Research Report Submitted to:

ALBUQUERQUE METROPOLITAN ARROYO FLOOD CONTROL AUTHORITY

(AMAFCA)

and

CITY OF ALBUQUERQUE

PHASE II -
RAINFALL INFILTRATION OF SELECTED SOILS IN THE ALBUQUERQUE DRAINAGE AREA

by

Civil Engineering Department
New Mexico State University
Las Cruces, New Mexico 88003

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FORWARD

This report is submitted to the Albuquerque Metropolitan Arroyo Flood Control Authority and the City of Albuquerque and presents the results of research conducted by the Civil Engineering Department at New Mexico State University. The results of the Phase II research are presented in three separate reports:

1. Arroyo Transmission Losses
2. Rainfall Infiltration of Selected Soils in the Albuquerque Drainage Area, and
3. Energy Dissipator/Grade Control Structures for Steep Channels.

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SECTION 1

INTRODUCTION

General

The design of urban flood control structures and the preparation of drainage plans in Albuquerque requires analytic techniques to estimate the amount and time distribution of runoff from a design rainfall event. Not all rainfall results in runoff; a majority of the rainfall loss is absorbed into the soil (infiltration), and some rainfall is lost to surface features such as ponding. Engineers in Albuquerque are using several analytic procedures to estimate rainfall loss, and the most popular techniques is the Soil Conservation Service (SCS) rainfall-runoff equation. This and other techniques requires an assumption about rainfall loss or infiltration rate. These assumptions are often based on institutionalized guidelines and engineering design aids that have not necessarily been developed or verified for use in the Albuquerque hydrologic environment. Furthermore, the assumptions are rather subjective which probably results in inconsistent estimates of runoff when performed by different individuals.

In this study rainfall loss and infiltration rate have been investigated on selected soil-vegetation-land use complexes in Albuquerque. The SCS rainfall-runoff equation has been cirtically examined and the fit of the equation to data has been performed. Infiltration parameters for the Green-Ampt infiltration equation have been determined for the selected sites in Albuquerque.

Rainfall-runoff data was obtained by using a portable rainfall simulator to collect field data and necessary samples from selected sites in Albuquerque. The sites were selected jointly by personnel of AMAFCA, the City Engineers Office, and the research team. The research was performed for the City of

Albuquerque and the Albuquerque Metropolitan Arroy Flood Control Authority (AMAFCA). The research was conducted by the Civil Engineering Department of New Mexico State University in Las Cruces.

Objective of Research

The objective of this research was to experimentally estimate the magnitude of rainfall losses and the infiltration rate of selected soils in the Albuquerque drainage area. Not all possible soil-vegetation-land use complexes in Albuquerque have been investigated, nor has a sufficiently broad data base been obtained to allow extrapolation of the results to complexes not included in this study.

SECTION 2

RAINFALL - RUNOFF

General Description

The transformation of rainfall to runoff involves the action and interaction of several physical processes. The first process is that of rainfall itself, and is usually considered in terms of rainfall depth, duration, and time distribution. Design rainfall information is usually obtained from available sources, such as the National Oceanic and Atmospheric Administration Atlas, or through regulatory documents such as the Albuquerque drainage criteria. The effect of the rainfall parameters on runoff are not the subject of this report. The second process is the conversion of rainfall to surface runoff. The difference between rainfall and runoff is called rainfall loss; and runoff is synonymous with rainfall excess. The quantification of rainfall loss is the objective of this research. The third process is the determination of the time rate at which rainfall excess drains from the land surface. This is governed by the laws of physics and is often incorporated into rainfall-runoff models with a unit-hydrograph. The hydraulics of the runoff process are not to be addressed.

Rainfall loss is generally considered to be a function of soil, vegetation, land use, and soil moisture. The rainfall-runoff process has three time phases as shown in Figure 1. The first phase is the period from the onset of rainfall until the occurrence of surface runoff. The rainfall loss during this phase is called initial abstraction. High antecedent soil moisture (moist soil) will shorten phase I, whereas low antecedent soil moisture (dry soil) will lengthen phase I. The first phase is also a function of rainfall intensity, high intensity rainfall will shorten this phase, and low intensity

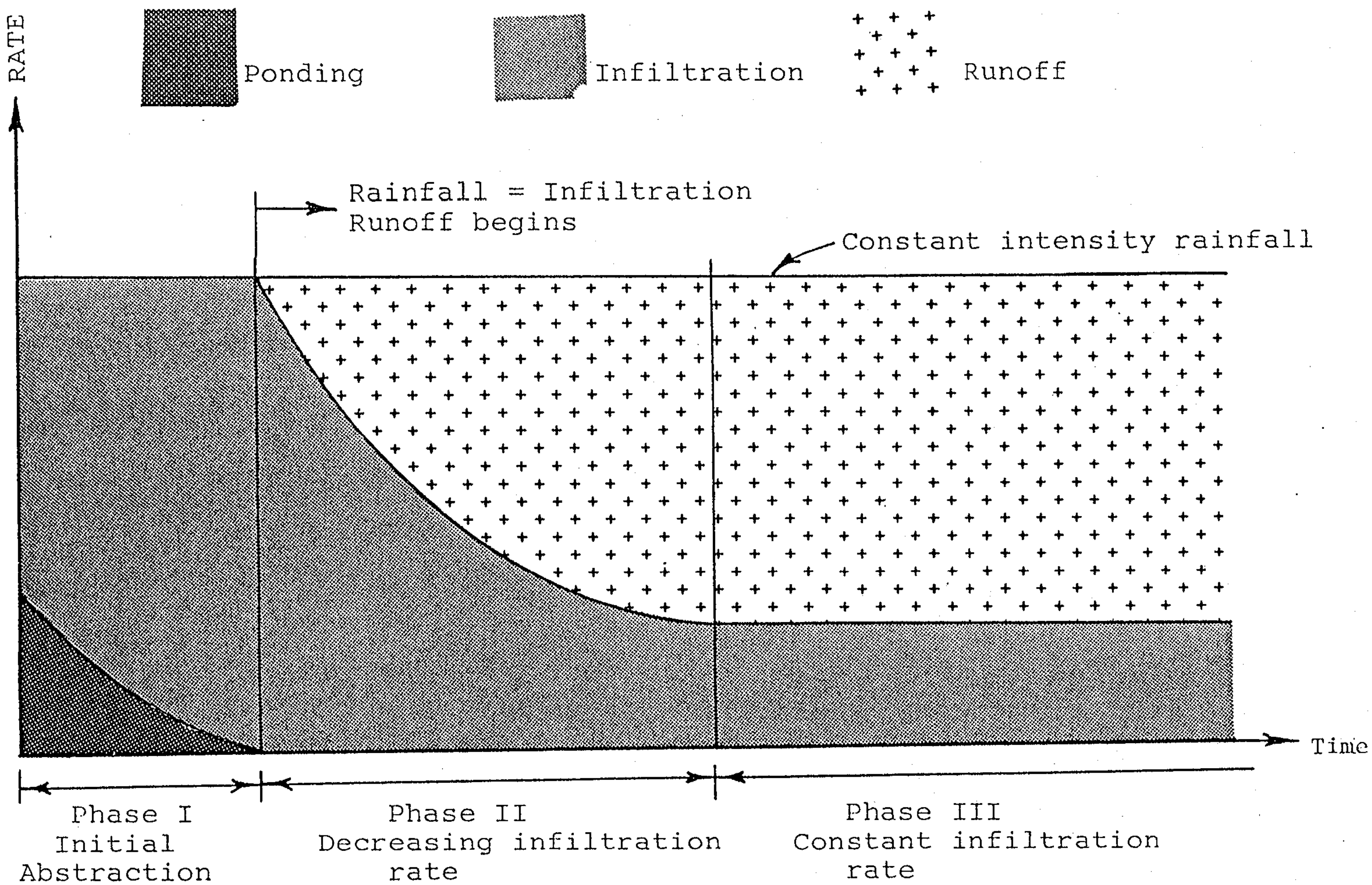


Figure 1.- Three phases of rainfall-runoff process.

will lengthen this phase. The second phase is the period from the onset of ponding until the infiltration rate becomes constant. The third phase exists after the infiltration rate has reached a constant. Both Phase II and III are primarily a function of the infiltration characteristics of the soil-vegetation-land use complex. It should be noted that Figure 1 is for the simplified situation where rainfall intensity is constant. Typical rainfall distributions in which the rainfall intensities vary with time, compounds the situation. For example, thunderstorm events in New Mexico can be typified by a short, low intensity initial period followed by a higher intensity period and concluded by a longer low intensity period. This type of pattern is characteristic of an advanced storm where well over half of the rainfall occurs within the first half of the storm, and all periods have rainfall intensities that can be quite variable. If such a pattern is utilized in Figure 1, the meaning of the phases would become less apparent. Phase I may be shortened (or lengthened), Phase II could be shortened (or lenthened), and Phase III may have periods of low intensity where the rainfall rate is less than the potential infiltration rate. This type of situation could be depicted, however for discussion purposes, the constant rainfall assumption is the best choice.

Initial Abstraction

Initial abstraction is the amount of rainfall that is lost before surface runoff begins. Initial abstraction is the sum of evaporation, interception, depression storage, and a portion of the total infiltration. The duration of design storms in Albuquerque is not sufficient to allow for any significant amount of evaporation. Interception is the amount of rain falling in the first part of the storm that is stored on vegetal cover. In the older established areas of Albuquerque, especially in the valley, this may be a significant amount; however, in the newer developments on the mesas, interception will not result in a significant rainfall loss. Depression storage is the rainfall that ponds and puddles on the land surface or is permanently captured by structural elements, such as roofs and roadway depressions, and this can be a major source of rainfall loss. Depression storage can be increased by urbanization through lawn contouring and construction of walls separating lots. During the initial abstraction period the rate at which water is made available to the soil is less than the rate at which the water can be retained by the soil-vegetation complex. Infiltration is a significant part of the initial abstraction and initial abstraction generally ends when rainfall intensity equals infiltration rate.

For Albuquerque design storms and undeveloped watersheds, only depression storage and infiltration are considered to be significantly important in quantifying initial abstraction. In developed areas storage on dense vegetation may play an important role.

Infiltration

After the initial abstraction is satisfied, infiltration governs the rate at which rainfall excess will be generated to produce direct surface runoff. Infiltration (F) is the volume of water per unit area, in inches, that has entered the soil at a point in time. Infiltration rate (f) is the time rate, in inches per hour, at which water enters the soil. Infiltration rate can be controlled by the land surface conditions; for example, the inwash of fine soil particles on the surface may partially seal the surface, even when surface soils are highly infilterable. Infiltration rate can also be controlled by underlying soil horizons that restrict the rate at which infiltrated water can be drained from the overlying soil; for example, soil underlain with a basaltic lava flow could have greatly reduced infiltration after an initial period of high infiltration due to the restricted permeability of the underlying basalt. This restricted permeability could create a saturated condition in the surface soil and a saturated overland flow condition if the soils were very shallow.

Numerous investigators have studied the infiltration process. Noteable because of its acceptance by hydrologists in its representation of the infiltration process, is the work of Horton (1935). Horton's description of the infiltration process is shown in Figure 2; and expressed by:

$$f = f_c + (f_o - f_c)e^{-kt} \qquad (1)$$

where f is the infiltration rate, in in/hr, at time t,

f_o is the initial infiltration rate,

f_c is the constant infiltration rate, and

k is a constant relating the rate of exponential decay.

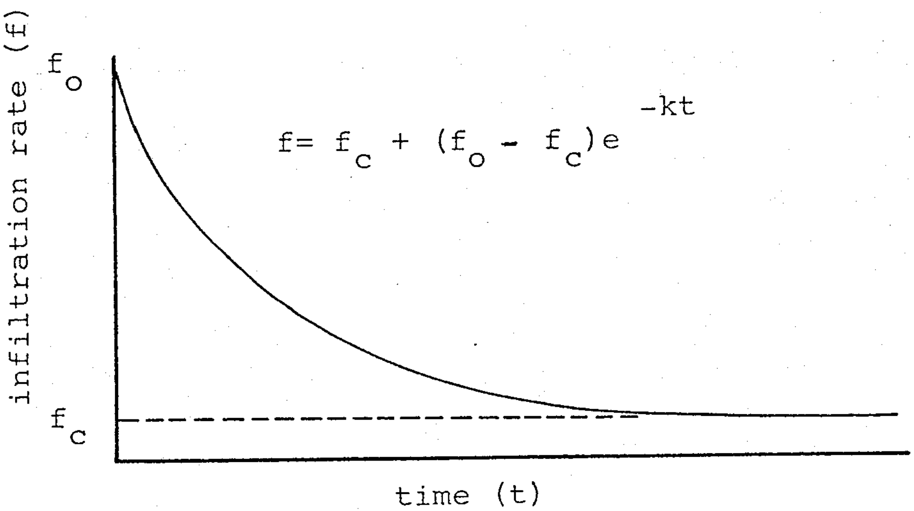


Figure 2.- Horton infiltration rate curve.

Infiltration rate starts with an initially high value (f_o) and decreases exponentially with time approaching a constant rate (f_c). This equation is simple in form, although difficulties in determining useful values of f_o and k restrict its use. Horton's work is mainly valueable in laying the foundation for subsequent investigations on infiltration. Infiltration rate is assumed to be represented by the general curve shown in Figure 2 for the intents of this report.

Rainfall Loss Models

Numerous techniques have been developed for the quantification of rainfall loss and the estimation of runoff directly from rainfall. The use of computers has resulted in the proliferation of computerized rainfall-runoff models incorporating different rainfall loss techniques. Several of the more popular computerized rainfall-runoff models are briefly discussed in regard to their rainfall loss functions. The most popular computational procedures for estimating runoff or rainfall loss are discussed in regard to their applicability for use in Albuquerque.

Computer models - Five rainfall-runoff computer models have been identified as being used by many consultants and agencies in New Mexico. The name of the model, the authorship, and type of rainfall loss function is shown in Table 1. Other computer models are available but the rainfall loss function of these is often be the same or similar to those listed in Table 1.

Table 1 - Computer models for rainfall-runoff analyses, authorship, and rainfall loss function.

MODEL	AUTHOR	RAINFALL LOSS FUNCTION
HEC-1	US Army Corps of Eng.	Variable loss rate
HYMO	Ag. Research Service	Curve Number
TR-20	Soil Cons. Service	Curve Number
USGS	U.S. Geol. Survey	Philips Equation
MULTSED	Colorado St. Univ.	Green-Ampt Equation

Numerous differences exist among models in the methods used to convert the rainfall excess to runoff and routing of the water. Each model also has advantages over the others in the performance of special routines such as stream routing, reservoir routing, unit-hydrograph generation, snowmelt, and sediment yield. Only the rainfall loss function of each program is of concern in these discussions.

Philip equation - This is similar to the Horton equation in that infiltration rate decreases as an exponential function of time. According to Philip (1954) infiltration rate is:

$$f = \frac{bt^{1/2}}{2} + a \qquad (2)$$

where a and b are empirical constants and t is time. This equation is only valid when rainfall intensity is greater than infiltration rate. In using the Philip equation, initial abstraction must be estimated independently. This equation is computationally easy to use; however, very little is known about the value of the constants a or b for a given soil-vegetation complex. The need for an independent evaluation of initial abstraction has detracted from its usefulness.

Variable loss rate - Rainfall losses are computed in the HEC-1 model by using either an initial abstraction followed by a uniform loss rate, or a function that relates loss rate to rainfall intensity and to soil moisture. The use of the simplified approach of initial abstraction followed by a uniform loss rate can be justified for long duration storms, such as 6-hours or longer, where neglecting the actual decreasing infiltration rate will not significantly affect the total volume of runoff. The use of this method for short, high intensity storms, such as 1-hour, is not justified.

The variable loss rate function used in the HEC-1 model is:

$$L = Ki^E \quad , \text{ for } L<i$$

$$L = i \quad , \text{ for } L \geq i \qquad (3)$$

where L is loss rate, in in/hr,

K is a coefficient decreasing with increased soil moisture,

i is rainfall intensity, in in/hr, and

E is an exponent between 0.0 and 1.0.

The variable loss rate function lumps initial abstraction and infiltration into one relationship.

For gaged watersheds, HEC-1 allows the user to input rainfall and runoff data from which the loss rate parameters are optimized to give a best fit to the data. For ungaged watersheds, the parameters are estimated based on information from similar watersheds and/or judgement. The HEC-1 users manual provides guidence on the general range of parameter values to be expected. These suggested values are based on data that may not be representative of Albuquerque conditions. Seldom in Albuquerque would the watershed of interest be gaged. A comprehensive study relating watershed conditions to the variable loss rate function parameters has not been undertaken; therefore, the transferability of parameter values from one watershed to another is uncertain.

SCS curve number method - In 1954 the Soil Conservation Service (SCS) published a unique procedure for estimating direct runoff from storm rainfall (SCS, NEH-4). The procedure, called the curve number (CN) method, was developed because of a need by the SCS to estimate direct runoff from small ungaged watersheds and to evaluate the effects of changes in agricultural land use on direct runoff. Since about 1970 the curve number method has increasingly been applied to hydrological analyses that were not within the original scope, including urban hydrology. In response to the increased use in urban planning the SCS provided additional guidence (SCS, 1975); however, the existing curve number method was not modified but the selection of appropriate CN's was expanded to include residential, municipal, and commerical land use. The wide acceptance of the curve number method is attested to by the exclusive adoption of this method through legislation or regulation by numerous state and local government agencies.

The curve number method is based on the postulated rainfall-runoff equation:

$$\frac{F}{S} = \frac{Q}{P-I_a} \qquad (4)$$

where F is the actual retention,

S is the potential maximum retention,

Q is the actual runoff,

I_a is the initial abstraction, and

P is the rainfall.

Considering a mass balance

$$F = P-I_a - Q. \qquad (5)$$

Substituting Eq. 5 into Eq. 4 and rearranging results in the runoff equation:

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

According to Eq. 6, runoff (Q) responds to a rainfall (P) as a function of two parameters; S and I_a. The equation was simplified to a one parameter model by developing a relation between I_a and S:

$$I_a = .2S. \qquad (7)$$

Substituting Eq. 7 into Eq. 6 results in the rainfall-runoff equation used in the curve number method.

$$Q = \frac{(P-0.2S)^2}{P + 0.8S}, \qquad P \geqq .2S \tag{8}$$

$$Q = 0 \qquad , \qquad P < .2S$$

Q is actually rainfall excess which is transformed into a time rate of runoff by a unit-hydrograph or hydraulic routing procedure.

The parameter S has been transformed into the curve number parameter (CN) by:

$$CN = \frac{1000}{S+10} \tag{9}$$

The transformation is used to make interpolating, averaging, and weighting operations more nearly liner.

The SCS has provided computational ease to the solution of Eq. 8 by a graphical method, as shown in Figure 3, and tabular form (SCS, 1976).

In recent years the curve number method has been critically examined Hawkins (1975, 1978a, 1978b, 1979, 1980), Hjelmfelt (1980a, 1980b), Bondelid and others (1982), Gray and others (1982), Chen (1982). These recent reevaluations have resulted in concern over the logical development of the rainfall-runoff equation, over the validity of the explicit and implicit assumptions, and in general over the applicability to which the method is presently being used.

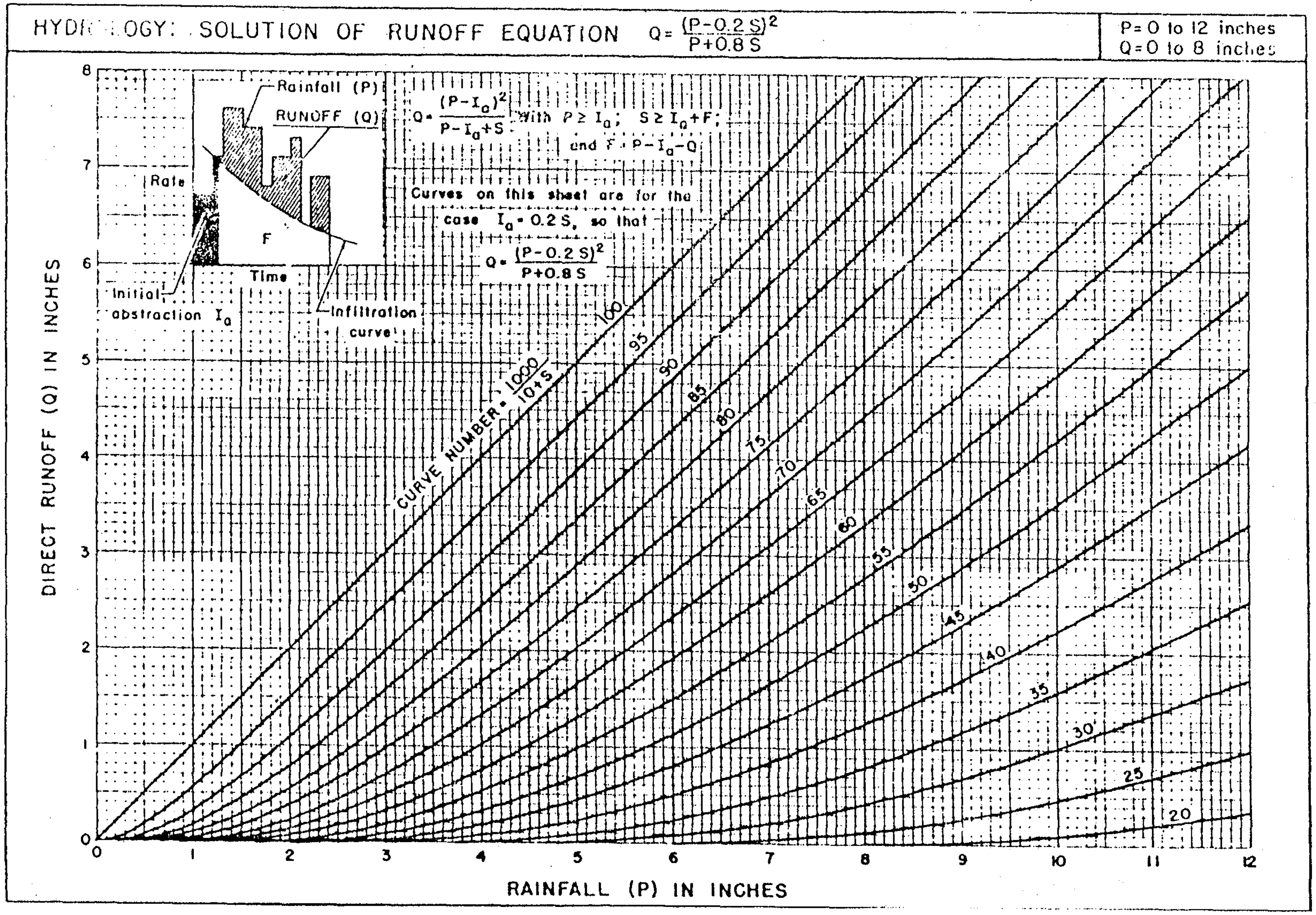


Figure 3.- Graphical solution of SCS rainfall-runoff equation, (SCS, NEH-4, Figure 10.1).

CN Selection

The estimation of rainfall excess by Eq. 8 requires a decision concerning the magnitude and time distribution of rainfall (P), and a selection of CN. Design rainfall magnitudes are commonly available from numerous sources. The selection of an appropriate CN is much more difficult.

The CN selection process is subjective and decisions by the design community may be based more on past acceptance of a value rather than a valid rationale. Soil survey maps are often used to assist in this selection by delineating "hydrologic soil groups" A,B,C, or D. However, the hydrologic soil group designation is based on soil and substrata classification and not actual retention capacity of the soil. Numerous charts and tables are available as a guide to CN selection, but often these values were developed for agricultural conditions in humid zones not reprsentative of Albuquerque. The most authoritative guide to the selection of CN for New Mexico is Table 2-1 of (SCS, 1973), as reproduced in Figure 4.

The CN is a function of soil, vegetation, and land use, and the CN for an undeveloped watershed would be expected to be different than for the same watershed after urbanization. The CN is also a function of soil moisture at the onset of rainfall. The SCS has provided guidence on the selection of the appropriate soil moisture condition to be used based on prior rainfall, as shown in Figure 5. In general useage the three soil moisture conditions are considered to be: AMC-I for "dry" soil, AMC-II for soil in an "average" condition of soil moisture, and AMC-III for "wet" soil. In comparing these general useage definitions to the criteria shown in Figure 5, it would seem that the average condition for Albuquerque mesa soils would be AMC-I. A recent study (Gray, and others, 1982) of precipitation records of 17 stations in Kentucky, Tennessee, and Indiana indicated that 80 to 89% of all days at these stations would be classified as AMC-I, and the average for the 17 stations was 84.8%, 7.2% and 8.1% for AMC-I, II, and III, respectively.

The selection of CN from charts and tables is based on the "average" soil moisture condition, AMC-II. Conversion can then be made to AMC-I or III conditions by Figure 6.

Table 2-1 - Runoff Curve Numbers for Hydrologic Soil-Cover Complexes

(Average antecedent moisture condition and I_a = 0.2 S)

Land Use	Cover Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	" and terraced	Poor	66	74	80	82
	" " "	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
	" and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded	Straight row	Poor	66	77	85	89
Legumes 1/	"	Good	58	72	81	85
or	Contoured	Poor	64	75	83	85
Rotation	"	Good	55	69	78	83
Meadow	" and terraced	Poor	63	73	80	83
	" " "	Good	51	67	76	80
Irrigated Pasture		----	30	58	71	78
Range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		----	74	84	90	92
Commercial and Impervious Areas		----	95	95	95	95
Residential Areas 3/						
High Density (50% to 75% impervious) Multiple Family			82	87	90	92
Medium Density (21% to 27% impervious) Single Family		(Common Lots = 1/4 ac.)	79	84	88	90
Low Density (15% to 18% impervious) Single Family		(Common Lots = 1/2 ac. or larger)	76	81	86	89

1/ Close-drilled or broadcast.
2/ Including right-of-way.
3/ Includes streets, etc.

Figure 4.- Chart for the selection of CN, (SCS, 1973, Table 2-1).

Table 4.2.--Seasonal rainfall limits for AMC.

AMC group	Total 5-day antecedent rainfall	
	Dormant season	Growing season
	Inches	Inches
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

Figure 5.- Criteria for the selection of AMC-I, II, or III, (SCS, NEH-4, Table 4.2).

