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A Model for Designing Surface Drainage Systems In Nearly Level Agricultural Lands

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A MODEL FOR DESIGNING SURFACE DRAINAGE SYSTEMS IN NEARLY LEVEL AGRICULTURAL LANDS

by

Rafael Maria Rojas

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Soil Science and Biometeorology

in

Soils and Irrigation

Approved by:

UTAH STATE UNIVERSITY
Logan, Utah

1976

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Finally, I would like to dedicate this work to the memory of my mother.

Rafael Maria Rojas

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PARTIAL LIST OF SYMBOLS

a	Exponent in Kostiakov's infiltration equation
AMC	Antecedent moisture condition
b	Intercept for t=1 in Kostiakov's infiltration equation
Bd	Bulk density
C	Intercept of the recession equation for Da=1
CN	Soil Conservation Service curve number
CV	Vegetative cover
Da	Storage in inches
F	Accumulated infiltration
f	Infiltration rate
fc	Constant infiltration rate
L	Length of plot
l	Residual length after rainfall
m	Routing coefficient
ml	Computed routing coefficient
n	Exponent of the recession curve
P	Accumulated precipitation
Pe	Excess precipitation
PT	Total precipitation
$\overline{pe}$	Average precipitation excess
Q	Accumulated runoff
qc	Constant runoff rate
qd	Design runoff rate
qe	Runoff rate at the end of rainfall simulation trial

PARTIAL LIST OF SYMBOLS (Continued)

q	Runoff rate
qr	Recession runoff rate
S	Potential infiltration
s	Slope of land
TP	Rainfall duration
tp	Time to peak
w	Width of plot

ABSTRACT

A Model for Designing Surface Drainage Systems In Nearly Level Agricultural Lands

by

Rafael M. Rojas, Doctor of Philosophy

Utah State University, 1976

Major Professor: Dr. R. J. Hanks
Department: Soil Science and Biometeorology

The increasing demand for reclamation of periodically waterlogged nearly level agricultural lands in humid tropical areas and the hazard of soil deterioration and soil moisture balance disturbances by current land forming methods suggests the need for investigations of new surface drainage design procedures. This report presents a rainfall-runoff model for simulating hydrographs from ungaged agricultural plots. The model is based on routing procedures and utilizes common soil and hydrologic data. Tests made with several small agricultural watersheds indicate that the model could be a useful tool in simulating surface drainage design.

Input data for the model consists of (a) rainfall data, (b) infiltration, (c) watershed characteristics, and (d) soil parameters. The model could be used with any computer or desk calculator. Since the model was developed for surface drainage purposes, its use is limited to wet conditions in homogeneous and rectangular plots.

(131 pages)

INTRODUCTION

Surface drainage has been one of the most important problems in the development of intensive agriculture in humid nearly level lands, especially in tropical and subtropical regions.

Surface drainage problems are commonly related to high precipitation, level topography, and fine textured soils. In most tropical regions, lands with surface drainage problems are generally regarded as marginal lands and are mainly cropped to rice and pasture. In recent years, the increasing demand for food has forced farmers to use some of these lands to produce more valuable crops, but the waterlogging condition associated with poor surface drainage is a limiting factor to producing economical benefits.

Research in surface drainage has been limited to the search for some method of improving land slope for a faster removal of excess water. The results, although good, generally can only be applied to those areas for which they were developed. Current methods of surface drainage design were developed for the main surface ditches. To insure a rapid water conveyance to these ditches, land reshaping is accomplished by land forming methods. Overdesign of these land surface changes are common and, therefore, soil disturbances occur. For deep soil, this is not a problem, but in shallow soils, it could be irreparable. Although, in most cases, yields increase after drainage, they still may not be optimum.

There is a need for a method to estimate runoff from agricultural plots which accounts for the minimum land surface changes necessary to provide an adequate removal of excess water and at the same time maintaining an acceptable moisture status for all crops in a rotation. The method should also apply to ungaged watersheds and, therefore, could be used in planning surface drainage works.

Objectives of the study

The purpose of this research was to develop a reliable surface drainage model for the design of surface drainage improvements. The model was proposed to be based on the rainfall-runoff relationship and flood routing procedures. Efforts were made to make the model as simple as possible to be used with common calculating facilities, and flexible enough to be applied to ungaged agricultural plots and requiring easily measurable soil and hydrological parameters and variables. Specifically, the main objectives of the study are:

1. To develop a surface drainage model with the following characteristics:
    a. The model should be simple to be used with common calculating machines.
    b. The model should be applicable to ungaged small watersheds.
    c. The model should use only those data commonly found in soil surveys and hydrological data publications.
    d. The model should be sensitive to those design characteristics as: slope and length of run.

2. To test the model with available small watershed data.
3. To develop a method for applying the model to surface drainage design.

REVIEW OF LITERATURE

Surface drainage design for small areas has not been considered before as an individual research topic. The literature used to conceive the ideas for this research has been divided into four categories: (a) surface drainage practices, (b) rainfall simulator analysis, (c) hydrology of small watersheds, and (d) crop production and surface drainage.

Surface drainage principles and practices

Surface drainage has been practiced for many years in a practical trial and error manner by means of land forming works. The first technical approach to the problem was made by McCrory and associates (30) when planning drainage improvements in the Cypress Creek Drainage District, Desha and Chicot Counties, Arkansas. McCrory developed the so-called "Cypress Creek Formula:"

$$Q = 36M^{5/6} \qquad [1]$$

in which Q is the ditch capacity in cfs, M is the area in square miles and 36 is the value of a certain coefficient that represents the characteristics of the drainage area and excess precipitation to be removed by surface drainage. The units of M (sq mi) indicate that this equation applies to large areas to calculate the capacity of the main outlet.

Stephen and Mills (45) obtained a relationship to apply the formula to other locations:

$$Q = (16.39 + 14.75\ Re)\ M^{5/6}$$

and can be applied to any location provided Re is known. Re is the excess rainfall in inches, and according to Stephen and Mills (45), should be determined in accordance with the SCS National Engineering Handbook, Section 4, Hydrology, Chapter 10 (48).

The Cypress Creek Formula, as mentioned before, applied only to the design of the main surface drainage ditch network and gives only the ditch capacity to remove the excess water in a given time, generally 24 hours. This equation could work satisfactorily providing that each of the individual small plots in the drainage area has the capacity to conduct the excess water to the collector drains and then to the outlet ditch, but the equation does not provide enough evidence to insure that this will occur, mainly because of the absence of certain watershed parameters and variables, such as (a) rainfall intensity and duration, (b) absolute slope of land, (c) time variation of infiltration, (d) microrelief, (e) vegetative cover, and (f) soil moisture content at the time of the design event. The absence of these factors in the design leads to the uncertainty as to whether the watershed characteristics and conditions at the time of the rainfall occurrence will prevent the removal of the excess water in the desired time.

The computation of Re considers vegetative cover and antecedent moisture condition, but as will be discussed later, the method has several limitations regarding the evaluation of cover and antecedent moisture. The main limitations are that it was developed mainly from large and fairly well drained watersheds with slopes generally greater than 1 percent, which is opposite to the recommended use of the Cypress Creek Formula (49).

Most of the current surface drainage design procedures are based on the Cypress Creek Formula and, therefore, have the same limitations. Among these, the most commonly used are: Bureau of Reclamation (46), Soil Conservation Service (49), and American Society of Agricultural Engineers (1).

Several practical handbooks, bulletins, and technical journal articles have been written to indicate, propose, and delineate methods for designing surface drainage systems. Most of them show methods of land forming to accelerate the disposal of excess surface water (Zwerman, 52; Coote and Zwerman, 11; Savenson, 41; Luthin, 29; Beauchamps, 4; and many others). Most of the textbooks on drainage give some indications of the methods for outlet design.

The most recent surface drainage methods for agricultural lands are those of Salamin (38) and Seginer (43). Salamin presents a hydrological approach to the solution of the problem and gives some considerations to the crop resistance and yield under different flooding conditions, but like the other authors, he considers only the design of the system for a large area. Seginer developed a model of surface drainage for agricultural lands, but his approach is more applicable to urban areas than to agricultural lands.

Rainfall simulators

In the late thirties and early forties there was a great concern for the study of infiltration and erosion, and consequently, runoff from small watersheds. This started the rainfall simulator era. Many rainfall simulator trials were made on small plots, generally 24 x 6 feet. One of the advantages of these plots is that the surface remains undisturbed and is thus similar to natural conditions. These rainfall simulator studies provided material for hydrological studies and very good results were gained from them. The pioneer of rainfall simulator analysis was Horton (18,19) who created the techniques for such analysis, and his method is still in use by hydrologists.

After Horton, many other researchers utilized rainfall simulator data for different hydrological studies which have become the basis for many hydrological methods (Izzard, 24,25; Duley, 12,13; Beutner, 5; Borst, 6; Wishmeir, 51; Neal, 33; and many others).

In a rainfall simulator, water is artificially applied at a known rate for a certain period of time. Accumulated runoff as a function of time is measured at the end of the plot until runoff stops. Data collected from these plots are: runoff measurements, initial moisture content, time to runoff start, surface detention, vegetation, and sediment production.

Figure 1 shows a sample hydrograph of a rainfall simulator trial.

Horton suggested that when runoff becomes constant, it is because infiltration is also constant. This may not be strictly true, but for practical purposes this assumption is probably reasonable. This assumption is the key point in rainfall simulator analysis. If both runoff and infiltration rate are essentially constant,

$$\frac{fc}{qc} = \text{constant}^{1} \qquad [3]$$

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[1] All symbols refer to Figure 1.

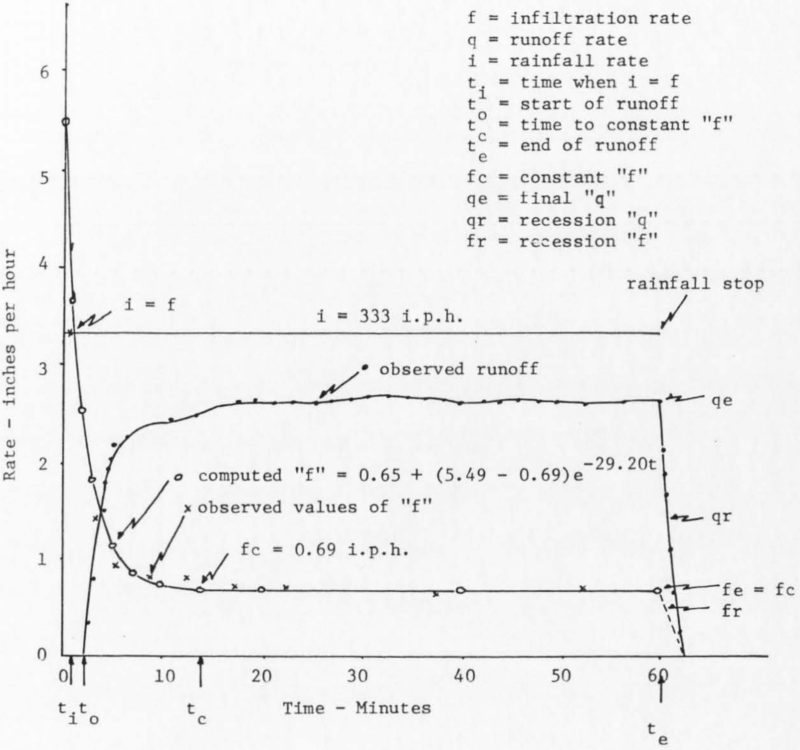

Figure 1. Rainfall simulator hydrograph (Taken from Beutner (5)).

and when rainfall stops

$$\frac{fe}{qe} = \frac{fc}{qc} = \text{constant.} \qquad [4]$$

In the recession part of the hydrograph q is measured. Since rainfall stopped, qr is a function of the storage on the plot Da, and therefore fr is also a function of the storage. From these, Horton also assumed that

$$\frac{fr}{qr} = \frac{fc}{qc}. \qquad [5]$$

The storage Da at the end of the trial can be computed from the measured qr as

$$Da = \left(\frac{fc}{qc} + 1\right) \sum_{i=1}^{i} \left(q_r^{i} + q_r^{i} - 1\right) \Delta t \qquad [6]$$

where q_r^i and q_r^i -1 are the measured runoff rates.

Δt is the time interval between q_r^i and q_r^i -1.

Infiltration rates during recession are computed by the equation

$$fr = qr \left(\frac{fc}{qc}\right) \qquad [7]$$

Knowing q_r^i and f_r^i, Da can be computed by successive subtraction of average qr's and fr's for each time interval.

Plotting Da vs qr gives the recession curve which in log-log paper results in a straight line (Figure 2). From this line the regression equation is obtained:

$$qr = C\ Da^{n} \qquad [8]$$

where C is the intercept when Da = 1 and n is the slope of the line.

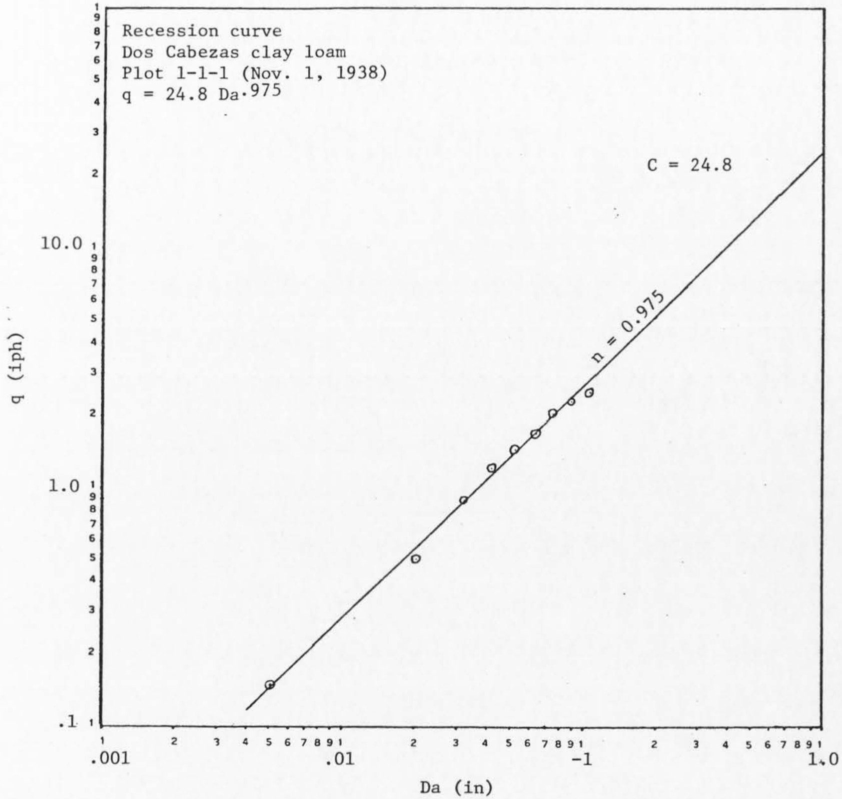

Figure 2. Typical storage-runoff relationship during recession. Data from Plot 1-1-1 of Arizona plots. (From Horton 18,19)

Analysis of many recession curves indicates that m is fairly constant for a particular place and depends mainly on the soil cover complex and slope of land, whereas C depends more on the length of the plot and soil-cover conditions.

Hydrology of small watersheds and surface drainage

The availability of hydrological data from small watersheds and the relative uniformity of those watersheds gave many hydrology researchers the opportunity to study the rainfall-runoff relationships and, therefore, to develop many of the present methods of hydrologic analysis. The literature on rainfall-runoff relationships is so extensive that it would be impractical to discuss it completely, therefore, only those works that most concern this research will be discussed. Chow (9) gives an extensive review of present knowledge.

Horton (18,19) and Izzard (24,25), as mentioned before, were two of the pioneers in the study of infiltration and runoff. Horton's infiltration equation is still widely used in hydrologic models, especially for its applicability in mathematical analysis for long duration storms. Izzard started the studies of overland flow by means of rainfall simulators and developed very good relationships between rainfall and runoff, especially for paved surfaces.

Izzard suggested that runoff was a function of surface storage Da and some watershed characteristics as given in the following equation similar to equation [8]:

$$q = C\ Da^{1.67} \qquad [9]$$

where 1.67 substitutes for n in equation [8] and is equal to the value of that exponent in Manning's equation for shallow flows. As is known for shallow flow in wide channels, the hydraulic radius R is approximated by the depth of flow Da. Mannings equation could be written as

$$V = \frac{1.486}{n} \left(\frac{Da}{12}\right)^{2/3} S^{1/2} \qquad [10]$$

or

$$V = C \left(\frac{Da}{12}\right)^{2/3} \qquad [11]$$

Equation [11] could then be written as

$$q = C \left(\frac{Da}{12}\right)^{5/3} \qquad [12]$$

where $5/3 - 1.67$ and C will include $S^{1/2}$, n and the conversion factors. The flow rate will then be in cubic feet per second.

Equation [12] could be used to synthesize a hydrograph providing that C could be evaluated and Da could be obtained by means of a continuity equation and values of precipitation, infiltration and previous Da, but the exponent is not really constant for all soil-cover complexes and n also changes during the storm. Finding the changes of this factor with respect to time and other variables will lead to very sophisticated mathematical analysis that until now has not been done.

After Horton's and Izzard's pioneer works, many studies have been made on rainfall runoff relationships, but most of them have been too theoretical or difficult to apply in cases of non-steady infiltration and precipitation. Eagelton (15) describes several methods, based on the kinematic wave theory, that are difficult to apply on ungaged watersheds.

Mockus (48), after analyzing data for a large number of small watersheds, developed a method for estimating runoff from precipitation data and watershed characteristics. He started with the basic assumption

$$\frac{F}{S} = \frac{Q}{Pe} \qquad [13]$$

in which F = actual infiltration after runoff started (inches)

S = potential infiltration (inches)

Q = actual runoff (inches)

Pe = Potential runoff (inches) or precipitation excess.

He defined Pe and F as follows:

$$Pe = P - Ia \qquad [14]$$

$$F = Pe - Q \qquad [15]$$

For practical reasons he considered Ia as the cumulative precipitation prior to runoff start, Ia is a function of interception, depression storage, and infiltration occurred before runoff started. Figure 3 shows all variables in Equation [13] as accumulative mass curves.

Combining equations [13], [14], and [15],

$$Q = \frac{(Pe)^2}{Pe + S}. \qquad [16]$$

From plot of Ia vs S, Mockus found that Ia = 0.2S, which upon substituting into equation [16] gives

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad [17]$$

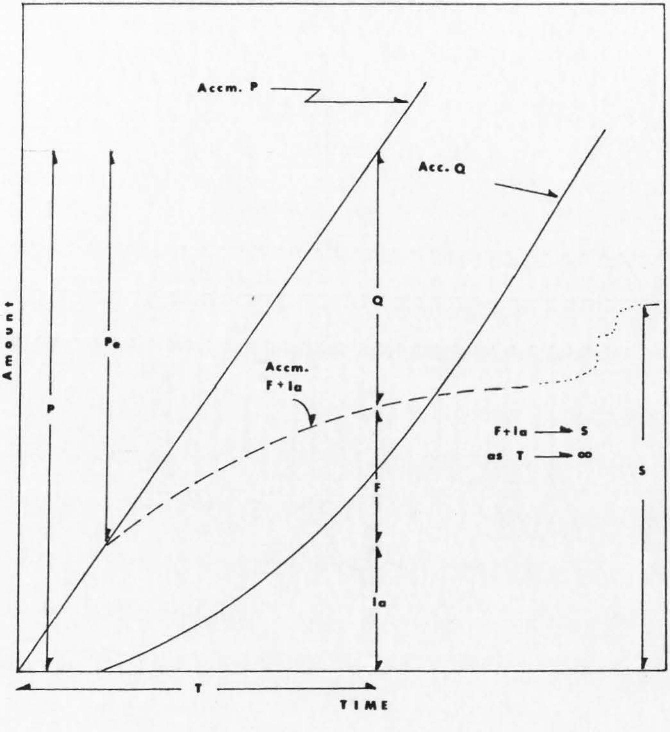

Figure 3. Schematic curves of accumulated P, Q, and F + Ia. (From Mockus in Chow's (9)).

This equation could be used to estimate total runoff in inches. Q could be used as precipitation excess on instantaneous hydrograph analyses, in this case, P is substituted by the cumulative P at the time of the estimate. The main limitation of this equation is the estimation of S which is made by using soil-cover complex, treatment or practice and antecedent soil moisture. Mockus made up tables to estimate values of CN (curve number), antecedent moisture conditions and hydrologic conditions. After finding the value of CN for a given condition, S can be computed as:

$$S = \frac{1000}{CN} - 10. \qquad [18]$$

Some other limitation of equation [17] are: Ia = 0.2S is not a good estimation, especially for dry conditions; antecedent moisture conditions (AMC) are grouped only in three categories and hydrologic soil classes are only four.

Chiang (8) modified the hydrologic soil classes into seven classes and provided a procedure to classify soils utilizing data from a detailed soil survey.

Assuming that precipitation excess could be computed by subtracting infiltration from precipitation or by Mockus's method when infiltration is unknown, synthesis of the hydrograph is still a problem due to the many factors involved in the transformation of the excess precipitation into runoff. Of the many techniques available, runoff routing is possibly the most simple and practical to utilize. Chow (9) and Carter (7) describe several methods of flood routing, in all cases a previous storage-outflow relationship has to be known and one to several coefficients must be obtained. Even in the case of a single peak hydrograph and rainfall simulator hydrographs, there is a hysteresis in the storage-runoff relationships. This hysteresis is responsible for the difficulty in synthesizing the rising part of the hydrograph.

Holtan and Overton (22,23) developed routing equations based directly on the continuity equation and storage-runoff relationships taken from the recession part of the hydrograph not sustained by rainfall. In essence, their equations are modifications of the "Plus Method" of routing. Their first equation is:

$$(pe_1 + pe_2) + \left(\frac{S_1}{\Delta t} + \frac{q_1}{2}\right) - q_1 = \left(\frac{S_2}{\Delta t} + \frac{q_2}{2}\right) \qquad [19]$$

in which pe = average precipitation excess

S = storage

q = outflow

Δt = time increment

1 and 2 refer to routing periods.

With a q vs $(\frac{S}{\Delta t} + \frac{q}{2})$ relationship (Figure 4) obtained from the recession part of the hydrograph unsustained by rainfall, q_2 can be obtained, providing all values for period 1 are known. These authors found that routing through half of the storage and making two routings, hysteresis can be overcome.

The limitation of this method is that the q vs $(\frac{S}{\Delta t} + \frac{q}{2})$ must be known, therefore the method could not be applied to ungaged watersheds. The authors also utilized what they called the routing coefficient, m, which was defined as the slope of the S versus q relationship which is considered to be a straight line (Figure 5).

