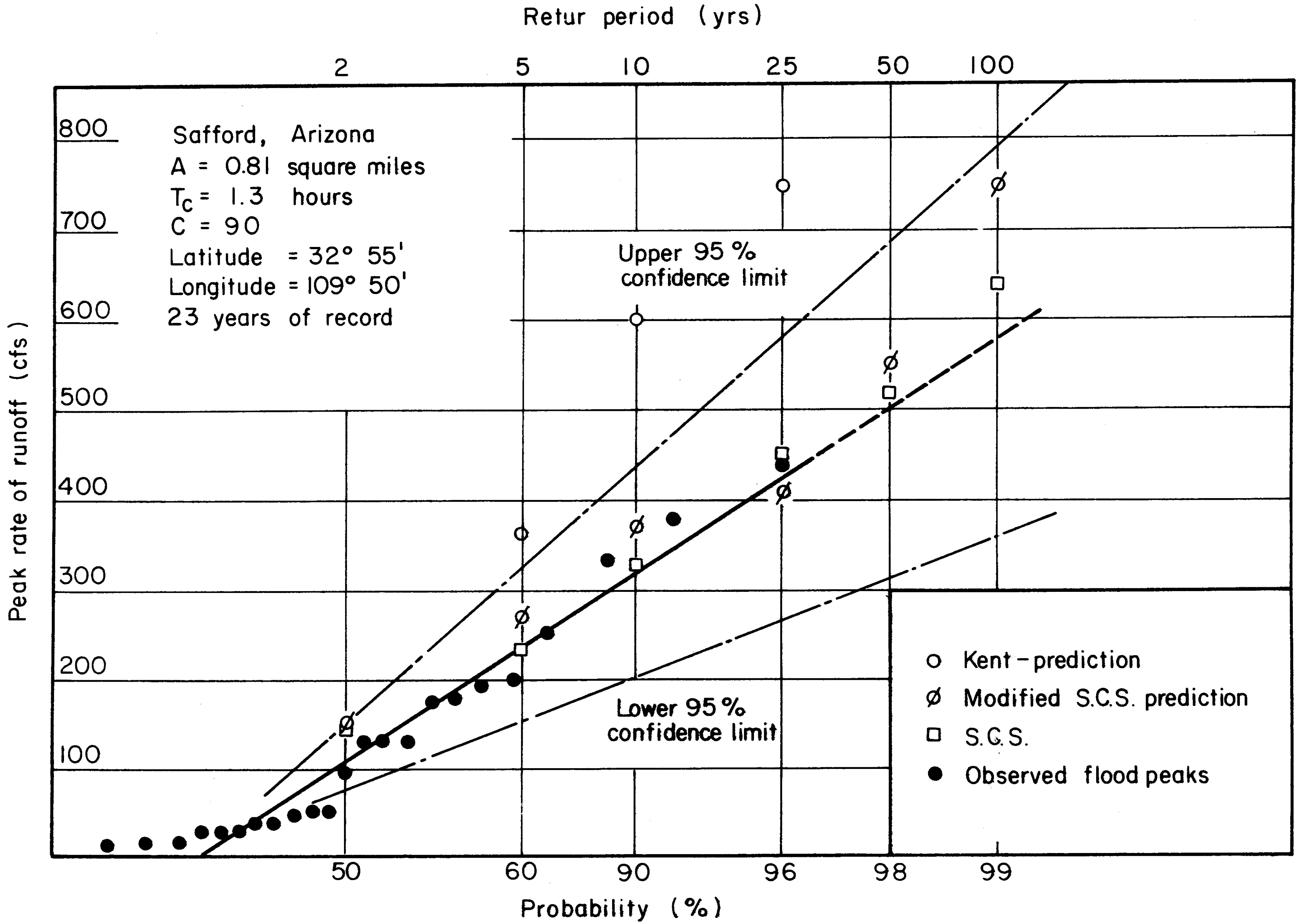

Fig. 8 Comparison of flood peak predictions, Safford, Arizona

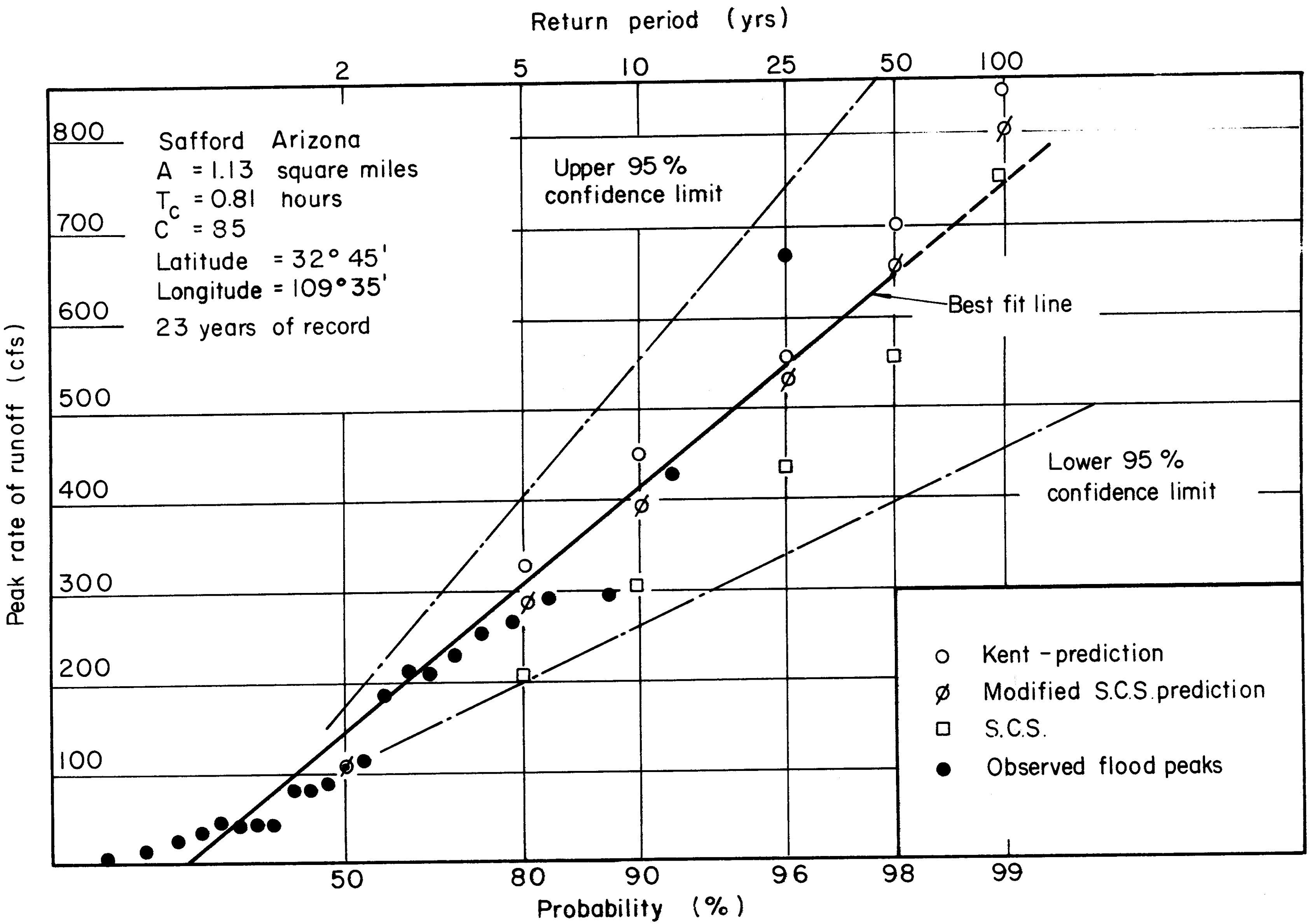

Fig. 7 Comparison of flood peak predictions, Safford, Arizona

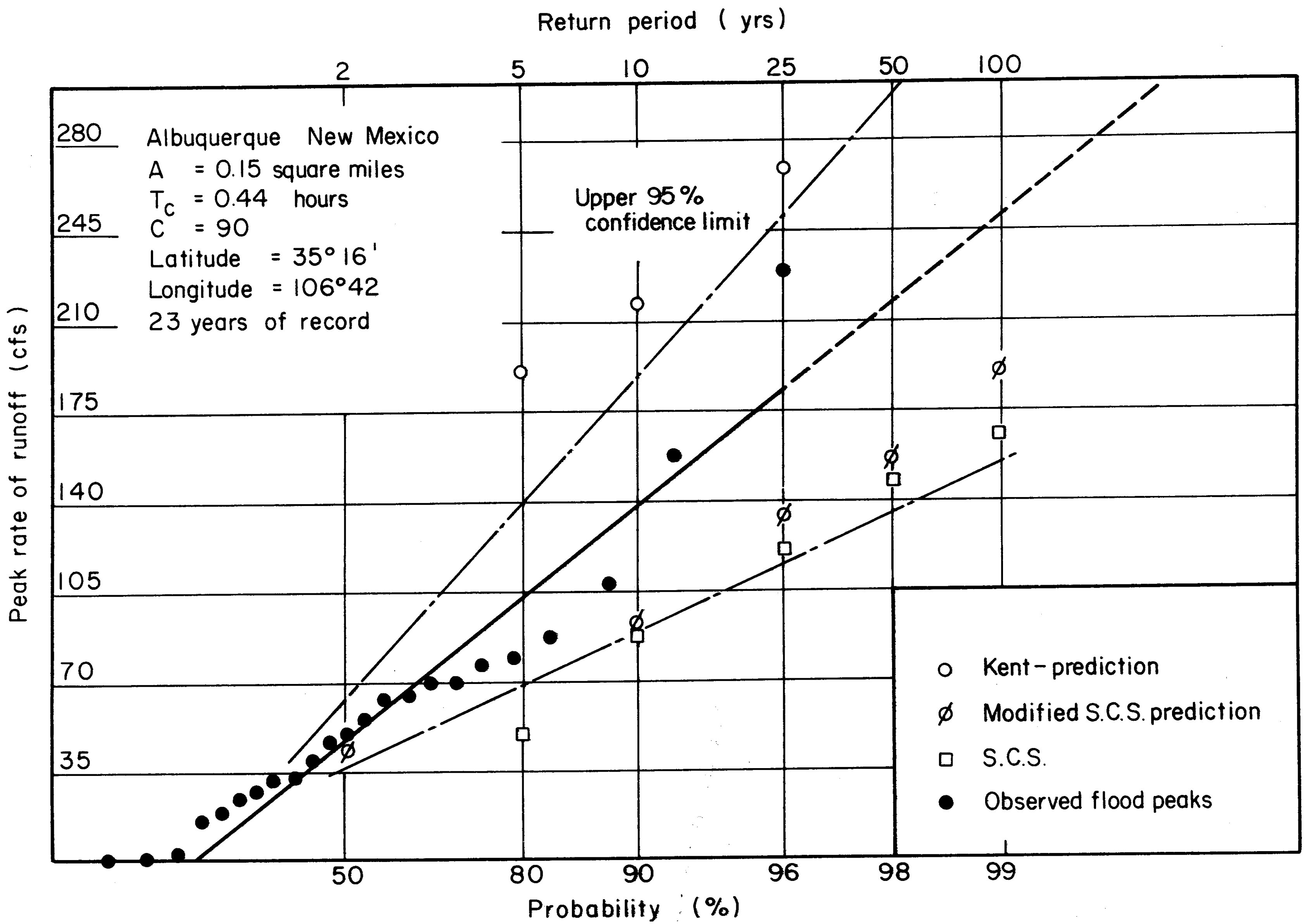

Fig. 9 Comparison of flood peak predictions, Albuquerque, New Mexico

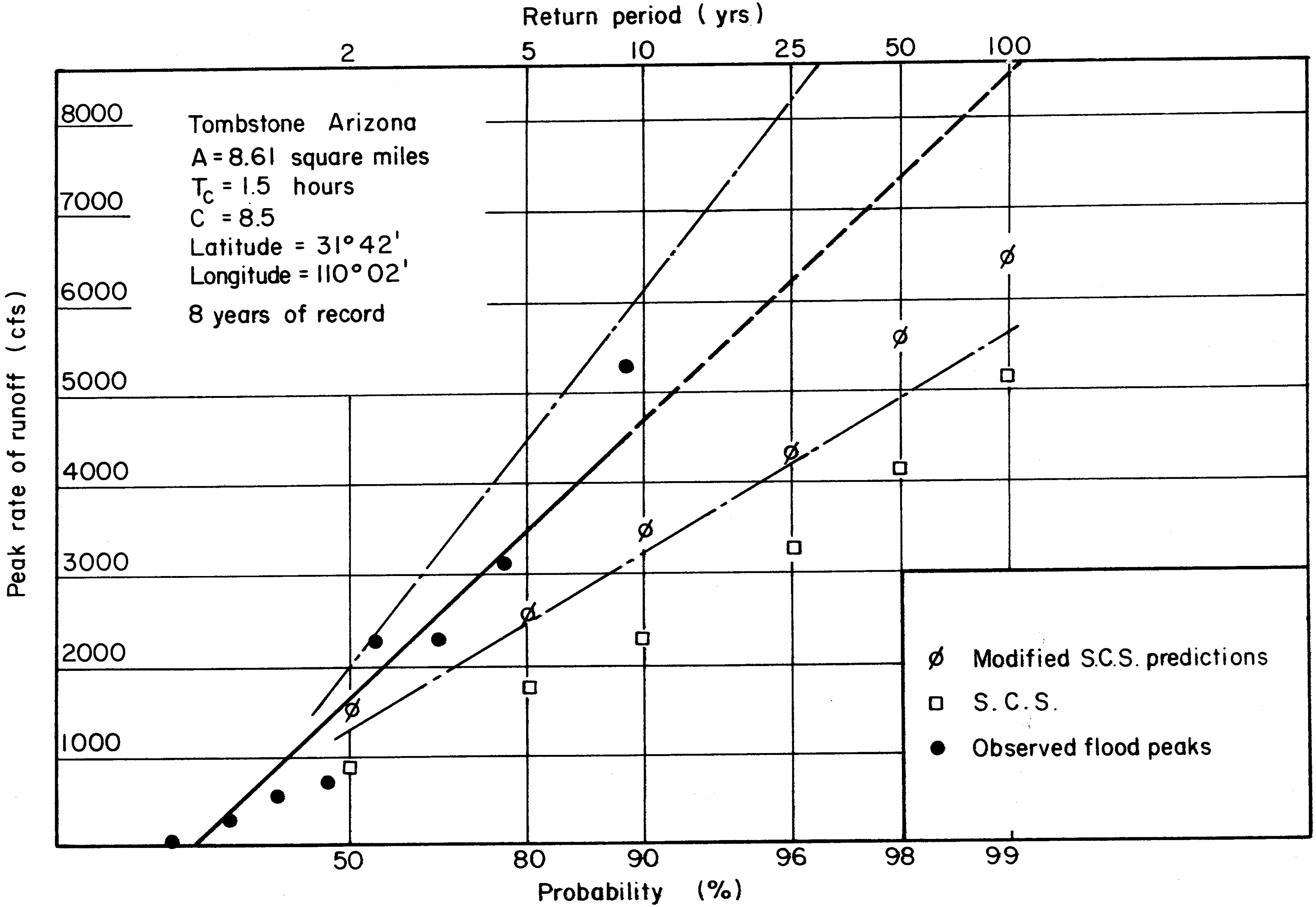

Fig. 10 Comparison of flood peak predictions, Tombstone, Arizona

VII. DISCUSSION AND CONCLUSION

7.1 Discussion

The SCS-Method was developed as a representative method to be applicable over a variety of catchments in the United States of America. Components of the method were based on average values obtained from small experimental catchments. In its