Table 10.1. Curve numbers (CN) and constants for the case $I_a = 0.2\ S$

1	2	3	4	5	1	2	3	4	5
CN for condition II	CN for conditions I	III	S values*	Curve* starts where P =	CN for condition II	CN for conditions I	III	S values*	Curve* starts where P =
			(inches)	(inches)				(inches)	(inches)
100	100	100	0	0	60	40	78	6.67	1.33
99	97	100	.101	.02	59	39	77	6.95	1.39
98	94	99	.204	.04	58	38	76	7.24	1.45
97	91	99	.309	.06	57	37	75	7.54	1.51
96	89	99	.417	.08	56	36	75	7.86	1.57
95	87	98	.526	.11	55	35	74	8.18	1.64
94	85	98	.638	.13	54	34	73	8.52	1.70
93	83	98	.753	.15	53	33	72	8.87	1.77
92	81	97	.870	.17	52	32	71	9.23	1.85
91	80	97	.989	.20	51	31	70	9.61	1.92
90	78	96	1.11	.22	50	31	70	10.0	2.00
89	76	96	1.24	.25	49	30	69	10.4	2.08
88	75	95	1.36	.27	48	29	68	10.8	2.16
87	73	95	1.49	.30	47	28	67	11.3	2.26
86	72	94	1.63	.33	46	27	66	11.7	2.34
85	70	94	1.76	.35	45	26	65	12.2	2.44
84	68	93	1.90	.38	44	25	64	12.7	2.54
83	67	93	2.05	.41	43	25	63	13.2	2.64
82	66	92	2.20	.44	42	24	62	13.8	2.76
81	64	92	2.34	.47	41	23	61	14.4	2.88
80	63	91	2.50	.50	40	22	60	15.0	3.00
79	62	91	2.66	.53	39	21	59	15.6	3.12
78	60	90	2.82	.56	38	21	58	16.3	3.26
77	59	89	2.99	.60	37	20	57	17.0	3.40
76	58	89	3.16	.63	36	19	56	17.8	3.56
75	57	88	3.33	.67	35	18	55	18.6	3.72
74	55	88	3.51	.70	34	18	54	19.4	3.88
73	54	87	3.70	.74	33	17	53	20.3	4.06
72	53	86	3.89	.78	32	16	52	21.2	4.24
71	52	86	4.08	.82	31	16	51	22.2	4.44
70	51	85	4.28	.86	30	15	50	23.3	4.66
69	50	84	4.49	.90					
68	48	84	4.70	.94	25	12	43	30.0	6.00
67	47	83	4.92	.98	20	9	37	40.0	8.00
66	46	82	5.15	1.03	15	6	30	56.7	11.34
65	45	82	5.38	1.08	10	4	22	90.0	18.00
64	44	81	5.62	1.12	5	2	13	190.0	38.00
63	43	80	5.87	1.17	0	0	0	infinity	infinity
62	42	79	6.13	1.23					
61	41	78	6.39	1.28					

*For CN in column 1.

Figure 6.- Table for the conversion of CN for AMC-II to CN for AMC-I or III, (SCS, NEH-4, Table 10.1).

Sensitivity of the Curve Number Method

The importance of accurate CN's in estimating storm runoff was initially reported by Hawkins (1975). Bondelid and others (1982) evaluated the sensitivity of the curve number method to errors in CN estimates. The proportional change (R_q) in rainfall excess (Q) per unit change in CN is:

$$R_Q = \frac{dQ/Q}{dCN} \qquad (10)$$

Application of Eq. 8 and 9 yields:

$$R_Q = \left(\frac{0.4}{P-.2S} + \frac{0.8}{P+.8S} \right) \frac{1000}{CN^2} \qquad (11)$$

which is based on the assumption $I_a = .2S$. Similar expressions based on the assumptions $I_a = .1S$ and $I_a = .3S$ can be developed. The proportional change in Q for a unit change in CN for the assumptions $I_a = .1S$, .2S, and .3S as a function of rainfall (P) is shown in Figure 7. For example, using the curves for $I_a = .2S$, CN = 70, and a rainfall (P) = 2.0 inches; a unit change in CN to either 69 or 71 results in a 10% change in runoff volume. At these same conditions, a CN error of ± 5 will produce runoff error of ± 50%.

The sensitivity of the curve number method to the assumption concerning the relation of I_a to S can be made graphically. To assist in this the sensitivity curve for CN = 70 from each of the I_a assumptions has been plotted as shown in Figure 8. For CN = 70 and P = 2.0 inches, the proportional change in runoff for a unit change in CN is 5.7%, 10.0%, and 20.0% for $I_a = .1S$, .2S, and .3S, respectively.

The curve number method is extremely sensitive to rainfalls less than about 3.0 inches, it is more sensitive to lower CN's than higher CN's, and it is significantly sensitive to the ratio of I_a to S. The curve number

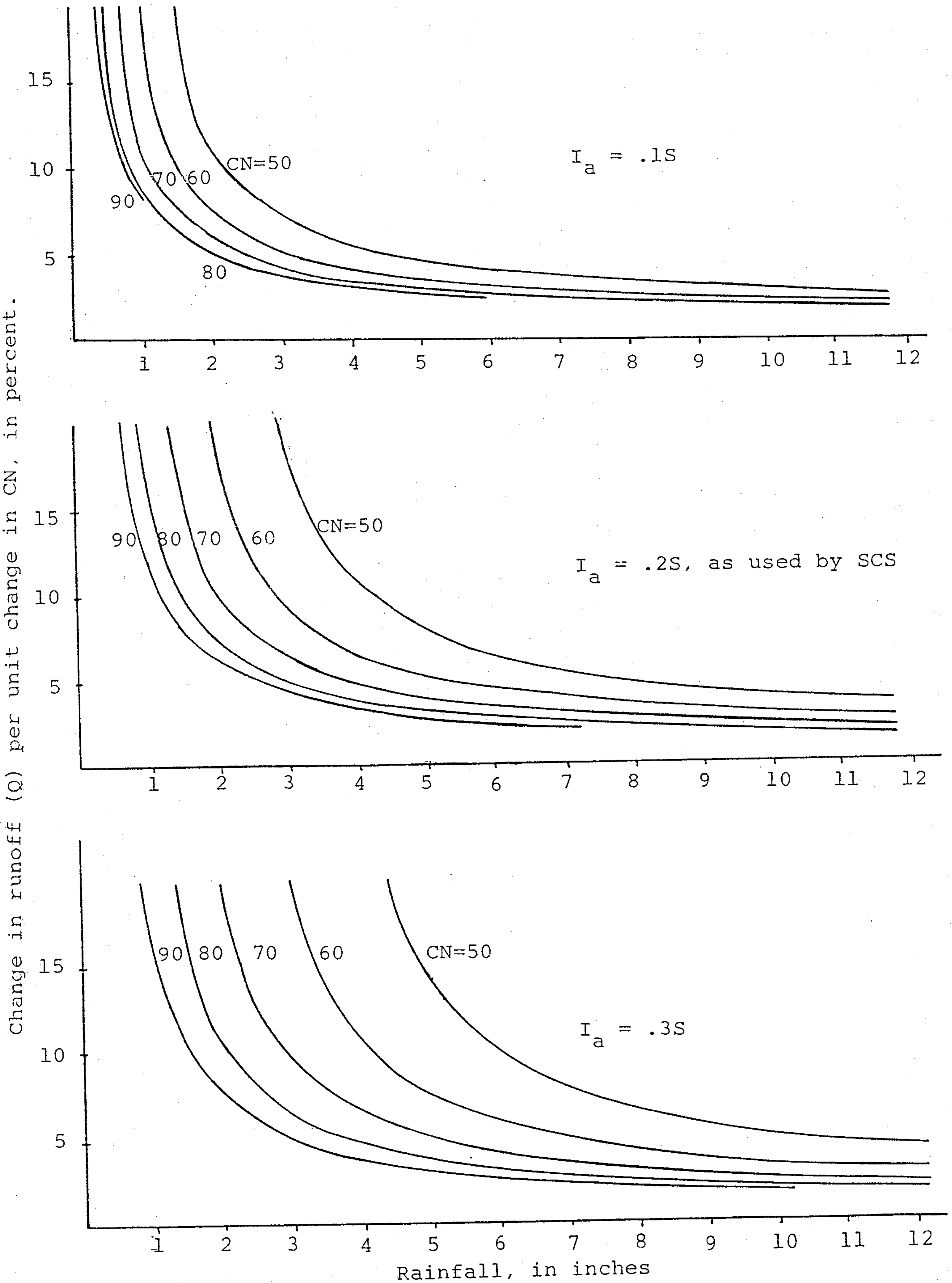


Figure 7.- Sensitivity of the SCS rainfall-runoff equation on the selection of CN.

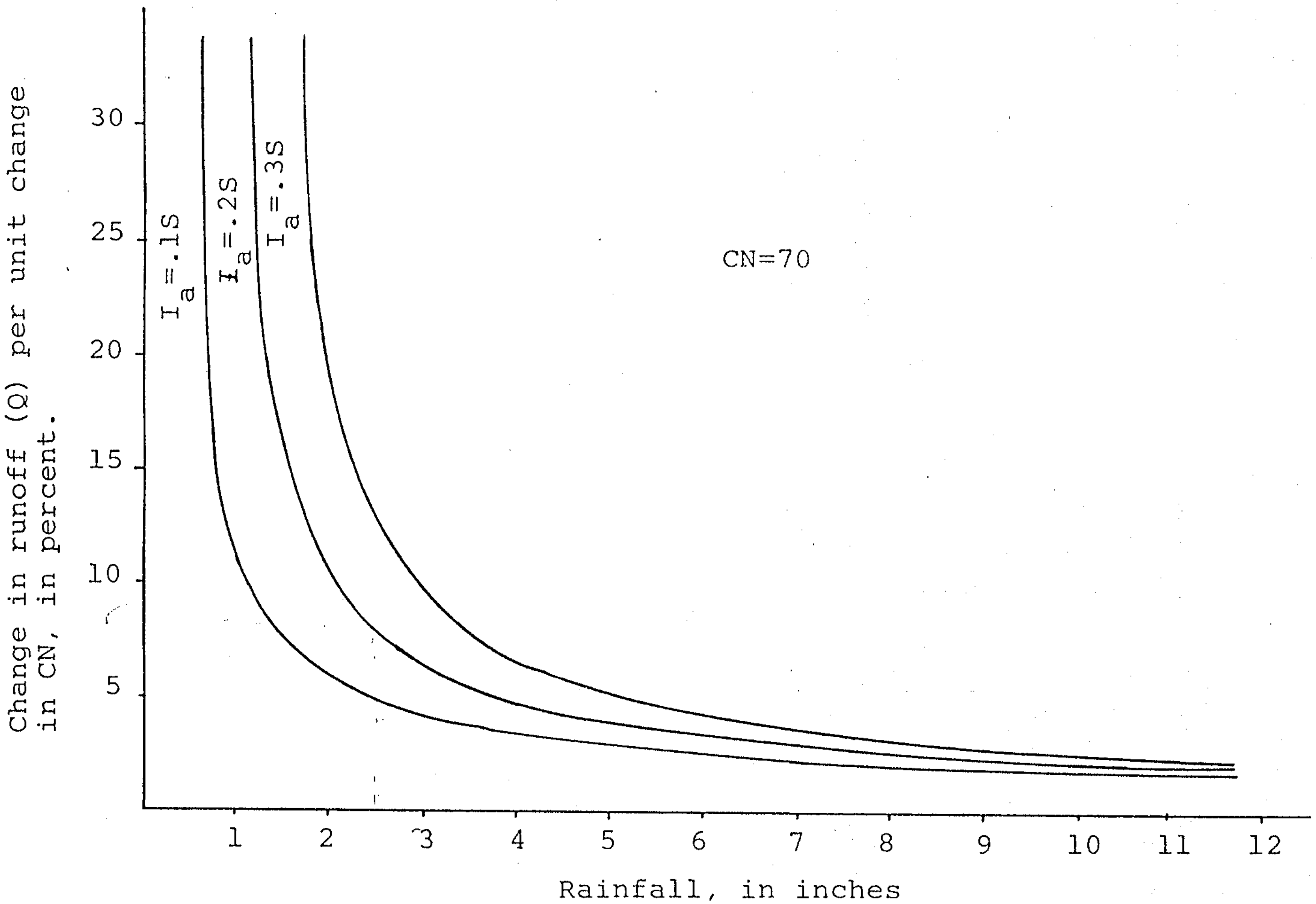


Figure 8.- Sensitivity of the SCS rainfall-runoff equation on the selection of CN and the assumption that I_a=.1S, .2S, or .3S.

method is not as sensitive to rainfall as it is to CN selection; that is, an error in the estimate of P will result in less runoff error than an equal percentage error in the selection of CN.

For Albuquerque, the design 100-yr rainfall varies from 2.2 inches on the west side to 2.8 inches along the foothills on the east, and the typically selected CN will often be in the 70 to 90 range. Consequently considerable error or discrepency in runoff among designers will be encountered. For PMF analyses the rainfall is about 11.0 inches and the CN is usually selected to be in the 90's for ACM-III, and less error or discrepency in runoff among designers would be encountered. Clearly, the critical problem is defining the most appropriate CN that would be representative of average conditions during the occurence of the more frequent (100-yr and less) rainfall events.

Discussion of Curve Number Method

The curve number method is well entrenched in the design community and is probably the most widely used and accepted method in Albuquerque. Its predominant use can be expected for at least the near future. Its vast acceptance indicates a need for an analytic procedure of this type; however, its application should not be accepted without due regard. Specific comments are used to concisely summarize major facts and limitations of the method.

1. The method was originally developed for agricultural use, and was later adopted pro forma for urban planning.
2. Recent investigations have resulted in critical concerns about the development of the rainfall-runoff equation.
3. It was developed in the early 1950's with obvious concern for computational ease, via a one-parameter (CN) equation. The present availability of computers and calculators no longer encourages computation expedience at the expense of analytic accuracy.
4. The method does not contain an expression for time; that is, a runoff from a 2.0-in rainfall in 1-hr will be exactly the same as a 2.0-in rainfall in 24-hrs.
5. The infiltration rate approaches zero rather than a physically justified constant rate (f_c).
6. Both comments 4 and 5 can be overcome by acceptance of a minimum retention loss rate.
7. The infiltration rate rises and falls with varying rainfall intensity, which is not consistent with the accepted Horton type infiltration behavior.

8. The assumption between initial abstraction (I_a) and maximum potential retention (S)

$$I_a = .2S$$

is not justified. Short intense storms are known to have a lesser I_a than long storms. This assumption is probably not valid for Albuquerque design events.

9. The selection of CN is too subjective and is based more on traditional acceptance than scientifically substantiated findings.

10. The guides to selecting CN were mainly developed from data in humid zones.

11. AMC-I has a much higher probability of occurrence than the normally accepted design condition AMC-II.

12. At low rainfalls (less than 4-in), runoff volume is much more sensitive to CN than to rainfall depth. More effort is justified to define accurate CN's than defining design rainfalls.

13. The method is much more sensitive to low CN's than to high CN's. Therefore, much more care should be exercised when selecting the CN for hydrologic soil groups A and B than for soils C and D.

14. The curve number is very sensitive to CN selection for the 100-yr design rainfall. Over estimate or under estimate of runoff volume by a factor of 2.0 could easily be made.

15. The curve number is <u>not</u> very sensitive to CN selection for PMF analyses. Although care must be exercised in CN selection, errors probably will not result in large over designs or under designs.

Green-Ampt equation - An infiltration equation for homogeneous soils was presented by Green and Ampt in 1911. The equation is based on Darcy's law for the movement of water through soil, and on an assumed constant capillary suction of water at the wetting front of the soil.

Several expressions of the Green-Ampt equation are available, one expression is:

$$\frac{F}{\delta} - \ell n \frac{(1 + F)}{\delta} = \frac{Kt}{\delta} \tag{12}$$

where F is infiltrated volume,

K is the hydraulic conductivity of the soil,

t is time, and

δ is the potential head parameter, defined as:

$$\delta = (\theta_w - \theta_i)\psi_{ave} \tag{13}$$

where θ_w is the moisture content of the soil after wetting,

θ_i is the antecedent moisture content, and

ψ_{ave} is the average suction head across the wetting front.

The Green-Ampt equation is a two parameter equation; hydraulic conductivity (K), and average suction head (ψ_{ave}). The solution of Eq. 12 for F cannot be performed directly but must be a trial-and-error type solution, which contributed to its unpopularity for many years.

Numerical analysis routines are available to make the solution of Eq. 12 practical with the use of computers and programmable calculators. The computer modeling of rainfall-runoff processes has resulted in a revived interest in the Green-Ampt equation. Childs and Bybordi (1969) have tested the Green-Ampt equation against infiltration experiments in layered columns of soil and found excellent agreement. Hillel and Gardner (1970) have applied it to infiltration through a surface crust and found the equation satisfactory.

Mein and Larson (1973) have shown the equation to be easily modified to account for infiltration during the period of initial abstraction. Li, Stevens, and Simons (1976) presented methods to solve Eq. 12 that are simple and easy to use with a computer or calculator. Neuman (1976) developed a theoretical expression for the suction head parameter to soil characteristics.

The Green-Ampt equation is a physically justified infiltration equation that has recently undergone significant improvement in regard to its computational ease. Its applicability has been verified for numerous uses. It is presently one of the more popular infiltration equations for computer rainfall-runoff modeling.

SECTION 3

RAINFALL SIMULATOR DATA

General

Rainfall losses, consisting of initial abstraction and infiltration, were estimated by collecting in situ field data. Rather than waiting for naturally occurring rainfall events, a rainfall simulator was employed. The general requirements of the rainfall simulator are that it must simulate the important characteristics of natural rainfall, be economical to use, and be portable. The Civil Engineering Department of New Mexico State University constructed a rainfall simulator based on experience with similar equipment (Sabol and others, 1982). A description of the rainfall simular and the field procedure is provided. The field data collection and rainfall simulator tests were conducted in Albuquerque during the period May 10 through 29, 1982.

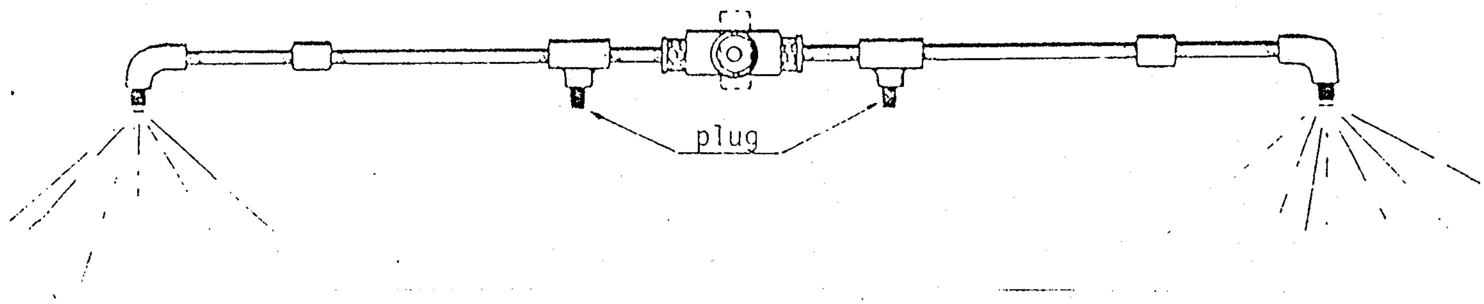
The physical characteristics of the watershed affect rainfall losses. Several of these physical characteristics were quantified by collecting samples, by field measurements, and by photographic documentation. The collected samples required laboratory analyses; these laboratory analyses and results are briefly presented.

Description of Equipment

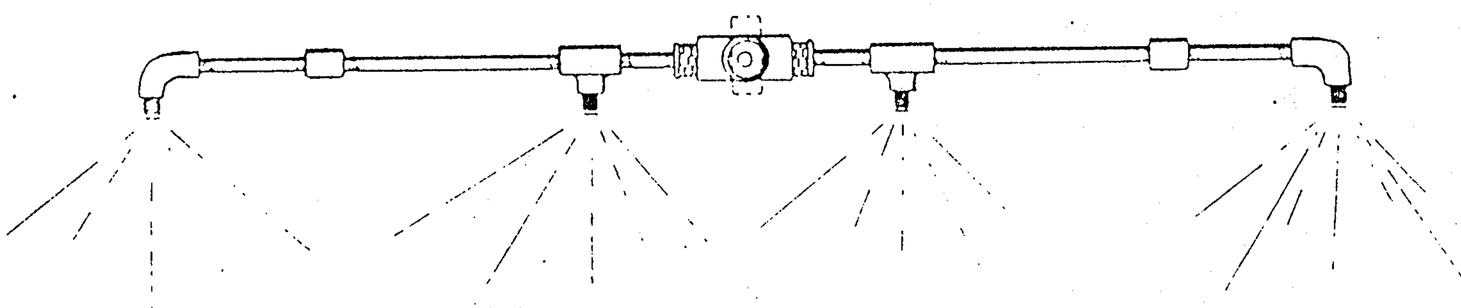
Natural rainstorms display a relationship between rainfall intensity and median drop diameter. For this study, this relationship must be simulated, since both intensity and drop diameter affect the runoff process. Rainfall intensity determines the rate at which water is applied to the land surface per unit of time; the corresponding drop diameter determines the raindrop mass and terminal fall velocity.

In the Albuquerque area, rainstorms which produce significant runoff have intensities from 2.0 to about 9.0 inches per hour (iph). The corresponding median drop diameter is estimated to be between 2.5 and 3.3 mm. These drops have a terminal fall velocity of about 20 feet per second (Meyer, 1979). Figure (9) shows a spray nozzle assembly designed to simulate these characteristics. The assembly contains four ¼-inch spray nozzles arranged in a straight line. Using only the two outer nozzles and a pressure of 2.5 psi produces a rainfall with an intensity of 3.4 iph. Operating all four nozzles at 2.0 psi increases intensity to 9.5 iph. Terminal velocity is achieved by supporting the assembly 9 feet above the test plot.

The rainfall simulator contained two such nozzle assemblies, permitting simultaneous simulation on two test plots. Water was pressurized and conveyed to the nozzles from a storage tank via a centrifugal pump. Gate valves installed between the pump and the nozzle assemblies controlled the pressure. Electricity to operate the pump was provided by a gasoline powered generator. Figure 10 shows the layout of the various components in schematic form. Mounted on a flatbed trailer, this equipment proved sufficiently portable for the study.



Two nozzles operate at 2.5 psi to produce 3.9 iph.



Four nozzles operate at 2.0 psi to produce 9.5 iph.

Figure 9.- Sprinkler head assembly for producing rainfall of either 3.9 iph or 9.5 iph.

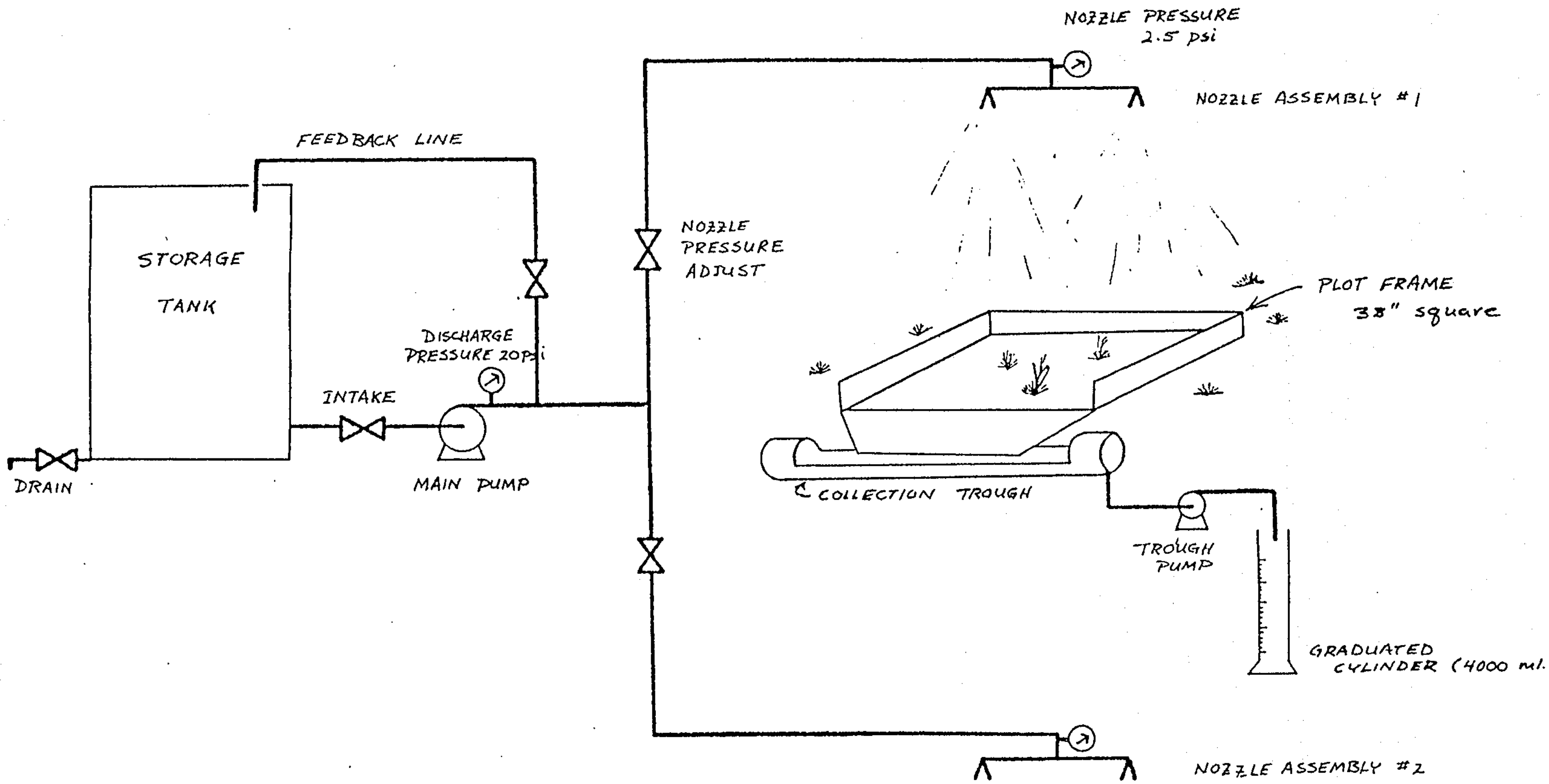


Figure 10.- Schematic layout showing major elements of Rainfall Simulator.

The nozzle assemblies were supported by two booms installed on the rear of the trailer. Both booms were of a fixed height, but adjustable in reach length and radial orientation. Suspending a plumb bob from the center of the nozzle assembly facilitated centering the nozzles over the test plot. Once in position, the booms were locked in place. To minimize wind distortion of the rainfall, a wind screen could be supported from the boom and staked to the ground around the test plot. The booms and wind screen are shown in Figures 11 and 12.