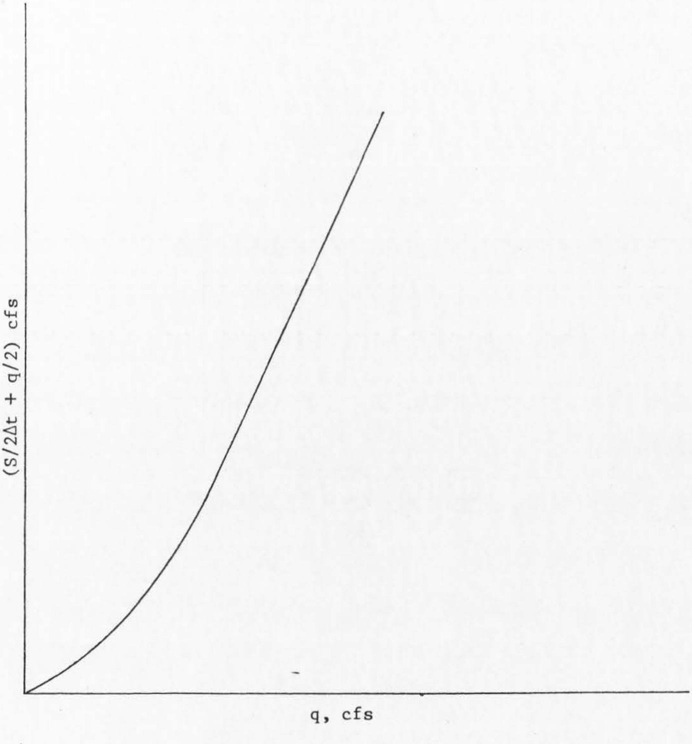

Figure 4. Typical (S/2Δt + q/2) vs q relationship.

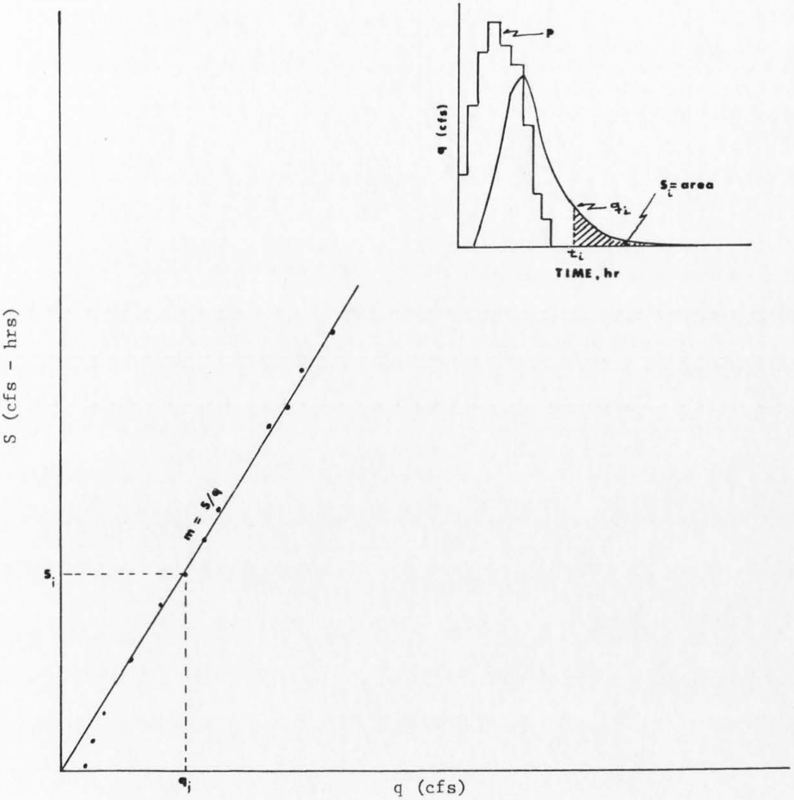

Figure 5. Computation of the routing coefficient, m.

$$m = S/q \qquad [20]$$

where m = routing coefficient in hours

S = storage (cfs/hr)

m is considered to be constant, therefore there is a linear relationship between storage and outflow.

Taking S = mq and considering half of the storage and two routings to minimize hysteresis, they obtained the equation

$$q_2^1 = (pe_1 + pe_2)\ (\frac{\Delta t}{m + \Delta t}) + q_1^1\ (\frac{m - \Delta t}{m + \Delta t}) \qquad [21]$$

where q_1^1 and q_2^1 are the outflow for the first routing. For the second routing, equation [21] becomes

$$q_2 = (q_1^1 + q_2^1)\ (\frac{\Delta t}{m + \Delta t}) + \frac{(m - \Delta t)}{(m + \Delta t)} \qquad [22]$$

q_2 is the final outflow for the period.

The example in their paper shows a very good fit between computed and observed hydrographs.

Overton (35), in a later paper, discussed the use of equations [21] and [22] and suggested that this was one of the most convenient ways of runoff routing for ungaged watersheds. He also suggested the importance of research to find a method of estimating m from soil and watershed parameters.

Narayana (32) and Amisial (2) developed analog models for surface runoff for short time intervals. These models were used in small watersheds, but the size of the watersheds was still too large for surface drainage of small plots (about 1 hectare). Another problem of the models is that they cannot be used, or are difficult to use in ungaged watersheds and an analog computer is needed to perform the simulation.

Crop production and surface drainage

The literature on crop damage due to flooding is not abundant. The research done is so diversified that good conclusions cannot be taken from those studies. Luthin (28) describes some of the studies on crop yield and flooding prior to 1957. Salamin (38) conducted a flooding damage study for conditions in Hungary which gives a list of crops yield reduction due to different flooding conditions.

Recently, Kramer (27) studied the flooding tolerance of tobacco plants and found that a 24-hour soil saturation could cause permanent plant injury. Rhoades (37) found that grasses are very tolerant to flooding for long periods of time. Beard (3) studied flood tolerance and temperature for four grasses and found that temperature had a great influence on flooding damage; with 30°C most of the plants died before 10 days. Williamson (50) found that most of the crops studied began to suffer from flooding in less than 24 hours of continuous flooding. Most of these research studies do not quantify the damages enough to compute monetary losses to justify any drainage improvement.

Savenson (41) working in sugarcane in Louisiana found that with surface drainage, yields could be increased by 2 tons of sugarcane per acre with a cost of less than $6.00 per acre. Salazar (39,40) studied surface drainage benefits on heavy soils in Venezuela where he found yield increases up to 100 percent in pasture and corn yields for 4.8 kg/ha with no surface drainage, to 1314 kg/ha with surface drainage. Surface drainage experiments in heavy soil in Portuguesa, Venezuela

(17) indicate yields could be increased up to 300 percent with furrow surface drainage.

The last four studies are examples of benefits from surface drainage works. The main objection to these data is they they were made only on a one-year basis, not considering that in a normal cycle there are wet and dry years. If the experiment was done in a wet year, it would be a success, but if it was a dry year, the results could be insignificant or negative. In the case of tropical humid countries with two crops, if a system is overdesigned, the second crop could suffer from moisture stress, especially if it is an end-of-rainfall season crop like sesame seed and beans.

The statements made in the last paragraph are supported by an experiment conducted by Miller (31) in Venezuela and by some trials in the Portuguesa study. Miller found that because of a dry year, surface drainage had negligible or negative results. In Portuguesa, the plots with wider collector drain distances gave better yields than the closer ones.

In Surinam and Trinidad (10), it was reported that lands formed in "beds" needed ten years to reach normal yields. This is because of soil disturbances during grading and leveling.

Summarizing, crop yields could be improved by surface drainage providing the design could be made in such a way that:

1. Minimum land leveling or grading is made.
2. Water removal should be fast enough to minimize crop drainage due to flooding and permit a reasonable infiltration to maintain a normal moisture balance throughout the cropping season.

3. The design storm, which is used for the basis of the design of the drains, should be selected considering both flood and drought return periods.

PROCEDURE

In order to be consistent with the objectives of this research and after the review of literature and several initial trials, it was decided to adopt the routing procedure developed by Holtan and Overton (22,23). Since this method required the elimination of the routing coefficient, m, from the storage-outflow curve of the recession hydrograph, it was also decided that the best source of reliable recession data was rainfall simulator studies. The routing coefficient, m was to be obtained for multiple regression analysis of the rainfall simulator data.

Precipitation excess, Pe, which is the input to the surface runoff component of the hydrologic system, was computed by subtracting infiltration from gross precipitation. Cumulative values of precipitation and infiltration were considered instead of instantaneous values. Precipitation excess, therefore, is defined as

$$Pe = P - F \qquad [23]$$

in which

Pe = precipitation excess

P = cumulative rainfall

F = cumulative infiltration

Infiltration, F, is represented by any available equation, such as Horton's (19), Philip's (36), or Kostiakov's (26). Horton's equation has been widely used in hydrologic modeling and its coefficients can be estimated from soil parameters (20,34). In the event that infiltration data are not available, Mockus' method (48) could be used.

The conceptual model is represented in schematic form by Figure 6 and it consists mainly of the following system blocks:

a. A set of initial conditions and watershed parameters data (soil, cover, antecedent moisture conditions, slope, length of field, width of plot, etc.). Data for this block are obtained from soil surveys and hydrologic data.

b. Infiltration potential, obtained from infiltration studies or Soil Conservation Service method (48).

c. Precipitation, obtained from rainfall frequency data.

d. Precipitation excess, computed from b and c.

e. Storage, computed from excess rainfall and runoff.

f. Storage-runoff system. This is the routing model based on recession curve analysis.

g. Outlet conditions. Since the routing model is designed for infinite outlet capacity, any outlet limitation will affect the runoff hydrograph.

h. Runoff. Final output from the hydrologic system.

Following the development of the conceptual model, the next step was to simulate a procedure for synthesizing the storage-runoff system from watershed parameters. The routing coefficient, m, proposed by Holtan and Overton was the main objective of this search. These authors said that m could be estimated by plotting storage against runoff, where storage was equal to the area under the hydrograph from a given time to the end of the runoff. In other words, storage at a

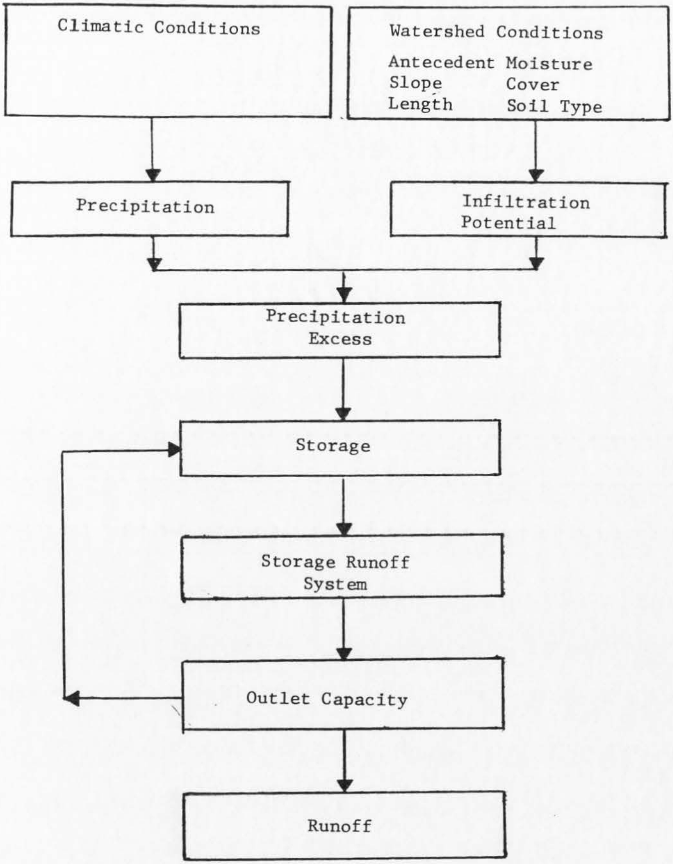

Figure 6. Rainfall-Runoff System for small plots.

given time is equal to total runoff less cumulative runoff at that time. This is not entirely accurate because infiltration during recession is not considered. Since infiltration from natural watersheds is difficult to estimate, the only way to reproduce a real storage-runoff relationship is with a controlled watershed. To meet this requirement, a rainfall simulator is frequently used to generate the needed data.

Data Collection and Analysis

Data collection

Time and climate conditions, cost, and availability of adequate equipment are the main factors that were considered in obtaining data for the development of the model. The existence of adequate data was the decisive factor in selecting rainfall simulator studies as the main source of information for this research. Unfortunately, these data were taken more than thirty years ago, therefore most of the original documents could not be found.

Four different sources were used to collect the rainfall simulator data:

1. Izzard's: "Preliminary Report of Analysis of Runoff Resulting from Simulated Rainfall on a Paved Plot" (24).
2. Professor Fletcher's files.[1]
3. Beutner's "Sprinkled-plot-runoff and Infiltration Experiments on Arizona Desert Soils" (5).
4. Holtan's "Plot Samples of Watershed Hydrology" (21).

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[1] Joel Fletcher. Personal files on rainfall simulator data, 1975.

Data utilized for testing the model were obtained from the ARS publication, "Hydrologic Data for Small Agricultural Watersheds" (47). Rainfall simulator data were tabulated and ordered for further analysis. Small watershed data were tabulated and interpolated when necessary.

Analysis of data

Rainfall simulator data were analyzed following Horton's method. Computations were made to obtain recession curves and such values as: potential infiltration, S, initial abstractions, Ia, constant infiltration rate, fc, and available porosity, ap. The data were selected so as to discard those trials which were incomplete or contained inconsistencies. All data are presented in Appendix B in Tables 5 through 11.

The procedure for obtaining the recession characteristics of each rainfall simulator trial, shown in Table 1, consists of the following steps:

1. From the rainfall simulator data (see Table 11, Appendix B), all data pertaining to the recession portion of the hydrograph are tabulated similar to Table 1. The data needed are time, accumulated time, time interval, and computed runoff. Other data to be taken from rainfall simulator trails are initial abstractions, rainfall rate, total precipitation, total runoff, constant rate of infiltration, and final runoff.
2. In this particular case, the final rate of infiltration is utilized instead of the constant rate. Since precipitation is constant, infiltration at the end of the rainfall is:

$$f_e = p - q_e \qquad [25]$$

in which f_e is the final rate of infiltration, p is the precipitation rate and q_e is the final runoff rate. From equation [3], the value of f_e/q_e is then computed.

3. Da at the end of rainfall is computed from equation [6] and its value is recorded at the time corresponding to the end of the rainfall, which is also the beginning of the recession period.
4. Infiltration during recession is computed by equation [7] and recorded in Table 1.
5. With q_r and f_r being known, Da for each point of the recession can be computed by the following relationship:

$$Da_2 = Da_1 - (\bar{q}_r + \bar{f}_r)\Delta t \qquad [26]$$

in which Da_1 is the previous value of Da; q_r and f_r are, respectively, average runoff and infiltration for the period in consideration and Δt is the time interval for the period.

6. Finally Da is plotted against q on log-log paper (Figure 7) for the example in Table 1. After the plot is completed and the best fit line is drawn, recession characteristics values are determined. In the example of Table 1, these values are

$m_1 = 0.091$

$n = 0.761$

$C = 6.3$

Final computation for regression analysis consists in the determination for S, which is obtained by equation [35]. Original rainfall

Table 1. Sample table for rainfall simulator analysis[1]

Time (min)	Accumulated time (sec)	Δt (sec)	q_r (iph)	f_r (iph)	Da (in)
60:00	--	--	2.04	1.180	0.1935
09	9	9	1.76	1.018	0.1860
26	26	17	1.67	0.966	0.1733
61:04	64	38	1.43	0.827	0.1474
25	85	21	1.36	0.787	0.1346
48	108	23	1.31	0.758	0.1211
62:12	132	24	1.15	0.665	0.1082
40	160	28	1.03	0.596	0.0948
63:10	190	30	0.94	0.544	0.0819
45	225	35	0.81	0.469	0.0684
64:25	265	40	0.68	0.393	0.0554
65:15	315	50	0.55	0.318	0.0419
65:20	380	65	0.40	0.231	0.0284
67:22	442	62	0.31	0.179	0.0187
68:25	505	63	0.19	0.110	0.0118
70:01	601	96	0.13	0.075	0.0051
71:47	707	106	0.06	0.035	0.0007
72:35	755	48	.00	0.000	0.0000

Plot data: Site = 17, Plot = 1, Run = 81, Slope = 1.60%, Precip. rate = 3.22 iph, Total precip. = 3.22 in, $\theta\omega$ = 7.1%, Runoff = 0.946 in, Cover = Heavy stand of tobasa chopped to 1 in.

Da computations

$$fc = 3.22 - 2.04 = 1.18;\ fc/qc = 1.18/2.04 = 0.5184$$

$$Da = \frac{1.5184}{7200} \sum (2.04 + 1.76)9 + (1.76 + 1.67)\ 17 + (1.67 + 1.43)\ 38 + (1.43 + 1.36)\ 21 + (1.36 + 1.31)\ 23 + (1.31 + 1.15)\ 24 + (1.15 + 1.03)\ 28 + (1.03 + 0.94)\ 30 + (.94 + .81)\ 35 + (.94 + .81)\ 35 + (.81 + .68)\ 40 + (.68 + .55)\ 50 + (.55 + .40)\ 65 + (.40 + .31)\ 62 + (.31 + .19)\ 63 + (.19 + .13)\ 96 + (.13 + .06)\ 106 + (.06)\ 48 =$$

$$\frac{882.85 \times 1.584}{7200} = 0.19354. \text{ (Equation 6)}$$

---

[1] Data for this example was taken from Table B-7, Appendix B.

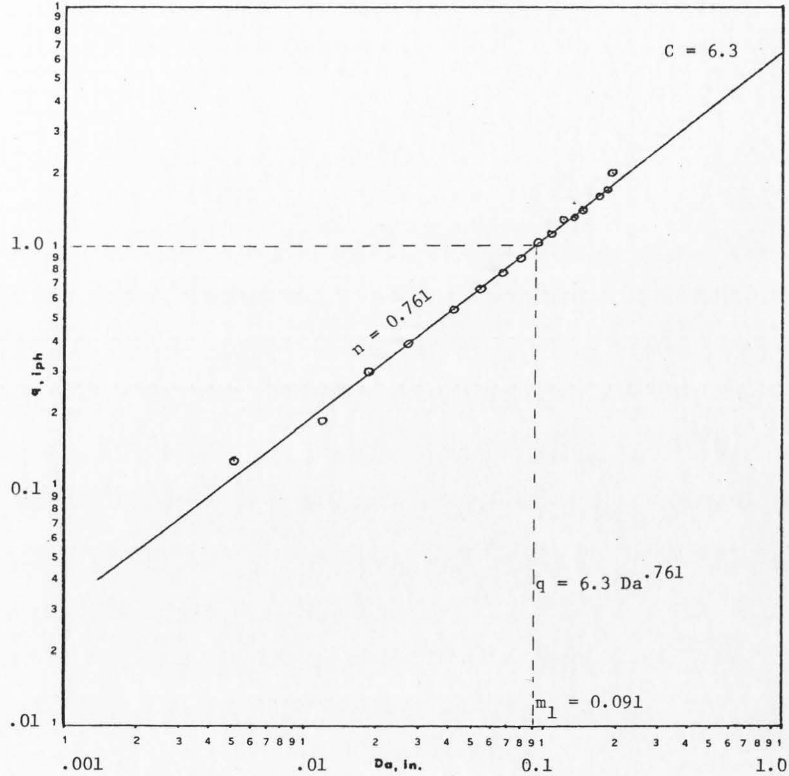

Figure 7. Recession curve for Trial 17-1-81, Ramona clay loam, 4-19-1939. Data from Beutner (5).

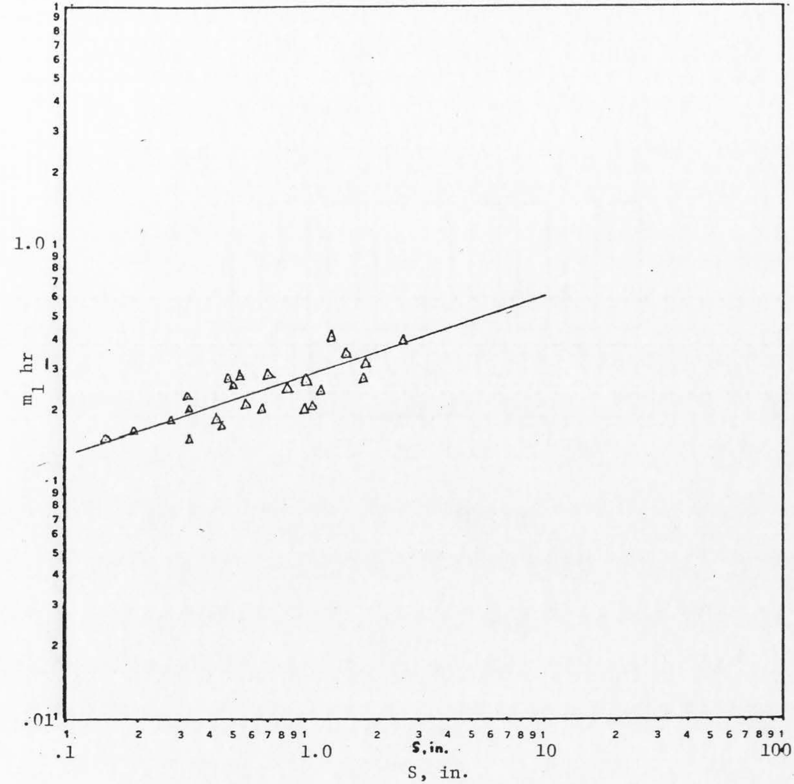

Figure 8. Infiltration potential versus routing coefficient m_1. Data from Beutner (5).