application, however, the method is used on individual catchments. In order to fit individual catchments some flexibility was built into the method in the estimation of a time-of-concentration, a runoff-curve-number, a rainfall amount and the area of the catchment under consideration. The success of the method is therefore dependent on the ability of the investigator to estimate or to calculate these needed values for the problem catchment. Available historical data, familiarity with the problem area and experience in the use of the SCS-Method are valuable assets for sound judgment in the evaluation of the values needed to apply the method and especially for the selection of the correct runoff curve number.

From the above it should be clear that the SCS-Method and its modifications are not yet fool-proof methods and care must be exercised in their application.

7.1.1 Comparison of Methods. From the results shown on Figs. 7 through 10 it seems as if the SCS-Method tends to underpredict flood peaks whereas the Kent-Method tends towards over-prediction. The modified SCS-Method of this report has predictions between the other two methods and for most of the cases shown, the results are acceptable as they fall within the region between the 95% confidence intervals.

Juggling of the runoff-curve number may favor any method. For example, a lower C might show results favorable to the Kent-Method and a higher C might favor the SCS-Method. The chosen C's were chosen to be realistic and not to favor any method. However, different investigators may choose different C's. This may change the position of the predictions on the figures relative to the observed values, but the position of the predictions relative to the other methods will not change very much.

In practice, it might be advisable to use the three methods simultaneously and to prepare a figure like Figs 7 through 10 before a final choice for a flood peak is made.

7.2 Conclusion

The modifications on the SCS-Method presented in this report seem to result in worth-while improvements of results when applied to very small catchments in the arid part of the Western United States of America.