Lateral isolation of the test plot from the surrounding soil was accomplished using a square steel frame. This frame was installed by hammering it into the soil to a depth of approximately 1-inch. One side of this frame was open, permitting runoff from the plot to flow into a collection trough. Periodically this trough was pumped dry in order to measure the incremental volume of runoff. A cumulative depth raingage was placed at each of the four corners of the test plot in order to measure applied rainfall.

The plot frame measured 38-inches square, providing a plot area of roughly 10 square feet. A typical installation of the plot frame and collection trough is shown in Figures 13 and 14.

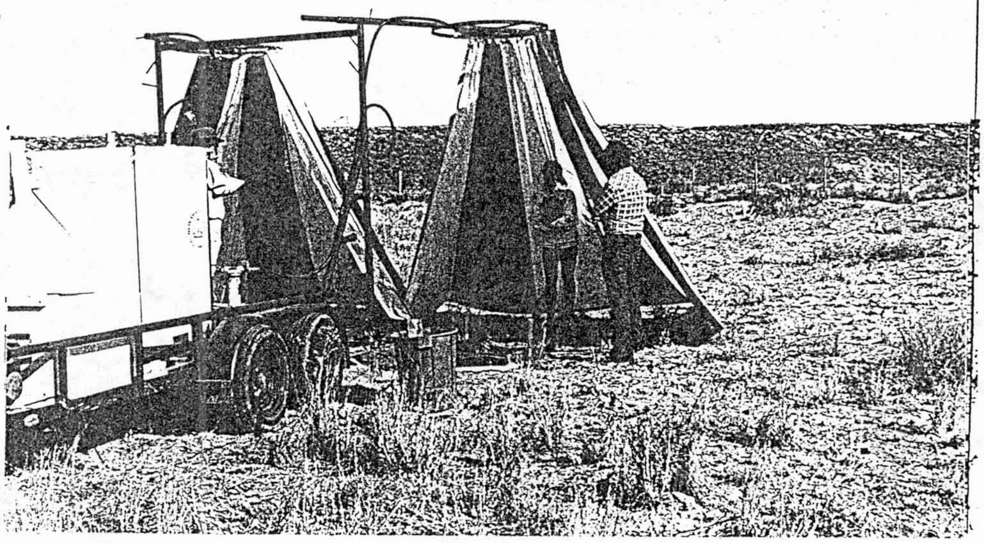


Figure 11.- Rainfall simulator set-up at Ladera golf course, natural conditions.

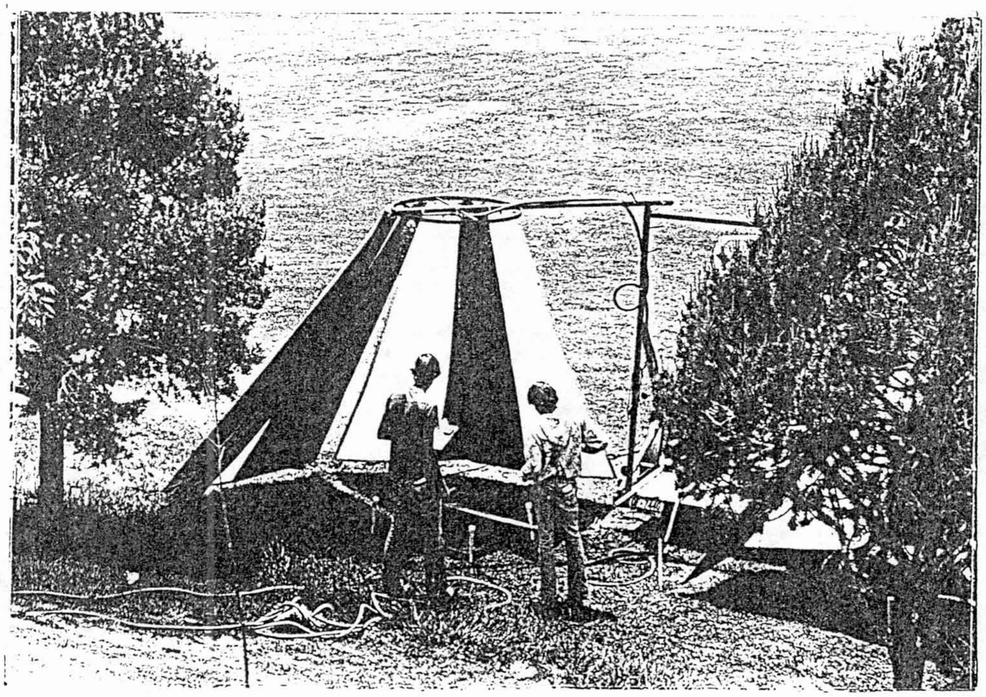


Figure 12.- Rainfall simulator set-up at Albuquerque Academy, developed conditions.

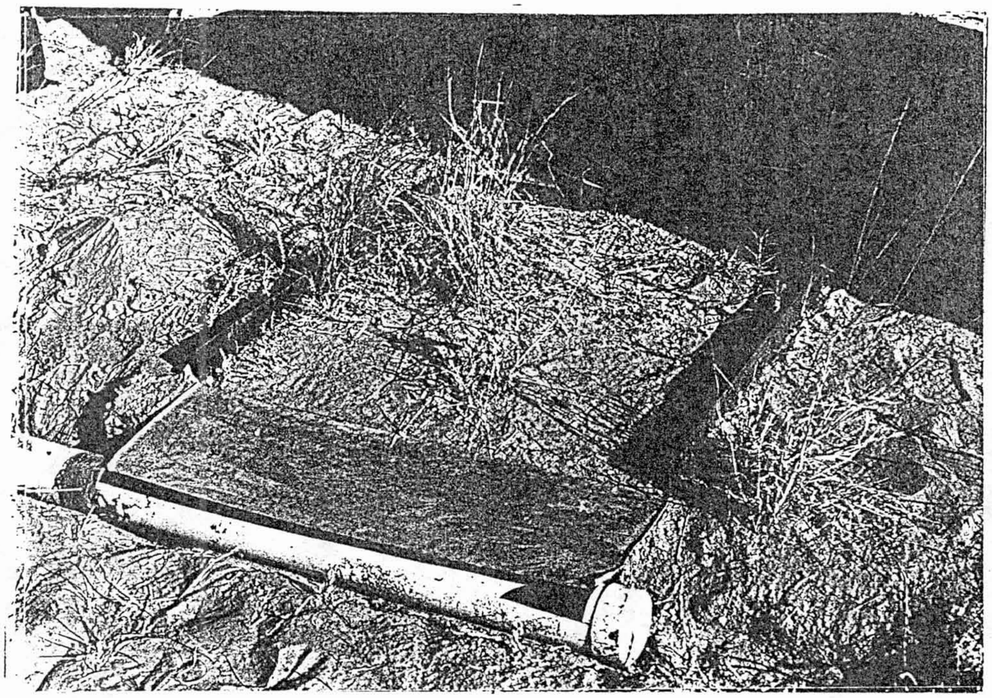


Figure 13.- Installed plot frame & collection trough prior to rainfall.

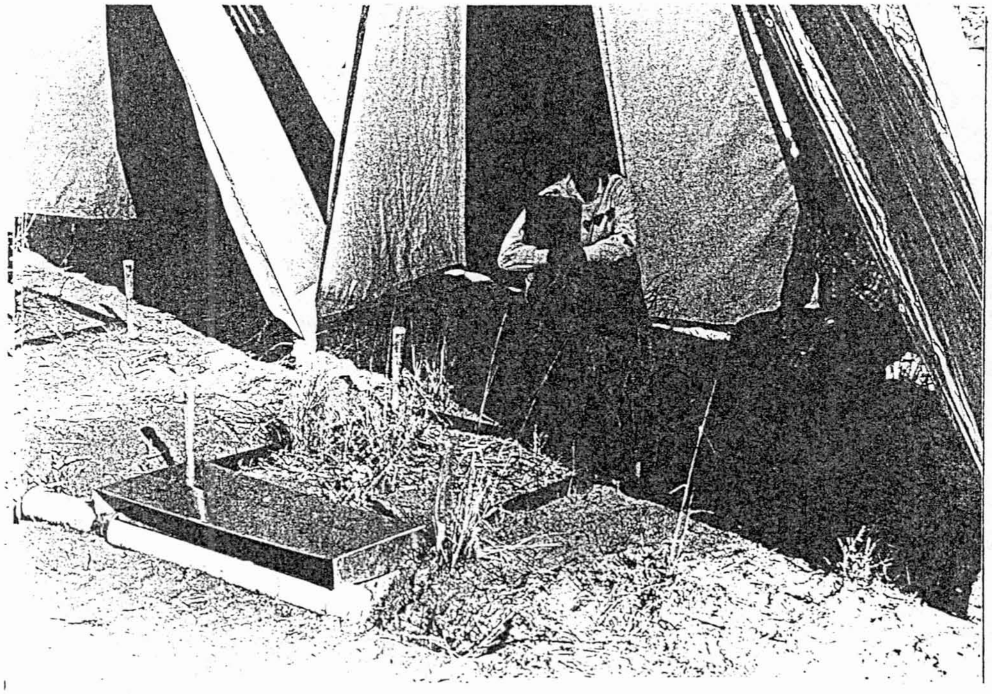


Figure 14.- Installed plot, raingages, and windscreen during rainfall.

Field Procedure

Rainfall and runoff data was generated by simulating a rainstorm of constant intensity above a laterally isolated, but essentially undisturbed plot of soil, a test plot. The runoff from each plot was collected and its volume measured incrementally as time progressed; this volume was expressed as an average depth of runoff from the test plot.

The corresponding depth of precipitation was computed by multiplying the constant rainfall intensity by the elapsed time to each runoff mesurement. In this manner, the relationship between rainfall and runoff over time was empirically determined for a representative sample of the watershed contained within the test plot.

Antecedent soil moisture has been shown to be a significant factor in watershed response to precipitation. Rainfall was simulated twice on each test plot, each simulation applied to different antecedent soil moisture conditions. The first soil moisture was that existing upon installation of the plot frame, while the second was that existing within the same plot following a "resting" period of 12 hours to 24 hours after the initial simulation. Thus, each test plot was subject to simulations on initially dry test plots ("dry" runs), and 12 to 24 hours later, a second simulation on each of these same plots under a condition of higher antecedent soil moisture ("wet" runs).

Simulated rainstorms lasted approximately 45 minutes for dry runs, and 30 minutes for wet runs. Nozzle line pressure was verified throughout the simulation and adjustments were made to maintain a value of either 2.0 psi or 2.5 psi, depending on the nozzle system in use. Upon termination of the storm, the depth of rainfall was recorded for each of the four rain gages. A hole dug in the vicinity of the plot revealed the depth of the wetting front, and a

Brunton compass was used to measure the average dip and strike of the test plot surface. Soil moisture samples were collected prior to each dry and wet run, and a soil gradation sample was removed from the center of the test plot following the wet.

Location of Tests

Rainfall simulator tests were conducted at seven locations in the Albuquerque area; six of the locations were on the west mesa and one location was in the northeast heights. At three of the locations more than one soil or land use classification was tested. In all, ten soil-vegetation-land use complexes (sites) were tested. At most of the sites, four replicate dry runs and four replicate wet runs were performed. A brief description of each of the sites and any deviation from the typical testing follows:

Albuquerque Academy, Developed - Tests were conducted on the Albuquerque Academy athletic field. The vegetation was irrigated turf that was primarily fesque. The soil is classified as Tijeras gravelly fine sandy loam, 1 to 5 percent slopes (TgB) and hydrologic soil group B. Because of mechanical problems and time limitations only two dry run and two wet run replicates could be obtained.

Albuquerque Academy, Natural - Tests were conducted at the Albuquerque Academy on undeveloped areas with natural vegetation. The native plant community is mainly grasses mixed with some shrubs and annual plants generally covering about 15 percent of the surface. The soil is classified as Tijeras gravelly fine sandy loam, 1 to 5 percent slopes (TgB), and hydrologic soil group B. Because of mechanical problems and time limitations only two dry run and two wet run replicates could be obtained.

Black's Arroyo - Tests were conducted in Sandoval County west of Rio Rancho off Southern Blvd. The native plant community is mainly grasses mixed with shrubs and annual plants. The soil is a fine sandy loam of the Grieta series (G), and hydrologic soil group B.

Ladera Golf Course, Developed - Tests were conducted on the Ladera Golf Course. The vegetation was irrigated turf. The soil is classified as Bluepoint loamy fine sand, 1 to 9 percent slopes (BCC), and hydrologic soil group A.

Ladera Golf Course, Natural - Tests were conducted at the Ladera Golf Course on undeveloped areas adjacent to the fairways. The native plant community is a grass-shrub mixture generally covering about 15 percent of the soil surface. The soil is classified as Bluepoint loamy fine sand, 1 to 9 percent slopes (BCC), and hydrologic soil group A.

Paradise Hills - Tests were conducted just south of Paradise Hills off of Paradise Blvd. The native plant community is mainly grasses mixed with some shrubs and annual plants generally covering about 15 percent of the soil surface. The soil is classified as Alameda sandy loam, 0 to 5 percent slopes (AmB), and hydrologic soil group C. The soil is underlain by lava flow in this area and the depth of overlying soil was determined at each plot. Four dry run replicates were obtained, but vandals began destroying the plots that were left for the following day wet runs and only two wet run replicates could be obtained.

Raymac - Two tests were conducted in the southwest portion of Albuquerque below the west mesa escarpment. This area is west of Coors Blvd. and south of Raymac Rd. The soil and vegetation was different for the two test sites. For the site with the designation BCC. The native plant community is mainly grasses mixed with shrubs and annual plants generally covering 10 to 15 percent of the soil surface. The soil is classified as Bluepoint loamy fine sand, 1 to 9 percent slopes (BCC), and hydrologic soil group A. For the site with designation BKD: The native plant community is a grass-shrub mixture that generally covers 10 to 15 percent of the soil surface, with some scattered cactuses. The soil is classified as Bluepoint-Kokan association, hilly (BKD), and hydrologic soil group A. The Kokan association has much more gravel than the Bluepoint, and gravel is mined in this area.

Boca Negra - Tests were conducted on the west mesa near the Boca Negra Park. The native plant community is mainly grasses mixed with some shrubs and annual plants generally covering 15 percent of the soil surface. The soil is classified as Alameda sandy loam, 0 to 5 percent slopes (AmB), and hydrolgic soil group C. The soil is underlain by lava in this area and the depth of overlying soil was determined at each plot.

Volcanos - Tests were conducted on the mesa west of the volcanos. The native plant community is mainly grasses mixed with some shrubs and annual plants generally covering 15 percent of the soil surface. The soil is classified as Maderez-Wink association of fine sandy loam, gently sloping (MWA), and hydrologic soil group B.

The test sites have each been assigned an identification notation as shown in Table 2.

Table 2. - Sites for Albuquerque Rainfall Simulator Tests and Identification Notation.

1.	AA	TGB	D	-	Albuquerque Academy, Developed
2.	AA	TGB		-	Albuquerque Academy, Natural
3.	BA	G		-	Black's arroyo
4.	BN	AMB		-	Boca Negra
5.	L	BCC	D	-	Ladera Golf Course, Developed
6.	L	BCC		-	Ladera Golf Course, Natural
7.	PH	AMB		-	Paradise Hills
8.	RA	BCC		-	Raymac on BCC Soil
9.	RA	BKD		-	Raymac on BKD Soil
10.	V	MWA		-	Volcanos

The following symbol is added to designate dry or wet run and the replicate:

D1 - dry run, 1st replicate

D2 - dry run, 2nd replicate

D3 - dry run, 3rd replicate

D4 - dry run, 4th replicate

W1 - Wet run, 1st replicate

W2 - Wet run, 2nd replicate

W3 - Wet run, 3rd replicate

W4 - Wet run, 4th replicate

Laboratory Analyses

A soil sample can be separated into its various size fractions using a set of nested sieves. The relative proportion of soil in each fraction determines the gradation of the soil, a property which directly affects the soil porosity and hence infiltration rate. A coarse, gravely or sandy soil is generally more infilterable than a tight, fine soil composed primarily of silts and clays. For our study, the following size fractions were defined:

Gravel - 2.0 to 75.0 mm

Sand - .074 to 2.0 mm

Silt and Clay - less than .074 mm

Separation of the silt and clay fractions from the soil samples was best accomplished by "washing" the sample on a #200 sieve (.074 mm dia. opening). In this process, known as wet sieving, a stream of tap water flows through the sample, softening the clay clods and carrying the silt and clay particles through the small sieve openings of the #200 sieve. The residue from the wet sieve process contains only sand and gravel, which is easily graded by gravity sieving through a sieve stack. The proportion of the various soil fractions of each soil sample was expressed in terms of percent by weight of the oven-dry soil sample.

Antecedent soil moisture within the test plot was measured using a soil sample, which was transported to the laboratory in a sealed moisture tin. Gravimetric soil moisture is expressed as grams of soil water contained in each gram of oven-dry soil. The moisture sample was weighed twice, first prior to opening the moisture tin, and later after the sample was oven dried at 105°C for 24 hours. The difference between these values is the grams of water; this divided by the grams of oven dry soil in the sample is the antecedent soil moisture as a fraction.

Test Site Data

Selected field data and accompanying laboratory analyses are listed in Table 3. These include total applied rainfall, total runoff, and rainfall duration. The incremental rainfall-runoff data are included in Appendix A. Color photographs of each plot were obtained. These photographs include a plan view of each plot, simulator set-up, and general surrounding area. These photographs are available for inspection by the project sponsors, their representatives, and other interested engineers and scientists.

The rainfall intensities were seldom exactly 3.9 inches per hour. Differences were related to wind, pump pressure, and position of the sprinkler over the plot. The rainfall was not uniform over the plot. The four raingages were located outside the plot, one at each corner, and the measured rainfall was less than the uniform equivalent rainfall over the plot. Calibration of the system indicated that the raingage values should be multiplied by a correction factor of approximately 1.22. After applying the correction factor, the 45 minute rainfalls averaged 3.86 inches per hour and the 30 minute rainfalls averaged 4.20 inches per hour. The nozzle system will be modified in the future to provide a more uniform distribution of water application over the plot. Nonuniformity does not adversely effect the results because the distribution is fairly symmetrical about the nozzle axis and not random in application. Therefore the rates are dependent on the nozzle position which is a controllable feature.

Table 3. - Summary of Rainfall and Runoff Data, and Certain Plot Characteristics

Site	Test	Rainfall, in Inches	Runoff, in Inches	Rainfall Duration in Minutes	% Gravel	% Sand	% Silt & Clay	Plot Slope, in %
AA TGB D	D1	2.87	1.42	45	28.0	51.8	20.2	19.4
AA TGB D	D2	3.60	1.78	45	28.2	44.0	26.9	17.5
AA TGB D	W1	3.02	0.61	41	28.0	51.8	20.2	19.4
AA TGB D	W2	1.72	1.03	30	28.2	44.0	26.9	17.5
AA TGB	D1	2.39	1.36	45	26.2	46.6	27.2	9.8
AA TGB	D2	2.26	0.76	45	26.6	47.5	25.9	4.7
AA TGB	W1	2.57	0.94	30	26.2	46.6	27.2	9.8
AA TGB	W2	2.15	0.52	31	26.6	47.5	25.9	4.7
BA G	D1	2.53	0.32	32	1.3	57.8	40.9	6.7
BA G	D2	3.11	0.14	31	0.1	81.7	18.2	2.0
BA G	D3	2.61	1.39	45	-	-	-	0.9
BA G	D4	2.70	0.69	45	1.7	62.0	36.3	4.7
BA G	W1	1.75	0.76	30	1.3	57.8	40.9	6.7
BA G	W2	1.89	0.34	30	0.1	81.7	18.2	2.0
BA G	W3	1.50	0.88	30	-	-	-	0.9
BA G	W4	1.73	0.52	30	1.7	62.0	36.3	4.7

Table 3. - Continued

Site	Test	Rainfall, in Inches	Runoff, in Inches	Rainfall Duration, in Minutes	% Gravel	% Sand	% Silt & Clay	Plot Slope, in %
BN AMB	D1	2.60	0.49	45	3.4	73.2	23.4	5.8
BN AMB	D2	2.67	0.30	45	4.4	75.4	20.3	7.7
BN AMB	D3	2.03	0.08	45	3.4	84.9	11.7	9.6
BN AMB	D4	3.52	0.18	45	6.5	80.2	13.3	3.8
BN AMB	W1	1.88	0.69	30	3.4	73.2	23.4	5.8
BN AMB	W2	1.81	0.27	30	4.4	75.4	20.3	7.7
BN AMB	W3	1.27	0.48	30	3.4	84.9	11.7	9.6
BN AMB	W4	1.84	0.14	30	6.5	80.2	13.3	3.8
L BCC D	D1	2.55	0.0	45	0.0	89.5	10.5	0.3
L BCC D	D2	2.88	0.0	45	0.0	87.1	12.9	4.1
L BCC D	D3	2.81	0.06	45	0.0	92.0	8.0	7.7
L BCC D	D4	2.76	0.0	45	0.0	92.4	7.6	2.0
L BCC D	W1	2.44	0.12	30	0.0	89.5	10.5	0.3
L BCC D	W2	2.85	0.0	45	0.0	87.1	12.9	4.1
L BCC D	W3	2.33	0.43	30	0.0	92.0	8.0	7.7
L BCC D	W4	2.24	0.27	30	0.0	92.4	7.6	2.0
L BCC	D1	3.39	0.50	45	0.0	87.5	12.5	7.9
L BCC	D2	3.57	0.15	45	0.0	93.2	6.8	7.9
L BCC	D3	3.00	0.02	45	0.0	92.0	8.0	6.4
L BCC	D4	3.55	0.0	45	0.5	91.4	8.1	7.9
L BCC	W1	2.37	0.74	30	0.0	87.5	12.5	7.9
L BCC	W2	1.69	0.52	30	0.0	93.2	6.8	7.9
L BCC	W3	2.10	0.11	30	0.0	92.0	8.0	6.4
L BCC	W4	1.90	0.34	30	0.5	91.4	8.1	7.9

Table 3. - Continued

Site	Test	Rainfall in Inches	Runoff in Inches	Rainfall Duration in Minutes	% Gravel	% Sand	% Silt & Clay	Plot Slope, in %
PH AMB	D1	2.89	0.66	45	3.6	72.4	24.0	5.8
PH AMB	D2	3.00	0.06	45	3.8	74.6	21.6	9.6
PH AMB	D3	2.35	0.53	45	-	-	-	-
PH AMB	D4	3.37	0.49	45	-	-	-	-
PH AMB	W1	1.92	0.55	30	3.6	72.4	24.0	5.8
PH AMB	W2	2.10	0.20	30	3.8	74.6	21.6	9.6
RA BCC	D1	3.72	0.41	45	1.9	81.7	16.4	3.8
RA BCC	D2	3.26	0.31	45	1.4	80.8	17.8	3.8
RA BCC	D3	3.15	0.06	45	2.4	78.9	18.7	5.8
RA BCC	D4	2.73	0.05	45	6.8	75.3	17.9	7.9
RA BCC	W1	2.11	0.95	30	1.9	81.7	16.4	3.8
RA BCC	W2	1.83	1.11	30	1.4	80.8	17.8	3.8
RA BCC	W3	2.25	0.79	30	2.4	78.9	18.7	5.8
RA BCC	W4	1.86	0.68	30	6.8	75.3	17.9	7.9
R BKD	D1	3.48	0.58	45	33.9	52.6	13.6	13.4
R BKD	D2	4.36	1.99	45	50.6	37.0	12.4	11.4
R BKD	D3	2.74	0.86	45	55.9	30.3	13.8	11.4
R BKD	D4	2.60	0.93	45	57.1	35.2	7.7	11.4
R BKD	W1	1.28	0.42	19	33.9	52.6	13.6	13.6
R BKD	W2	0.92	0.54	19	50.6	37.0	12.4	11.4
R BKD	W3	2.05	0.97	30	55.9	30.3	13.8	11.4
R BKD	W4	3.21	1.63	30	57.1	35.2	7.7	11.4

Table 3. - Continued

Site	Test	Rainfall, in Inches	Runoff, in Inches	Rainfall Duration, in Minutes	% Gravel	% Sand	% Silt & Clay	Plot Slope, in %
V MWA	D1	2.83	1.25	45	0.0	51.9	48.1	3.2
V MWA	D2	3.15	1.64	45	0.0	48.0	52.0	2.0
V MWA	D3	3.91	1.74	45	0.0	68.4	31.6	4.0
V MWA	D4	2.38	1.02	45				1.9
V MWA	W1	2.70	1.61	30	0.0	51.9	48.1	3.2
V MWA	W2	2.32	1.46	30	0.0	48.0	52.0	2.0
V MWA	W3	2.09	1.01	30	0.0	68.4	31.6	4.0
V MWA	W4	1.96	1.14	30				1.9

SECTION 4

DATA ANALYSIS

General

The data from the rainfall simulations have been analyzed to determine the rainfall losses for the test sites. These analyses have been limited to an investigation of the soil moisture content that can be expected prior to summer thunderstorms; the initial abstraction and ponding loss prior to the beginning of runoff; the ratio of runoff to rainfall; fitting of the data to the SCS rainfall-runoff equation; and estimation of the Green-Ampt infiltration parameters. The basic rainfall-runoff data are included in Appendix A. Data was also collected on the sediment that was eroded from the plot and carried off as suspended load and bed load. The sediment data has not been analyzed but is available for analysis in the future.

Initial Abstraction

Initial abstraction is the total of all rainfall losses prior to runoff. For test sites this would primarily be infiltration and surface ponding. The initial abstractions for all the test plots are listed in Table 4. Initial abstraction was calculated as the product of rainfall intensity times the elapsed time to observed runoff. The average initial abstraction for the dry and wet replicates was 0.67 and 0.19 inches, respectively. The amount of depression storage would be approximately the same for both dry and wet replicates with the difference of 0.48 inches being almost exclusively infiltration. The data indicate that depression storage losses in undeveloped areas of Albuquerque are about 0.1 to 0.2 inch.

In Albuquerque, flood detention dams are often designed for the 100-year rainfall event of 2.2 to 2.6 inches. The depression storage loss would be about 4 to 10 percent of the rainfall. At this time, based upon the limited amount of data a depression storage loss of 0.1 inch could probably be conservatively assumed for Albuquerque undeveloped areas. Sufficient data are presently not available to estimate the depression storage loss for developed areas.

Table 4. - Initial abstraction, in inches.