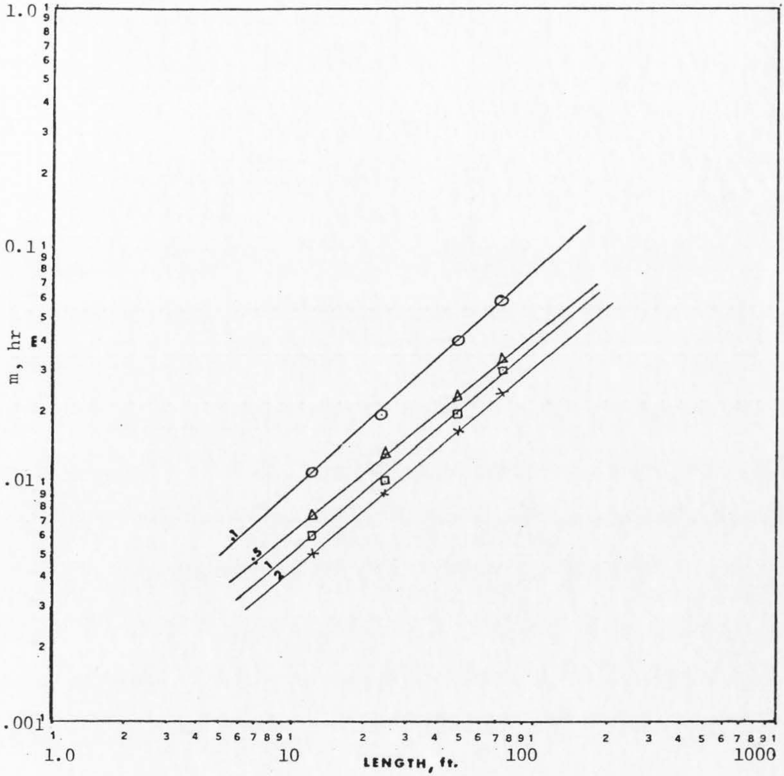

Figure 9. Length of run versus routing coefficient m_1. Data from Izzard (25).

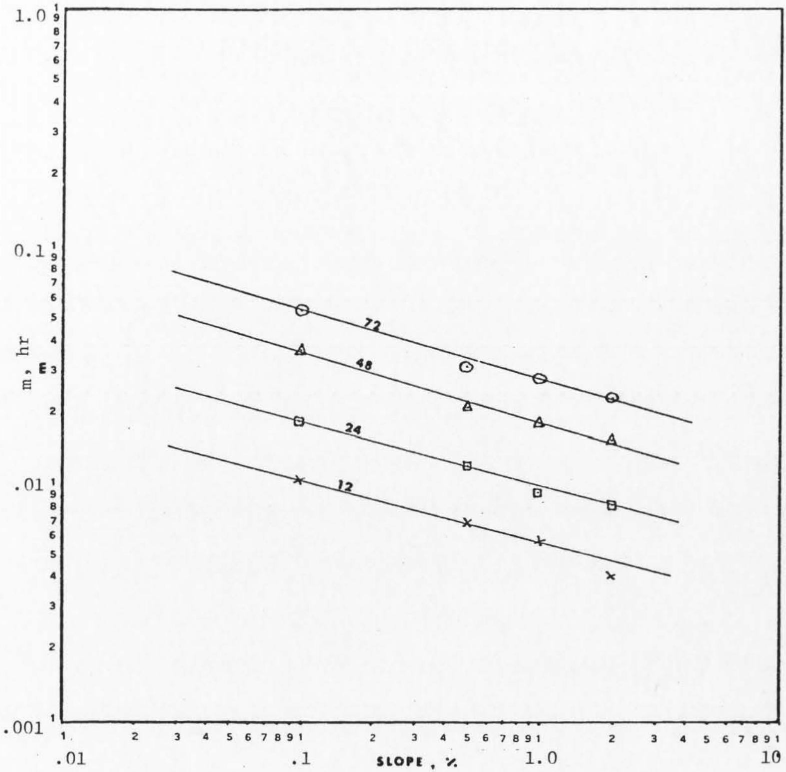

Figure 10. Slope versus routing coefficient m_1. Data from Izzard (25).

A study was made to identify a procedure for estimating hydrograph recession characteristics from watershed and soil parameters. In this study four particular characteristics were considered, namely (a) the routing coefficient, m, (b) the slope of the recession curve, n, (3) the intercept, C, of the recession curve for Da = 1, and (d) the value of Da when q = 1.

The routing coefficient, m, as defined by Holtan (24) is

$$m = Da/q \qquad [24]$$

in which m is the routing coefficient in hours, Da is the average storage depth in inches and q is the runoff in inches per hour corresponding to that Da. Assuming a linear relationship between storage and runoff, m can be computed if any value of Da and its corresponding q are known. A preliminary analysis of rainfall simulator data showed that the routing coefficient, m, is affected by the length of the plot, the slope of the land, the coefficient S, and vegetative cover.

Length of slope determines the volume of water left on the plot. Slope affects the velocity of flow and water surface profile. S is used as an indicator of infiltration and soil characteristics, and cover reflects both infiltration capacity and roughness of the field. Since these four watershed parameters can be obtained rather easily, it was assumed that if a good correlation could be obtained between them and the routing coefficient, then utilizing a multiple correlation, m could be estimated.

A multiple regression analysis was then conducted, and from this the following equation was developed:

$$m_1 = 0.24\ L^{0.274}\ s^{-0.131}\ CV^{0.189}\ S_1^{-0.0535} \qquad [27]$$

in which m_1 is the value of Da when $q = 1$ is numerically equal to m in equation [24]. The reason for using m_1 instead of m is that information for defining recession curves usually is available in most of the data sources. Figure 11 shows a plot of computed versus measured m.

The intercept of C of equation [8] usually gives very unrealistic results, probably because it represents an extrapolation of the curve and the doubtful assumption that the relationship continues to be a straight line. In this manner m_1, which is always present in the recession curve, was chosen to represent the intercept. C was computed from m_1 and n by the following equation:

$$C = m_1^{1/n} \qquad [28]$$

Equation [28] results from substituting m_1 for Da in equation [8] and making $q - 1$. From equation [24], when $q = 1$, $Da = m_1$.

If m_1 is already available, to reproduce the recession equation, only n is needed. An analysis of the rainfall simulator data indicates the n is affected by vegetative cover and S. Izzard's data (24), in which S and cover are both equal to zero, indicates that n is not significantly affected by length of run and slope of land. In view of the previous findings, a multiple regression analysis was conducted to correlate n to S and cover. The resulting equation is as follows:

$$n = 1.0CV^{0.013}\ S_1^{-0.19} \qquad [29]$$

Figure 12 shows plots of computed versus measured values for n.

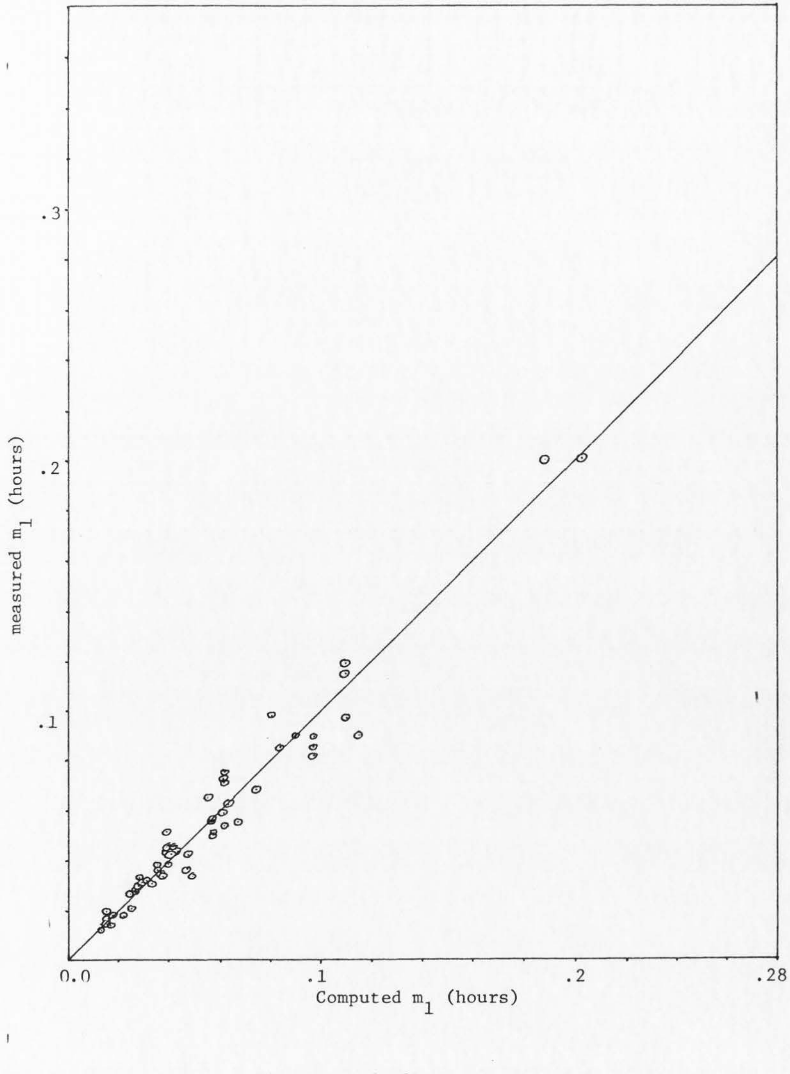

Figure 11. Computed m_1 (equation [27]) versus measured m_1. Data from Beutner (5) and Izzard (25).

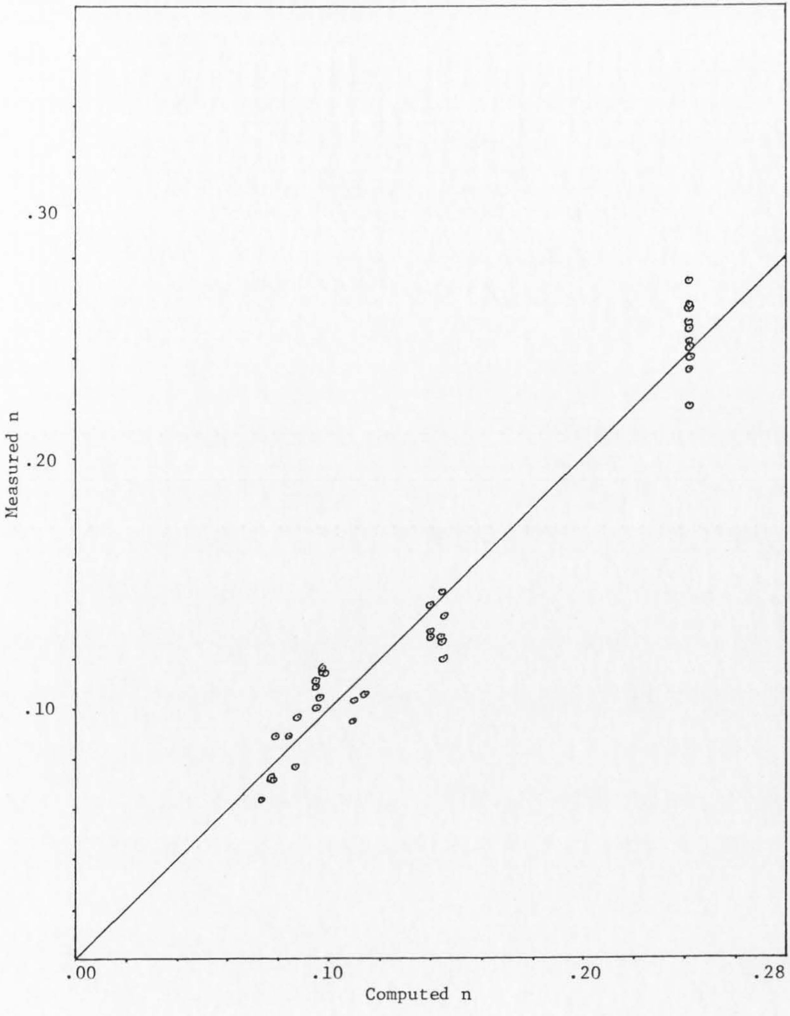

Figure 12. Computed n (equation [29]) versus measured n. Data from Beutner (5) and Izzard (25).

Developing the Model

The development of the model was based on previous research with rainfall simulators and hydrology of small watersheds. The tools used were mainly taken from Horton's (18) rainfall simulator analysis, Mockus' (48) runoff method and Holtan and Overton's (22,23) routing procedures. Infiltration, being the most important factor affecting the runoff hydrograph, was given the highest priority in the development of the model. Most of the ideas used on infiltration relationships came from Horton's work (18,19) and Hanks' Soil Physics class material.[1]

All phases of the model were synthetized on the Utah State University's Burroughs 6900 computer and its built-in library. The program for the model was written in Fortran IV.

First model

After some preliminary trials, a mathematical-numerical method was developed. This model was based directly on Holtan-Overton's routing method (22,23) and consists of four main sections as follows: (a) an input section in which the input data are read, (b) a section to compute recession characteristics, (c) a routine to compute rainfall excess and perform the runoff routing, and (d) an output or writing section. Figure 13 shows the flow diagram of the model.

The input to the model consists of watershed, precipitation, and infiltration data as follows:

Watershed data. (a) length of plot, l, (b) width of plot, w, (c) slope, s, (d) vegetative cover, CV, (e) antecedent moisture

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[1] R. J. Hanks, Soil Physics 565 and 614 class material. Department of Soil Science and Biometeorology, Utah State University, Logan, 1973.

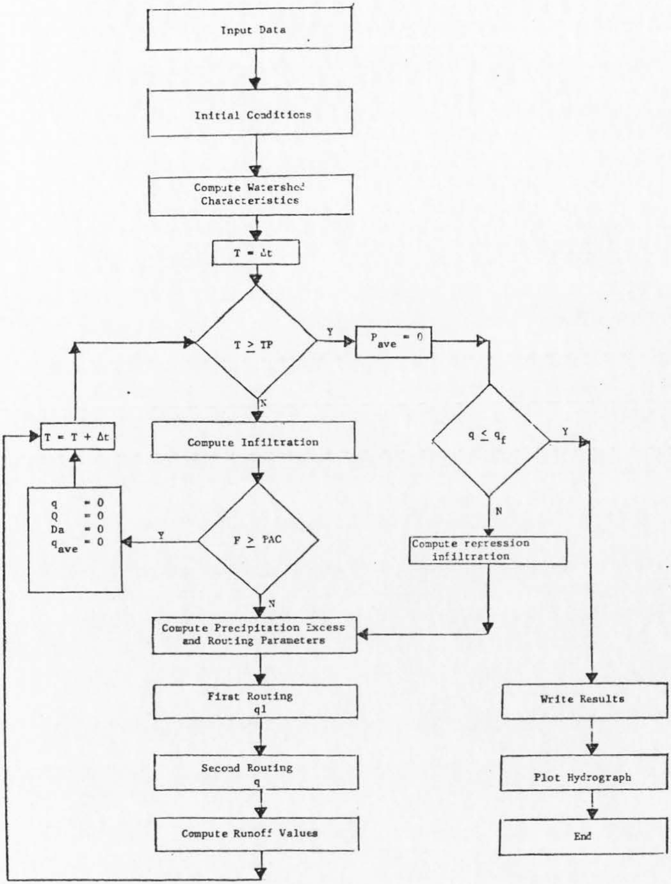

Figure 13. Flow diagram of the surface drainage model.

condition, AMC, (f) soil type, and (g) bulk density (apparent specific gravity).

Precipitation data (a) storm duration, TP, (b) cumulative precipitation array, PAC(I), (c) total precipitation, PT.

Infiltration data (a) infiltration equation or (b) equations to estimate S and Ia, and (c) initial abstraction (only for tests).

Recession characteristics are computed by equations [24], [27], and [28]. The routing section is the main part of the model. It first computes precipitation excess by equation [23], then calculates average excess precipitation, $\overline{pe}$, and performs the routing utilizing equations [21] and [22].

The routing coefficient utilized in the model is m_1 which is computed in the preceding section by equation [27].

Average excess precipitation is computed as:

$$\overline{pe}_2 = (Pe_2 - Pe_1)/2 \qquad [30]$$

in which

Pe = excess precipitation from equation [23] (in)

$\overline{pe}$ = average excess preciptitation (iph)

subscripts 1 and 2 refer to routing times.

Making

$$\frac{\Delta t}{m + st} = C_1 \qquad [31]$$

and

$$\frac{m - st}{m + st} = C_2 \qquad [32]$$

By substituting equations [30] and [31], equations [21] and [22] become

$$q_2^1 = (pe_1 + pe_2)\ C_1 + q_1^1\ C_2 \qquad [33]$$

$$q_2 = (q_1^1 + q_2^1)\ C_1 + q_1\ C_2 \qquad [34]$$

The final section of the model writes the results and plots the runoff hydrograph.

Testing the Model

The model was tested with data from several small watersheds at Hastings, Nebraska and Waco, Texas. In Appendix B, all watersheds utilized in testing the model are extensively described.

Because some of the data needed for the model were not available for the selected watersheds, estimates were made. For example, vegetative cover was evaluated on the basis of its density and some coefficients suggested by Holtan (20). Potential infiltration, S, was computed from storm data as:

$$S = \frac{Pe^2}{Q} - Pe \qquad [35]$$

in which Pe = P - Ia (16).

Ia = initial abstraction, estimated from the hydrograph.

Q = total runoff, taken from the hydrograph

S could also be computed by the Mockus procedure (48), but when sufficient information is available, equation [35] gives a more realistic estimate. For ungaged watersheds, it is necessary to estimate S by the Mockus method or some other procedure.

Infiltration was computed from the hydrograph data and the recession curve. The Kostiakov equation:

$$F = a\ t^{b} \qquad [36]$$

was chosen because of its simplicity and applicability to situations where data are not complete. Equation [36] is not recommended for application over long periods of time because it assumes that infiltration continuously decreases. It is well established that the capacity of infiltration rate eventually reaches a constant equal to the saturated hydraulic conductivity. In spite of this limitation, however, equation [36] yields realistic results for short time periods. Sharp [44] developed a graphical method to estimate infiltration from watershed storm data but it us a tedious and complicated procedure that requires storms of more than one peak and the model of this study is not intended to apply for complex storms of this nature.

Since equation [36] plots as a straight line on logarithmic paper, it is assumed that if two points are determined, the equation can be synthesized. The first point considered was Ia which is determined directly from the hydrograph. The second point corresponded to the last point in time on the hydrograph when the area subject to precipitation was entirely covered by water. Since the only point in the recession curve in which all the watershed is still covered with water is at the end of rainfall, this was chosen as the second point. Cumulative infiltration at this point is as follows:

$$F_{er} = PT - Q_{er} - Da_{er} \qquad [37]$$

in which

F_{er} = cumulative infiltration at end of rainfall

PT = total precipitation

Q_{er} = cumulative runoff at end of rain

$$Da_{er} = (q_{er}/C)^{1/n} \quad [38]$$

where q_{er} is the runoff rate at the end of the rainfall.

With all values in equation [37] being known, F_{er} is then computed and b of equation [36] is determined as

$$b = \frac{\log F_{er} - \log Ia}{\log TP - \log TIa} \quad [39]$$

where TP is the duration of the rainfall in minutes and TIa is the time to start of runoff, or time to Ia.

$$a = \frac{F_{er}}{TP^{b}} \quad [40]$$

Equation [36], as used here, does not give infiltration but rather total rainfall abstractions. Because Ia includes infiltration, depression storage, and interception, its value cannot be taken as accumulated infiltration up to the start of runoff. However, since F_{er} also includes the same initial abstractions, equation [36] can be assumed to be valid for routing purposes.

The model was tested with watershed data from Waco, Texas and Hastings, Nebraska (46). Data are in Appendix C. The reasons these watersheds were chosen were: (a) they were fairly uniform in soil, cover, and geometric features, and (b) slopes were not so steep and contour lines were moderately uniform.

3. All watersheds have good rainfall and runoff data.

The objectives of the test were to observe the behavior and limitations of this first model. Tests were designed to check the following:

1. Accuracy of the model and to synthesize the runoff hydrograph.
2. To test the validity of using a constant value of the routing coefficient, m.
3. To test the accuracy of infiltration estimates.

Initial trials were made to check point 2 (constant routing coefficient). These trials were made utilizing data from events with small unfiltration volume, to avoid discrepancies due to failures in infiltration estimates. Three different values for the routing coefficient were utilized: (a) Holtan's routing coefficient, m, (b) m_1 obtained from equation [27], and (c) $m_1/2$. The last value was included to test the influence of a smaller m value on the shape of the hydrograph.

Holtan's routing coefficient, m, is computed from the recession limb of the hydrograph as the time lag in hours from a value q_o to the occurrence of another value equal to q_o/e. This value should be equal to the slope of the storage runoff relationship presented in Figure 5. The value of m_1 should be equal to m as demonstrated in a previous discussion.

Figures 14 and 15 present the simulated hydrographs obtained by using the different values of m. An analysis of those hydrographs shows the following:

1. Computed and estimated values of m do not give similar hydrograph patterns.

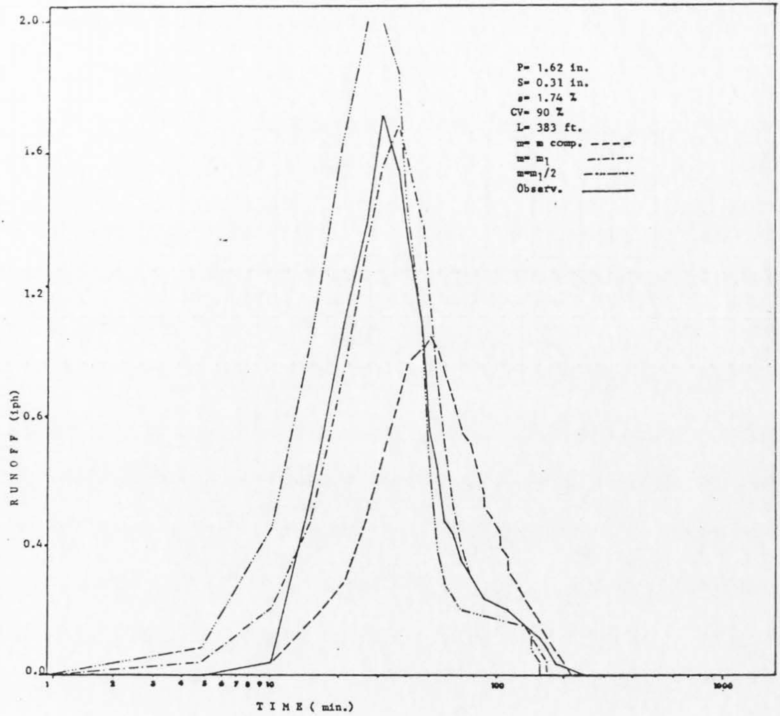

Figure 14. Observed and simulated runoff hydrographs using m, m_1, and $m_1/2$ as routing coefficients. Event of May 13, 1975, SW-17, Waco, Texas. Data from USDA (46).

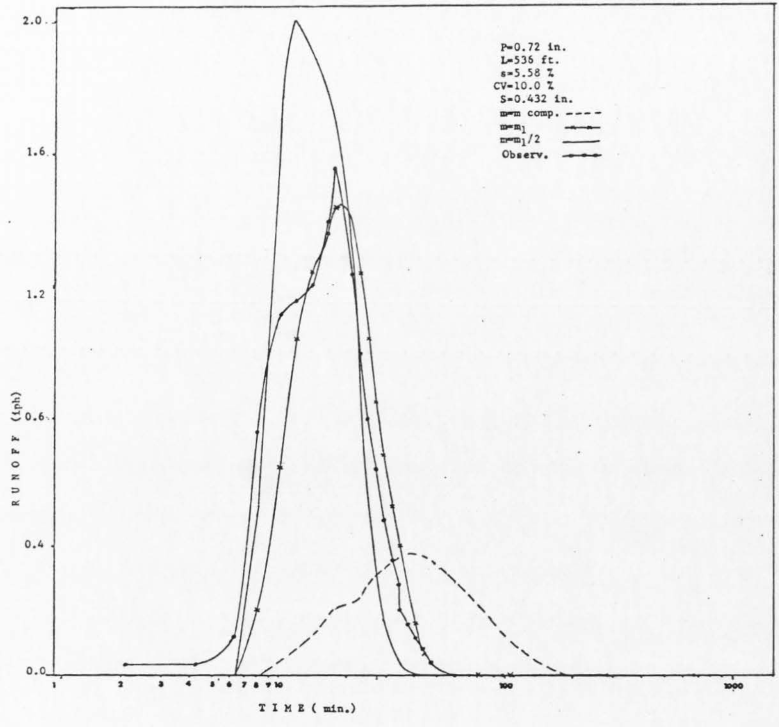

Figure 15. Observed and simulated runoff hydrographs using different values of m (m, m_1, and $m_1/2$). Event July 18, 1958, 3-H, Hastings, Nebraska. Data from USDA (46).

2. Routing with m_1 as the routing coefficient, gives a better simulated hydrograph shape and and timing.
3. Smaller values of m give a larger and earlier peak.
4. All simulated hydrographs have a shorter recession limb than the observed hydrograph.
5. Computed values of m give a shorter peak and a longer tail which suggests that this value of m is larger than the true value.

The second test was done to observe the variation due to different infiltration patterns. The event of May 13, 1957 at SW-17, Waco, Texas, was chosen for this test. Since this event occurred under wet conditions, it could be assumed that infiltration rate was nearly constant. Figure 16 shows the difference in hydrograph shape obtained when using different infiltration values. It is observed that infiltration does not greatly change hydrograph shape and timing.

All previous tests indicate that the routing coefficient is more responsible for hydrograph shape and timing than infiltration. Infiltration has more influence on the magnitude of runoff. Another observation obtained from the tests was that the routing coefficient is not constant and that it probably should increase as storage decreases.

Second Model

The tests made on the first model suggested that the routing coefficient was not constant and that, in order to reproduce the "tail" of the hydrograph, m should increase as runoff decreases. An analysis of equations [33] and [34] clearly demonstrates that in the last part

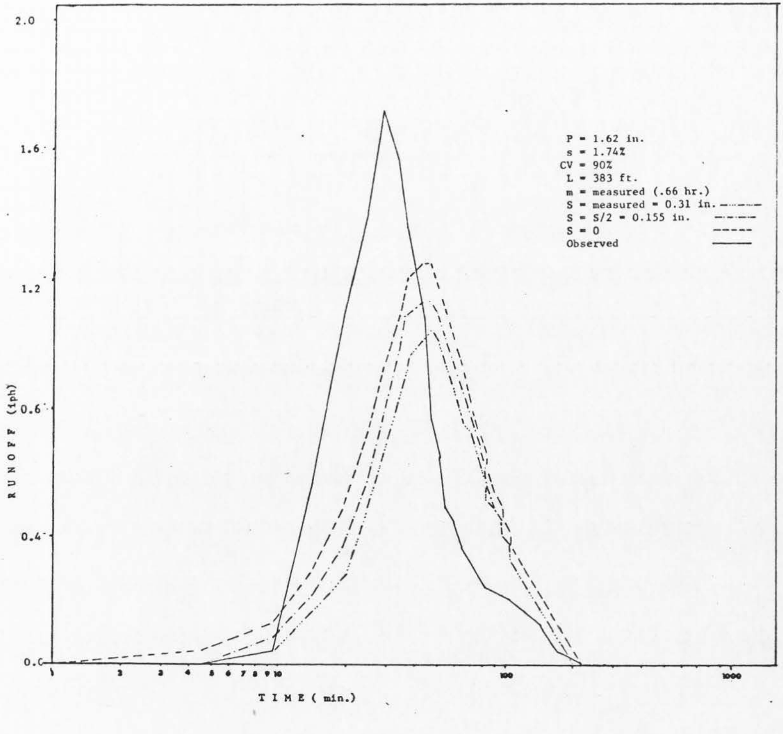

Figure 16. Simulated and observed hydrograph using measured m and different infiltration estimates. Event May 13, 1957, SW-17, Waco, Texas. Data from USDA (46).

of the hydrograph, when runoff is decreasing, C2 should be large and C1 small. In equation [32], it is noted that as m increases, C2 increases.

Regression curves of natural larger watersheds show the same phenomena described before. To overcome the change of m, equation [24] was introduced in the model, and then the routing coefficient was computed for each new value of q. At the beginning of the routing, since q is zero, a modification of equation [24] was developed by combining the recession equation [8] and equation [24]. From equation [10] Da can be defined as:

$$\mathrm{Da} = \left(\frac{q}{c}\right)^{1/n} \qquad [41]$$

and substituting this equation [24], equation [42] is obtained:

$$m = \frac{\mathrm{Da}^{1-n}}{C} \qquad [42]$$

After several trials it was found that there is a different behavior of runoff in the rising and falling limbs of the hydrograph. This is probably due to the hysteresis of the storage-runoff relations previously described. It was also found that using equation [42] in the rising limb and equation [24] in the falling limb of the hydrograph minimizes hysteresis effects.

To compute Da, a simple application of the continuity equation was used:

$$\mathrm{Da}_2 = \mathrm{Da}_1 + \Delta\mathrm{Da} - \Delta Q$$

in which

$$\Delta Da = PE_2 - DE_1$$

$$\Delta Q = q_{ave_1} \Delta t.$$

Subscripts 1 and 2 indicate routing periods.

Equation [43] does not give an accurate value of Da, but it is only utilized in the routing section to evaluate m.

Theoretically, the rising limb of the hydrograph ends at the peak rate of runoff. The time to peak tp could be estimated by the time lag between peak rainfall excess and peak runoff, this time lag is usually very small for short watersheds.

Since the model is intended to be used with small watersheds and time intervals Δt of 5 minutes, it was assumed that peak runoff will probably occur at Δt after peak excess precipitation. For practical reasons, this time was considered to be a time interval after q' becomes smaller than q.

With all considerations previously explained, model II was assembled. This model had all basic components of the first model, except for the inclusion of equation [24], [42], and [43] in the routing section.

The same data used in the first model was utilized to test model II. The only modification in the data was the adoption of a different relationship to compute Da_{er}, because equation [38] was found to give some unrealistic values. A modification of equation [6] was utilized to compute Da_{er}:

$$Da_{er} = [(\frac{fc}{qe}) + 1] \, Qer \qquad [44]$$

Figures 15 and 16 show the sensitivity of the model in simulating peak runoff, time base and time to peak. From these graphs, it is observed that the model is more sensitive in the lower values of slope and length of run. This is very important because surface drainage is required in very flat lands and for a faster removal of excess water, length of run has to be generally short.

Figures 17 through 20 show different hydrographs from four small watershed events. Comparing the results of these tests with those of the first model, it is clear there is a great improvement in hydrograph shape and timing. This test also proved that infiltration estimates utilizing potential infiltration S as an indicator of infiltration, gave better results than any other infiltration method.

After the model was considered to be sufficiently tested for its accuracy in synthetizing the runoff hydrograph, a series of sensitivity tests were performed. Those tests included:

1. Sensitivity to length of run changes
2. Sensitivity to slope changes
3. Sensitivity to infiltration changes
4. Sensitivity to cover changes.

Figures 21 to 24 show the results of those tests. All tests indicate a good response of the model to changes of soil and watershed parameters and the resulting simulated hydrographs showed a logical behavior. Increasing length of run causes a smaller peak and a delay in the time of peak. An increase in slope produces an earlier and larger peak rate. Vegetation or cover changes a delay in the peak and a reduction in peak rates. Infiltration changes affect the magnitude of the peaks and total volume of runoff.

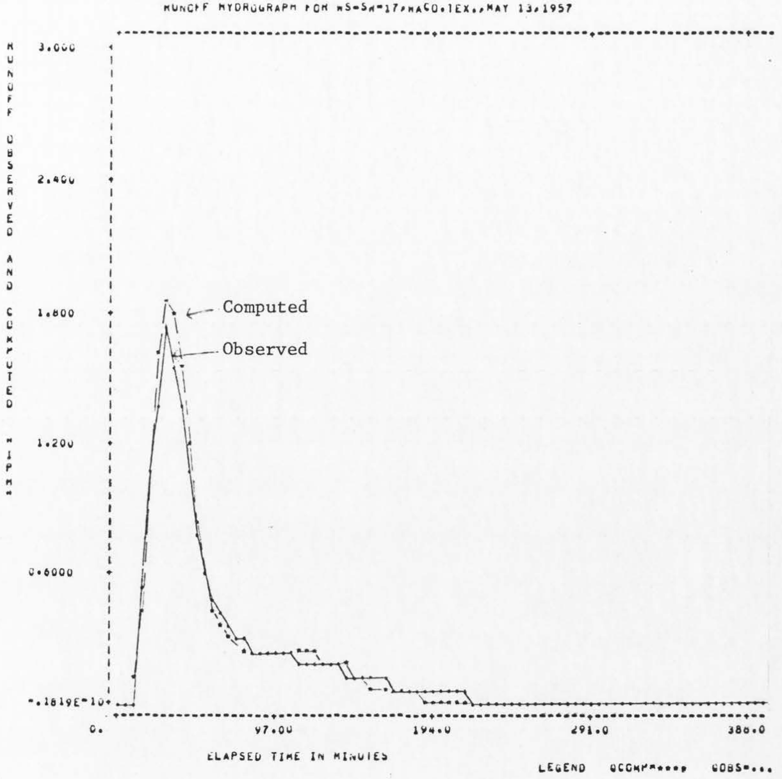

Figure 17. Simulated and observed runoff hydrograph for event May 13, 1957 at SW-17, Waco, Texas. Data from USDA (46).

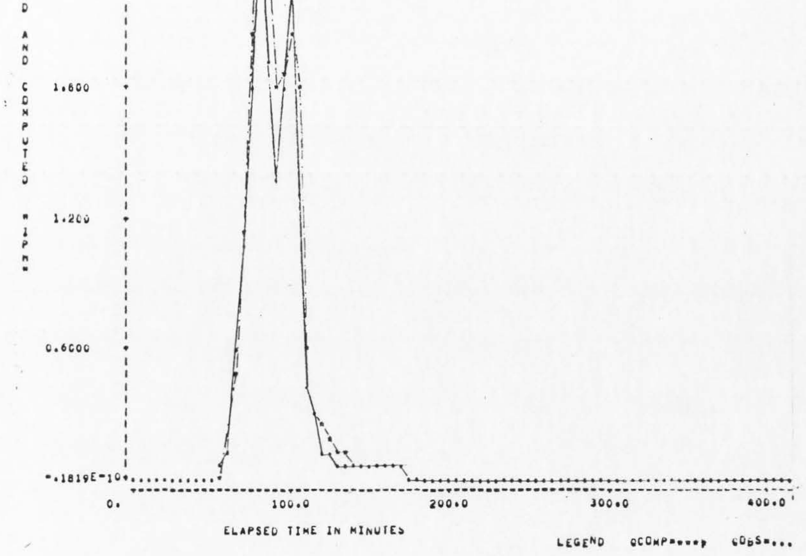

Figure 18. Simulated and observed runoff hydrograph for event May 15, 1960 at WS-3H, Hastings, Nebraska. Data from USDA (46).

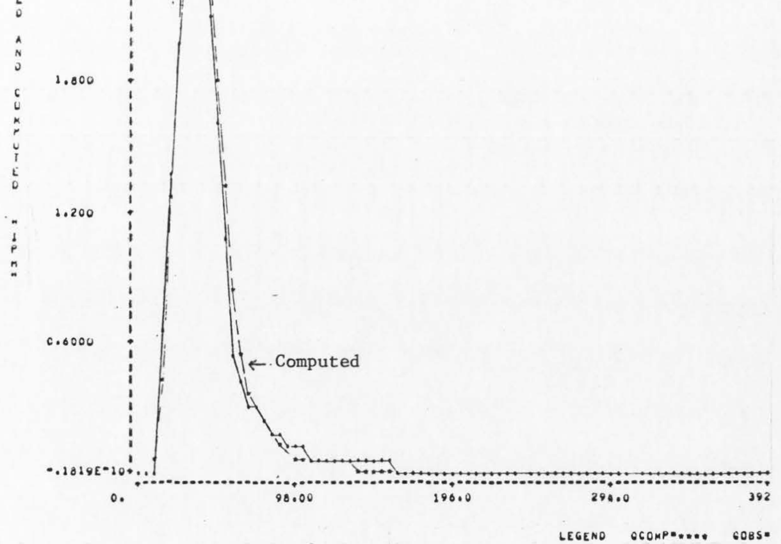

Figure 19. Simulated and observed runoff hydrographs for event April 24, 1957, SW-17, Waco, Texas. Data from USDA (46).

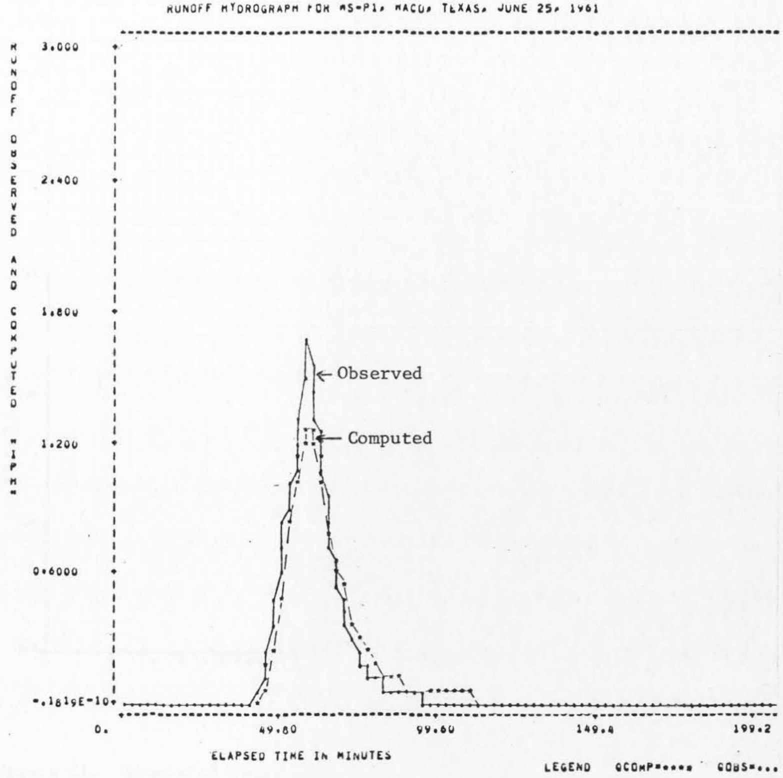

Figure 20. Simulated and observed runoff hydrograph for event June 25, 1961, at P-1, Waco, Texas. Data from USDA (46).

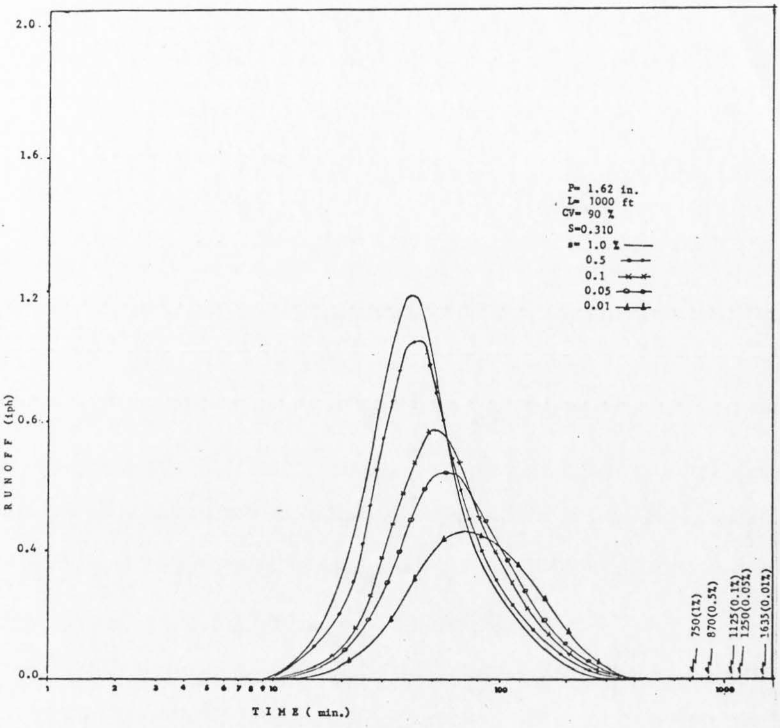

Figure 21. Simulated runoff hydrograph for different slope values.

Figures 17 through 20 show different hydrographs from four small watershed events. Comparing the results of these tests with those of the first model, it is clear that there is a great improvement in hydrograph shape and timing. This test also proved that infiltration estimates utilizing potential infiltration, S, as an indicator of infiltration, gave better results than any other infiltration method.

After the model was considered to be sufficiently tested for its ccuracy in synthetizing the runoff hydrograph, a series of sensitivity tests were performed. Those tests included:

1. Sensitivity to length of run changes
2. Sensitivity to slope changes
3. Sensitivity to infiltration changes
4. Sensitivity to cover changes

Figures 21 to 24 show the results of those tests. All tests indicate a good response of the model to changes of soil and watershed parameters and the resulting simulated hydrographs showed a logical behavior. Increasing the length of run causes a smaller peak and a delay in the time to peak. An increase in slope produces an earlier and larger peak rate. Vegetation or cover changes causes a delay in the peak and reduction in peak rates. Infiltration changes only affect the magnitude of the peaks and total volume of runoff.

Application of the model to surface drainage system

Design of surface drainage improvements consists of the determination of such design characteristics as (a) collector drains capacity, (b) drain spacing, and (c) land grading requirements.

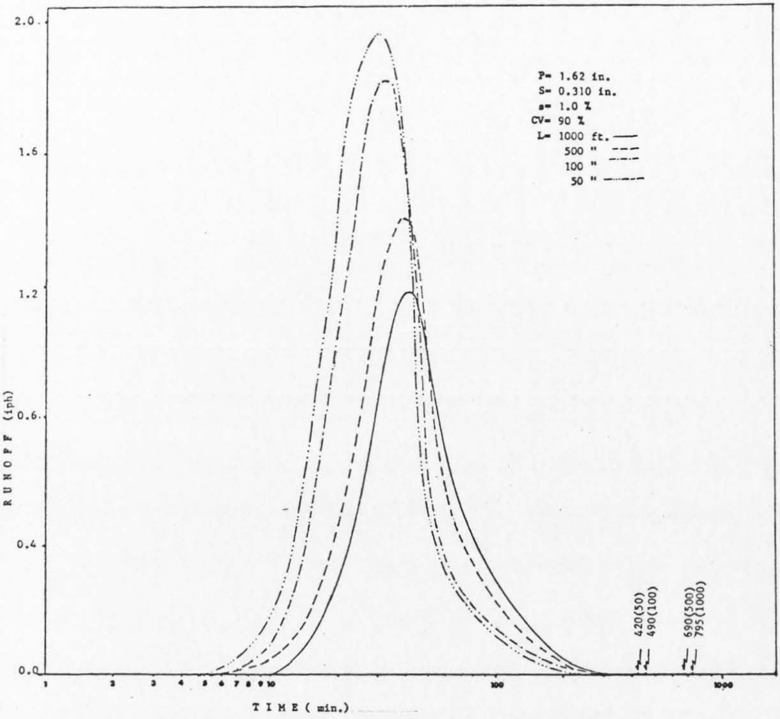

Figure 22. Simulated runoff hydrograph for different lengths of run.

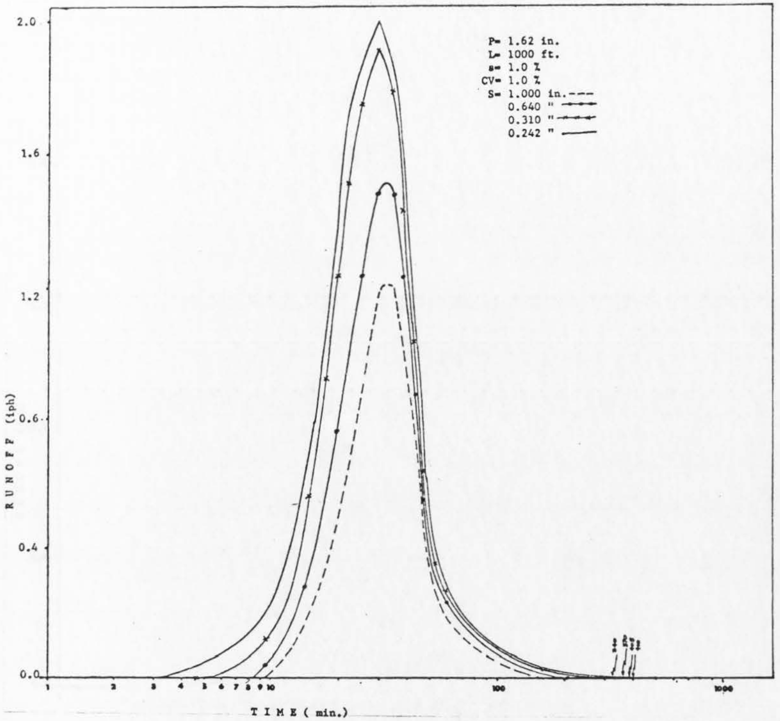

Figure 23. Simulated runoff hydrograph for different values of S.