	Dry Replicates					Wet Replicates				
Site	D1	D2	D3	D4	Avg	W1	W2	W3	W4	Avg
AA-TGB-D	0.52	0.20	-	-	0.36	0.10	0.29	-	-	0.20
AA-TGB	0.21	0.25	-	-	0.23	0.15	0.12	-	-	0.14
BA-G	0.43	0.95	0.15	0.18	0.43	0.16	0.16	0.25	0.20	0.14
BN-AMB	0.39	0.44	0.68	0.58	0.52	0.25	0.26	0.07	0.58	0.29
L-BCC-D	*	*	1.41	*	1.41	1.95	*	1.07	1.36	1.46
L-BCC	0.62	1.23	1.57	*	1.14	0.16	0.10	0.17	0.09	0.13
PH-AMB	0.74	2.22	0.13	0.42	0.88	0.24	0.47	-	-	0.36
RA-BCC	0.97	1.47	1.59	2.43	1.62	0.11	0.12	0.28	0.19	0.18
RA-BKD	0.39	0.28	0.34	0.29	0.33	0.14	0.12	0.09	0.23	0.15
V-MWA	0.09	0.14	0.17	0.11	0.13	0.13	0.12	0.14	0.10	0.12

Mean ± one standard deviation

(for undeveloped areas only)

Dry - 0.67 ± 0.64

Wet - 0.19 ± 0.11

Means significantly different at 1% level from t-test.

- Indicates test not run.

* Indicates missing data.

Antecedent Soil Moisture

The soil moisture contents prior to the initiation of rainfall for all the replicates are listed in Table 5. The average soil moisture content for the dry replicates was 4.1%. Two of these sites were developed and would have been subject to frequent irrigation, therefore having higher soil moisture. The average soil moisture of the eight natural sites is 2.3%. Antecedent moisture content (AMC) for the SCS method is not defined in terms of percent soil moisture (see Figure 5); however, it is reasonable to assume that the soil moisture prior to the dry runs on undeveloped sites would best be described as AMC-I. An AMC-II probably occurs on irrigated lawns.

The average soil moisture content for the eight natural site wet runs was 9.6%. This is about a four fold increase in soil moisture resulting from about 3.0 inches of rainfall on the previous day (12 to 24 hours earlier). According to the SCS criteria (see Figure 5) this would constitute sufficient antecedent rainfall to be classified as AMC-III. After 3.0 inches of rainfall on the preceeding day the soil was about 20 to 25% of saturation. This bodes well for runoff potential as the soils drained quickly to provide a sink for the next rainfall.

Table 5. - Antecedent soil moisture content by gravimetric basis, in percent

	Dry Replicates					Wet Replicates				
	D1	D2	D3	D4	Avg.	W1	W2	W3	W4	Avg
AA-TGB-D	*	17.0	-	-	17.0	22.0	28.0	-	-	25.0
AA-TGB	3.0	3.0	-	-	3.0	9.0	8.0	-	-	8.5
BA-G	1.8	2.0	1.9	1.6	1.8	9.9	9.7	13.3	12.5	11.4
BN-AMB	*	2.6	1.2	1.0	1.6	11.4	12.7	7.8	7.3	9.8
L-BCC-D	*	*	6.1	*	6.1	12.1	*	9.7	10.2	10.7
L-BCC	0.7	0.8	0.6	*	0.7	7.5	8.1	7.5	6.5	7.4
PH-AMB	1.3	*	1.2	0.8	1.1	13.8	*	-	-	13.8
RA-BCC	1.3	1.5	1.5	1.3	1.4	7.1	5.5	6.4	7.5	6.6
RA-BKD	1.4	0.9	1.6	1.2	1.3	6.5	6.3	5.7	5.5	6.0
V-MWA	10.0	10.0	5.0	4.0	7.2	17.0	21.0	14.0	12.0	16.0

Mean $\pm$ one standard deviation

(for undeveloped areas only)

Dry 2.3 $\pm$ 2.4

Wet 9.6 $\pm$ 3.8

Means significantly different at 1% level by t-tests.

- Indicates test not run.

* Indicates missing data.

Ratio of Runoff to Rainfall

The Rational Equation is a computational rainfall-runoff model. Prior to the development of more sophisticated methods it was the most widely used method for designing drainage facilities for urban areas and highways. Its use today in the design of facilities for drainage areas larger than a few acres is not justified. Nevertheless, its use is well entrenched in civil engineering and has value as a preliminary estimating technique.

The Rational Equation was introduced in the United States by Emil Kuichling in 1889. It is an equation for estimating peak runoff rates and neither a runoff hydrograph nor runoff volume are obtained.

The equation is:

$$q_p = CiA \tag{14}$$

where q_p is the peak runoff rate, in cfs,

C is the runoff coefficient,

i is the average rainfall intensity, in in/hr, lasting for a critical period of time, t_c,

t_c is the time of concentration for the watershed, and

A is the drainage area, in acres.

The runoff coefficient is dimensionless because 1.008 acre-inch/hr is equivalent to 1.0-cfs. The range of C is from 1.008 for an impervious surface to 0.0 for a completely absorbent surface. The range of C is usually taken from 1.0 to 0.0 leading to C being thought of in terms of percent runoff; however, this range is simply a fortuitous quirk of the dimensions of the equation.

The product Ci is the peak runoff intensity, in in/hr, which can be calculated from the rainfall simulation data by:

$$Ci = q_p \tag{15}$$

and C estimated by:

$$C = \frac{q_p}{i} \tag{16}$$

where q_p is the peak runoff rate in inches per hour, and

i is the rainfall simulator intensity.

However, since $q_p = \Delta Q/\Delta t$ and $i = \Delta P/\Delta t$

$$C = \frac{\Delta Q}{\Delta P} \tag{17}$$

For a previous soil, q_p increases with time as infiltration decreases, therefore C increases with time. To be consistent, the runoff coefficient has been estimated for each site from the rainfall simulation data using total runoff and total rainfall for the duration of the test as ΔQ and ΔP, respectively. These results are shown in Table 6. For each of the sites the runoff coefficients for the dry replicates and the wet replicates have been averaged, and the runoff coefficient to be applied to initially dry soil differs from that to be applied to soil with high initial soil moisture. The average ratio of runoff to rainfall for undeveloped sites on dry soil is 0.22 and the ratio for wet soil is 0.37, or a 170% increase. This can be compared to the 400% increase in soil moisture and a 70% decrease in initial abstraction. These percentages indicate that although abstractions and soil moisture storage are decreasing there is not a like increase in runoff. This implies that infiltration rate is a strong control on runoff.

Table 6. - Ratio of runoff to rainfall (estimated runoff coeffiecient for the Rational Equation).

	Dry Replicates					Wet Replicates				
Site	D1	D2	D3	D4	Avg.	W1	W2	W3	W4	Avg.
AA-TGB-D	.49	.50	-	-	.50	.20	.60	-	-	.40
AA-TGB	.57	.34	-	-	.46	.37	.24	-	-	.30
BA-G	.12	.05	.53	.26	.24	.43	.18	.59	.30	.38
BN-AMB	.19	.11	.04	.05	.10	.37	.15	.38	.08	.24
L-BCC-D	*	*	.02	*	.02	.05	*	.20	.11	.12
L-BCC	.15	.04	.01	*	.07	.31	.31	.05	.18	.21
PH-AMB	.23	.02	.23	.15	.16	.28	.09	-	-	.18
RA-BCC	.11	.10	.02	.02	.06	.45	.61	.35	.37	.44
RA-BKD	.17	.47	.31	.36	.33	.32	.58	.47	.51	.47
V-MWA	.44	.52	.45	.43	.46	.60	.63	.48	.58	.57

Mean ± one standard deviation

(for undeveloped areas)

Dry .22 ± .18

Wet .37 ± .17

Means significantly different at 1% by t-test.

- Indicates test was not run.

* Indicates no runoff.

Fit to SCS Rainfall-Runoff Equation

Several mathematical methods were attempted to relate the rainfall simulator data to the SCS rainfall-runoff equation and to the determination of the "best" CN value. One method was the calculation of S from Eq. 4 and the conversion of S to CN by Eq. 9. The result of this indicated that CN decreased with time during the rainfall. For example, for test plot RA BCC D2 the calculated CN decreased during the 45 minute rainfall duration as 97, 84, 73, 64, and 54 for the five measured rainfall & runoff coordinates. All data sets but a few demonstrated this decreasing CN behavior. The decrease of CN with time during rainfall has been reported by other researchers (Hawkins, 1979). This method gave inconclusive results and was unsettling because it demonstrated the inability of the SCS rainfall-runoff equation to fit the data.

Another method was attempted to fit both the parameters I_a and S from Eq. 4. This was accomplished using a nonlinear least square statistical fit procedure. The results were not acceptable because the statistical best fit often resulted in a negative value for I_a. A negative I_a is physically impossible. This implies that an optimal I_a is very small and the mathematical procedure is producing results that fluctuate about zero. This is unacceptable as measured abstractions have values greater than zero.

The method that has been adopted for data presentation with respect to the SCS rainfall-runoff equation is plotting the calculated rainfall (P) and the measured runoff (Q) on enlarged graphs of the SCS rainfall-runoff equation (Figure 3). Two graphs were used for each site, one for dry replicates and the other for wet replicates. These are shown in Figures 15 through 34.

The accumulated rainfall was calculated by multiplying the rainfall intensity by the elapsed time from the start of rainfall to the measurement of runoff. The initial abstraction is shown for each run as the data point on the abscissa (maximum P for which Q equals zero). The envelope containing all data points is stippled. By this method the range of the CN value can be demonstrated and the most appropriate CN for a given P can be selected.

Conclusions that have been made in analyzing the data with respect to the SCS rainfall-runoff equation are:

1. The use of hydrologic soil group and SCS aids for the selection of CN does not in general indicate the most appropriate CN for tested plots.
2. The rainfall-runoff data do not follow a constant CN line, but rather CN generally decreases with time during rainfall. This may indicate a deficiency in the basic rainfall-runoff equation or in the assumptions.
3. In two cases the same soil classification was tested at two different sites; that is, BCC soil was tested at Raymac and Ladera, and AMB was tested at Paradise Hills and Boca Negra. In both of these cases the data is sufficiently similar to conclude that rainfall simulator results can be transferred to other areas of the same soil classification.
4. There is a high degree of variability from one plot to another for a site and four replicates may not be sufficient to obtain a statistically significant sample, but provides a basis for quantitative comparisons between sites and hypothesis testing using nonparametric statistics.

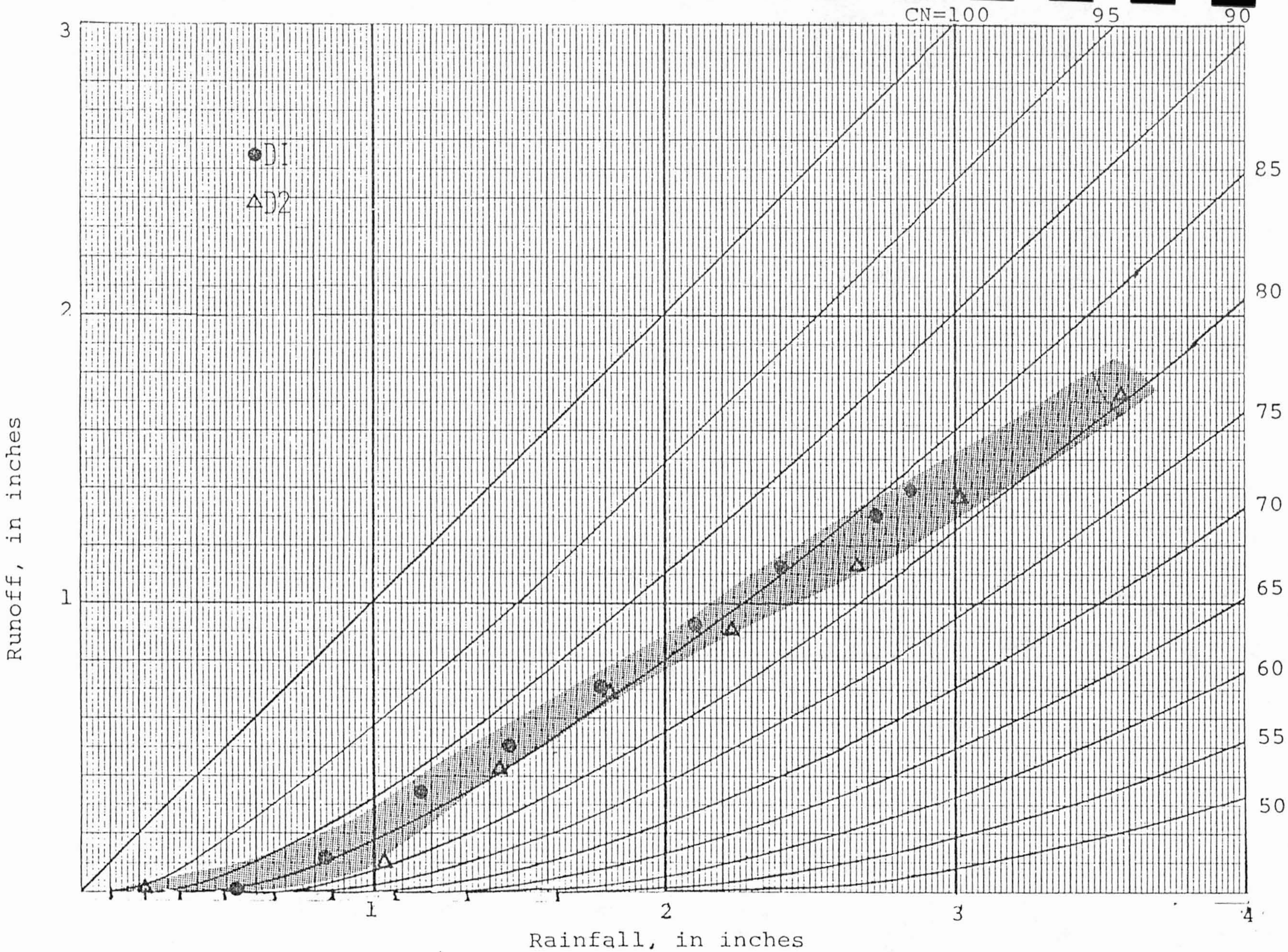


Figure 15.- Fit to SCS rainfall-runoff equation for site AA-TGB-D, dry runs.

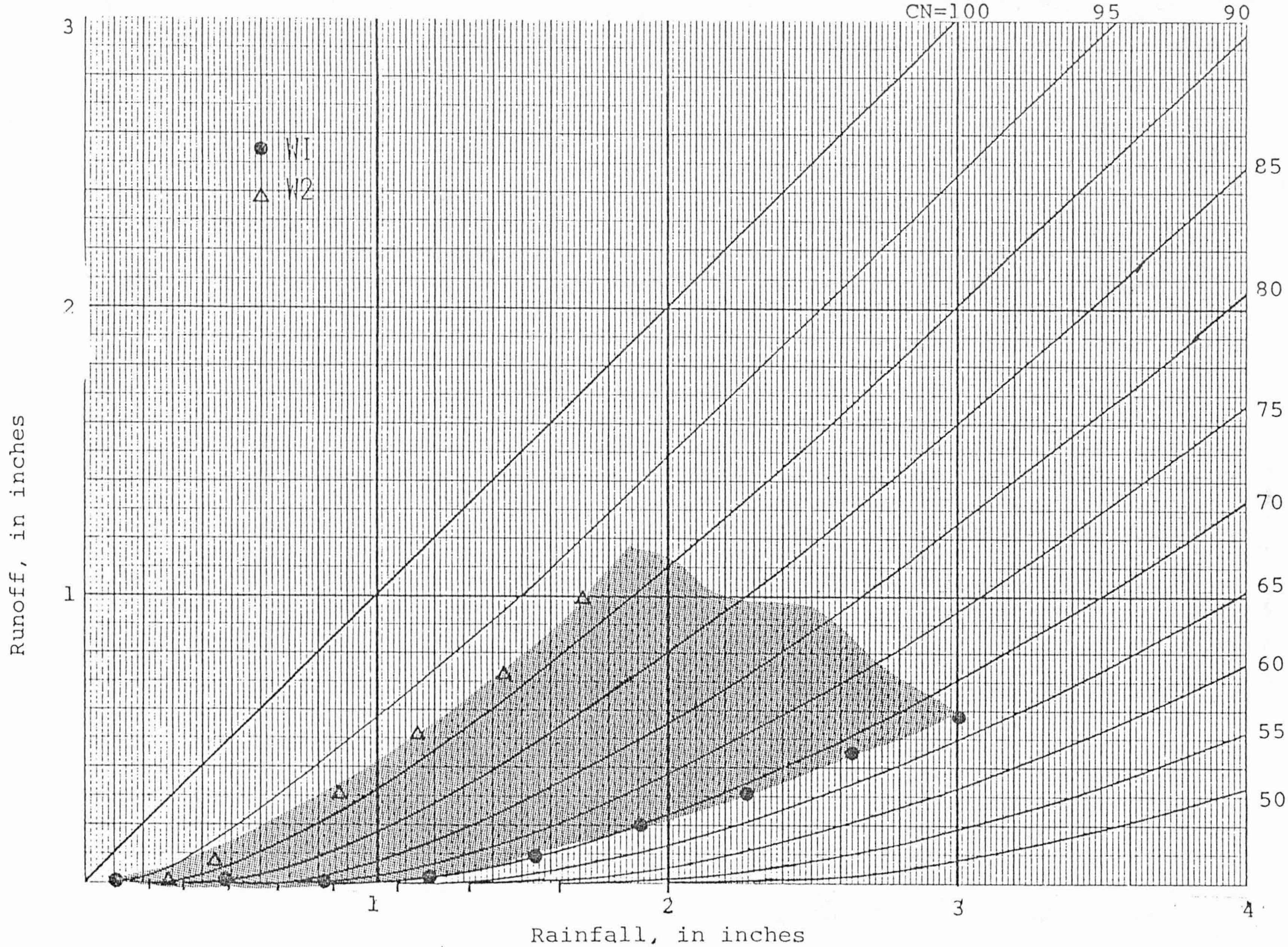


Figure 16.- Fit to SCS rainfall-runoff equation for site AA-TGB-D, wet runs

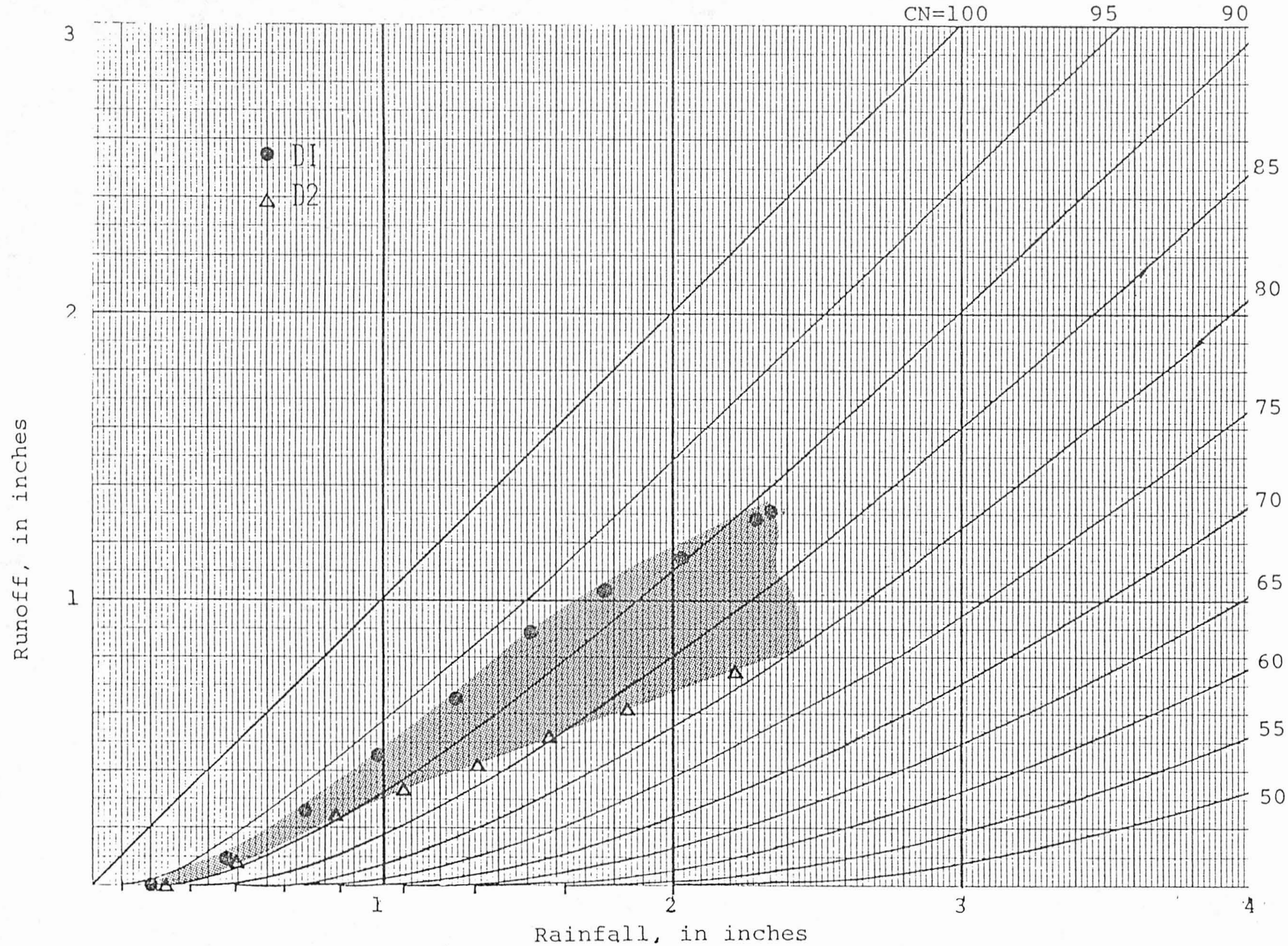


Figure 17.- Fit to SCS rainfall-runoff equation for site AA-TGB , dry runs. CN=79, selected from SCS criteria (Figure 4).

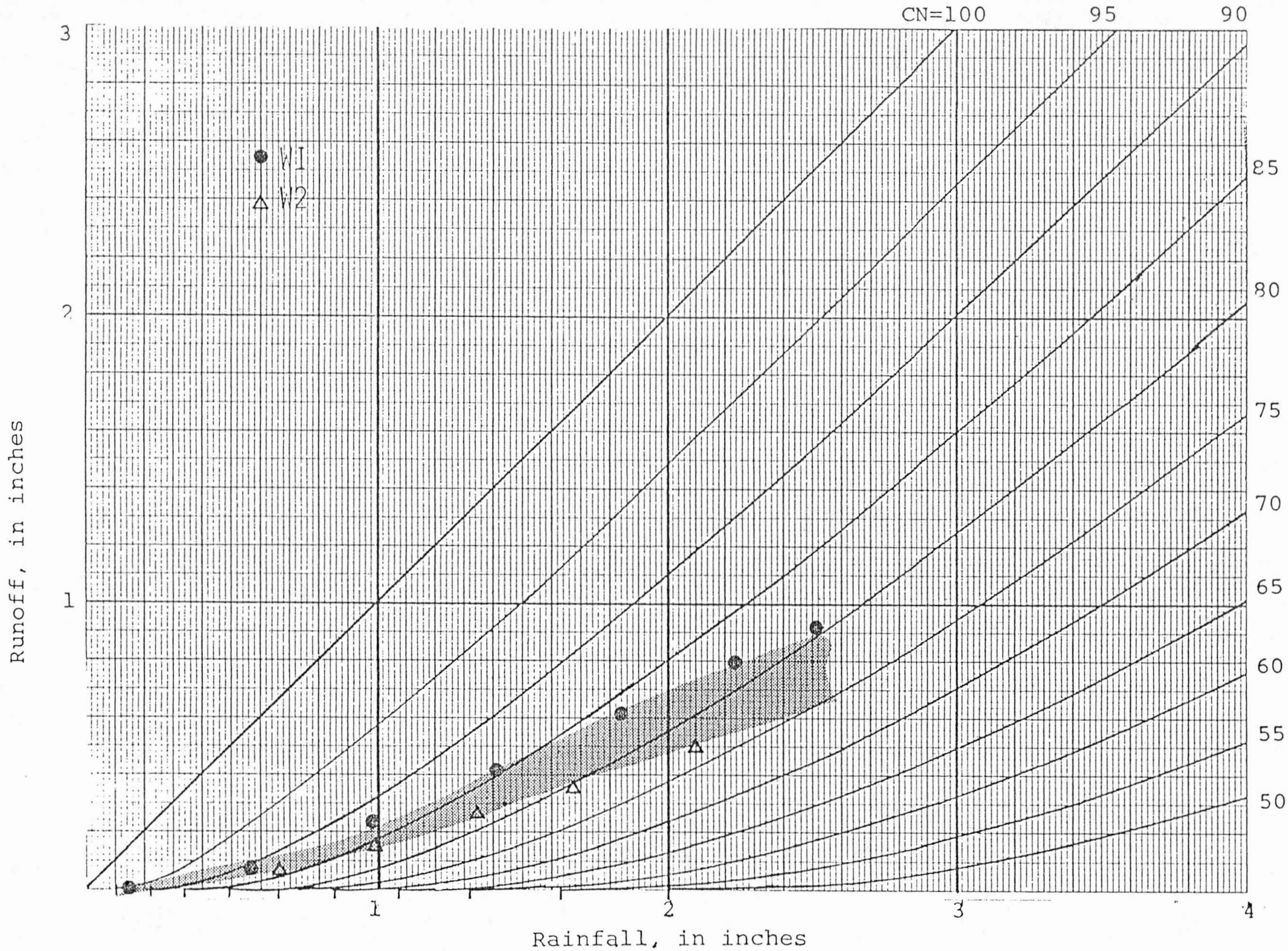


Figure 18.- Fit to SCS rainfall-runoff equation for site AA-TGB, wet runs.
CN=91, selected from SCS criteria (Figures 4 & 6).