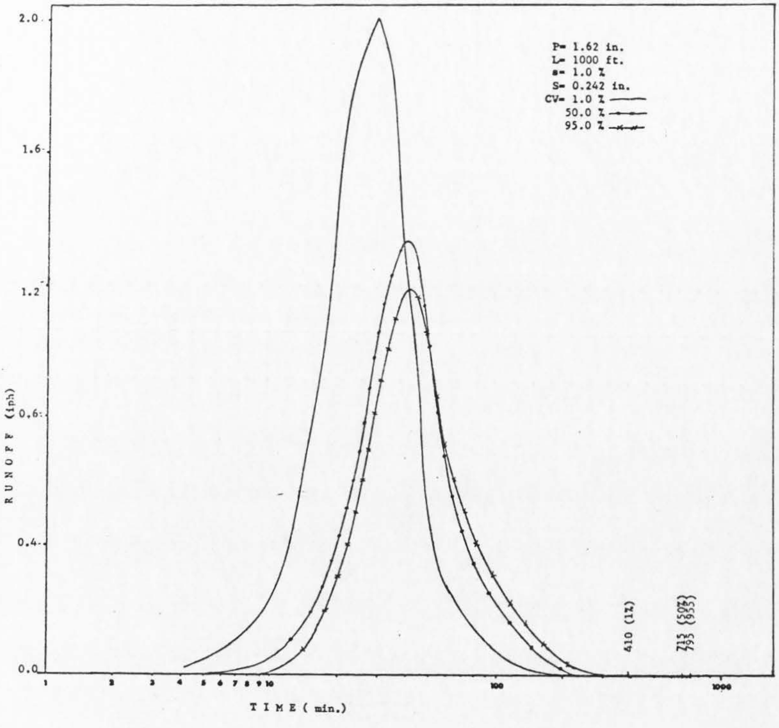

Figure 24. Simulated runoff hydrograph for different cover densities.

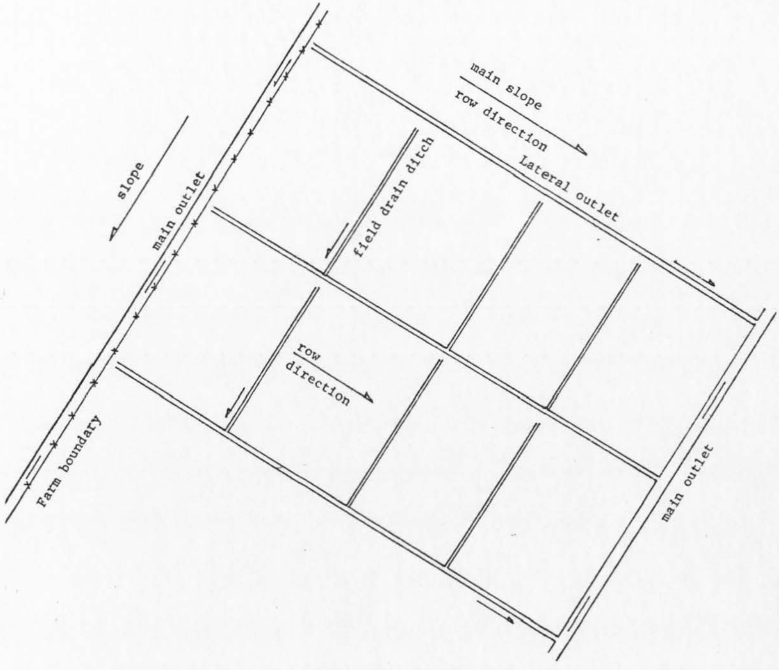

Figure 25. Idealized surface drainage system layout.

   b. Physical properties of soils
   c. Hydrological soil group (A, B, C, D)
3. Crop flooding tolerance data
4. Topographical data
   a. Planimetry
   b. Altimetry
   c. Outlet conditions

With all these basic data, three main sets of computations have to be made. The first one will be the determination of the design storm; second, infiltration patterns; and third, the watershed runoff characteristics.

1. Design storm. The design storm will be selected, taking into account: (a) frequency, and (b) duration. The frequency of the storm will be decided on economical consideration. The duration of the storm will be chosen according to the crop tolerance to flooding, taking into account prevailing temperature conditions.
2. Infiltration patterns. Infiltration measurements and/or soil physical characteristics will be utilized to determine the infiltration pattern to be expected for a given set of conditions under which a storm is supposed to occur. In the event that pertinent information is not available, the SCS method could be utilized, always having in mind the limitations of the procedure.
3. Watershed runoff characteristics. These will be determined from soil, cover, and topographic parameters. The model has a built-in capacity for computing these characteristics.

The model will then be fed with those three sets of values and a runoff hydrograph is produced. After this, a technical-economical decision has to be made regarding the duration of the runoff hydrograph and the crop drainage requirement previously decided. If an adequate drainage is not reached under the present circumstances, a topographical change has to be made and another simulation will be performed; this will be repeated until an optimum design is obtained. Figure 26 shows a flow chart of all mentioned steps.

Some assumptions and considerations regarding surface drainage design

It will normally be impossible and uneconomical to design a system for an optimal surface drainage performance under all conditions. Because of this, some practical considerations and assumptions have to be made.

1. Soil moisture at the time of the designing event is considered to be at a point between field capacity and saturation. This will correspond to AMC III of the SCS method (48).
2. The design storm will have a frequency of 5-10 years (10-20 percent).
3. Drainage requirement will include crop resistance and farm tillage requirements.
4. The design storm is assumed to be single-peaked.
5. For the initial trial, drain capacity will be estimated by the SCS (49) method.
6. Initial surface condition will be considered as smooth. This will be the minimum land surface improvement.

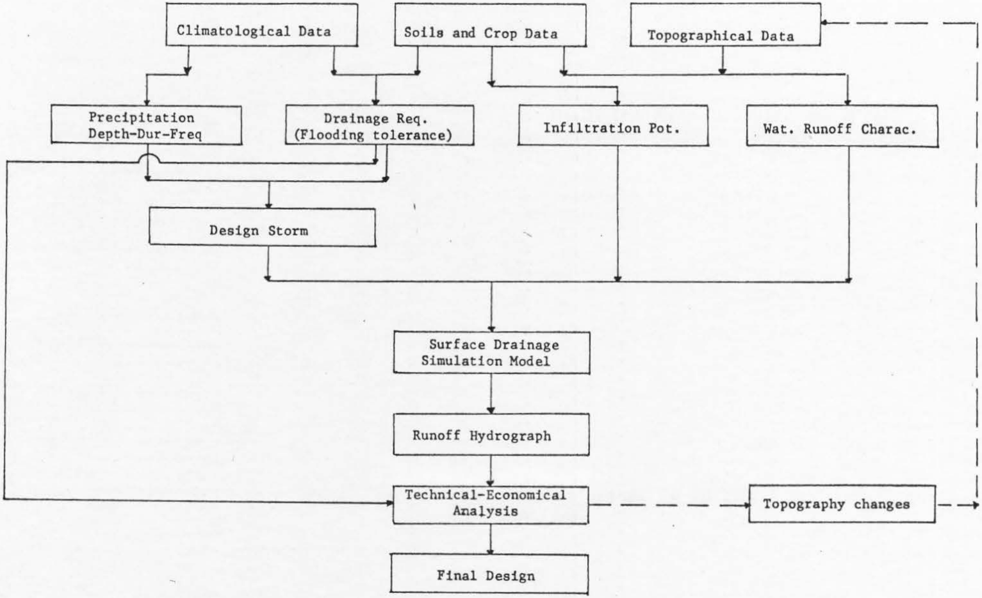

Figure 26. Steps in surface drainage design.

7. Topography changes should start with those characteristics more easily to be implemented such as outlet capacity and spacing. Only if these changes are not sufficient, slope change will be attempted.
8. Spacing of field drains should be selected in such a way as to permit a reasonable farm machinery operation and to obtain a uniform plot size.

Practical Application of the Model

To test the model applicability to real surface drainage design problems, an area of flat land in the Venezuelan Llanos was selected. The main characteristics of the area are:

The area

General. The problem area is located in the Portuguesa State on a recently developed agricultural area which is mainly cultivated with corn, cotton, rice and sesame seed. Surface drainage is one of the limiting factors to more intensive agriculture.

Topography. The general topography is nearly level with slopes ranging from 0.05 percent to 1.0 percent. The micro-relief is very irregular with many small depressions.

Soils. A recent soil survey shows that soils are inceptisols and and are classified as: vertic tropaquepts, fine, mixed, isohyperthermic.

Land use. Most areas are cropped to corn and rice. Corn is cultivated in the less affected areas and rice in those areas with severe surface drainage problems.

Nature of the problem. The problem is caused by high precipitation and heavy soils. Surface depressions aggravate the situation. Some experiments in the area have proven that surface drainage could improve corn yields about 200 percent.

Hydrology. Annual precipitation ranges from 1000 to 1500 mm. Precipitation in the corn growing season ranges from 734 to 1342 mm. Individual storms reach values of more than 90 mm with durations of 6 to 12 hours. Table 2 and Figure 27 describe some climatological values for a nearby climatological station.

Design parameters

Considering all the information in the area, it was decided that the design was to be made based on the following criteria:

1. Slopes: Maximum, 0.2 percent
2. Length of run: To facilitate land preparation and other tillage practices a minimum length of 150 feet was adopted
3. Design storm: A design storm of 12 hours duration and 5 years return period was selected (Figure 27)
4. Maximum time for drainage was selected as 12 hours
5. Infiltration: To estimate excess precipitation, the Soil Conservation Service method (49) was adopted

Surface drainage simulation

With the design parameters, several trials were made to represent some combinations of slope and length of run. Results are presented in Table 3 and Figure 28. From these results it was established that optimum design is that which combines a length of run of 330 feet and

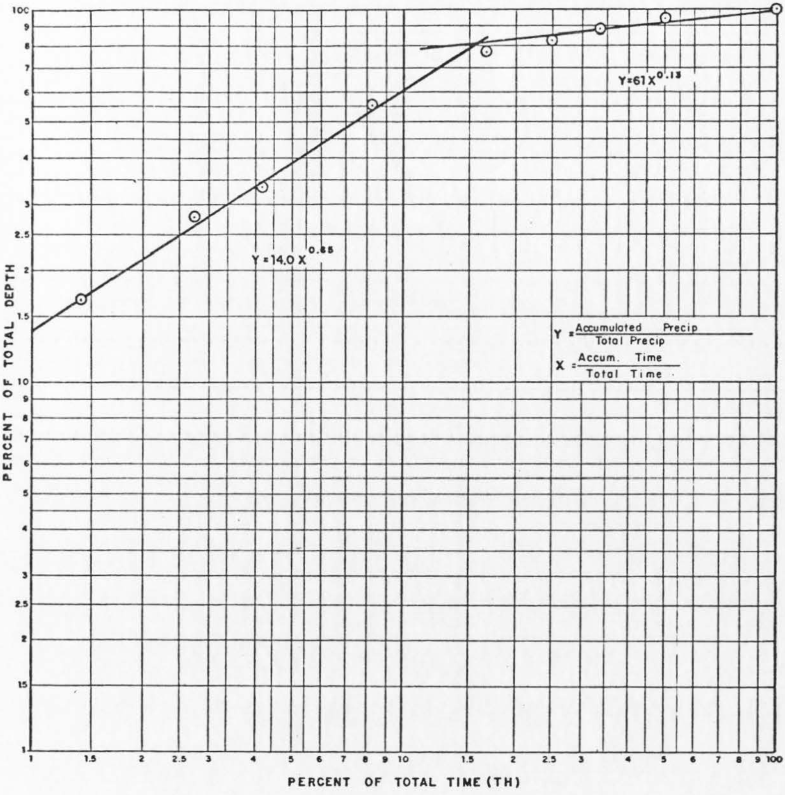

Figure 27. Design storm for Agua Blanca, Portuguesa, Venezuela. Return period = 5 years.

Table 2. Mean values of some climatological factors for Majaguas and Agua Blanca, Portuguesa, Venezuela[1]

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Precipitation (mm)													
Majaguas	8.1	5.4	4.2	43.3	19.15	224.6	224.0	159.3	166.1	91.5	186.1	43.3	1347.5
Agua Blanca	13.4	8.6	13.6	80.0	180.6	250.0	256.0	200.0	168.8	131.1	81.1	40.0	1432.2
Evaporation (mm)*	223.4	244.6	293.6	239.6	169.2	139.0	140.6	141.7	142.1	164.1	168.5	197.0	2263.2
Temperature (C)*	26.8	27.8	28.5	28.9	28.2	27.5	26.8	27.4	27.1	27.1	27.8	27.6	

*Majaguas station

[1] See Footnotes 1 and 2, page 73.

Table 3. Simulated variation of total runoff and time of runoff with slope and length of run[1]

Slope	Length of Run (ft)	RO	QP	TP	TT	DA at peak	Veloc. at peak
0.0005	150	2.972	2.25	40	645		
	330	2.971	2.18	50	720	0.821	
	465	2.970	2.15	50	750		
	660	2.970	2.11	50	790		
0.001	150	2.973	2.28	40	605		
	330	2.972	2.22	45	675		
	465	2.971	2.19	45	710	.817	
	660	2.970	2.16	50	745		
0.01	150	2.974	2.38	30	510		
	330	2.973	2.33	35	555		
	495	2.973	2.31	35	580		
	660	2.973	2.28	40	605		

[1] Design parameters

$S = 1.60''$ $PT = 4.00''$

$S_1 = 0.989''$ $TP = 360$ min.

$CV = 10\%$ $DT = 5$ min.

Precipitation is given by:

$PAC(I) = 14.0*TH^{0.65}*PT/100$ $T < 15.5\%$ of TP

$PAC\ (I) = 61 \times TH^{0.13}*PT/100$ $T > 15.5\%$ of TP

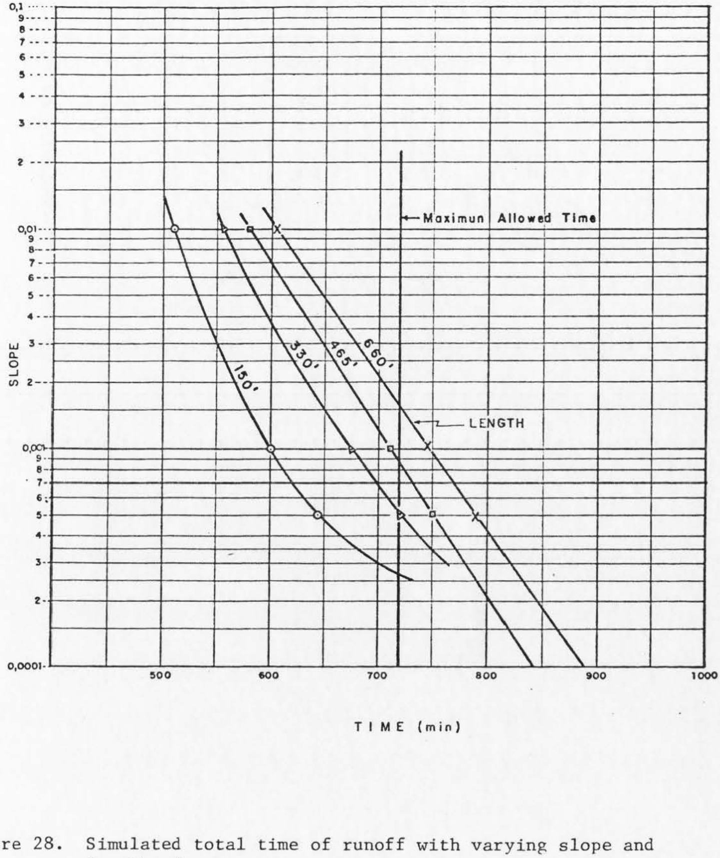

Figure 28. Simulated total time of runoff with varying slope and length of run.

a slope of 0.05 percent. For steeper slopes a greater length of run could be used (see Figure 28).

Marcano, in a nearby experimental station, found that a length of run of 57 m (173 ft) with a slope of 0.8 percent was adequate for disposing of excess run-off water in a corn experiment.[1] De Leon, evaluating Marcano's data found that the surface drainage system was overdesigned and because of that corn yields in dry years were lower than the expected. In further analysis, De Leon found that the design was made for a 12-hour storm with a return period of 10 years.[2]

To compare the above data with those obtained with the model, the 10-year storm, when correlated with the 5-year storm, was found to be equivalent to a 5 year-7 hour storm. According to Figure 28, the length of run for this storm (540 minutes) and a slope of 0.8 percent is 200 feet, which is close to Marcano's 173 ft (57 m).

The results show that the model may provide an acceptable criteria on surface drainage design.

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[1] Marcano, Filipe L. Mejoramiento del Drenaje Superficial de Suelos Pesados para la produccion de maiz. Foremaiz, Venezuela. Unpublished report, 1975.

[2] De Leon, Alfredo. Evaluacion de un Sistema de Drenaje Superficial en los Altos Llanos Occidentales de Venezuela. Unpublished report, 1976.

DISCUSSION AND CONCLUSIONS

The results from the tests made on the model indicate that it could be a useful tool in simulating surface drainage design alternatives. Limited sensitivity to slope and length of run changes does not indicate that a model fails to simulate those changes; actual data from small agricultural watersheds indicate that it is what happened in nature. One limiting factor in simulating runoff hydrographs is the estimation of infiltration; the soil conservation method developed by Mockus (48) seems to be a fairly good approach to substitute infiltration estimates in the cases of wet antecedent moisture conditions.

Estimation of recession curve characteristics by using equations [27] and [29] does not give an accurate measure of the real values, but for routing purposes they are probably acceptable. In most cases they are in the range of measurement accuracy. Moreover, measurements of those recession characteristics will require very bulky equipment and a large number of determinations.

The model proved to be fairly accurate in simulating runoff hydrographs for single-peaked storms on homogeneous, rectangular, small agricultural watersheds under wet conditions. Those conditions are similar to those for which surface drainage is designed. Although the model was not intended to estimate peak runoff, it gives a very good measurement of peak magnitude and timing. Applications of the model to dry conditions are subjected to more accurate infiltration estimates.

It is possible that if more controlled and diversified rainfall simulator trials are made, a better relationship of recession characteristics and soil parameters could be found. The parameters used in the model were those common to all data and, therefore, were limited to four. Future experiments should include more variety of slope and length values, more accurate vegetation estimates and more soil parameters such as soil moisture, bulk density, saturated hydraulic conductivity, soil textural analysis, organic matter, etc.; some of those parameters are commonly evaluated in detailed soil surveys.

One of the most interesting things observed in the tests is the fact that water removal is possible even with a very flat slope which demonstrates that the main obstacle in a rapid removal of excess water is not slope, but a lack of an appropriate water disposal system. It is to be noted that the tests were made assuming a fairly smooth surface and that the design supposes that at least a land smoothing job has to be made.

It is suggested an improvement in the Soil Conservation method here described be made to obtain better infiltration estimates under dry conditions. Most of the research in infiltration is directed toward an application to irrigation, but with the increasing demand for agricultural lands, surface drainage could be the key to opening new agricultural frontiers.

The following conclusions resulted from this study:

1. The developed model proved to be adequate to simulate surface drainage alternatives.
2. The model is limited to:

   a. Single-peak storm events
   b. Homogeneous rectangular plots
   c. Wet conditions

3. The most limiting factor in successfully applying the model is infiltration.
4. The model could be improved if additional rainfall simulator experiments are conducted.
5. Tests on the model indicate that surface drainage problems are probably more affected by micro-relief conditions (depressions) than by flat slopes.
6. Land smoothing and proper surface ditch network design should, in most cases, solve waterlogging problems.
7. In spite of not being developed to estimate peak runoff, the model could be utilized successfully in estimating peak runoff from small plots.
8. All parameters used in the model are easily obtained. In the event of the absence of a detailed soil survey, these parameters could be estimated or measured directly on the field.

SUGGESTIONS FOR FUTURE RESEARCH

The importance of surface drainage for agricultural development in humid tropical regions and the findings of the model described in this report suggest the following future research topics:

1. Rainfall simulator studies to better understand the infiltration and hydrological characteristics of small agricultural watersheds.
2. A more detailed study of recession characteristics of agricultural plots.
3. Agroeconomical studies of surface drainage benefits for long periods of time.
4. Soil moisture balance under various surface drainage patterns.
5. Hydrological regional analysis of surface drainage improvements.
6. Socio-economical impact of surface drainage improvements in humid tropical areas.

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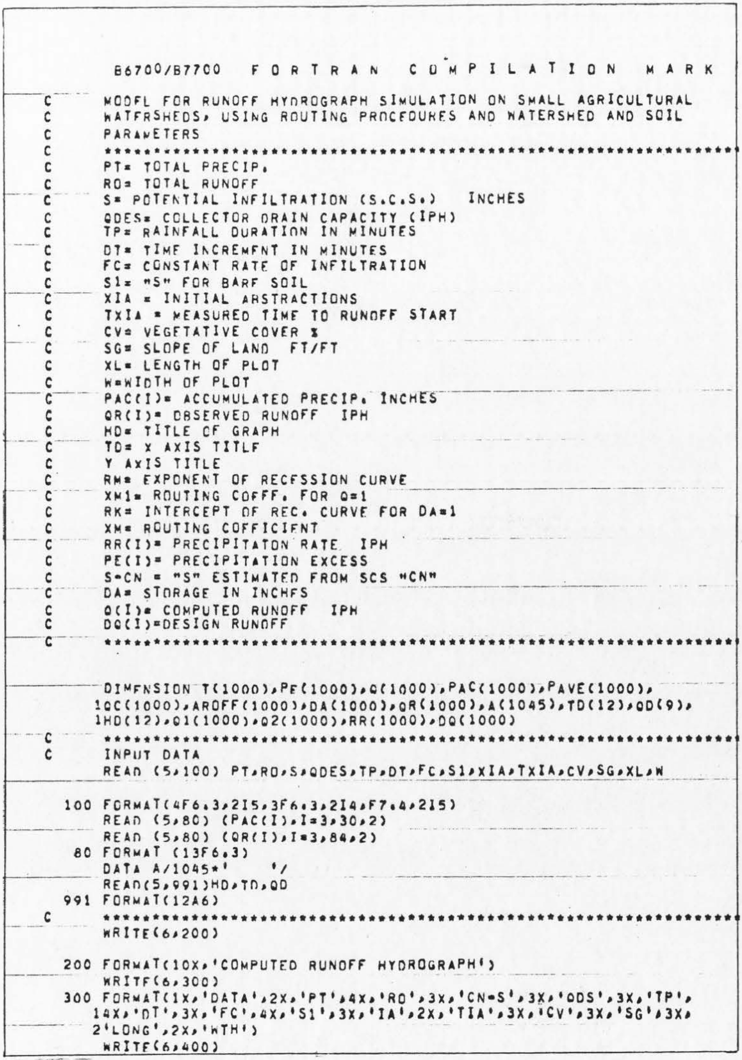
APPENDIXES

Appendix A

Table 4. Computer program name for different variables and parameters in the model.