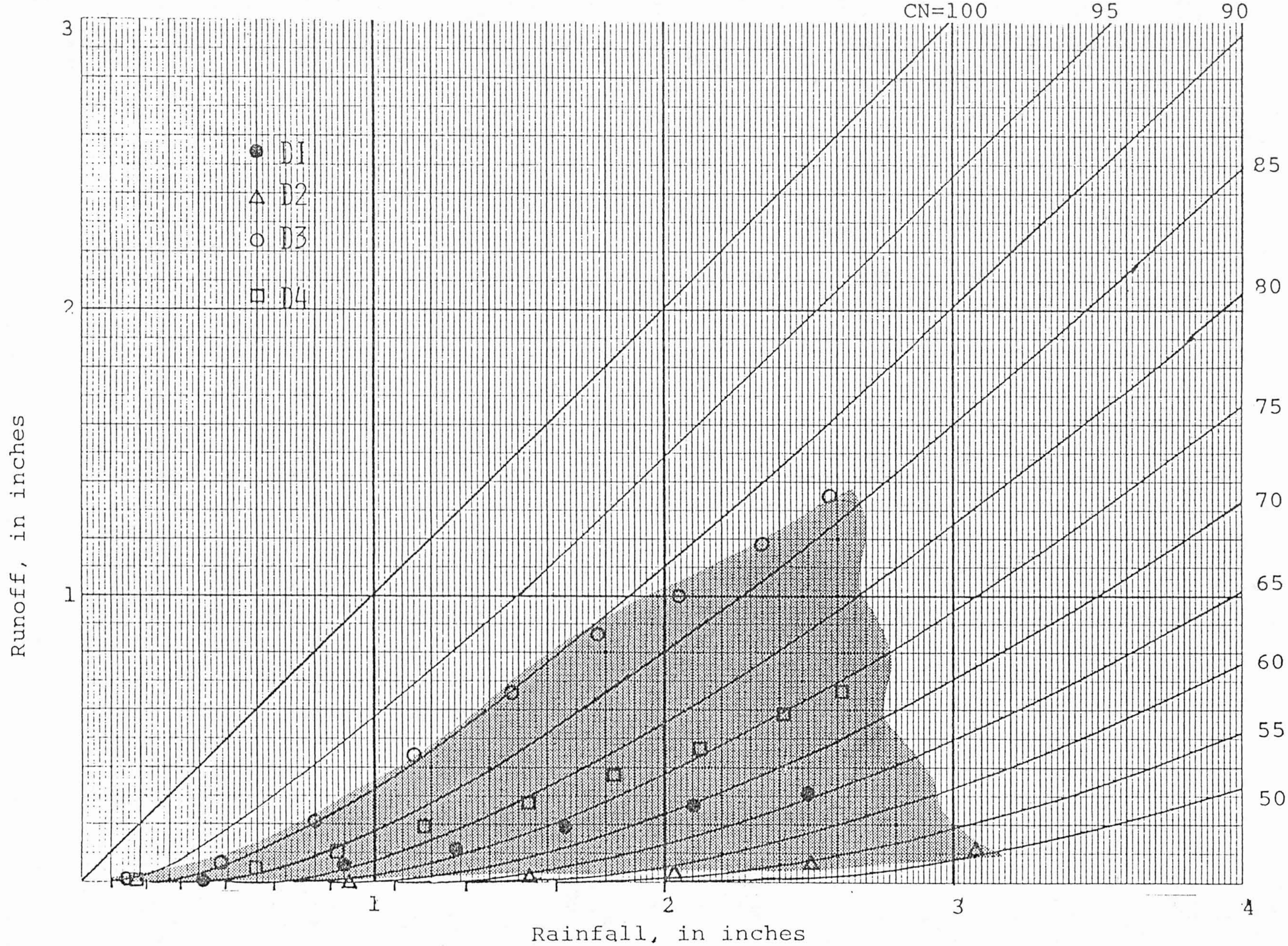


Figure 19.- Fit to SCS rainfall-runoff equation for site BA-G, dry runs. CN=79, selected from SCS criteria (Figure 4).

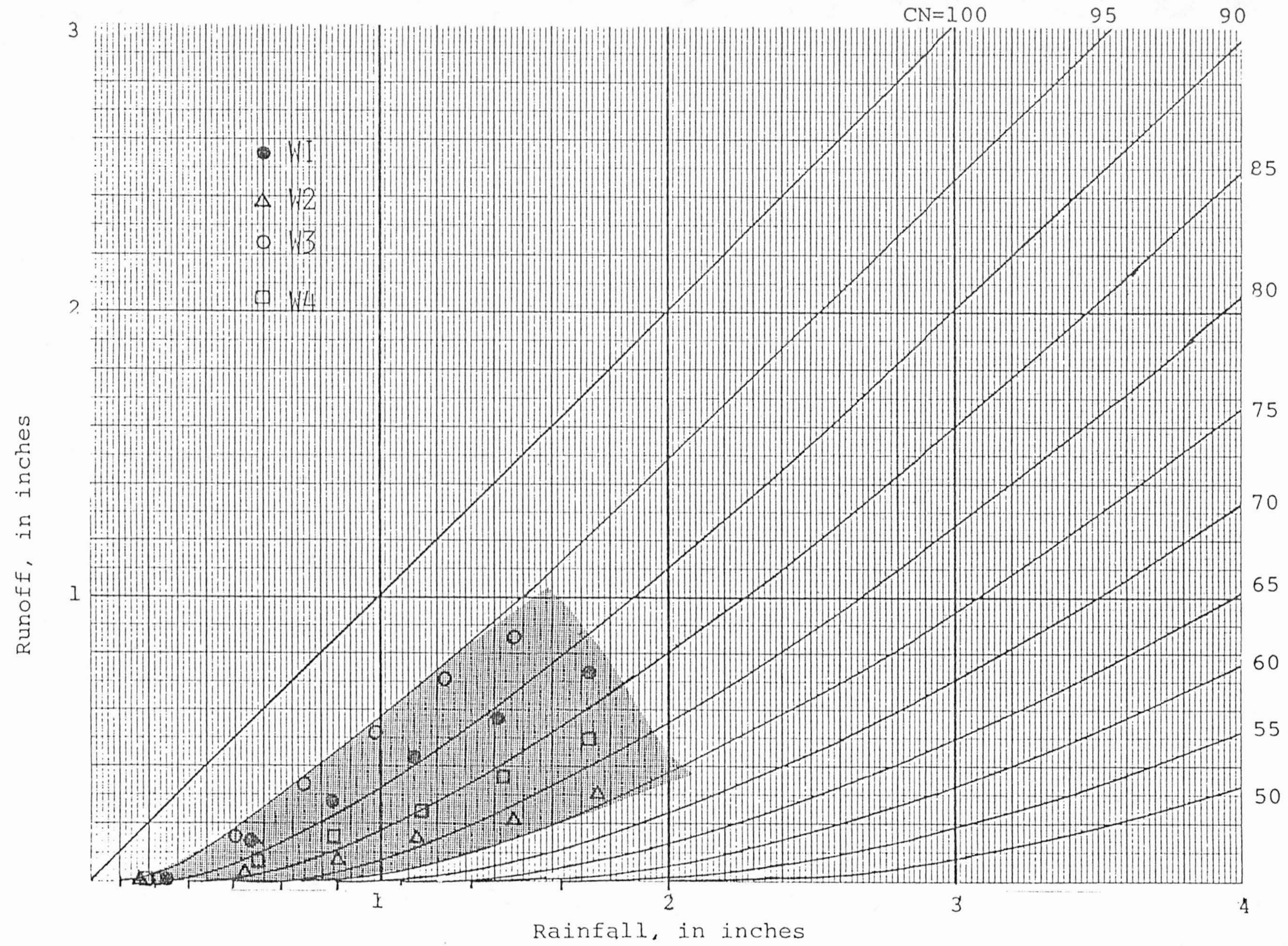


Figure 20.- Fit to SCS rainfall-runoff equation for site BA-G, wet runs. CN=91, selected from SCS criteria (Figures 4 & 6).

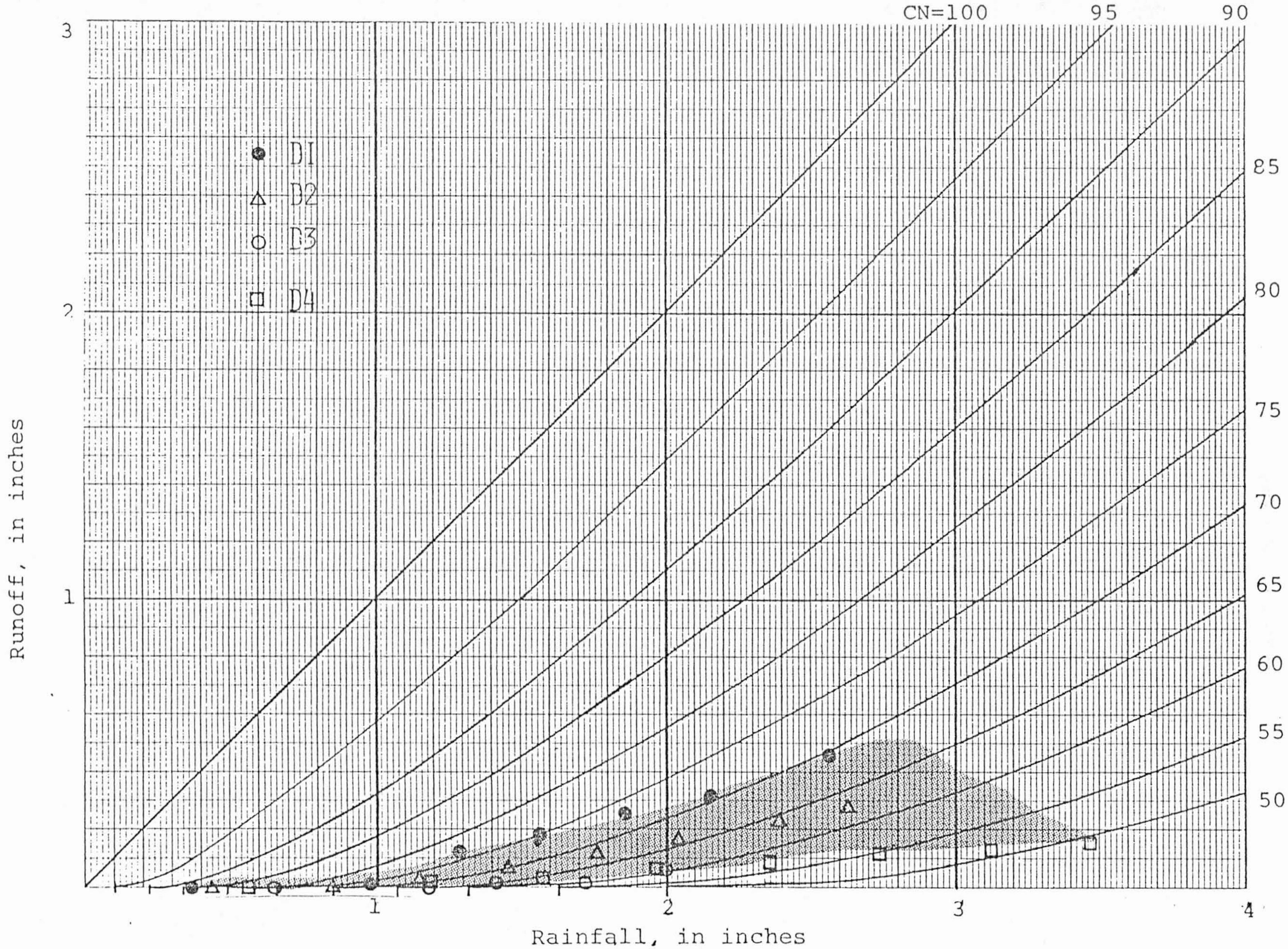


Figure 21.- Fit to SCS rainfall-runoff equation for site BN-AMB, dry runs. CN=86, selected from SCS criteria (Figure 4).

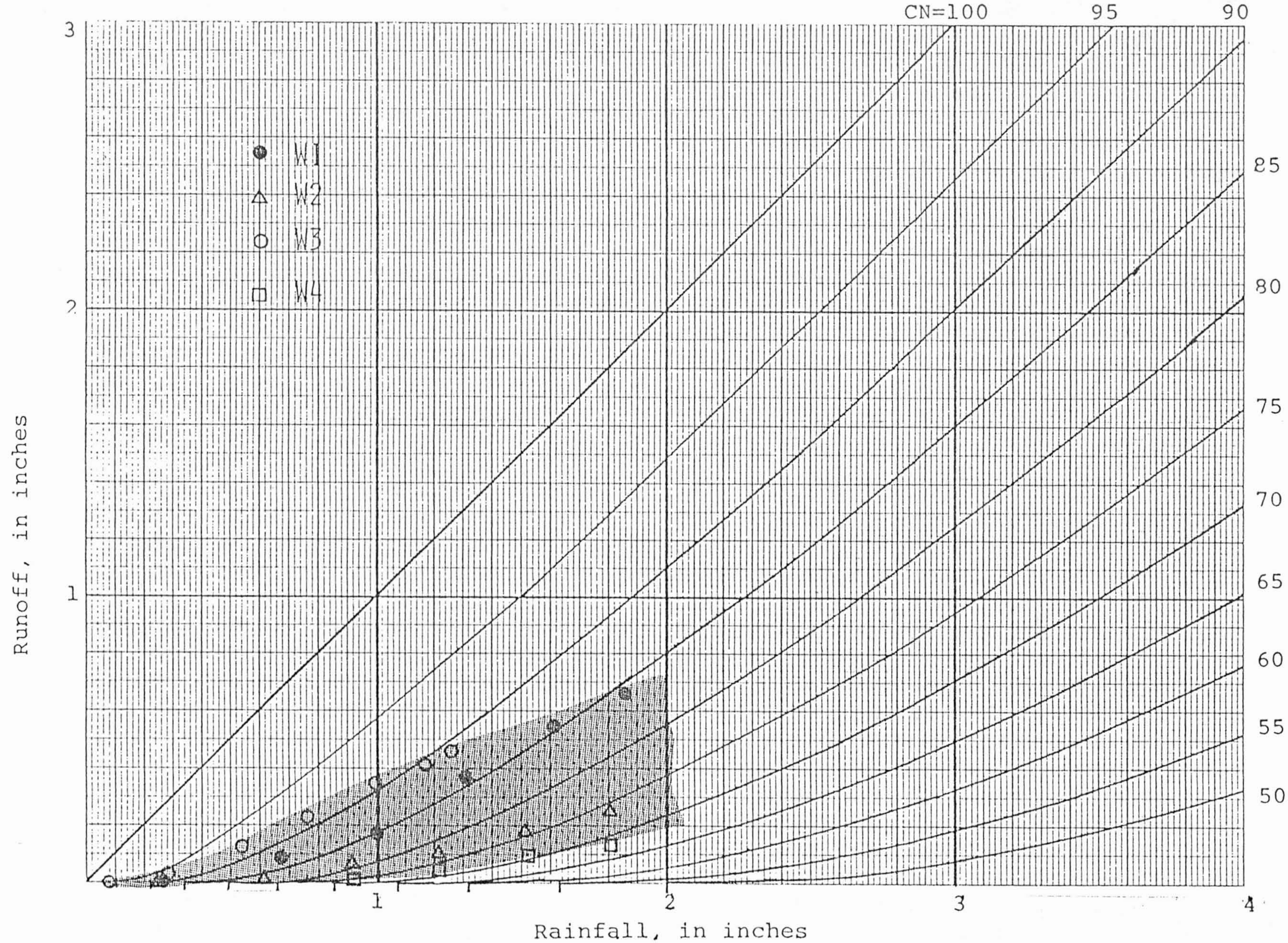


Figure 22.- Fit to SCS rainfall-runoff equation for site BN-AMB, wet runs.
CN=94, selected from SCS criteria (Figures 4 & 6).

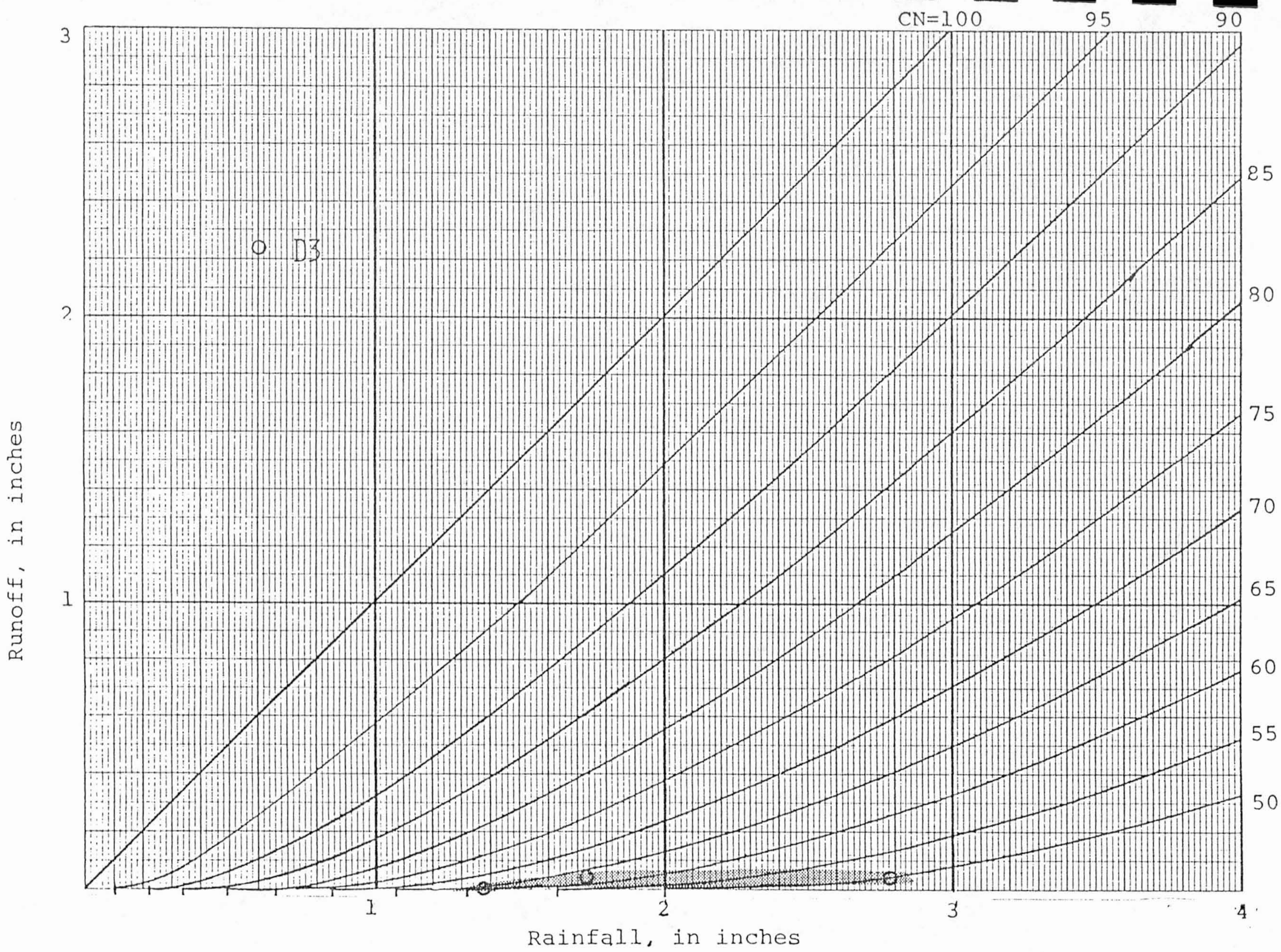


Figure 23.- Fit to SCS rainfall-runoff equation for site L-BCC-D, dry runs.

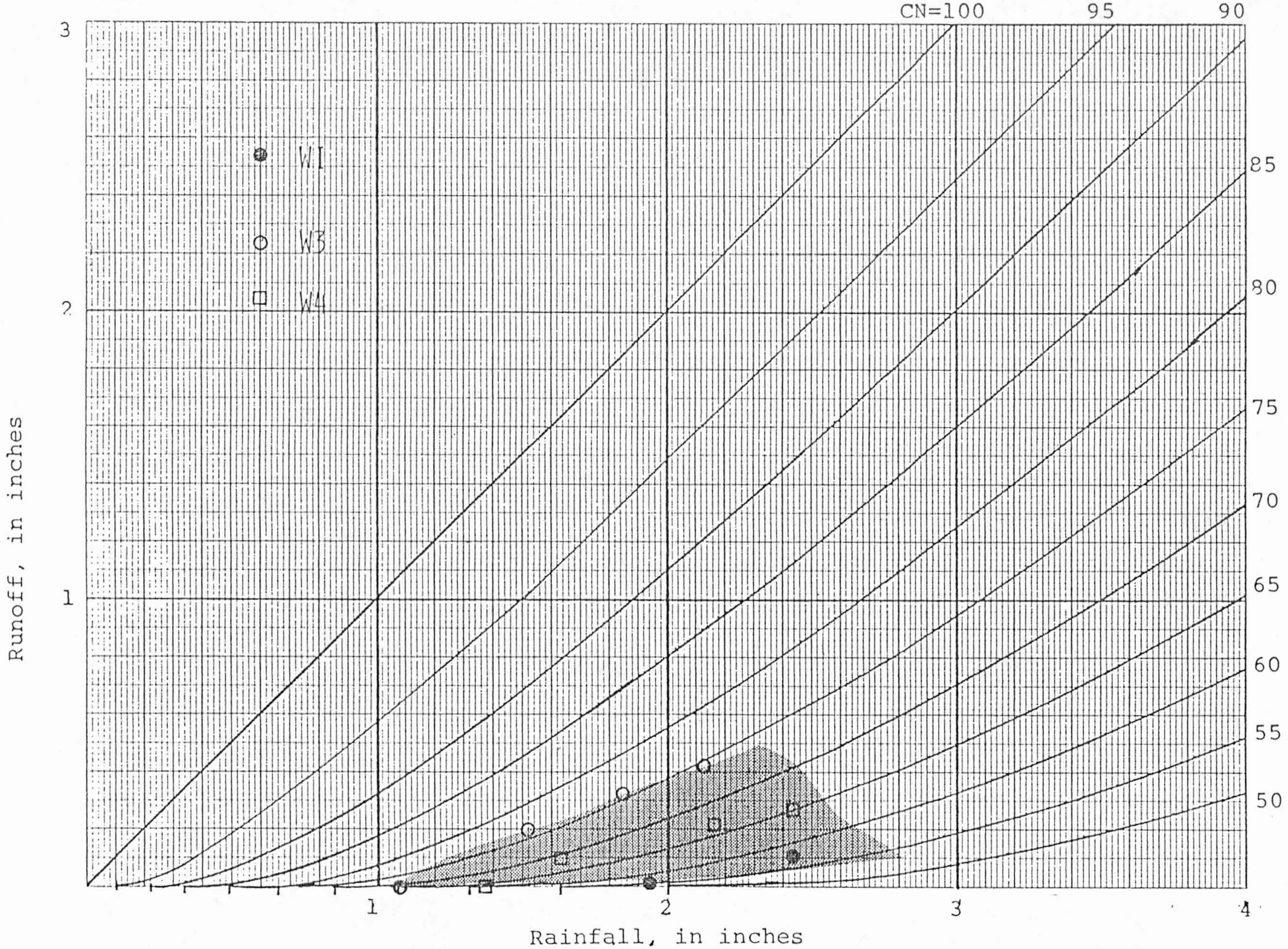


Figure 24.- Fit to SCS rainfall-runoff equation for site L-BCC-D, wet runs.

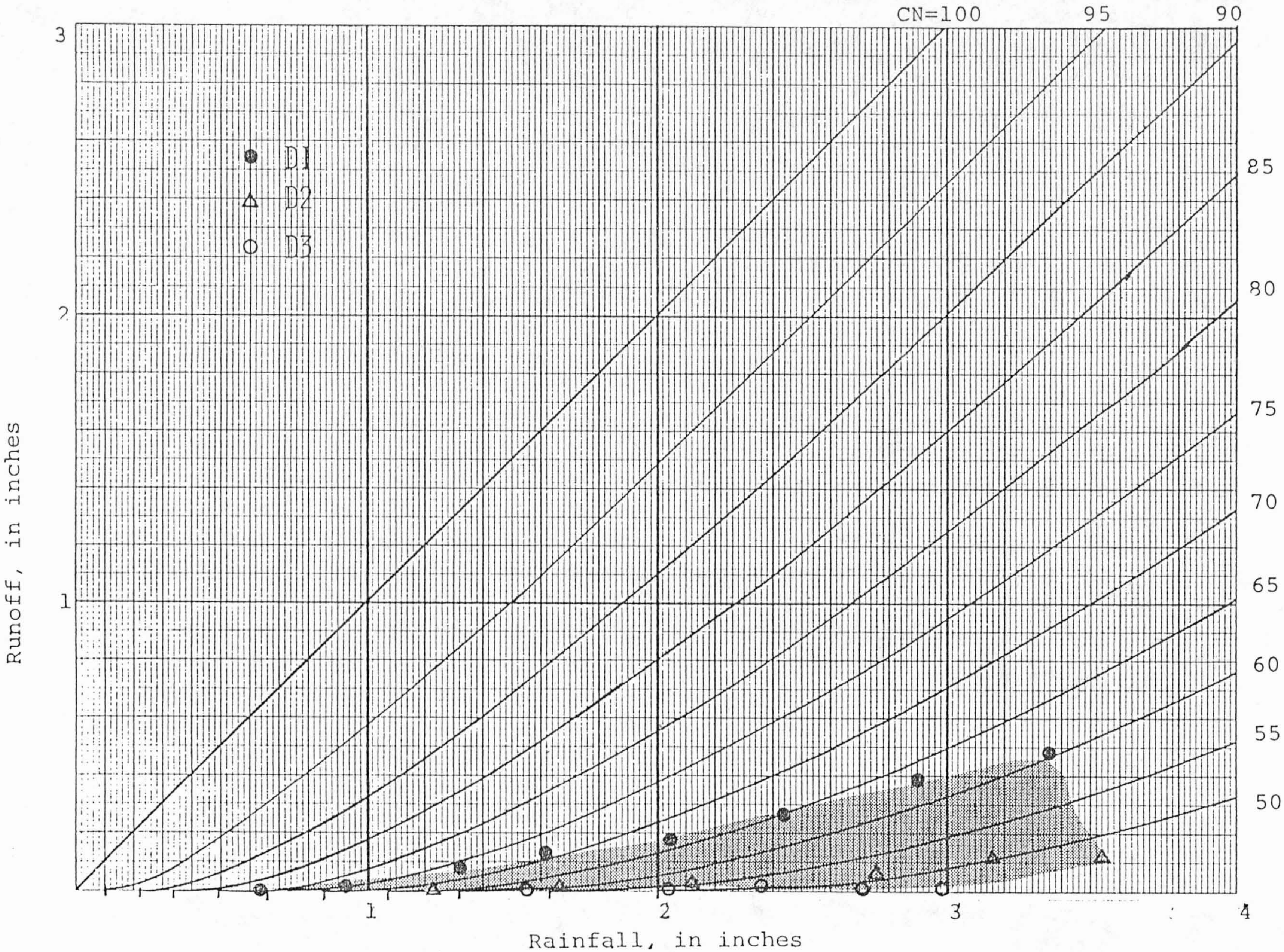


Figure 25.- Fit to SCS rainfall-runoff equation for site L-BCC, dry runs CN=68, selected from SCS criteria (Figure 4).

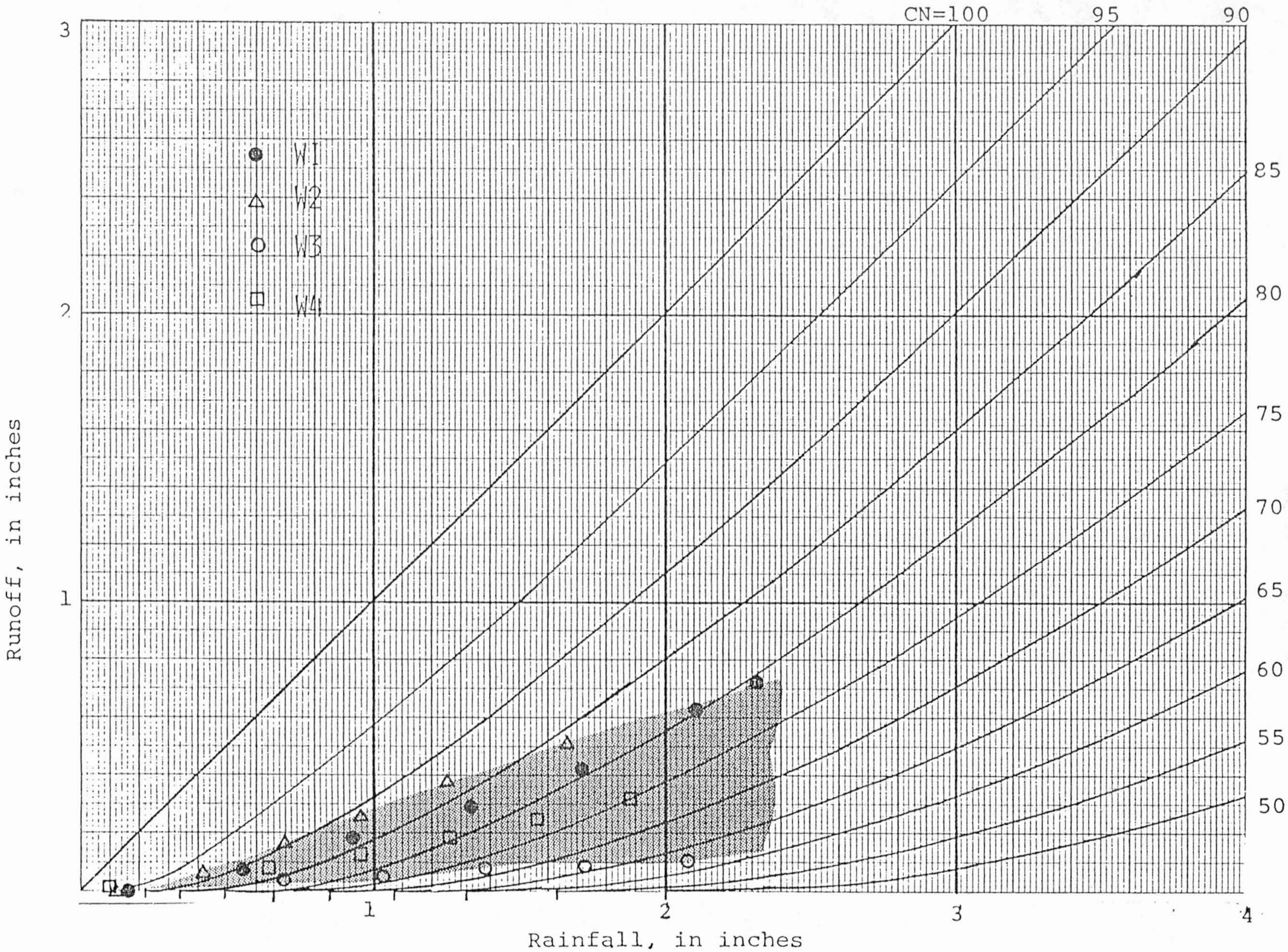


Figure 26.- Fit to SCS rainfall-runoff equation for site L-BCC, wet runs. CN=84, selected from SCS criteria (Figures 4 & 6).

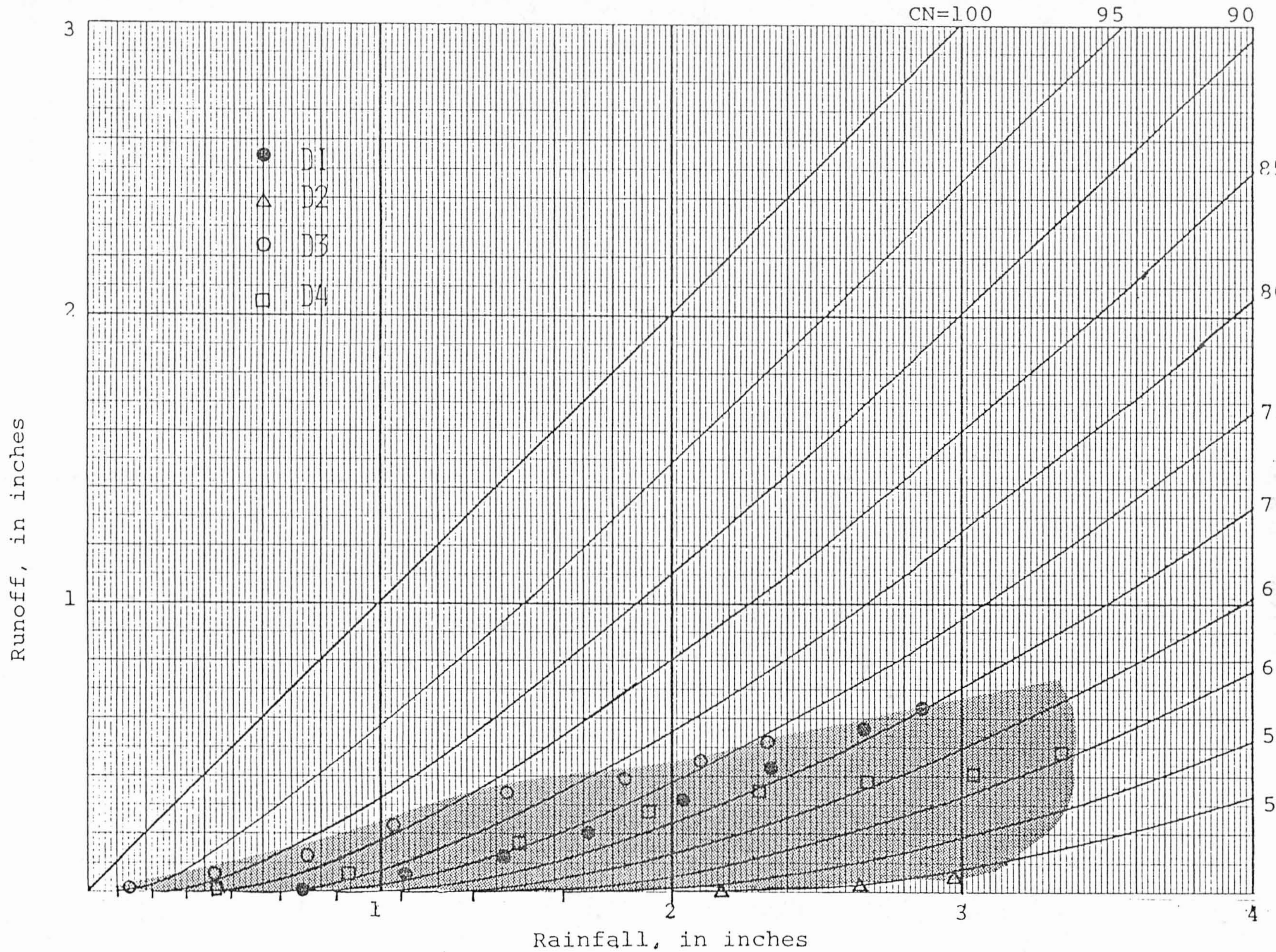


Figure 27.- Fit to SCS rainfall-runoff equation for site PH-AMB, dry runs.
CN=86, selected from SCS criteria (Figure 4).

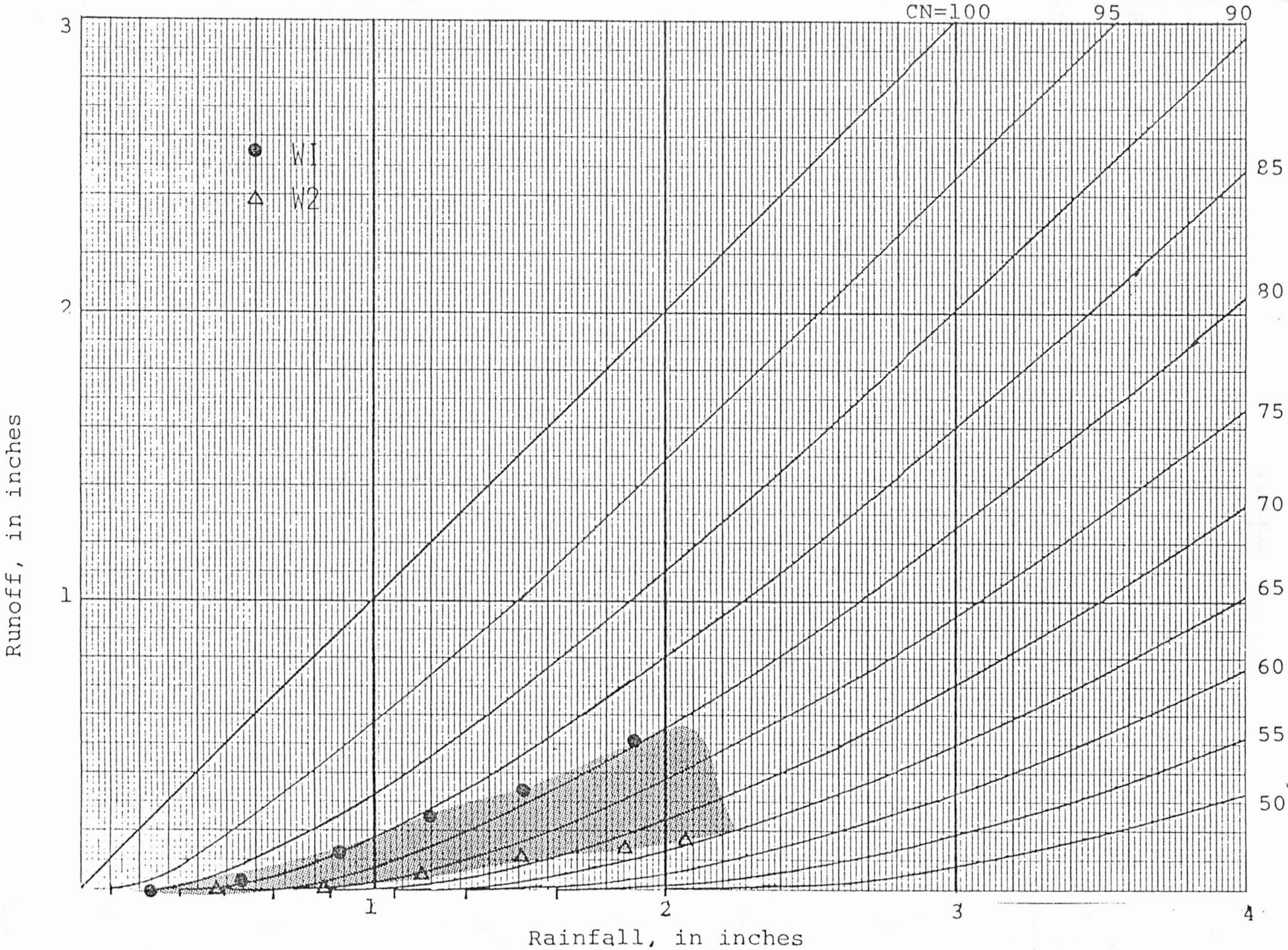


Figure 28.- Fit to SCS rainfall-runoff equation for site PH-AMB, wet runs.
CN=68, selected from SCS criteria (Figure 4).

94

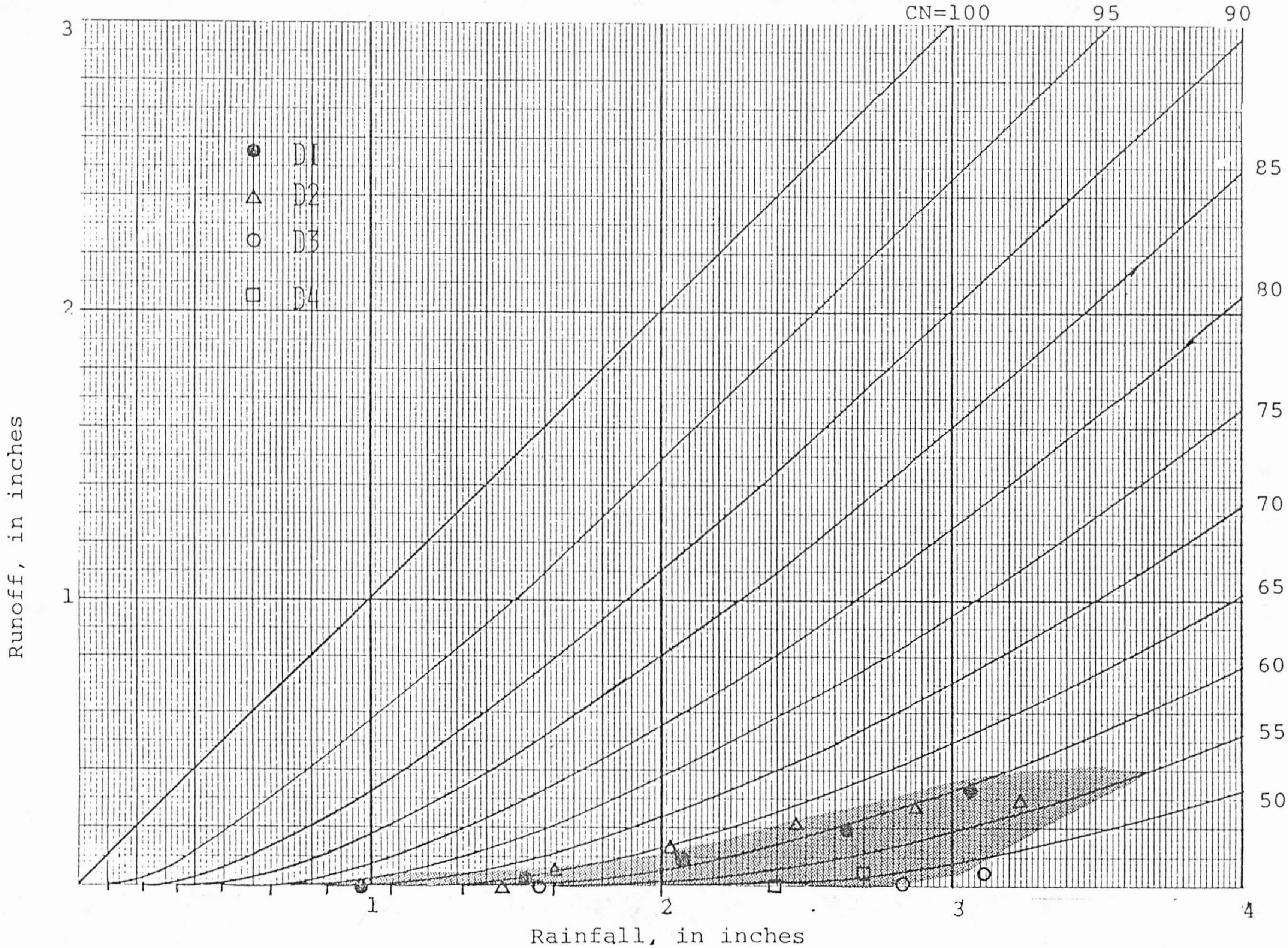


Figure 29.- Fit to SCS rainfall-runoff equation for site RA-BCC, dry runs. CN=68, selected from SCS criteria (Figure 4).

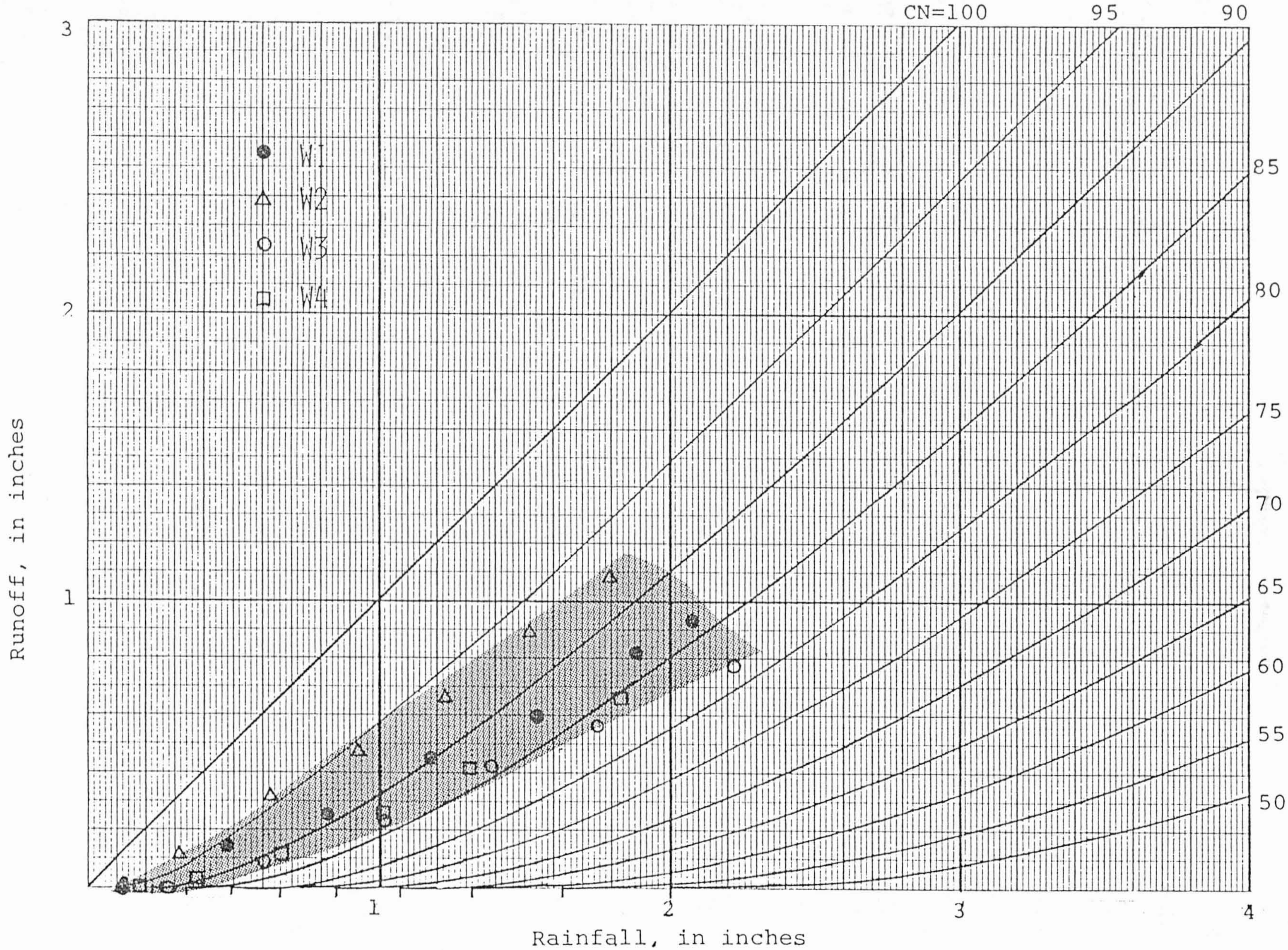


Figure 30.- Fit to SCS rainfall-runoff equation for site RA-BCC, wet runs. CN=84, selected from SCS criteria (Figures 4 & 6).

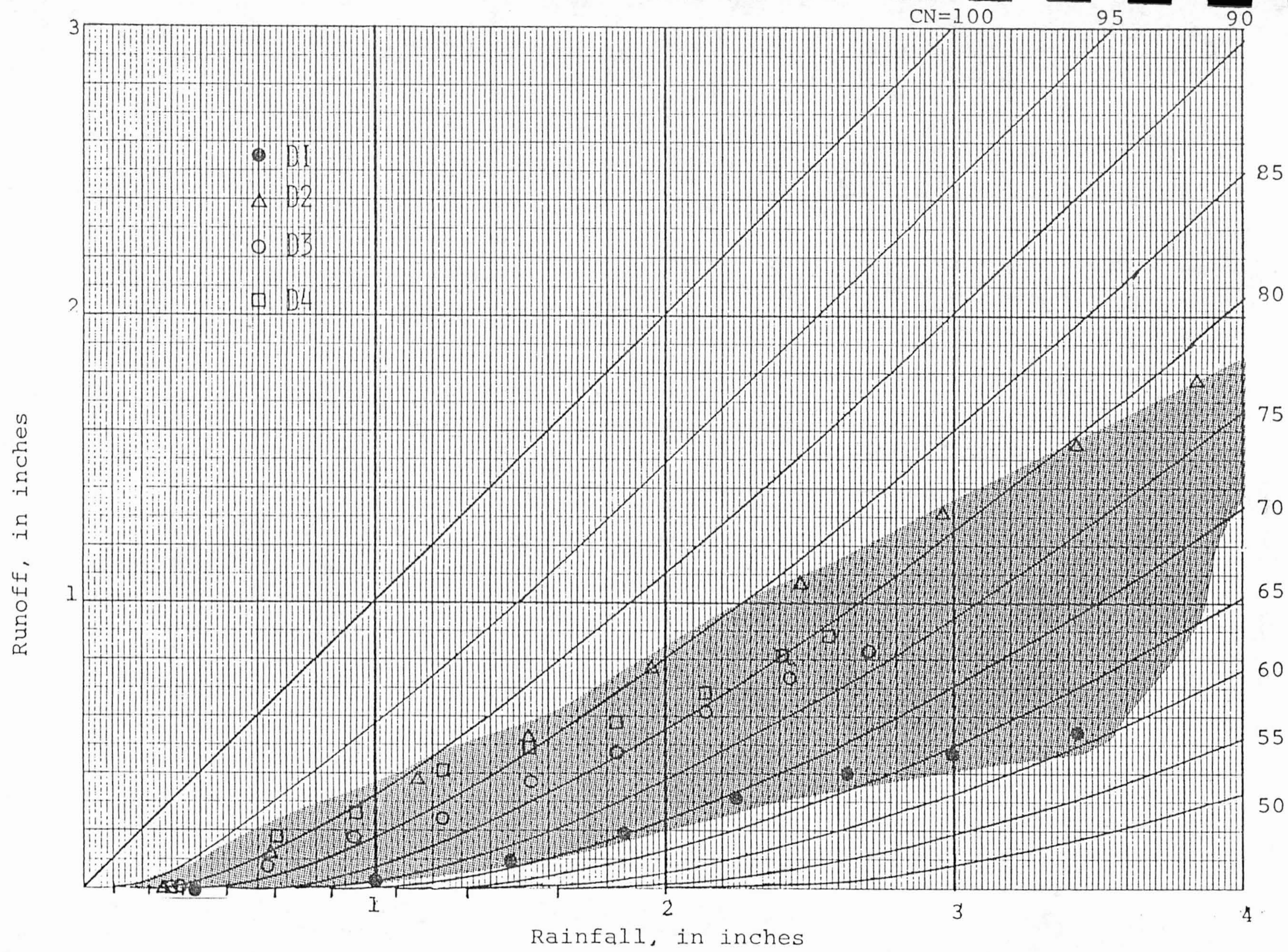


Figure 31.- Fit to SCS rainfall-runoff equation for site RA-BKD, dry runs. CN=68, selected from SCS criteria (Figure 4).

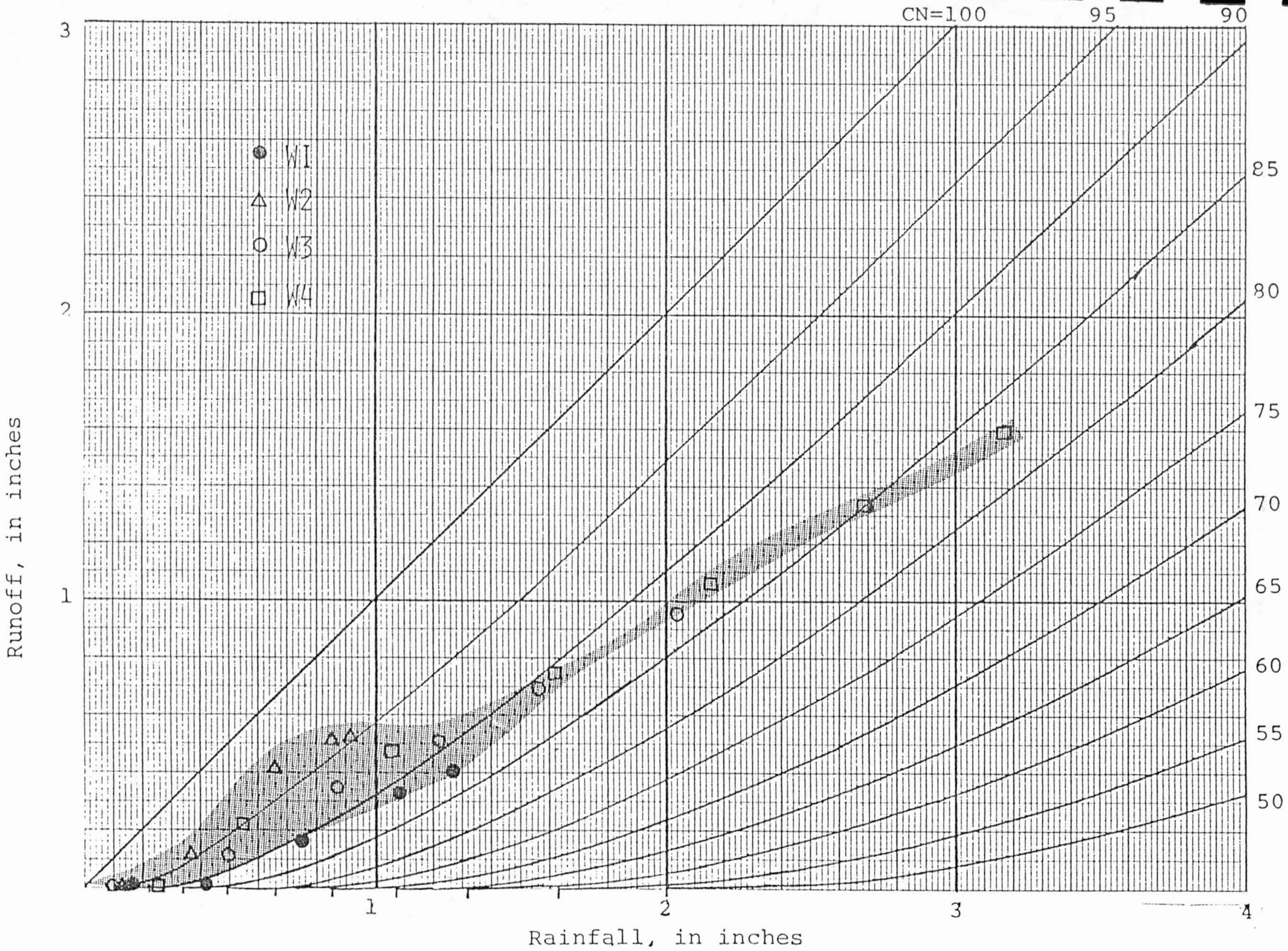


Figure 32.- Fit to SCS rainfall-runoff equation for site RA-BKD, wet runs. CN=84, selected from SCS criteria (Figures 4 & 6).