Symbol in text	Computer name
A	
a	FK
b	FN
C	RK
CV	CV
Da	DA(I)
F	XF
f	FR
fc	FC
L	XL
l	XLP
m	XM
ml	XM1
n	RM
P	ACP(I)
Pe	PE(I)
PT	PT
pe	PAVE(I)
Q	AROFF(I)
qd	QDES
q	Q(I)
S	S
s	SG
TP	TP
tp	TPEAK
w	W

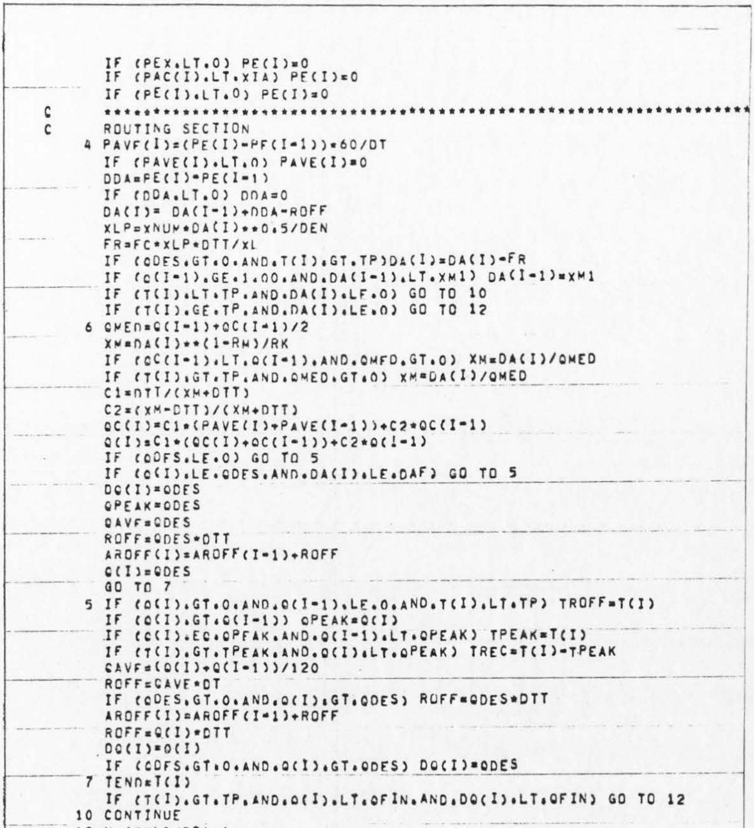


```
        B6700/B7700   F O R T R A N   C O M P I L A T I O N   M A R K
C       MOOFL FOR RUNOFF HYDROGRAPH SIMULATION ON SMALL AGRICULTURAL
C       WATFRSHEDS, USING ROUTING PROCFDURES AND WATERSHED AND SOIL
C       PARAMETERS
C       ****************************************************************
C       PT= TOTAL PRECIP.
C       RO= TOTAL RUNOFF
C       S= POTENTIAL INFILTRATION (S.C.S.)   INCHES
C       QDES= COLLECTOR DRAIN CAPACITY (IPH)
C       TP= RAINFALL DURATION IN MINUTES
C       DT= TIMF INCREMFNT IN MINUTES
C       FC= CONSTANT RATE OF INFILTRATION
C       S1= "S" FOR BARF SOIL
C       XIA = INITIAL ARSTRACTIONS
C       TXIA = MEASURED TIMF TO RUNOFF START
C       CV= VEGFTATIVE COVER %
C       SG= SLOPE OF LAND  FT/FT
C       XL= LENGTH OF PLOT
C       W=WIDTH OF PLOT
C       PAC(I)= ACCUMULATED PRECIP. INCHES
C       QR(I)= OBSERVED RUNOFF  IPH
C       HD= TITLE CF GRAPH
C       TD= X AXIS TITLF
C       Y AXIS TITLE
C       RM= EXPONENT OF RECFSSION CURVE
C       XM1= ROUTING COFFF. FOR Q=1
C       RK= INTERCEPT OF REC. CURVE FOR DA=1
C       XM= ROUTING COFFICIFNT
C       RR(I)= PRECIPITATON RATE  IPH
C       PE(I)= PRECIPITATION EXCESS
C       S-CN = "S" ESTIMATED FROM SCS "CN"
C       DA= STORAGE IN INCHFS
C       Q(I)= COMPUTED RUNOFF  IPH
C       DQ(I)=DESIGN RUNOFF
C       ****************************************************************


        DIMFNSION T(1000),PF(1000),Q(1000),PAC(1000),PAVE(1000),
       1QC(1000),AROFF(1000),DA(1000),QR(1000),A(1045),TD(12),QD(9),
       1HD(12),Q1(1000),Q2(1000),RR(1000),DQ(1000)
C       ****************************************************************
C       INPUT DATA
        READ (5,100) PT,RO,S,QDES,TP,DT,FC,S1,XIA,TXIA,CV,SG,XL,W

    100 FORMAT(4F6.3,2I5,3F6.3,2I4,F7.4,2I5)
        READ (5,80) (PAC(I),I=3,30,2)
        READ (5,80) (QR(I),I=3,84,2)
     80 FORMAT (13F6.3)
        DATA A/1045*'     '/
        READ(5,991)HD,TD,QD
    991 FORMAT(12A6)
C       ****************************************************************
        WRITE(6,200)

    200 FORMAT(10X,'COMPUTED RUNOFF HYDROGRAPH')
        WRITF(6,300)
    300 FORMAT(1X,'DATA',2X,'PT',4X,'RO',3X,'CN-S',3X,'QDS',3X,'TP',
       14X,'DT',3X,'FC',4X,'S1',3X,'IA',2X,'TIA',3X,'CV',3X,'SG',3X,
       2'LONG',2X,'WTH')
        WRITF(6,400)
```

Figure 29. Computer program for the surface drainage model.

```
  400 FORMAT(7X,'IN',4X,'IN',3X,'IN',3X,'IPH',3X,'MIN',3X,'MIN',3X,
     1'IPH',4X,'IN',3X,'IN',2X,'MIN',4X,'%',3X,'F/F',4X,'FT',3X,'FT')
      WRITF (6,101) PT,RO,S,QDES,TP,DT,FC,S1,XIA,TXIA,CV,SG,XL,W
  101 FORMAT(5X,4F6.3,2I5,3F6.3,2I4,F7.4,2I5)
C     INITIAL CONDITIONS
      QFIN=C.001
      PAVF(1)=0
      DA(1)=0
      QR(1)=0
      T(1)=0
      PE(1)=0
      Q(1)=0
      QC(1)=0
      DQ(1)=0
      PAC(1)=0
      AROFF(1)=0
      RR(1)=0
C     PRELIMINARY COMPUTATIONS
      ANGA=ATAN(SG)
      DEN=SIN (ANGA)
      XNUM=(XL*SG/6)**0.5
      SG*SG*100
      N=250
      AREA=XL*W/43560
      DTT=DT/60
      IF (RO.LE.0) GO TO 1
      S=((PT-XIA)**2)/RO-(PT-XIA)
      GO TO 2
    1 XIA=0.2*S
    2 C0=0.024
      C1=0.274
      C2=-0.181
      C3=0.189
      C4=-0.0535
      XM1=C0*XL**C1*SG**C2*CV**C3*S1**C4
      RM=1.08*CV**(0.013)*S1**(-0.19)
      RK=1/XM1**RM
      RMI=1/RM
      BDA=QDFS/RK
      IF (QDFS.LE.0) BDA=1
      DAF=BDA**RMI
C     EXCFSS PRECIPITATION  COMPUTATIONS
      DO 10 I=2,N
      T(I)=FLOAT(I)*DT-DT
      IF (T(I).LT.TP.AND.PAC(I).LF.0) PAC(I)=(PAC(I-1)+PAC(I+1))/2
      IF (QR(I).LE.0) QR(I)=(QR(I-1)+QR(I+1))/2
      RR(I)=(PAC(I)-PAC(I-1))/DTT
      IF (T(I).GE.TP) PAC(I)=PT
      IF (XIA.LE.0.AND.TXIA.LE.0) GO TO 3
C     PRECIPITATION FXCESS COMPUTFD FROM INFILTRATION  EQUATIONS
C     XF CAN BE SUBSTITUDED BY ANY CUMULATIVE INFILTRATION EQUATION
      XF=T(I)**FN*FK
      PE(I)=PAC(I)-XF
      IF (PAC(I).LT.XIA) PE(I)=0
      IF (PAC(I).LT.XF) PF(I)=0
      IF (PE(I).LT.0) PE(I)=0
      GO TO 4
C     PRECIPITATION EXCESS COMPUTED FROM "S" VALUES
    3 PEX=PAC(I)-XIA
      IF (PEX.LT.0) PFX=0
      PE(I)=PEX**2/(PFX+S)
```

Figure 29. Continued.



```
      IF (PEX.LT.0) PE(I)=0
      IF (PAC(I).LT.XIA) PE(I)=0
      IF (PE(I).LT.0) PE(I)=0
C     ****************************************************************
C     ROUTING SECTION
    4 PAVF(I)=(PE(I)-PF(I-1))*60/DT
      IF (PAVE(I).LT.0) PAVE(I)=0
      DDA=PE(I)-PE(I-1)
      IF (DDA.LT.0) DDA=0
      DA(I)= DA(I-1)+DDA-ROFF
      XLP=XNUM*DA(I)**0.5/DEN
      FR=FC*XLP*DTT/XL
      IF (QDES.GT.0.AND.T(I).GT.TP)DA(I)=DA(I)-FR
      IF (Q(I-1).GE.1.00.AND.DA(I-1).LT.XM1) DA(I-1)=XM1
      IF (T(I).LT.TP.AND.DA(I).LF.0) GO TO 10
      IF (T(I).GE.TP.AND.DA(I).LE.0) GO TO 12
    6 QMED=Q(I-1)+QC(I-1)/2
      XM=DA(I)**(1-RM)/RK
      IF (QC(I-1).LT.Q(I-1).AND.QMFD.GT.0) XM=DA(I)/QMED
      IF (T(I).GT.TP.AND.QMED.GT.0) XM=DA(I)/QMED
      C1=DTT/(XM+DTT)
      C2=(XM-DTT)/(XM+DTT)
      QC(I)=C1*(PAVE(I)+PAVE(I-1))+C2*QC(I-1)
      Q(I)=C1*(QC(I)+QC(I-1))+C2*Q(I-1)
      IF (QDFS.LE.0) GO TO 5
      IF (Q(I).LE.QDES.AND.DA(I).LE.DAF) GO TO 5
      DQ(I)=QDES
      QPEAK=QDES
      QAVF=QDES
      ROFF=QDES*DTT
      AROFF(I)=AROFF(I-1)+ROFF
      Q(I)=QDES
      GO TO 7
    5 IF (Q(I).GT.0.AND.Q(I-1).LE.0.AND.T(I).LT.TP) TROFF=T(I)
      IF (Q(I).GT.Q(I-1)) QPEAK=Q(I)
      IF (Q(I).EQ.QPFAK.AND.Q(I-1).LT.QPEAK) TPEAK=T(I)
      IF (T(I).GT.TPEAK.AND.Q(I).LT.QPEAK) TREC=T(I)-TPEAK
      QAVF=(Q(I)+Q(I-1))/120
      ROFF=QAVE*DT
      IF (QDES.GT.0.AND.Q(I).GT.QDES) ROFF=QDES*DTT
      AROFF(I)=AROFF(I-1)+ROFF
      ROFF=Q(I)*DTT
      DQ(I)=Q(I)
      IF (QDFS.GT.0.AND.Q(I).GT.QDES) DQ(I)=QDES
    7 TEND=T(I)
      IF (T(I).GT.TP.AND.Q(I).LT.QFIN.AND.DQ(I).LT.QFIN) GO TO 12
   10 CONTINUE
   12 N=(TFND/DT)+1
      WRITE(6,500)
  500 FORMAT(4X,'C1',4X,'C2',5X,'S')
      WRITF (6,550) C1,C2,S
  550 FORMAT(1X,3F6.3)
      WRITF(6,600)
  600 FORMAT(1X,'TIMF',2X,'ACP',3X,'PAV',4X,'QC',4X,'QO',4X,'QR',3X,
     1'AROFF',3X,'DA',4X,'DQ')
      WRITF(6,700)
  700 FORMAT(2X,'MIN',3X,'IN',3X,'IPH',3X,'IPH',3X,'IPH',3X,'IPH',4X,
     1'IN',5X,'IN',3X,'IPH')
  109 FORMAT(1X,I5,8F6.3)
      WRITF (6,109) T(I-1),PAC(I-1),PAVE(I-1),QC(I-1),Q(I-1),QR(I-1),
     1AROFF(I-1),DA(I-1)
```

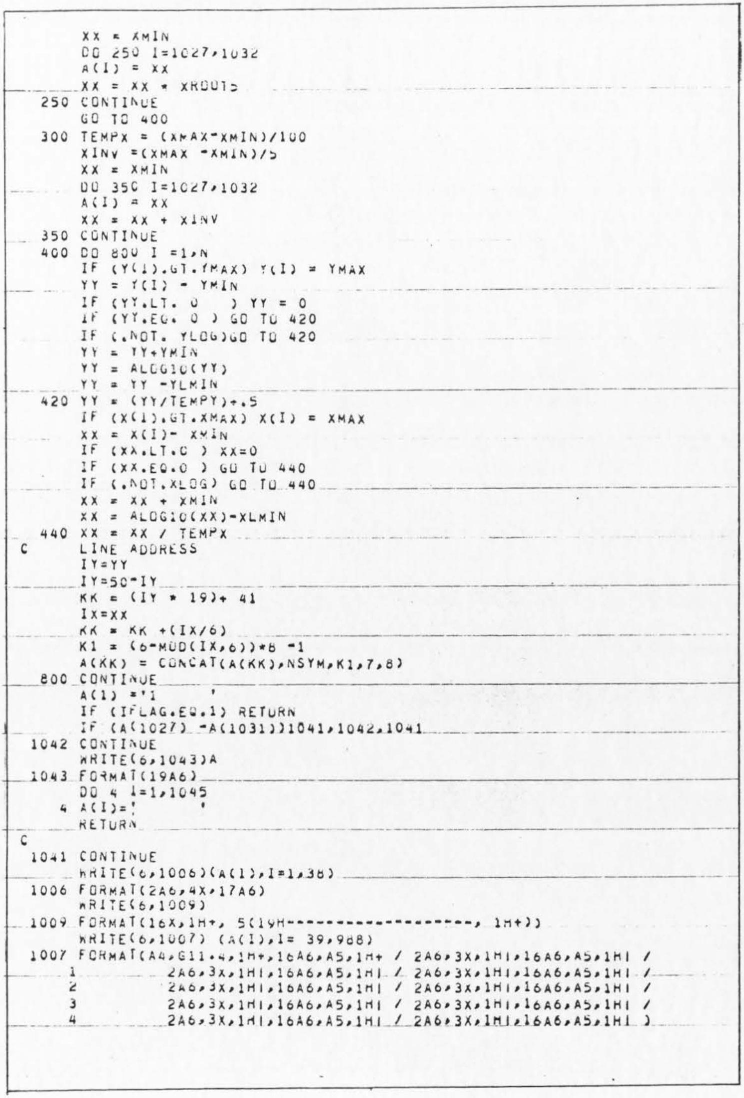
Figure 29. Continued.

```
 21 WRITE(6,980)
980 FORMAT(4X,'XFN',4X,'FK',2X,'XMQ1',4X,'XM',3X,'RO',4X,'RM',6X,
   1'RK')
    WRITE(6,990)FN,FK,XM1,XM,RO,RM,RK
990 FORMAT(1X,6F6.3,F8.2)
    WRITE (6,997)
997 FORMAT(1X,'TROFF',1X,'TPEAK',1X,'TREC',1X,'TEND',1X,'QPEAK')
    WRITE(6,998) TROFF,TPEAK,TREC,TEND,QPEAK
998 FORMAT(1X,I5,1X,3I5,F6.3)
    IF (QOFS.LE.0) GO TO 25
    CALL PL360 (N,A,T,1,3125,TD,DQ,0.,2.0,QD,HD,-1092)
    GO TO 26
 25 CALL PL360 (N,A,T,1,3125,TD,Q,0.,2.0,QD,HD,-1092)
 26 CALL PL360 (N,A,T,1,3125,TD,QR,0.,2.0,QD,HD,1075)
    WRITE(6,999)
999 FORMAT(70X,'LEGEND',3X,'QCOMP=****',3X,'QOBS=....')
    STOP
    END
```

Figure 29. Continued.

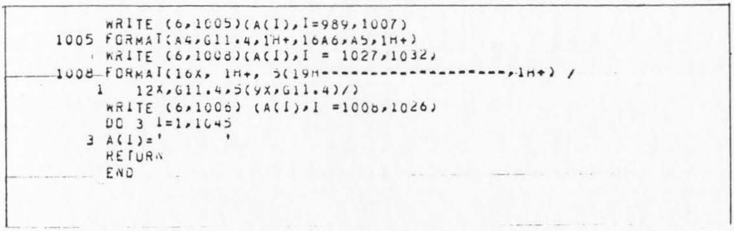
```
      SUBROUTINE PL360(N,A,X,XMIN,XMAX,XLABEL,Y,YMIN,YMAX,YLABEL,HEAD,
     1NSYM)
      DIMENSION        X(1),XLABEL(12),Y(1),YLABEL(9),HEAD(12)
      LOGICAL XLOG,YLOG
      DIMENSION A(1045)
      IFLAG=0
      IF(NSYM.LT.0) IFLAG=1
      IF(NSYM.LT.0) NSYM=-NSYM
      XLOG=.FALSE.
      YLOG=.FALSE.
      IF (NSYM .LT. 1000) GO TO 20
      IF (NSYM .GT. 2000) GO TO 5
      NSYM = NSYM -1000
      XLOG = .TRUE.
      GO TO 20
    5 IF (NSYM .GT. 3000) GO TO 10
      NSYM = NSYM -2000
      YLOG = .TRUE.
      GO TO 20
   10 NSYM = NSYM -3000
      XLOG =.TRUE.
      YLOG =.TRUE.
   20 DO 22 I=1,12
      A(I+3) = HEAD(I)
   22 CONTINUE
      DO 24 I=1,12
      A(I+1011)= XLABEL (I)
   24 CONTINUE
      KK =39
      DO 30 I= 1,53
      II=I-1
      N2= II/6 +1
      N1=(6- MOD(II,6)) * 8 -1
      A(KK) = CONCAT(A(KK),YLABEL(N2),31,N1,8)
      KK= KK +19
   30 CONTINUE
      IF (.NOT. YLOG) GO TO 100
      YLMAX = ALOG10(YMAX)
      YLMIN = ALOG10(YMIN)
      TEMPY =(YLMAX - YLMIN)/50
      YROOT5 = (YMAX/YMIN)**.2
      XX = YMAX
      DO 50 I = 40,990,190
      A(I)= XX
      XX = XX/ YROOT5
   50 CONTINUE
      GO TO 200
  100 TEMPY =(YMAX-YMIN)/50
      YINV = (YMAX-YMIN)/5
      XX = YMAX
      DO 150 I = 40,990,190
      A(I) = XX
      XX = XX - YINV
  150 CONTINUE
  200 IF (.NOT. XLOG) GO TO 300
      XLMAX = ALOG10(XMAX)
      XLMIN = ALOG10(XMIN)
      TEMPX = (XLMAX-XLMIN)/100
      XROOT5 = (XMAX/XMIN)**.2
```

Figure 29. Continued.



```
      XX = XMIN
      DO 250 I=1027,1032
      A(I) = XX
      XX = XX * XROOT5
  250 CONTINUE
      GO TO 400
  300 TEMPX = (XMAX-XMIN)/100
      XINV =(XMAX -XMIN)/5
      XX = XMIN
      DO 350 I=1027,1032
      A(I) = XX
      XX = XX + XINV
  350 CONTINUE
  400 DO 800 I =1,N
      IF (Y(I).GT.YMAX) Y(I) = YMAX
      YY = Y(I) - YMIN
      IF (YY.LT. 0   ) YY = 0
      IF (YY.EQ. 0 ) GO TO 420
      IF (.NOT. YLOG)GO TO 420
      YY = YY+YMIN
      YY = ALOG10(YY)
      YY = YY -YLMIN
  420 YY = (YY/TEMPY)+.5
      IF (X(I).GT.XMAX) X(I) = XMAX
      XX = X(I)- XMIN
      IF (XX.LT.0 ) XX=0
      IF (XX.EQ.0 ) GO TO 440
      IF (.NOT.XLOG) GO TO 440
      XX = XX + XMIN
      XX = ALOG10(XX)-XLMIN
  440 XX = XX / TEMPX
C     LINE ADDRESS
      IY=YY
      IY=50-IY
      KK = (IY * 19)+ 41
      IX=XX
      KK = KK +(IX/6)
      K1 = (6-MOD(IX,6))*8 -1
      A(KK) = CONCAT(A(KK),NSYM,K1,7,8)
  800 CONTINUE
      A(1) ='1          '
      IF (IFLAG.EQ.1) RETURN
      IF (A(1027) -A(1031))1041,1042,1041
 1042 CONTINUE
      WRITE(6,1043)A
 1043 FORMAT(19A6)
      DO 4 I=1,1045
    4 A(I)='          '
      RETURN
C
 1041 CONTINUE
      WRITE(6,1006)(A(I),I=1,38)
 1006 FORMAT(2A6,4X,17A6)
      WRITE(6,1009)
 1009 FORMAT(16X,1H+, 5(19H-------------------, 1H+))
      WRITE(6,1007) (A(I),I= 39,988)
 1007 FORMAT(A4,G11.4,1H+,16A6,A5,1H+ / 2A6,3X,1HI,16A6,A5,1HI /
     1          2A6,3X,1HI,16A6,A5,1HI / 2A6,3X,1HI,16A6,A5,1HI /
     2          2A6,3X,1HI,16A6,A5,1HI / 2A6,3X,1HI,16A6,A5,1HI /
     3          2A6,3X,1HI,16A6,A5,1HI / 2A6,3X,1HI,16A6,A5,1HI /
     4          2A6,3X,1HI,16A6,A5,1HI / 2A6,3X,1HI,16A6,A5,1HI )
```

Figure 29. Continued.



```
      WRITE (6,1005)(A(I),I=989,1007)
 1005 FORMAT(A4,G11.4,1H+,16A6,A5,1H+)
      WRITE (6,1008)(A(I),I = 1027,1032)
 1008 FORMAT(16X, 1H+, 5(19H-------------------,1H+) /
     1    12X,G11.4,5(9X,G11.4)/)
      WRITE (6,1006) (A(I),I =1008,1026)
      DO 3 I=1,1045
    3 A(I)='      '
      RETURN
      END
```