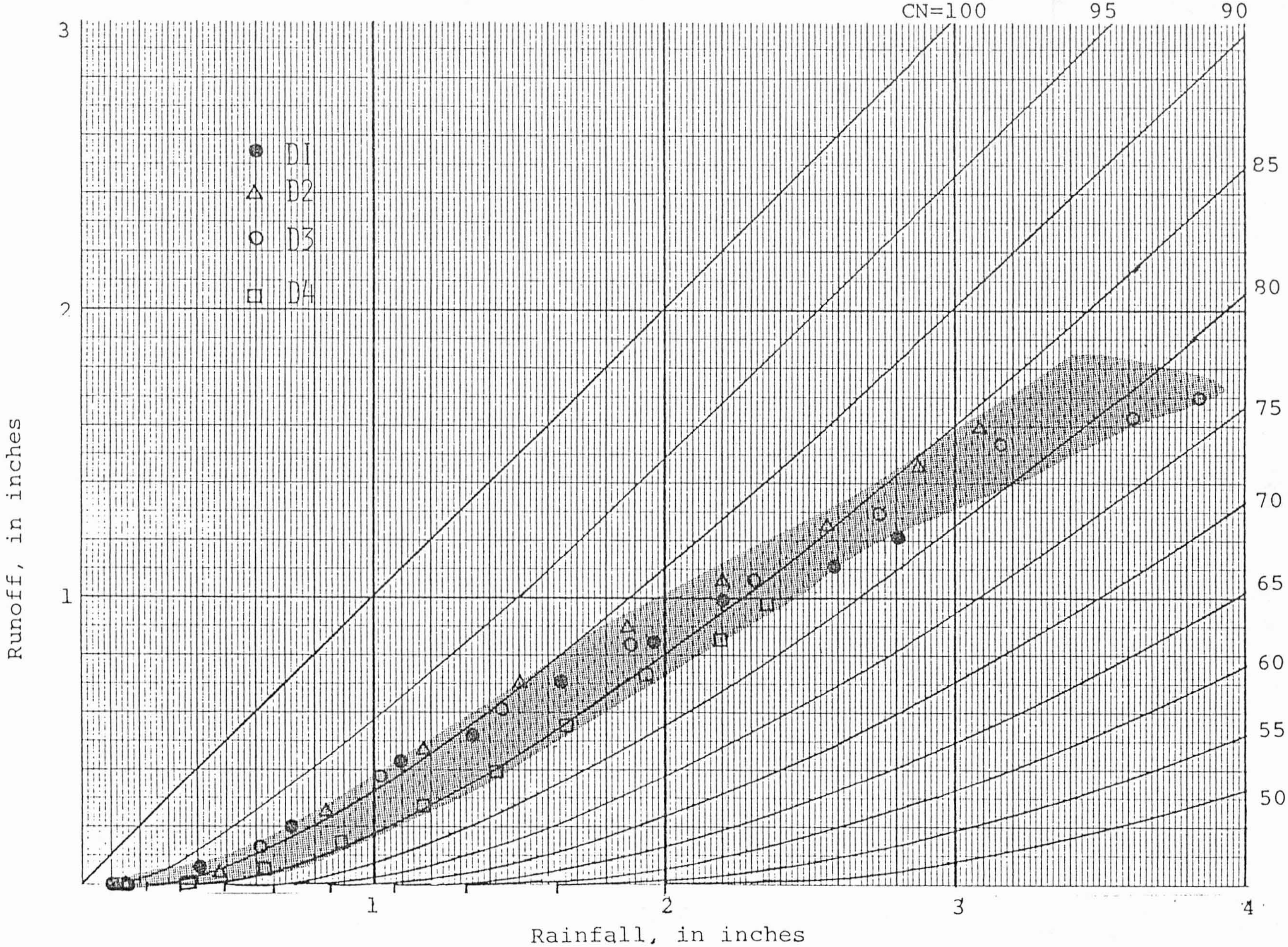


Figure 33.- Fit to SCS rainfall-runoff equation for site V-MWA, dry runs. CN=79, selected from SCS criteria (Figure 4).

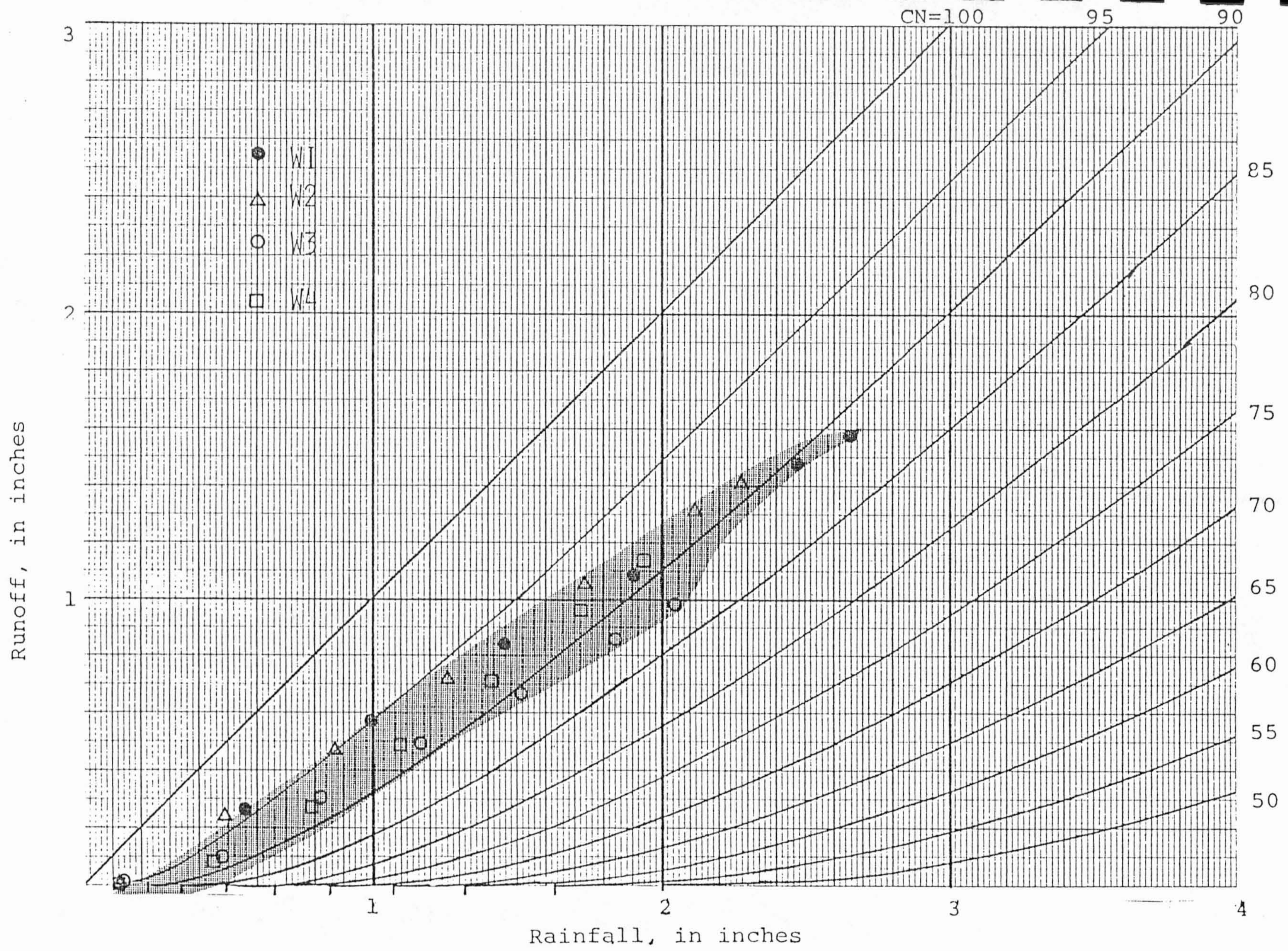


Figure 34.- Fit to SCS rainfall-runoff equation for site V-MWA, wet runs CN=91, selected from SCS criteria (Figures 4 & 6).

Green-Ampt Parameters

Use of the Green-Ampt equation requires estimates of the soil parameters K, Ψ, Θ_w and Θ_i. Although all four parameters can be evaluated directly through analysis of soil samples, measurements of K and Ψ involve tedious lab procedures applied to a number of undisturbed soil samples. For this reason, use of the Green-Ampt equation generally involves direct measurement of Θ_w and Θ_i, and estimation of K and Θ from actual rainfall-runoff measurements.

Gravimetric content of the soil is defined as the quantity of water in grams contained in a sample of soil, of a size which weighs 1.0 gram when oven dry. Measurement involves collection of a soil sample in the field. This sample is weighed, dried, and reweighed in the lab to provide the weight of water in the sample along with the oven-dry weight of the sample. Dividing the water weight by the oven-dry sample weight yields the moisture content of the sample. Initial or antecedent valumetric moisture content (Θ_i) and the moisture content after wetting (Θ_w) can be determined as follows:

$$\Theta_i = \frac{WG}{1+e} \qquad (18)$$

where W is gravimetric moisture content,

G is specific gravity of soil particles, and

e is void ratio.

For saturated soil,

$$\Theta_w = \frac{e}{1+e} \qquad (19)$$

Void ratio (e) was determined from the approximate in-place volume of the soil moisture sample:

$$e = \frac{VT - V_s}{V_s} \tag{20}$$

$$V_S = \frac{W_s}{G_s \gamma_w} \tag{21}$$

$$e = \frac{2.65\ V_t\ - W_s}{W_s}$$

where V_v is volume of voids,

V_s is volume of solid particles,

V_t is volume of moisture sample,

W_s is oven-dry weight of moisture sample, and

γ_w is density of water (1gm/cc).

Determination of Θ_w and Θ_i leaves the Green-Ampt equation with two parameters to evaluate K and Ψ. Rainfall simulation provides accumulated volume of precipitation and runoff for various values of elapsed time, t, with infiltration volume, F, as the difference between precipitation and runoff. Each simulation replication produced several coordinate sets of F and t. The substitution of a coordinate set of F and t into the Green-Ampt equation results in an equation with two unknowns; an additional (F,t) data set results in two equations with two unknowns and the parameters K and Ψ can be determined.

During simulation, an (F,t) data set was obtained from each replicate for each of the sites. The best values for K and Ψ were obtained by using all the (F,t) data sets for a site and optimizing the fit of the equation to this data by minimizing the residual error. That is, K and Ψ were estimated by using all available data points and a computerized optimization selection of K and Ψ until a pair was found which when substituted into the Green-Ampt equation provided the best fit to the (F,t) simulation data. Inspection of the residuals indicated the quality of fit, the residuals being defined as the difference between the predicted and the measured infiltration values for each time t. The over-all quality of the fit is summarized in a single value by summing the squares of all residuals; this summation is termed the least squares function (LSF) for the selected values of K and Ψ. The best fit is obtained when using values for K and Ψ which minimize the LSF.

Use of a computer program facilitated evaluation of K and Ψ by this LSF minimization scheme. Instead of a trial-and-error selection of K and Ψ however, this program selected K and Ψ by numerical techniques. Given starting value for K and Ψ, the program incrementally searches from these values, evaluating the LSF with each new pair of K and Ψ for the available data sets. The size of increment and direction of search depends on the response of the LSF, search being in a direction which produces a decrease in the LSF. When an apparent minimum of the LSF has been bracketed by a pair of K and ψ points, the values of K and Ψ at the minimum are found by successive polynomial approximations to the LSF.

The Green-Ampt equation parameters were determined by this process for each site and for wet and dry conditions. For a few of the sites sufficient data were not available or data anomolies, such as unmeasured variations in rainfall rate, existed which precluded determination of the Green-Ampt equation parameters. The optimum parameters are presented in Table 7.

Table 7 requires some further discussion. Conceptually, the K values should be about the same for dry or wet runs. When both were computed, they were in most cases. An increase for AA-TGB-D from 0.7 to 1.6 inches per hour may be a result of peculiarities, such as the dense vegetation, for the developed site. The drop in K for RA-BCC is also notable. However the values are still reasonably close to one another. The difference between RA-BCC and RA-BKD was suspected before this study. Ring infiltrometer tests by Sabol and Ward (unpublished data) showed a similar difference. The BA-G value for K seems a bit low, but may be related to fine particle content. However, the V-MWA data should also indicate a lower K value, which it doesn't. This might be a result of the quantity of clay in the BA-G fine material versus the clay in the V-MWA soils. Clay content was not determined in this study.

The Ψ values seem reasonable with most below 10 inches. Because Ψ computations require measurements or estimation of three parameters, values are expected to be quite variable. In general, K and Ψ are inversely related, i.e. high K indicating a low Ψ. For example, sand would have a high K but a low Ψ. In this respect, all values seem reasonable except, again, AA-TGB-D, where lower Ψ values were expected. Another conceptual trend that was not apparent is a decrease in Ψ from dry to wet runs (capillarity destroyed). Again this may be data variability.

The tabulated values of K and Ψ can be compared with those provided by Rawls and other (unpublished). Their estimated K values averaged between 0.4 and 4.6 inches per hour for the soil textures at the test sites. The Ψ values averaged about 2.0 and 4.0 inches with variation as much as 12.0 inches in some cases.

It appears that the optimized values are realistic although more effort is warranted to investigate the Green-Ampt equation and the parameters. Other approaches for estimating K and Ψ are yet to be applied. It is anticipated that these other methods will provide similar results, but may remove some of the annoying peculiarities, as mentioned above, in the parameters.

Table 7.- Green-Ampt equation parameters for the Albuquerque soil sites

Site	Hydraulic Conductivity (K), in inches per hour		Suction Head (Ψ), in inches	
	Dry	Wet	Dry	Wet
AA-TGB-D	0.7	1.6	17.9	26.9
AA-TGB	-	-	-	-
BA-G	0.4	0.5	26.4	17.1
BN-AMB	3.5	-	2.0	-
L-BCC-D	-	-	-	-
L-BCC	-	2.9	-	0.5
PH-AMB	2.1	-	2.1	-
RA-BCC	2.5	1.9	4.4	0.05
RA-BKD	1.4	1.3	5.7	7.2
V-MWA	1.9	1.9	0.2	0.2

SECTION 5

SUMMARY AND CONCLUSIONS

Rainfall losses and infiltration have been studied for selected soils in the Albuququerque drainage area. Data has been obtained for ten sites using a portable rainfall simulator, and this data has been used to evaluate the adequacy of the SCS rainfall-runoff equation for use in Albuquerque. The data has also been used to determine parameters for the Green-Ampt infiltration equation. The SCS rainfall-runoff equation was critically reviewed regarding its historic development, assumptions, selection of the CN parameter, and the sensitivity of the technique to parameter (CN) selection.

The conclusions of this study are:

1. A portable rainfall simulator can be used to obtain reliable estimates of rainfall loss and infiltration rate of soils.
2. There appears to be valid transferability of infiltration data among sites of the same soil classification.
3. The SCS rainfall-runoff equation was not developed for use as an urban hydrology model. Its application, especially in Albuquerque, is based on assumptions which may be too generalized and may be in error.
4. The institutionalized design aids for the selection of CN do not yield values that are consistent with measured data.
5. The CN selection process is subjective and decisions by the design community may be based more on past acceptance of a value rather than a valid rationale.
6. The SCS rainfall-runoff equation is extremely sensitive to CN selection. For example, for a design rainfall of 2.0-in

a CN error of $\pm$ 5 could result in a runoff volume error of more than $\pm$ 50%.

7. The SCS rainfall-runoff equation is more sensitive to CN selection at low rainfalls and low CN's that at high rainfalls and high CN's. Therefore, more error is inherent in the procedure for 100-yr flood analyses than for PMF analyses.
8. Other researchers have also recently noted many of the failings and possible errors in the SCS procedure, and the SCS is currently reevaluating the procedure.
9. Parameters for the Green-Ampt infiltration equation have been determined where possible. Parameter results are reasonable and comparable values are obtained for the sites. Parameter values are comparable to the results obtained by others for similar soils.
10. Surface detention in undeveloped areas of Albuquerque is probably in the 0.1 to 0.2-in range. A detention storage of 0.1-in is a conservative assumption.
11. The most likely antecedent soil moisture condition prior to the occurrence of a 100-yr thunderstorm in Albuquerque is AMC-I.
12. The Albuquerque soils had a high rainfall retention capacity. The ratio of runoff to rainfall for a 3.0-in rain in 45 minutes on dry soil was 0.22. For storms of lower intensity the ratio would be lower and approach zero.
13. The rainfall simulator can and should be used to determine the infiltration rate of soils in Albuquerque for many drainage studies and flood control designs.

14. Additional field studies need to be performed with the rainfall simulator to determine analytic techniques to assess the infiltration rate change due to urbanization.

15. The USGS urban flood hydrograph data needs to be analyzed for rainfall loss and the results of this compared to results obtained with the rainfall simulator.

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APPENDIX A
Rainfall-Runoff Data

The basic rainfall-runoff data, certain recorded data, and the result of laboratory analysis are presented.

Notation and definitions

Time to ponding - Is the elapsed time from the start of rainfall until water was observed to begin ponding on the surface.

Time to runoff - Is the elapsed time from the start of rainfall until water was observed to begin running off into the collection trough.

Constant rain rate - Is the rainfall intensity.

Initial abstraction - Is the depth of rainfall from the start of rainfall until runoff began. This was calculated by multiplying rainfall intensity of time to runoff.

Antecedent moisture - Is the soil moisture content prior to the start of rainfall.

TI - Is elapsed time since the start of rainfall.

PI - Is the rainfall at time TI.

QI - Is the runoff depth measured at time TI.

D1

TIME TO PONDING = 0.0 HOURS
TIME TO RUNOFF = 0.135 HOURS
CONSTANT RAIN RATE = 3.824 IN.PER.HR
INITIAL ABSTRACTION= 0.517 INCHES
ANTECEDENT MOISTURE= 0.0 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2186	0.8361	0.1229
0.3020	1.1550	0.3676
0.3853	1.4734	0.5308
0.4687	1.7923	0.7448
0.5520	2.1109	0.9524
0.6354	2.4296	1.1474
0.7187	2.7482	1.3370
0.7500	2.8679	1.4175

**** NOTES:
RAINED FOR 4 MIN 50 SEC, THEN STOPPED
FOR 3 HRS TO CHANGE PUMP

D2

TIME TO PONDING = 0.014 HOURS
TIME TO RUNOFF = 0.042 HOURS
CONSTANT RAIN RATE = 4.795 IN.PER.HR
INITIAL ABSTRACTION= 0.200 INCHES
ANTECEDENT MOISTURE= 0.1700 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2167	1.0390	0.1165
0.3001	1.4390	0.4376
0.3834	1.8385	0.7056
0.4668	2.2380	0.9344
0.5584	2.6775	1.1718
0.6334	3.0371	1.4048
0.7500	3.5960	1.7799

**** NOTES:
RAINED FOR 4 MIN 50 SEC, THEN
STOPPED FOR 3 HRS TO CHANGE PUMP

Table 1.- Data for AA-TGB-D, dry tests.

W1

TIME TO PONDING = 0.0 HOURS
TIME TO RUNOFF = 0.022 HOURS
CONSTANT RAIN RATE = 4.386 IN.PER.HR
INITIAL ABSTRACTION= 0.099 INCHES
ANTECEDENT MOISTURE= 0.2200 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1058	0.4642	0.0042
0.1892	0.8297	0.0074
0.2725	1.1952	0.0117
0.3559	1.5608	0.1134
0.4392	1.9263	0.2214
0.5225	2.2918	0.3422
0.6059	2.6573	0.4778
0.6892	3.0226	0.6071

**** NOTES:
LOOSE LIP FOR THE FIRST 16 MINUTES OF THE RUN

W2

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.083 HOURS
CONSTANT RAIN RATE = 3.441 IN.PER.HR
INITIAL ABSTRACTION= 0.287 INCHES
ANTECEDENT MOISTURE= 0.2800 DIMENSIONLESS

***RAINFALL INCREASED TO AVOID NEG INFILT

TI HOURS	PI INCHES	QI INCHES
0.0167	0.4107	0.1240
0.2501	0.8606	0.3305
0.3334	1.1473	0.5446
0.4168	1.4341	0.7617
0.5000	1.7205	1.0255

Table 2.- Data for AA-TGB-D, wet tests.

D1

TIME TO PONDING = 0.021 HOURS
TIME TO RUNOFF = 0.066 HOURS
CONSTANT RAIN RATE = 3.181 IN.PER.HR
INITIAL ABSTRACTION= 0.209 INCHES
ANTECEDENT MOISTURE= 0.0300 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1492	0.4746	0.1250
0.2325	0.7398	0.2680
0.3159	1.0050	0.4736
0.3993	1.2702	0.6876
0.4826	1.5353	0.9132
0.5659	1.8002	1.0531
0.6492	2.0653	1.1908
0.7325	2.3304	1.3190
0.7500	2.3859	1.3593

D2

TIME TO PONDING = 0.029 HOURS
TIME TO RUNOFF = 0.083 HOURS
CONSTANT RAIN RATE = 3.009 IN.PER.HR
INITIAL ABSTRACTION= 0.251 INCHES
ANTECEDENT MOISTURE= 0.0300 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1667	0.5016	0.0964
0.2834	0.8527	0.2405
0.3667	1.1034	0.3517
0.4500	1.3542	0.4492
0.5334	1.6049	0.5435
0.6223	1.8724	0.6463
0.7500	2.2568	0.7649

Table 3.- Data for AA-TGB, dry tests.

W1

TIME TO PONDING = 0.016 HOURS
TIME TO RUNOFF = 0.029 HOURS
CONSTANT RAIN RATE = 5.135 IN.PER.HR
INITIAL ABSTRACTION= 0.150 INCHES
ANTECEDENT MOISTURE= 0.0900 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1125	0.5778	0.0826
0.1959	1.0060	0.2553
0.2793	1.4339	0.4418
0.3626	1.8618	0.6314
0.4459	2.2897	0.8221
0.5000	2.5674	0.9408

W2

TIME TO PONDING = 0.006 HOURS
TIME TO RUNOFF = 0.029 HOURS
CONSTANT RAIN RATE = 4.086 IN.PER.HR
INITIAL ABSTRACTION= 0.119 INCHES
ANTECEDENT MOISTURE= 0.0800 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1667	0.6811	0.0932
0.2500	1.0216	0.1854
0.3334	1.3621	0.2861
0.4167	1.7027	0.3952
0.5250	2.1452	0.5244

***** NOTES:
TIME TO RUNOFF WAS NOT NOTICED;

USED TIME TO RUNOFF FOR W1 RUN...ANDY

Table 4.- Data for AA-TGB, wet tests.

D1

TIME TO PONDING = 0.007 HOURS
TIME TO RUNOFF = 0.092 HOURS
CONSTANT RAIN RATE = 4.736 IN.PER.HR
INITIAL ABSTRACTION= 0.434 INCHES
ANTECEDENT MOISTURE= 0.0180 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1917	0.9078	0.0636
0.2750	1.3024	0.1229
0.3584	1.6971	0.1907
0.4500	2.1312	0.2733
0.5333	2.5258	0.3242

**** NOTES:
STOPPED AND STARTED RAIN AT 33 MINUTES TILL ??

D2

TIME TO PONDING = 0.009 HOURS
TIME TO RUNOFF = 0.160 HOURS
CONSTANT RAIN RATE = 5.897 IN.PER.HR
INITIAL ABSTRACTION= 0.945 INCHES
ANTECEDENT MOISTURE= 0.0200 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2667	1.5726	0.0191
0.3500	2.0641	0.0487
0.4333	2.5555	0.0954
0.5278	3.1124	0.1409

**** NOTES:
STOPPED AND STARTED RAIN AT 33 MINUTES TILL ?

D4

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.042 HOURS
CONSTANT RAIN RATE = 3.483 IN.PER.HR
INITIAL ABSTRACTION= 0.145 INCHES
ANTECEDENT MOISTURE= 0.0190 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1417	0.4935	0.0795
0.2334	0.8128	0.2288
0.3334	1.1613	0.4651
0.4334	1.5095	0.6971
0.5168	1.7997	0.8878
0.6000	2.0898	1.0298
0.6834	2.3802	1.2279
0.7500	2.6120	1.3932

D5

TIME TO PONDING = 0.011 HOURS
TIME TO RUNOFF = 0.049 HOURS
CONSTANT RAIN RATE = 3.596 IN.PER.HR
INITIAL ABSTRACTION= 0.177 INCHES
ANTECEDENT MOISTURE= 0.0160 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1667	0.5994	0.0551
0.2500	0.8991	0.1250
0.3334	1.1987	0.2013
0.4334	1.5584	0.2945
0.5167	1.8580	0.3899
0.6000	2.1577	0.4937
0.6834	2.4574	0.6039
0.7500	2.6970	0.6929

Table 5.- Data for BA-G, dry tests.

W1

```
TIME TO PONDING       =  0.006 HOURS
TIME TO RUNOFF        =  0.046 HOURS
CONSTANT RAIN RATE    =  3.493 IN.PER.HR
INITIAL ABSTRACTION   =  0.162 INCHES
ANTECEDENT MOISTURE   =  0.0990 DIMENSIONLESS
```

TI HOURS	PI INCHES	QI INCHES
0.1584	0.5531	0.1547
0.2417	0.8442	0.2808
0.3250	1.1353	0.4439
0.4084	1.4263	0.5880
0.5000	1.7463	0.7575

W2

```
TIME TO PONDING       =  0.007 HOURS
TIME TO RUNOFF        =  0.042 HOURS
CONSTANT RAIN RATE    =  3.782 IN.PER.HR
INITIAL ABSTRACTION   =  0.158 INCHES
ANTECEDENT MOISTURE   =  0.0970 DIMENSIONLESS
```

TI HOURS	PI INCHES	QI INCHES
0.1417	0.5358	0.0434
0.2250	0.8510	0.0869
0.3084	1.1662	0.1600
0.3917	1.4814	0.2278
0.5000	1.8910	0.3380

W3

```
TIME TO PONDING       =  0.004 HOURS
TIME TO RUNOFF        =  0.083 HOURS
CONSTANT RAIN RATE    =  2.993 IN.PER.HR
INITIAL ABSTRACTION   =  0.249 INCHES
ANTECEDENT MOISTURE   =  0.1330 DIMENSIONLESS
```

TI HOURS	PI INCHES	QI INCHES
0.1667	0.4989	0.1632
0.2501	0.7485	0.3560
0.3334	0.9979	0.5318
0.4168	1.2473	0.7395
0.5000	1.4964	0.8804

W4

```
TIME TO PONDING       =  0.006 HOURS
TIME TO RUNOFF        =  0.057 HOURS
CONSTANT RAIN RATE    =  3.466 IN.PER.HR
INITIAL ABSTRACTION   =  0.196 INCHES
ANTECEDENT MOISTURE   =  0.1250 DIMENSIONLESS
```

TI HOURS	PI INCHES	QI INCHES
0.1667	0.5777	0.0657
0.2500	0.8665	0.1610
0.3334	1.1554	0.2659
0.4167	1.4442	0.3867
0.5000	1.7329	0.5160

**** NOTES:
BAD DATA...HOSE TO RUNOFF TRAY WAS LOOSE

Table 6.- Data for BA-G, wet tests.

D1

TIME TO PONDING = 0.026 HOURS
TIME TO RUNOFF = 0.112 HOURS
CONSTANT RAIN RATE = 3.471 IN.PER.HR
INITIAL ABSTRACTION= 0.389 INCHES
ANTECEDENT MOISTURE= 0.0 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2908	1.0095	0.0477
0.3778	1.3113	0.1430
0.4597	1.5957	0.2066
0.5472	1.8994	0.2702
0.6292	2.1838	0.3475
0.7500	2.6031	0.4895

D2

TIME TO PONDING = 0.014 HOURS
TIME TO RUNOFF = 0.125 HOURS
CONSTANT RAIN RATE = 3.555 IN.PER.HR
INITIAL ABSTRACTION= 0.444 INCHES
ANTECEDENT MOISTURE= 0.0260 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2417	0.8591	0.0085
0.3306	1.1750	0.0424
0.4208	1.4960	0.0943
0.5056	1.7971	0.1388
0.5861	2.0835	0.1918
0.6825	2.4261	0.2553
0.7500	2.6660	0.3019

D3

TIME TO PONDING = 0.025 HOURS
TIME TO RUNOFF = 0.250 HOURS
CONSTANT RAIN RATE = 2.705 IN.PER.HR
INITIAL ABSTRACTION= 0.676 INCHES
ANTECEDENT MOISTURE= 0.0120 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.3639	0.9844	0.0
0.4500	1.2174	0.0021
0.5333	1.4428	0.0148
0.6500	1.7584	0.0456
0.7500	2.0289	0.0795

D4

TIME TO PONDING = 0.020 HOURS
TIME TO RUNOFF = 0.122 HOURS
CONSTANT RAIN RATE = 4.691 IN.PER.HR
INITIAL ABSTRACTION= 0.575 INCHES
ANTECEDENT MOISTURE= 0.0100 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2583	1.2120	0.0265
0.3417	1.6029	0.0477
0.4250	1.9939	0.0901
0.5083	2.3848	0.1123
0.5917	2.7757	0.1356
0.6750	3.1667	0.1568
0.7500	3.5185	0.1843

Table 7.- Data for BN-AMB, dry tests.

W1

TIME TO PONDING = 0.004 HOURS
TIME TO RUNOFF = 0.067 HOURS
CONSTANT RAIN RATE = 3.766 IN.PER.HR
INITIAL ABSTRACTION = 0.251 INCHES
ANTECEDENT MOISTURE = 0.1140 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1834	0.6906	0.1017
0.2667	1.0044	0.1865
0.3526	1.3280	0.3793
0.4362	1.6429	0.5636
0.5000	1.8832	0.6886

W2

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.071 HOURS
CONSTANT RAIN RATE = 3.627 IN.PER.HR
INITIAL ABSTRACTION = 0.253 INCHES
ANTECEDENT MOISTURE = 0.1270 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1722	0.6247	0.0335
0.2556	0.9269	0.0699
0.3389	1.2292	0.1187
0.4222	1.5315	0.1971
0.5000	1.8135	0.2723

W3

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.029 HOURS
CONSTANT RAIN RATE = 2.535 IN.PER.HR
INITIAL ABSTRACTION = 0.074 INCHES
ANTECEDENT MOISTURE = 0.0780 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1125	0.2852	0.0424
0.2167	0.5493	0.1377
0.3000	0.7605	0.2437
0.3917	0.9928	0.3634
0.4667	1.1829	0.4259
0.5000	1.2673	0.4768

W4

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.156 HOURS
CONSTANT RAIN RATE = 3.683 IN.PER.HR
INITIAL ABSTRACTION = 0.576 INCHES
ANTECEDENT MOISTURE = 0.0730 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2500	0.9207	0.0244
0.3333	1.2276	0.0509
0.4167	1.5345	0.1017
0.5000	1.8414	0.1398

Table 8.- Data for BN-AMB, wet tests.

D3

TIME TC PCNDING = 0.033 HOURS
TIME TC RUNOFF = 0.375 HOURS
CCNSTANT RAIN RATE = 3.748 IN.PER.HR
INITIAL ABSTRACTICN= 1.406 INCHES
ANTECEDENT MCISTURE= 0.0610 DIMENSICNLESS

TI HOURS	PI INCHES	QI INCHES
0.4667	1.7494	0.0636
0.7500	2.8114	0.0645

Table 9.- Data for L-BCC-D, dry tests.

W1

TIME TO PONDING = 0.0 HOURS
TIME TO RUNOFF = 0.400 HOURS
CONSTANT RAIN RATE = 4.873 IN.PER.HR
INITIAL ABSTRACTION= 1.949 INCHES
ANTECEDENT MOISTURE= 0.1210 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.5000	2.4365	0.1229

W3

TIME TO PONDING = 0.0 HOURS
TIME TO RUNOFF = 0.250 HOURS
CONSTANT RAIN RATE = 4.256 IN.PER.HR
INITIAL ABSTRACTION= 1.074 INCHES
ANTECEDENT MOISTURE= 0.0970 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.3501	1.5040	0.2129
0.4334	1.8617	0.3433
0.5000	2.1479	0.4344

***** NOTES:
LOW PRESSURE (FLUCUATED THROUGHOUT RUN)

W4

TIME TO PONDING = 0.0 HOURS
TIME TO RUNOFF = 0.280 HOURS
CONSTANT RAIN RATE = 4.861 IN.PER.HR
INITIAL ABSTRACTION= 1.362 INCHES
ANTECEDENT MOISTURE= 0.1020 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.3334	1.6204	0.0901
0.4459	2.1673	0.2119
0.5000	2.4304	0.2702

***** NOTES:
LOW PRESSURE (FLUCUATED TRHOUGHOUT RUN)

Table 10.- Data for L-BCC-D, wet tests.

D1

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.137 HOURS
CONSTANT RAIN RATE = 4.514 IN.PER.HR
INITIAL ABSTRACTION= 0.618 INCHES
ANTECEDENT MOISTURE= 0.0070 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2042	0.9217	0.0244
0.2911	1.3142	0.0964
0.3583	1.6176	0.1367
0.4583	2.0690	0.1960
0.5417	2.4452	0.2892
0.6500	2.9343	0.4058
0.7500	3.3855	0.4990

***** NOTES:
LOW PRESSURE

D2

TIME TO PONDING = 0.010 HOURS
TIME TO RUNOFF = 0.258 HOURS
CONSTANT RAIN RATE = 4.766 IN.PER.HR
INITIAL ABSTRACTION= 1.231 INCHES
ANTECEDENT MOISTURE= 0.0080 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.3500	1.6680	0.0191
0.4500	2.1446	0.0360
0.5833	2.7801	0.0901
0.6667	3.1772	0.1208
0.7500	3.5743	0.1515

***** NOTES:
LOW PRESSURE

D3

TIME TO PONDING = 0.024 HOURS
TIME TO RUNOFF = 0.392 HOURS
CONSTANT RAIN RATE = 4.002 IN.PER.HR
INITIAL ABSTRACTION= 1.568 INCHES
ANTECEDENT MOISTURE= 0.0060 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.5133	2.0546	0.0064
0.5967	2.3881	0.0093
0.6800	2.7216	0.0144
0.7500	3.0018	0.0195

Table 11.- Data for L-BCC, dry tests.

W1

TIME TO PONDING = 0.003 HOURS
TIME TO RUNOFF = 0.034 HOURS
CONSTANT RAIN RATE = 4.730 IN.PER.HR
INITIAL ABSTRACTION= 0.162 INCHES
ANTECEDENT MOISTURE= 0.0750 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1167	0.5520	0.0784
0.2000	0.9462	0.1896
0.2834	1.3404	0.3051
0.3667	1.7346	0.4301
0.4501	2.1290	0.6336
0.5000	2.3651	0.7416

W2

TIME TO PONDING = 0.006 HOURS
TIME TO RUNOFF = 0.031 HOURS
CONSTANT RAIN RATE = 3.373 IN.PER.HR
INITIAL ABSTRACTION= 0.103 INCHES
ANTECEDENT MOISTURE= 0.0810 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1250	0.4217	0.0752
0.2084	0.7028	0.1737
0.2917	0.9838	0.2786
0.3750	1.2649	0.3878
0.5000	1.6864	0.5223

W3

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.041 HOURS
CONSTANT RAIN RATE = 4.201 IN.PER.HR
INITIAL ABSTRACTION= 0.170 INCHES
ANTECEDENT MOISTURE= 0.0750 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1667	0.7001	0.0180
0.2500	1.0502	0.0487
0.3333	1.4003	0.0911
0.4167	1.7503	0.0954
0.5000	2.1003	0.1059

W4

TIME TO PONDING = 0.006 HOURS
TIME TO RUNOFF = 0.024 HOURS
CONSTANT RAIN RATE = 3.807 IN.PER.HR
INITIAL ABSTRACTION= 0.090 INCHES
ANTECEDENT MOISTURE= 0.0650 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1667	0.6345	0.0710
0.2500	0.9518	0.1303
0.3333	1.2690	0.1896
0.4167	1.5862	0.2532
0.5000	1.9034	0.3358

Table 12.- Data for L-BCC, wet tests.

D1

TIME TO PONDING = 0.025 HOURS
TIME TO RUNOFF = 0.192 HOURS
CONSTANT RAIN RATE = 3.856 IN.PER.HR
INITIAL ABSTRACTION= 0.739 INCHES
ANTECEDENT MOISTURE= 0.0130 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2833	1.0925	0.0572
0.3722	1.4352	0.1250
0.4500	1.7351	0.2119
0.5334	2.0564	0.3305
0.6167	2.3777	0.4386
0.7000	2.6991	0.5848
0.7500	2.8917	0.6632

***** NOTES:
GAGES NO. 1 AND NO. 2 WERE KNOCKED CVER

D2

TIME TO PONDING = 0.020 HOURS
TIME TO RUNOFF = 0.555 HOURS
CONSTANT RAIN RATE = 4.005 IN.PER.HR
INITIAL ABSTRACTION= 2.222 INCHES
ANTECEDENT MOISTURE= 0.0 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.6667	2.6702	0.0212
0.7500	3.0039	0.0636

***** NOTES:
RUNOFF PONDED AT FRONT DUE TO ADVERSE

GRADIENT INTO RUNOFF TRAY

D3

TIME TO PONDING = 0.011 HOURS
TIME TO RUNOFF = 0.042 HOURS
CONSTANT RAIN RATE = 3.138 IN.PER.HR
INITIAL ABSTRACTION= 0.131 INCHES
ANTECEDENT MOISTURE= 0.0120 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1417	0.4446	0.0678
0.2417	0.7583	0.1388
0.3417	1.0721	0.2426
0.4334	1.3597	0.3517
0.5917	1.8565	0.4068
0.6750	2.1180	0.4704
0.7500	2.3532	0.5340

***** NOTES:
LOW PRESSURE TILL 28 MINUTES

D4

TIME TO PONDING = 0.011 HOURS
TIME TO RUNOFF = 0.094 HOURS
CONSTANT RAIN RATE = 4.493 IN.PER.HR
INITIAL ABSTRACTION= 0.422 INCHES
ANTECEDENT MOISTURE= 0.0080 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2000	0.8987	0.0614
0.3334	1.4978	0.1727
0.4334	1.9471	0.2913
0.5167	2.3214	0.3507
0.6000	2.6958	0.3899
0.6833	3.0702	0.4386
0.7500	3.3697	0.4937

***** NOTES:
LOW PRESSURE TILL 28 MINUETS

Table 13.- Data for PH-AMB, dry tests.

W1

TIME TO PONDING = 0.004 HOURS
TIME TO RUNOFF = 0.062 HOURS
CONSTANT RAIN RATE = 3.844 IN.PER.HR
INITIAL ABSTRACTION= 0.240 INCHES
ANTECEDENT MOISTURE= 0.1380 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1472	0.5659	0.0487
0.2334	0.8970	0.1335
0.3167	1.2173	0.2723
0.4000	1.5376	0.3761
0.5000	1.9218	0.5456

W2

TIME TO PONDING = 0.014 HOURS
TIME TO RUNOFF = 0.112 HOURS
CONSTANT RAIN RATE = 4.197 IN.PER.HR
INITIAL ABSTRACTION= 0.472 INCHES
ANTECEDENT MOISTURE= 0.0 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2000	0.8395	0.0201
0.2833	1.1893	0.0625
0.3667	1.5391	0.1250
0.4500	1.8889	0.1674
0.5000	2.0987	0.1981

Table 14.- Data for PH-AMB, wet tests.

D1

TIME TO PONDING = 0.043 HOURS
TIME TO RUNOFF = 0.194 HOURS
CONSTANT RAIN RATE = 4.962 IN.PER.HR
INITIAL ABSTRACTION= 0.965 INCHES
ANTECEDENT MOISTURE= 0.0130 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.3164	1.5701	0.0345
0.4472	2.2194	0.1187
0.5375	2.6674	0.2159
0.6334	3.1430	0.3517
0.7500	3.7217	0.4136

D2

TIME TO PONDING = 0.022 HOURS
TIME TO RUNOFF = 0.339 HOURS
CONSTANT RAIN RATE = 4.348 IN.PER.HR
INITIAL ABSTRACTION= 1.474 INCHES
ANTECEDENT MOISTURE= 0.0150 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.3797	1.6512	0.0697
0.4756	2.0679	0.1375
0.5722	2.4883	0.2174
0.6667	2.8989	0.2880
0.7500	3.2612	0.3111

D3

TIME TO PONDING = 0.025 HOURS
TIME TO RUNOFF = 0.378 HOURS
CONSTANT RAIN RATE = 4.205 IN.PER.HR
INITIAL ABSTRACTION= 1.591 INCHES
ANTECEDENT MOISTURE= 0.0150 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.6825	2.8697	0.0153
0.7500	3.1535	0.0625

D4

TIME TO PONDING = 0.036 HOURS
TIME TO RUNOFF = 0.667 HOURS
CONSTANT RAIN RATE = 3.637 IN.PER.HR
INITIAL ABSTRACTION= 2.425 INCHES
ANTECEDENT MOISTURE= 0.0130 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.7500	2.7280	0.0525

Table 15.- Data for RA-BCC, dry tests.

W1

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.025 HOURS
CONSTANT RAIN RATE = 4.224 IN.PER.HR
INITIAL ABSTRACTION= 0.136 INCHES
ANTECEDENT MOISTURE= 0.0710 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1170	0.4942	0.1451
0.1981	0.8368	0.2615
0.2834	1.1973	0.4659
0.3695	1.5609	0.6174
0.4515	1.9073	0.8410
0.5000	2.1122	0.9491

W2

TIME TO PONDING = 0.019 HOURS
TIME TO RUNOFF = 0.032 HOURS
CONSTANT RAIN RATE = 3.658 IN.PER.HR
INITIAL ABSTRACTION= 0.118 INCHES
ANTECEDENT MOISTURE= 0.0550 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.0867	0.3171	0.1155
0.1751	0.6405	0.3295
0.2584	0.9451	0.4768
0.3418	1.2501	0.6780
0.4251	1.5550	0.9069
0.5000	1.8290	1.1124

W3

TIME TO PONDING = 0.007 HOURS
TIME TO RUNOFF = 0.062 HOURS
CONSTANT RAIN RATE = 4.498 IN.PER.HR
INITIAL ABSTRACTION= 0.281 INCHES
ANTECEDENT MOISTURE= 0.0640 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1389	0.6249	0.0890
0.2292	1.0310	0.2437
0.3126	1.4061	0.4291
0.3959	1.7807	0.5891
0.5000	2.2491	0.7946

W4

TIME TO PONDING = 0.007 HOURS
TIME TO RUNOFF = 0.052 HOURS
CONSTANT RAIN RATE = 3.720 IN.PER.HR
INITIAL ABSTRACTION= 0.193 INCHES
ANTECEDENT MOISTURE= 0.0750 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1006	0.3741	0.0233
0.1845	0.6862	0.1102
0.2750	1.0232	0.2617
0.3584	1.3332	0.4248
0.5000	1.8600	0.6844

**** NOTES:
HOSE CONNECTION ON RUNOFF TRAY SLIGHTLY LOOSE

Table 16.- Data for RA-BCC, wet tests.

D1

TIME TO PONDING = 0.056 HOURS
TIME TO RUNOFF = 0.083 HOURS
CONSTANT RAIN RATE = 4.641 IN.PER.HR
INITIAL ABSTRACTION= 0.387 INCHES
ANTECEDENT MOISTURE= 0.0140 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.2167	1.0056	0.0318
0.3195	1.4826	0.1187
0.4053	1.8810	0.2045
0.4898	2.2730	0.3305
0.5731	2.6597	0.4217
0.6561	3.0451	0.4958
0.7500	3.4807	0.5838

**** NOTES:
NOT ENOUGH RAIN ON BACK OF PLOT

D2

TIME TO PONDING = 0.014 HOURS
TIME TO RUNOFF = 0.050 HOURS
CONSTANT RAIN RATE = 5.683 IN.PER.HR
INITIAL ABSTRACTION= 0.284 INCHES
ANTECEDENT MOISTURE= 0.0090 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1145	0.6506	0.1229
0.2071	1.1767	0.3856
0.2750	1.5632	0.5424
0.3501	1.9898	0.8094
0.4418	2.5108	1.1092
0.5257	2.9875	1.3529
0.6098	3.4658	1.6040
0.6862	3.8999	1.8275
0.7500	4.2625	1.9928

D3

TIME TO PONDING = 0.012 HOURS
TIME TO RUNOFF = 0.094 HOURS
CONSTANT RAIN RATE = 3.649 IN.PER.HR
INITIAL ABSTRACTION= 0.344 INCHES
ANTECEDENT MOISTURE= 0.0160 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1756	0.6408	0.0985
0.2600	0.9489	0.1790
0.3434	1.2530	0.2680
0.4309	1.5724	0.3924
0.5139	1.8755	0.5047
0.5973	2.1796	0.6456
0.6806	2.4837	0.7749
0.7500	2.7370	0.8575

***** NOTES:
VERY ROCKY PLOT

D4

TIME TO PONDING = 0.009 HOURS
TIME TO RUNOFF = 0.083 HOURS
CONSTANT RAIN RATE = 3.472 IN.PER.HR
INITIAL ABSTRACTION= 0.289 INCHES
ANTECEDENT MOISTURE= 0.0120 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1923	0.6677	0.1960
0.2750	0.9549	0.2617
0.3584	1.2443	0.4206
0.4486	1.5577	0.5032
0.5381	1.8682	0.6007
0.6236	2.1653	0.7247
0.7000	2.4305	0.8645
0.7500	2.6040	0.9281

Table 17.- Data for RA-BKD, dry tests.

W1

TIME TO PONDING = 0.014 HOURS
TIME TO RUNOFF = 0.035 HOURS
CONSTANT RAIN RATE = 3.970 IN.PER.HR
INITIAL ABSTRACTION= 0.140 INCHES
ANTECEDENT MOISTURE= 0.0650 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1069	0.4246	0.0170
0.1912	0.7589	0.1716
0.2792	1.1085	0.3337
0.3222	1.2792	0.4153

***** NOTES:
MOVED BOOM DURING RAIN

W2

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.042 HOURS
CONSTANT RAIN RATE = 2.867 IN.PER.HR
INITIAL ABSTRACTION= 0.119 INCHES
ANTECEDENT MOISTURE= 0.0630 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1320	0.3784	0.1123
0.2251	0.6454	0.4153
0.2984	0.8554	0.5043
0.3222	0.9238	0.5350

W3

TIME TO PONDING = 0.006 HOURS
TIME TO RUNOFF = 0.021 HOURS
CONSTANT RAIN RATE = 4.105 IN.PER.HR
INITIAL ABSTRACTION= 0.086 INCHES
ANTECEDENT MOISTURE= 0.0570 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1236	0.5076	0.1123
0.2140	0.8785	0.3560
0.3000	1.2318	0.5170
0.3862	1.5855	0.7183
0.5000	2.0527	0.9726

W4

TIME TO PONDING = 0.007 HOURS
TIME TO RUNOFF = 0.036 HOURS
CONSTANT RAIN RATE = 6.417 IN.PER.HR
INITIAL ABSTRACTION= 0.230 INCHES
ANTECEDENT MOISTURE= 0.0550 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.0834	0.5354	0.2267
0.1668	1.0702	0.4905
0.2551	1.6370	0.7692
0.3410	2.1879	1.0870
0.4243	2.7226	1.3773
0.5000	3.2085	1.6326

Table 18.- Data for RA-BKD, wet tests.

D1

TIME TO PONDING = 0.012 HOURS
TIME TO RUNOFF = 0.025 HOURS
CONSTANT RAIN RATE = 3.776 IN.PER.HR
INITIAL ABSTRACTION = 0.094 INCHES
ANTECEDENT MOISTURE = 0.1000 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1083	0.4092	0.0604
0.1917	0.7239	0.2214
0.2918	1.1018	0.4524
0.3584	1.3532	0.5393
0.4418	1.6682	0.7384
0.5250	1.9827	0.8846
0.6084	2.2974	1.0277
0.6917	2.6120	1.1590
0.7500	2.8322	1.2501

D2

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.033 HOURS
CONSTANT RAIN RATE = 4.199 IN.PER.HR
INITIAL ABSTRACTION = 0.140 INCHES
ANTECEDENT MOISTURE = 0.1000 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1167	0.4900	0.0678
0.2001	0.8403	0.2871
0.2834	1.1902	0.5096
0.3668	1.5402	0.7289
0.4501	1.8901	0.9260
0.5334	2.2399	1.0534
0.6209	2.6075	1.2978
0.7001	2.9400	1.5002
0.7500	3.1496	1.6411

D3

TIME TO PONDING = 0.011 HOURS
TIME TO RUNOFF = 0.033 HOURS
CONSTANT RAIN RATE = 5.216 IN.PER.HR
INITIAL ABSTRACTION = 0.174 INCHES
ANTECEDENT MOISTURE = 0.0500 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1167	0.6088	0.1568
0.2001	1.0438	0.4047
0.2834	1.4784	0.6357
0.3668	1.9131	0.8687
0.4501	2.3478	1.0997
0.5334	2.7825	1.3444
0.6168	3.2171	1.5712
0.7000	3.6515	1.6792
0.7500	3.9121	1.7449

D4

TIME TO PONDING = 0.009 HOURS
TIME TO RUNOFF = 0.033 HOURS
CONSTANT RAIN RATE = 3.170 IN.PER.HR
INITIAL ABSTRACTION = 0.106 INCHES
ANTECEDENT MOISTURE = 0.0400 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1167	0.3699	0.0212
0.2000	0.6341	0.0614
0.2834	0.8983	0.1557
0.3750	1.1890	0.2966
0.4500	1.4267	0.4248
0.5334	1.6909	0.5742
0.6167	1.9551	0.7427
0.7000	2.2193	0.8952
0.7500	2.3777	1.0171

Table 19.- Data for V-MWA, dry tests.

W1

TIME TO PONDING = 0.008 HOURS
TIME TO RUNOFF = 0.024 HOURS
CONSTANT RAIN RATE = 5.409 IN.PER.HR
INITIAL ABSTRACTION= 0.128 INCHES
ANTECEDENT MOISTURE= 0.1700 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1071	0.5790	0.2924
0.1904	1.0298	0.5954
0.2737	1.4804	0.8603
0.3570	1.9311	1.1082
0.4653	2.5165	1.5044
0.5000	2.7043	1.6104

W2

TIME TO PONDING = 0.003 HOURS
TIME TO RUNOFF = 0.025 HOURS
CONSTANT RAIN RATE = 4.638 IN.PER.HR
INITIAL ABSTRACTION= 0.116 INCHES
ANTECEDENT MOISTURE= 0.2100 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1084	0.5029	0.2490
0.1918	0.8893	0.4958
0.2751	1.2758	0.7395
0.3793	1.7590	1.0658
0.4626	2.1454	1.3285
0.5000	2.3188	1.4567

W3

TIME TO PONDING = 0.010 HOURS
TIME TO RUNOFF = 0.033 HOURS
CONSTANT RAIN RATE = 4.171 IN.PER.HR
INITIAL ABSTRACTION= 0.139 INCHES
ANTECEDENT MOISTURE= 0.1400 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1167	0.4867	0.1218
0.2001	0.8346	0.3231
0.2834	1.1821	0.5096
0.3668	1.5297	0.6939
0.4501	1.8773	0.8868
0.5000	2.0855	1.0097

W4

TIME TO PONDING = 0.003 HOURS
TIME TO RUNOFF = 0.025 HOURS
CONSTANT RAIN RATE = 3.918 IN.PER.HR
INITIAL ABSTRACTION= 0.098 INCHES
ANTECEDENT MOISTURE= 0.1200 DIMENSIONLESS

TI HOURS	PI INCHES	QI INCHES
0.1167	0.4573	0.1038
0.2001	0.7840	0.2977
0.2834	1.1106	0.5054
0.3668	1.4371	0.7395
0.4501	1.7637	0.9758
0.5000	1.9592	1.1378

Table 20.- Data for V-MWA, wet tests.