Figure 29. Continued.

```
          COMPUTED RUNOFF HYDROGRAPH
DATA   PT     RO    CN-S    QDS    TP     DT    FC     S1    IA   TIA   CV    SG    LONG  WTH
       IN     IN    IN     IPH    MIN    MIN   IPH    IN    IN   MIN    %    F/F     FT   FT
    1.620 1.360 0.310 0.000   135     5 0.025 0.200 0.000     0   95 0.0174   383   340
  C1    C2     S
0.016 0.967 0.310
TIME  ACP    PAV    QC     QO     QR    ARUFF   DA
 MIN   IN    IPH    IPH    IPH    IPH    IN     IN
   0 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
   5 0.172 0.733 0.081 0.009 0.014 0.000 0.061 0.009
  10 0.343 1.430 0.449 0.103 0.028 0.005 0.180 0.103
  15 0.569 2.258 1.144 0.448 0.555 0.028 0.359 0.448
  20 0.795 2.444 1.645 1.056 1.082 0.091 0.525 1.056
  25 0.961 1.850 2.029 1.593 1.398 0.201 0.592 1.593
  30 1.126 1.882 1.928 1.831 1.713 0.344 0.616 1.831
  35 1.209 0.952 1.627 1.800 1.545 0.495 0.542 1.800
  40 1.292 0.957 1.203 1.557 1.377 0.635 0.472 1.557
  45 1.312 0.231 0.798 1.187 1.070 0.749 0.362 1.187
  50 1.332 0.231 0.436 0.823 0.763 0.833 0.282 0.823
  55 1.350 0.203 0.316 0.579 0.628 0.891 0.230 0.579
  60 1.367 0.203 0.263 0.442 0.492 0.934 0.199 0.442
  65 1.384 0.191 0.235 0.360 0.425 0.967 0.178 0.360
  70 1.400 0.191 0.218 0.308 0.358 0.995 0.164 0.308
  75 1.419 0.215 0.213 0.274 0.320 1.020 0.156 0.274
  80 1.437 0.215 0.213 0.253 0.281 1.041 0.151 0.253
  85 1.459 0.250 0.220 0.241 0.266 1.062 0.151 0.241
  90 1.480 0.250 0.229 0.236 0.251 1.062 0.152 0.236
  95 1.497 0.192 0.227 0.233 0.242 1.101 0.148 0.233
 100 1.513 0.192 0.215 0.229 0.233 1.121 0.145 0.229
 105 1.531 0.204 0.210 0.224 0.224 1.140 0.143 0.224
 110 1.548 0.204 0.208 0.219 0.214 1.158 0.141 0.219
 115 1.567 0.216 0.209 0.215 0.207 1.176 0.141 0.215
 120 1.585 0.216 0.211 0.214 0.199 1.194 0.141 0.214
 125 1.597 0.134 0.199 0.211 0.192 1.212 0.134 0.211
 130 1.608 0.134 0.177 0.203 0.184 1.229 0.128 0.203
 135 1.620 0.140 0.164 0.192 0.173 1.245 0.123 0.192
 140 1.620 0.000 0.131 0.177 0.162 1.261 0.107 0.177
 145 1.620 0.000 0.084 0.152 0.148 1.274 0.092 0.152
 150 1.620 0.000 0.055 0.124 0.134 1.286 0.079 0.124
 155 1.620 0.000 0.038 0.100 0.121 1.295 0.069 0.100
 160 1.620 0.000 0.027 0.081 0.108 1.303 0.061 0.081
 165 1.620 0.000 0.020 0.066 0.097 1.309 0.054 0.066
 170 1.620 0.000 0.016 0.055 0.085 1.314 0.048 0.055
 175 1.620 0.000 0.012 0.046 0.075 1.318 0.044 0.046
 180 1.620 0.000 0.010 0.039 0.065 1.322 0.040 0.039
 185 1.620 0.000 0.008 0.034 0.058 1.325 0.037 0.034
 190 1.620 0.000 0.007 0.029 0.051 1.327 0.034 0.029
 195 1.620 0.000 0.006 0.026 0.046 1.330 0.031 0.026
 200 1.620 0.000 0.005 0.023 0.041 1.332 0.029 0.023
 205 1.620 0.000 0.004 0.020 0.038 1.334 0.027 0.020
 210 1.620 0.000 0.004 0.018 0.034 1.335 0.026 0.018
 215 1.620 0.000 0.003 0.016 0.031 1.337 0.024 0.016
 220 1.620 0.000 0.003 0.014 0.028 1.338 0.023 0.014
 225 1.620 0.000 0.002 0.013 0.026 1.339 0.022 0.013
 230 1.620 0.000 0.002 0.012 0.024 1.340 0.021 0.012
 235 1.620 0.000 0.002 0.011 0.023 1.341 0.020 0.011
 240 1.620 0.000 0.002 0.010 0.021 1.342 0.019 0.010
 245 1.620 0.000 0.002 0.009 0.020 1.343 0.018 0.009
 250 1.620 0.000 0.001 0.008 0.018 1.343 0.017 0.008
 255 1.620 0.000 0.001 0.008 0.017 1.344 0.016 0.008
```

Figure 30. Sample of output data.

```
  260 1.620 0.000 0.001 0.007 0.015 1.345 0.016 0.007
  265 1.620 0.000 0.001 0.007 0.015 1.345 0.015 0.007
  270 1.620 0.000 0.001 0.006 0.014 1.346 0.015 0.006
  275 1.620 0.000 0.001 0.006 0.014 1.346 0.014 0.006
  280 1.620 0.000 0.001 0.005 0.013 1.347 0.014 0.005
  285 1.620 0.000 0.001 0.005 0.013 1.347 0.013 0.005
  290 1.620 0.000 0.001 0.005 0.012 1.348 0.013 0.005
  295 1.620 0.000 0.001 0.005 0.012 1.348 0.012 0.005
  300 1.620 0.000 0.001 0.004 0.011 1.348 0.012 0.004
  305 1.620 0.000 0.001 0.004 0.011 1.349 0.011 0.004
  310 1.620 0.000 0.001 0.004 0.010 1.349 0.011 0.004
  315 1.620 0.000 0.001 0.004 0.009 1.349 0.011 0.004
  320 1.620 0.000 0.000 0.003 0.008 1.350 0.011 0.003
  325 1.620 0.000 0.000 0.003 0.008 1.350 0.010 0.003
  330 1.620 0.000 0.000 0.003 0.007 1.350 0.010 0.003
  335 1.620 0.000 0.000 0.003 0.007 1.350 0.010 0.003
  340 1.620 0.000 0.000 0.003 0.006 1.351 0.009 0.003
  345 1.620 0.000 0.000 0.003 0.006 1.351 0.009 0.003
  350 1.620 0.000 0.000 0.003 0.005 1.351 0.009 0.003
  355 1.620 0.000 0.000 0.002 0.005 1.351 0.009 0.002
  360 1.620 0.000 0.000 0.002 0.004 1.352 0.009 0.002
  365 1.620 0.000 0.000 0.002 0.004 1.352 0.008 0.002
  370 1.620 0.000 0.000 0.002 0.004 1.352 0.008 0.002
  375 1.620 0.000 0.000 0.002 0.004 1.352 0.008 0.002
  380 1.620 0.000 0.000 0.002 0.003 1.352 0.008 0.002
  385 1.620 0.000 0.000 0.002 0.003 1.352 0.008 0.002
  390 1.620 0.000 0.000 0.002 0.003 1.353 0.008 0.002
  395 1.620 0.000 0.000 0.002 0.003 1.353 0.007 0.002
  400 1.620 0.000 0.000 0.002 0.002 1.353 0.007 0.002
  405 1.620 0.000 0.000 0.002 0.002 1.353 0.007 0.002
  410 1.620 0.000 0.000 0.002 0.002 1.353 0.007 0.002
  415 1.620 0.000 0.000 0.002 0.001 1.353 0.007 0.002
  420 1.620 0.000 0.000 0.001 0.001 1.353 0.007 0.001
  425 1.620 0.000 0.000 0.001 0.000 1.354 0.007 0.001
  430 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  435 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  440 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  445 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  450 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  455 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  460 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  465 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  470 1.620 0.000 0.000 0.001 0.000 1.354 0.006 0.001
  475 1.620 0.000 0.000 0.001 0.000 1.355 0.006 0.001
  480 1.620 0.000 0.000 0.001 0.000 1.355 0.005 0.001
  485 1.620 0.000 0.000 0.001 0.000 1.355 0.005 0.001
  XFN     FK XMQ1    XM   RO    RM      RK
 0.000 0.000 0.286 5.044 1.360 1.556   7.03
TRUFF TPEAK TREC TEND QPEAK
    5   30   455  485 1.831
```

Figure 30. Continued.

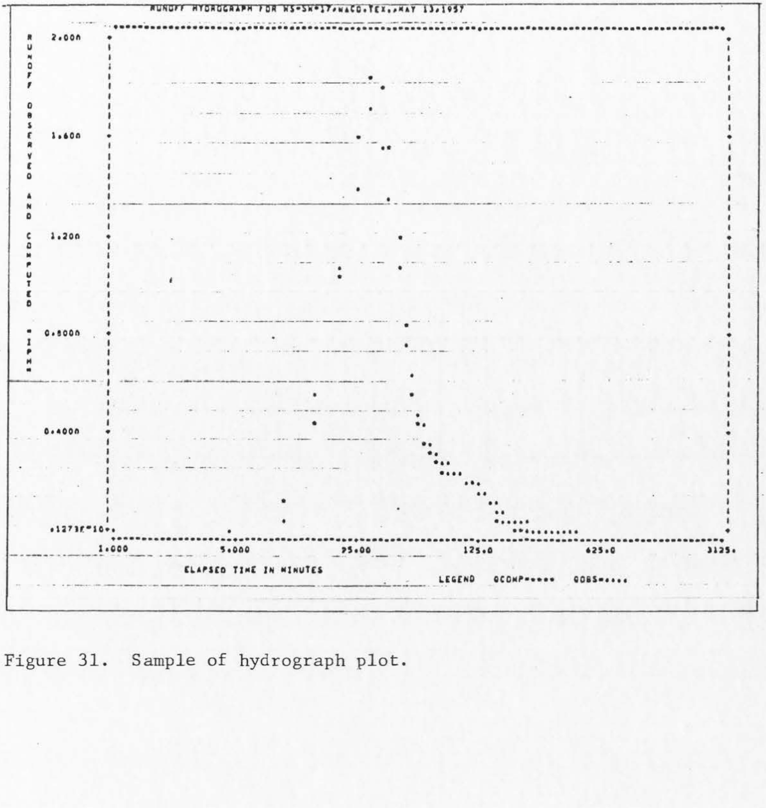


Figure 31. Sample of hydrograph plot.

Appendix B

Table 5. Soil and watershed characteristics for rainfall simulator plots of Illinois trials.[1] All plots are 12' x 6'

Plot	Soil	Depth (in)	Slope %	Cover	SCS Hyd. Class
1	Alma Silt loam		11.72	Alfalfa	C
2	Alma Silt loam		9.62		+D
3	Bogota Silt loam		0.83	New alfalfa	C
4	Bogota Silt loam		1.30	New alfalfa	C
5	Bogota Silt loam		1.22	Alfalfa	+D
6	Bogota Silt loam		1.00	Alfalfa	+D
7	Bogota Silt loam		1.36	Pasture	+D
8	Bogota Silt loam		1.30	Pasture	+D
9	Alma Silt loam		8.27	Virgin pasture	C
10	Alma Silt loam		8.30	Virgin pasture	+D
11	Bogota Silt loam		1.25	Virgin pasture	C
12	Bogota Silt loam		1.67	Virgin pasture	C
13	Elco Silt loam		15.25	Virgin pasture	C
14	Elco Silt loam		16.83	Virgin pasture	C
15	Elco Silt loam		12.11	Virgin pasture	C
16	Elco Silt loam		11.11	Virgin pasture	+D

---

[1] Unpublished data of H. N. Holtan.

Table 6. Soil and watershed characteristics of rainfall simulator sites. Arizona trials.[1] All plots are 24' x 12'

Site	Soil	Slope	Cover	SCS Hyd. Class
1	Dos Cabezas clay loam	0.84	Few plants	C
4	McClellan clay loam	1.24	Sparce	B
5	Mohave sandy loam	5.48	None	B
6	Mohave gravelly sandy loam	9.06	None	B
7	Mohave gravelly sandy loam	13.70	None	B
13	Gila silt loam	0.80	Sparce	B
15	Ramona sandy clay loam	1.32	None	B
17	Ramona clay loam	1.60	Heavy stand of Tobasa	B
23-6	White House gravelly silt loam	3.60	Good cover of black grama	C
25A	Ramona clay loam	0.50	None	B

---

[1] Data from original documents provided by Professor Joel Fletcher.

Table 7. Soil characteristics of Arizona desert plots (Beutner, 5)

Site No.	Soil type	Surface Soil	Subsoil	Topography & Origin	Degree of Erosion	Cover
5 6 7	Mohave gravelly sandy loam	Reddish brown, gritty friable calcareous	Redder, finer texture more compact. Lime accumulations	Rolling to flat topped terraces and fans. Largely from granite	Slow sheet erosion. Coarse sand and fine gravel erosion pavement	None, except for very little annual plant litter
10	Gila fine sandy loam	Light brown to pinkish brown, calcareous,	Light colored, stratified recent stream deposits	Recent bottom soils. Mixed origin	Severe sheet erosion "A" horizon 2" to 4"	None
11	"	"	"	"	Sandy overwash "A" horizon 6" to 10"	Very sparse Few burroweeds present were removed
12	"	"	"	"	No recent erosion "A" horizon 8" to 10"	
13	Gila silt loam	"	"	"	No recent erosion	Some annual plants and litter
14	Cajon sand	Light grayish brown, calcareous, coarse	Similar to surface Deep stratified, sandy deposits	Alluvial fans and flood plains outwash from granite rocks	No recent erosion	Some filaree and litter
15	Ramona sandy clay loam	Brown to grayish brown, gritty surface soil	Heavier moderately compact, grading to gravelly sediments	Upper and lower fans. From granitic materials	Recent overwash Surface badly checked	None
16	"	"	"	"	Slight erosion, fine gravelly erosion pavement	Fair cover annual plants and litter
18	Mohave sandy clay loam	Reddish brown gritty, friable calcareous	Redder, finer texture very compact	Lower fans and terraces, Derived from granite	Slight sheet erosion	Sparse weed cover
19	Teague stony loam	Grayish brown, calcareous. Very rocky	Dark brown calcareous Clay loam. Caliche hardpan	Alluvial fans and terraces. Derived from basalt	Gravelly erosion pavement	None
20	White house stony loam	Friable, granular dull-brown	Tough red clay Cobbly	Upper fans. Granite origin	Moderate sheet erosion. Stony pavement	Sparse cover of caliandra and grama gras
21	Sonoita sandy loam	Reddish-brown medium to coarse	Compact heavy clay loam	Alluvial fans Rhyolitic origin	Slight erosion	Sparse cover annual plants, Some litter

Table 8. Rainfall simulator data for Illinois plots

Plot	Date	Length	Slope	S	n hr^{-1}	C iph	Cover %	Fc iph	Si in	m hr	Ia in
11	3-21-41	12.0	1.250	1.836	1.538	11.5	95.00	0.015	2.50	0.190	0.238
4	6-2-41	12.0	1.300	5.382	1.125	13.2	15.00	0.150	2.50	0.105	0.286
3	6-4-41	12.0	0.830	5.159	1.094	10.1	20.00	0.090	2.50	0.130	0.404
1	6-10-41	12.0	11.720	2.079	1.443	48.0	15.00	0.010	2.50	0.067	0.229
2	6-11-41	12.0	9.620	2.942	1.414	60.0	25.00	0.110	2.20	0.066	0.191
6	6-18-41	12.0	1.000	4.325	1.155	14.0	25.00	0.240	2.20	0.105	0.228
5	6-20-41	12.0	1.220	3.426	1.118	22.0	25.00	0.110	2.20	0.098	0.274
7	6-24-41	12.0	1.360	4.081	1.155	14.0	50.00	0.000	2.20	0.090	0.225
8	6-27-41	12.0	1.300	9.303	1.441	17.0	40.00	0.300	2.20	0.141	0.272
9	7-1-41	12.0	8.270	10.071	1.447	48.0	95.00	0.120	2.50	0.068	0.226
10	7-2-41	12.0	8.300	7.783	1.825	43.0	95.00	0.075	2.20	0.124	0.206
13	7-15-41	12.0	12.250	8.508	1.240	35.0	60.00	0.290	2.50	0.056	0.204
14	7-17-41	12.0	16.830	7.275	1.824	58.0	75.00	0.220	2.20	0.084	0.338
15	7-21-41	12.0	12.110	2.555	1.000	31.0	15.00	0.340	2.50	0.035	0.236
16	7-23-41	12.0	11.110	2.605	1.054	35.0	15.00	0.390	2.20	0.034	0.165
1	5-20-41	12.0	11.720	0.377	1.293	76.3	20.00	0.090	0.31	0.035	0.027
1	6-18-41	12.0	11.720	0.406	1.250	42.3	20.00	0.180	0.31	0.050	0.070
6	6-21-41	12.0	1.000	1.442	1.327	26.3	30.00	0.280	0.26	0.085	0.266
7	6-26-41	12.0	1.360	1.094	0.961	11.4	75.00	0.410	0.26	0.079	0.156
8	6-27-41	12.0	1.300	1.133	1.053	9.3	75.00	0.390	0.26	0.120	0.324
2	7-16-41	12.0	9.620	0.600	1.268	38.7	15.00	0.190	0.26	0.056	0.101
1	7-18-41	12.0	11.720	0.458	1.470	67.4	20.00	0.090	0.31	0.057	0.056
6	7-24-41	12.0	1.000	3.021	1.200	14.1	30.00	0.500	0.26	0.110	0.081
7	7-30-41	12.0	1.360	1.880	1.002	11.4	75.00	0.450	0.26	0.068	0.180
8	8-2-41	12.0	1.300	1.897	1.116	11.2	75.00	0.420	0.26	0.115	0.230
3	8-27-41	12.0	0.830	2.123	0.946	11.0	70.00	0.495	0.31	0.079	0.135
1	8-31-41	12.0	11.720	1.370	1.418	68.0	20.00	0.050	0.31	0.051	0.149
6	9-14-41	12.0	1.000	1.263	1.007	11.3	30.00	0.360	0.26	0.090	0.222
9	9-24-41	12.0	1.820	1.874	1.284	34.8	95.00	0.340	0.31	0.063	0.118
7	5-7-40	12.0	1.360	1.846	0.000	0.0	75.00	0.600	2.20	0.082	0.111
13	5-27-40	12.0	15.250	4.461	0.000	0.0	70.00	0.500	2.50	0.072	0.190
14	5-28-40	12.0	16.830	1.322	0.000	0.0	75.00	0.465	1.83	0.064	0.125
15	6-3-40	12.0	12.110	2.075	0.000	0.0	5.00	0.320	2.50	0.046	0.152
16	6-4-40	12.0	11.110	3.701	0.000	0.0	5.00	0.490	2.20	0.052	0.208
12	6-5-40	12.0	1.670	4.418	0.000	0.0	95.00	0.030	2.50	0.142	0.195
5	6-19-40	12.0	1.220	2.773	0.000	0.0	30.00	0.280	2.20	0.084	0.248
10	6-29-40	12.0	8.300	7.052	0.000	0.0	100.00	0.360	2.20	0.113	0.076
11	7-1-40	12.0	1.250	7.477	0.000	0.0	95.00	0.210	2.50	0.152	0.568
12	7-2-40	12.0	1.670	8.523	0.000	0.0	95.00	0.220	2.50	0.142	0.256
13	7-8-40	12.0	15.250	10.172	0.000	0.0	70.00	0.330	2.50	0.072	0.204
14	7-5-40	12.0	16.830	4.048	0.000	0.0	75.00	0.420	2.20	0.076	0.193
15	7-10-40	12.0	12.110	2.830	0.000	0.0	5.00	0.380	2.50	0.052	0.179
16	7-12-40	12.0	11.110	3.331	0.000	0.0	5.00	0.320	2.20	0.046	0.229
10	8-5-40	12.0	8.300	5.022	0.000	0.0	100.00	0.060	2.20	0.105	0.186
13	8-13-40	12.0	15.250	3.237	0.000	0.0	70.00	0.410	2.50	0.060	0.121
14	8-15-40	12.0	16.830	3.310	0.000	0.0	75.00	0.390	2.20	0.057	0.071
15	8-19-40	12.0	12.110	0.929	0.000	0.0	5.00	0.220	2.54	0.044	0.056
16	8-20-40	12.0	11.110	0.910	0.000	0.0	5.00	0.150	2.20	0.039	0.062

Table 9. Rainfall simulator data for Izzard's (25) experiments.

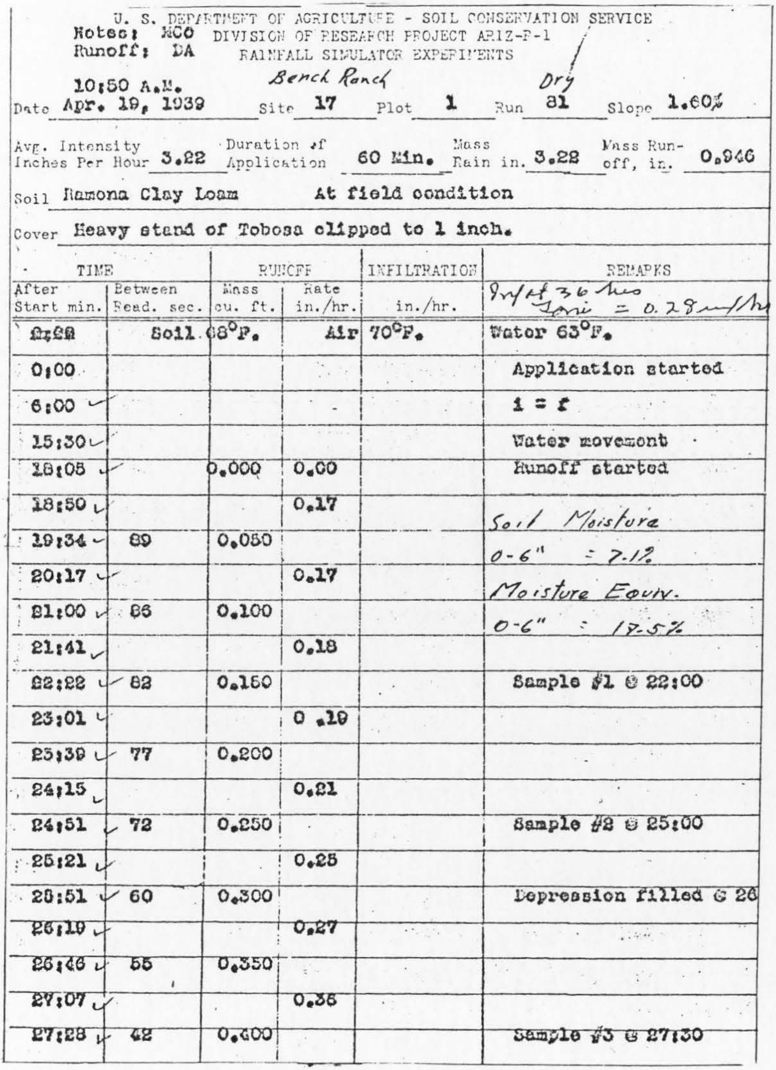
Length (ft)	Slope (%)	S (in)	n	C (iph)	Cover (%)	Fc (iph)	Si (in)	m	Ia
72.0	0.100	0.000	2.524	439.9	0.00	0.000	0.01	0.090	0.000
72.0	0.500	0.000	2.708	4874.4	0.00	0.000	0.01	0.043	0.000
72.0	1.000	0.000	2.579	3472.0	0.00	0.000	0.01	0.042	0.000
72.0	2.000	0.000	2.445	3687.4	0.00	0.000	0.01	0.035	0.000
48.0	0.100	0.000	3.245	2364.9	0.00	0.000	0.01	0.091	0.000
48.0	0.500	0.000	2.490	2390.2	0.00	0.000	0.01	0.044	0.000
48.0	1.000	0.000	2.409	2801.6	0.00	0.000	0.01	0.037	0.000
48.0	2.000	0.000	2.447	5361.7	0.00	0.000	0.01	0.031	0.000
24.0	0.100	0.000	3.082	3992.1	0.00	0.000	0.01	0.068	0.000
24.0	0.500	0.000	2.528	3694.2	0.00	0.000	0.01	0.039	0.000
24.0	1.000	0.000	2.201	1948.6	0.00	0.000	0.01	0.032	0.000
24.0	2.000	0.000	2.368	6337.6	0.00	0.000	0.01	0.025	0.000
12.0	0.100	0.000	3.641	29958.7	0.00	0.000	0.01	0.059	0.000
12.0	0.500	0.000	2.600	5796.5	0.00	0.000	0.01	0.036	0.000
12.0	1.000	0.000	2.526	9589.4	0.00	0.000	0.01	0.027	0.000
12.0	2.000	0.000	2.442	17302.0	0.00	0.000	0.01	0.018	0.000

Table 10. Rainfall simulator data for Arizona plots.[1]

Site	Plot	Run	Date	Length (ft)	Slope %	S in	n hr^{-1}	C iph	Cover %	Fc iph	Si in	m hr	Ia in
5	1	19	11-30-38	24.0	5.480	0.942	0.713	21.0	0.00	0.950	3.89	0.015	0.154
5	1	20	12-1-38	24.0	5.480	0.323	1.013	56.0	0.00	0.480	0.64	0.016	0.104
6	1	23	12-5-38	24.0	9.060	2.049	0.548	8.6	0.00	1.640	3.89	0.020	0.224
6	1	24	12-6-38	24.0	9.060	0.564	0.950	18.0	0.00	0.770	0.64	0.015	0.113
17	1	81	4-19-39	24.0	1.600	3.116	0.773	6.5	90.00	1.180	3.89	0.090	0.966
17	1	82	4-20-39	24.0	1.600	0.398	0.973	9.6	90.00	0.280	0.64	0.097	0.425
4	1	14	11-22-38	24.0	1.240	0.714	0.891	32.0	0.00	0.590	3.89	0.020	0.083
7	1	27	12-7-38	24.0	13.700	1.010	0.622	14.8	0.00	1.140	3.89	0.013	0.146
13	2	66	3-25-39	24.0	0.800	0.509	0.910	31.0	1.00	0.290	0.64	0.023	0.093
15	1	71	4-5-39	24.0	1.320	0.219	1.080	74.0	0.10	0.240	3.89	0.018	0.080
15	1	72	4-6-39	24.0	1.320	0.167	1.064	70.0	0.10	0.140	0.64	0.019	0.078
13	1	63	3-25-39	24.0	0.800	1.360	0.891	31.0	1.00	0.450	3.89	0.021	0.242
13	1	64	3-26-39	24.0	0.800	0.482	0.931	35.0	1.00	0.350	0.64	0.021	0.083
1	1	1	11-1-38	24.0	0.840	0.275	0.975	24.8	0.10	0.620	2.50	0.037	0.147
1	1	2	11-2-38	24.0	0.840	0.120	0.738	18.0	0.10	0.310	0.31	0.021	0.105
25A	51	370	8-19-40	24.0	0.500	0.622	0.714	16.0	0.00	0.340	3.89	0.021	0.092
25A	51	371	8-20-40	24.0	0.500	0.375	1.003	31.5	0.00	0.340	0.64	0.033	0.156
23	61	326	6-17-40	24.0	3.600	10.776	0.643	8.2	80.00	4.550	9.99	0.038	0.236
23	61	328	6-18-40	24.0	3.600	3.005	0.746	14.4	80.00	2.640	2.00	0.028	0.151

[1] Data obtained from Prof. Joel Fletcher's files.

Table 11. Sample of rainfall simulator data.



U. S. DEPARTMENT OF AGRICULTURE - SOIL CONSERVATION SERVICE
Notes: MCO DIVISION OF RESEARCH PROJECT ARIZ-R-1
Runoff: DA RAINFALL SIMULATOR EXPERIMENTS

10:50 A.M. Bench Ranch Dry
Date Apr. 19, 1939 Site 17 Plot 1 Run 31 Slope 1.60%

Avg. Intensity Inches Per Hour 3.22 Duration of Application 60 Min. Mass Rain in. 3.28 Mass Run-off, in. 0.946

Soil Ramona Clay Loam At field condition

Cover Heavy stand of Tobosa clipped to 1 inch.

TIME		RUNOFF		INFILTRATION	REMARKS
After Start min.	Between Read. sec.	Mass cu. ft.	Rate in./hr.	in./hr.	Inf at 36 hrs Tori = 0.28 in/hr
[illegible]	Soil 68°F.		Air	70°F.	Water 63°F.
0:00					Application started
6:00 ✓					i = f
15:30 ✓					Water movement
18:05 ✓		0.000	0.00		Runoff started
18:50 ✓			0.17		Soil Moisture
19:34 ✓	89	0.050			0-6" = 7.1%
20:17 ✓			0.17		Moisture Equiv.
21:00 ✓	86	0.100			0-6" = 17.5%
21:41 ✓			0.18		
22:22 ✓	82	0.150			Sample #1 @ 22:00
23:01 ✓			0.19		
23:39 ✓	77	0.200			
24:15 ✓			0.21		
24:51 ✓	72	0.250			Sample #2 @ 25:00
25:21 ✓			0.25		
25:51 ✓	60	0.300			Depression filled @ 26
26:19 ✓			0.27		
26:46 ✓	55	0.350			
27:07 ✓			0.36		
27:28 ✓	42	0.400			Sample #3 @ 27:30

Table 11. Continued.

Date ______ Site ______ Plot ______ Run 81

TIME		RUNOFF		INFILTRATION	REMARKS
After Start min.	Between Read. sec.	Mass cu. ft.	Rate in./hr.	in./hr.	
27:46			0.42		
28:04	36	0.450			
28:20			0.47		
28:36	32	0.500			
28:51			0.52		
29:05	29	0.550			
29:18			0.58		
29:31	26	0.600			
29:55			0.64		Sample #4 @ 30:00
30:18	47	0.700			
30:39			0.73		
30:59	41	0.800			
31:18			0.79		
31:37	38	0.900			
31:55			0.86		
32:12	35	1.000			
33:29			0.98		
34:45	153	1.500			
35:47			1.20		Sample #5 @ 35:00
36:49	124	2.000			
37:45			1.35		
38:40	111	2.500			
39:32			1.45		Sample #6 @ 40:00
40:23	103	3.000			
41:14			1.49		
42:04	101	3.600			

Table 11. Continued.

Date ______ Site ______ Plot ______ Run 81

TIME		RUNOFF		INFILTRATION	REMARKS
After Start min.	Between Read. sec.	Mass cu. ft.	Rate in./hr.	in./hr.	
42:52			1.58		
43:39	95	4.000			
44:27			1.56		
45:15	96	4.500			
46:03			1.61		
46:48	93	5.000			
48:18			1.68		
49:47	179	6.000			
51:13			1.74		Sample #7 @ 50:00
52:39	172	7.000			
53:54			2.00		
55:19	160	8.000			
56:35			1.98		
57:50½	~~15½~~ 151½	9.000			
58:55			2.04		Sample #8 @ 60:00
60:00	129½	9.880			App. Stopped
60:09			1.76		
60:17	17	9 .980			
60:26			1.67		
60:35	18	10.080			
60:44			1.67		
60:53	18	10.180			Sample #9 @
61:04			1.43		
61:14	21	10.280			
61:25			1.36		
61:36	22	10.330			

Table 11. Continued.

Date		Site		Plot	Run 01
TIME		RUNOFF		INFILTRATION	REMARKS
After Start min.	Between Read. sec.	Mass cu. ft.	Rate in./hr.	in./hr.	
61:48			1.31		
61:59	23	10.480			
62:12			1.15		
62:25	26	10.580			
62:40			1.03		
62:54	29	10.680			
63:10			0.94		Depression storage 80%
63:26	32	10.780			
63:45			0.81		
64:03	37	10.880			
64:25			0.68		
64:47	44	10.980			
65:15			0.55		
65:42	55	11.080			Depression storage 50%
66:20			0.40		
66:57	75	11.180			Depression storage 40 %
67:22			0.31		
67:46	49	11.230			
68:25			0.19		
69:03	77	11.280			Depression storage 25%
70:01			0.13		
70:58	115	.330 11.330			
71:47			0.06		
72:35	97	11.350	0.00		Runoff stopped
76:00					Depression storage 10%
78:30					Depression storage 3%

Table 11. Continued.

Date ____ Site ____ Plot ____ Run ____

TIME		RUNOFF		INFILTRATION	REMARKS
After Start min.	Between Read. sec.	Mass cu. ft.	Rate in./hr.	in./hr.	
	During	run water	stood	1 inch deep	in depressions.
			Infiltration 10"		
	At	end of exp.		Soil 66°F.	Air 74°F. Water 64°F.

Appendix C

Table 12. Soil and hydrological characteristics of small watershed utilized in testing the model.

Watershed[1]					Soil		Topsoil			Subsoil		Internal Drainage	SCS[3] Hydrol. Class
	Area (acres)	Length[2] (ft)	Width[2] (ft)	Slope[2] (%)	Serie	Area (%)	Depth (in)	Structure	Permeability	Structure	Permeability		
3H, Hastings, Nebr.	3.77	536	306	5.58	Holdredge silt loam	75	12	Moderate fine to medium granular	Moderate	Mod. fine to med. subang. blocky	Moderate to moderately	Medium	+C
					Holdredge silty clay loam	25	5	Weak fine crumb	Mod. to mod. slow	Same as above	Slow	Medium	C
5H, Hastings, Nebr.	4.02	645	271	5.53	Holdredge silt loam	50	12	Mod. fine to med. granular	Moderate	Mod. fine to mod. sub-ang. blocky	Moderate to	Medium	+C
					Holdredge silty clay loam	50	5	Weak fine crumb	Mod. to mod. slow	Same as above	Moderately slow	Medium	C
P-1, Waco, Texas	0.243	168	63	2.82	Houston black clay	100	60	Moderate fine to medium, granular					
SW-17, Waco, Texas	2.99	383	340	1.74	Houston black clay	100	60	Same as above	Same as above	Same as above	Same as above	Same as above	D

[1] Data from reference ( )
[2] Average values
[3] Soil Conservation Service Method (3), Modified by Chiang ( )

Table 13. Hydrologic data for Watershed 3H, Hastings, Nebraska.

SELECTED RUNOFF EVENTS					Hastings, Nebraska Watershed 3-H			
Antecedent condition			Rainfall			Runoff		
Date	Rainfall (inches)	Runoff (inches)	Date and time	Intensity (in/hr)	Acc. (inches)	Date and time	Rate (in/hr)	Acc. (inches)
				Event of May 15-16, 1960				
4-16-60	0.20	0	5-15-60	Raingage B-36-R		5-15-60		
4-25	.11	0	8:54p	0	0	9:50p	0	0
4-27	.07	0	9:04	.96	.16	:55	.106	T
4-28	.08	0	:14	.24	.20	:58	.829	.02
4-29	.29	0	:40	.09	.24	10:00	1.38	.06
5-3	.18	0	:44	.60	.28	:04	1.06	.14
5-5	1.61	.47	:52	1.73	.51	:08	2.45	.24
5-6	.14	.01	:56	3.90	.77	:10	4.32	.35
			10:02	1.90	.96	:15	2.04	.70
			:10	4.73	1.59	:20	.982	.81
			:16	.60	1.65	:25	1.49	.91
Watershed Conditions: 100% fallow. No field operation since harvest of sorghum on 10/14/59; good cover.			:22	1.60	1.81	:31	2.98	1.123
			:28	3.00	2.11	:33	2.52	1.218
			:32	2.55	2.28	:35	1.89	1.30
			:52	.15	2.33	:39	.829	1.38
						:44	.421	1.42
						:55	.106	1.47
						11:00	.0695	1.477
						:10	.0474	1.49
						5-16-60		
						12:30a	.009	1.51
						5:00	.0049	1.53
						6:00p	0	1.56
				Event of July 18 and 19, 1958 (Area - 3.95 acres)				
6-20-58	.20	0	7-18-58	Raingage	B-36-R	7-18-58		
6-24,25	.20	0	11:28p	0	0	11:28p	0	0
7-3	.95	T	:30	.30	.01	:33	.0508	T
7-4	.38	0	:34	4.35	.30	:34	.112	T
7-10	.42	T	:36	3.90	.43	:37	1.10	.02
7-12	.08	0	:41	1.32	.54	:41	1.20	.11
7-15	.31	0	:43	3.90	.67	:45	1.56	.20
7-16	.08	0	:48	.36	.70	:49	1.10	.29
7-17	1.07	.20	7-19-58			:54	.630	.35
			12:48a	.02	.72	:57	.402	.39
Watershed Conditions: Wheat harvested on July 8 and 9. Stubble 1 ft. high.						7-19-58		
						12:01a	.223	.41
						:05	.127	.42
						:13	.0583	.43
						:37	.0135	.44
						2:06 3/	.0018	.45
				Event of July 3, 1959 (Area - 3.77 acres)				
6-18-59	.05	0	7-3-59	Raingage	B-36-R	7-3-59		
6-19	.37	T	8:31p	0	0	8:34p	0	0
6-20	1.31	.62	:33	3.00	.10	:36	.421	.01
6-21	.03	0	:37	5.70	.48	:38	2.87	.06
6-27,28	1.93	1.04	:39	8.10	.75	:41	6.45	.31
6-29	[illegible]	[illegible]	:41	7.50	1.00	:42	[illegible]	[illegible]
6-30	.22	[illegible]	:43	5.10	1.17	:45	[illegible]	.59
Watersheds Conditions: Sorghum - about 6" high and in good condition. Weeds beginning to grow. Last field operations on June 26.			:49	2.50	1.42	:49	[illegible]	.92
			:52	2.00	1.52	:52	[illegible]	1.03
			:55	3.20	1.68	:55	2.74	1.14
			9:01	2.00	[illegible]	:59	[illegible]	[illegible]
			:09	3.30	2.32	9:01	[illegible]	[illegible]
			[illegible]	2.40	[illegible]	:02	[illegible]	1.42
			[illegible]	3.60	[illegible]	:04	[illegible]	[illegible]

Notes: To convert runoff in in/hr to cfs, multiply by 3.983 for event of July 18-19, 1958; by 3.802 for event of July 3, 1959. 1/ Area changed 1-1-58 from 3.95 acres to 3.77 acres. 3/ Beginning of new runoff event.

Table 14. Hydrological data for event of June 25, 1961, P-1, Waco, Texas.

MONTHLY PRECIPITATION 1/ AND RUNOFF (Inches) — RIESEL (WACO), TEXAS — Watershed P-1

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1960	P	2.02	2.02	1.55	2.01	1.72	4.90	0.36	2.83	0.96	6.07	2.38	7.71	34.53
	Q	.90	.28	.08	0	0	T	0	0	0	0	0	2.18	3.44
1961	P	4.97	4.74	2.16	.41	2.18	8.51	3.86	.43	4.70	2.04	2.10	2.24	38.34
	Q	2.37	2.24	0	0	0	1.42	.04	0	T	0	0	.12	6.19

ANNUAL MAXIMUM DISCHARGES IN INCHES PER HOUR AND ANNUAL MAXIMUM VOLUMES OF RUNOFF IN INCHES FOR SELECTED TIME INTERVALS — RIESEL (WACO), TEXAS — Watershed P-1

YEAR	MAXIMUM DISCHARGE		MAXIMUM VOLUME FOR SELECTED TIME INTERVAL													
			1 hour		2 hours		6 hours		12 hours		1 day		2 days		8 days	
	Date	Rate	Date	Vol.	Date	Vol.	Date	Vol.	Date	Vol.	Date	Vol.	Date	Vol.	Date	Vol.
1960	1-13	0.60	1-13	0.32	12-7	0.40	12-7	0.65	12-7	1.23	12-7	2.14	12-7	2.15	12-7	2.18
1961	6-25	1.67	6-25	.44	2-5	.58	2-5	1.35	2-5	1.62	2-5	1.64	2-5	1.75	1-6	2.37

Notes: Quality of records: Monthly P, excellent; monthly Q and annual max. discharges and volumes, good.
1/ Raingage W-9.

SELECTED RUNOFF EVENTS — RIESEL (WACO), TEXAS — Watershed P-1

Antecedent conditions			Rainfall			Runoff		
Date	Rainfall (inches)	Runoff (inches)	Date and time	Intensity (in/hr)	Acc. (inches)	Date and time	Rate (in/hr)	Acc. (inches)
			Event of June 25, 1961					
	Raingage W-9							
5-26-61	0.05	0	6-25-61	Raingage W-9		6-25-61		
6-5	.07	0	6:26a	0	0	9:08a	0	0
6-6	.30	0	:31	.84	.07	:10	.0612	T
6-8	.11	0	:34	2.00	.17	:12	.131	T
6-12	.01	0	:38	3.00	.37	:15	.465	.02
6-14	.94	0	:41	2.00	.47	:18	.845	.05
6-15	2.46	.0604	:44	1.20	.53	:20	1.00	.08
6-16	.39	.0032	:56	.20	.57	:22	1.17	.12
6-17	.80	.0279	9:06	1.50	.87	:25	1.67	.19
6-18	1.92	.8728	:18	3.00	1.27	:29	1.23	.29
6-19	0	T	:24	1.60	1.45	:31	.947	.32
6-25	.03 2/	0	:30	.30	1.48	:35	.539	.37
						:39	.310	.40
						:44	.151	.42
						:48	.100	.43
						:58	.0396	.44
						10:05	.0229	.44
						:18	.0110	.45
						11:30	.0012	.45
						1:00p	0	.45
			Event of July 16-17, 1961					
	Raingage W-9							
6-16-61	0.39	0.0032	7-16-61	Raingage W-9		7-16-61		
6-17	.80	.0279	9:41p	0	0	9:59p	0	0
6-18	1.92	.8728	:44	2.2[illegible]	.11	10:02	.0163	T
6-19	0	T	:47	2.00	.21	:04	.0396	T
6-25	1.51	.4519	:49	3.30	.32	:06	.100	T
7-2	.01	0	:[illegible]	2.[illegible]	.42	:[illegible]	.131	.01
7-3	.26	[illegible]	:5[illegible]	3.[illegible]	.53	:13	.0735	.02
7-8	.02	0	:55	3.00	.63	:23	.0306	.03
7-9	.25	0	10:[illegible]	.74	.74	:43	.0069	.03
7-10	.46	0	:[illegible]8	1.50	.84	:58	.0028	.03

Watershed Conditions: 100% Bermuda-grass pasture, good cover, grass 6" high. 9.54 inches available soil moisture in 0-60" profile June 23.

Notes: To convert runoff in in/hr to cfs, multiply by 0.245. 2/ Prior to 8:20a.

Table 15. Hydrological data for events: April 24 and May 13, 1957, SW-17, Waco, Texas

SELECTED RUNOFF EVENTS					Riesel (Waco), Texas		Watershed SW-17	
Antecedent conditions			Rainfall			Runoff		
Date	Rainfall (inches)	Runoff (inches)	Date and time	Intensity (in/hr)	Acc. (inches)	Date and time	Rate (in/hr)	Acc. (inches)
				Event of April 24, 1957				
3-27-57	0.88	T	4-24-57	Raingage	W-2A	4-24-57		
3-31	1.35	.24	2:32p	0	0	2:33p	T	0
4-1	0	T	:40	.23	.03	:42	.0096	T
4-3	.24	0	:44	2.85	.22	:46	.222	.01
4-4	.03	0	:48	1.50	.32	:49	.703	.03
4-8	.04	0	:52	5.10	.66	:52	1.37	.08
4-13	.04	0	:56	2.10	.80	:56	1.97	.19
4-15	.02	0	:59	3.80	.99	3:00	2.41	.34
4-1[illegible]	4.73	3.00	3:03	3.30	1.21	:08	2.90	.70
4-20	.23	.12	:11	2.10	1.49	:14	2.34	.96
				Event of April 24, 1957 - Continued				
4-21-57	0.21	T	4-24-57	Raingage	W-2A	4-24-57		
4-22	.30	T	3:16p	1.32	1.60	3:21p	1.70	1.20
4-23	3.98	3.35	:22	1.00	1.70	:34	.770	1.46
4-24	.02 1/	0	:28	.30	1.73	:43	.498	1.55
			:50	.05	1.75	:53	.310	1.62
Watershed Conditions: 100% Bermuda grass pasture with weeds and grass 10" high.						4:06	.182	1.67
						:21	.112	1.70
						:38	.0710	1.73
						:56	.0464	1.75
						5:45	.0202	1.77
						7:40	.0046	1.79
						12:00 m	.0007	1.80
				Event of May 13, 1957				
4-13-57	0.04	0	5-13-57	Raingage	W-2A	5-13-57		
4-15	.02	0	8:22a	0	0	8:24a	0.0003	0
4-19	4.73	3.00	:25	2.00	.10	:28	.0013	0
4-20	.23	.12	:29	1.95	.23	:30	.0063	T
4-21	.21	T	:33	2.25	.38	:32	.0282	T
4-22	.30	T	:36	4.60	.61	:34	.0981	T
4-23	3.98	3.35	:41	1.92	.77	:36	.295	.01
4-24	1.83	1.80	:45	1.50	.87	:38	.604	.02
4-25	0	T	:51	2.40	1.11	:40	.816	.05
4-26	1.44	.81	:56	.96	1.19	:45	1.48	.15
4-27	.27	.35	:59	1.80	1.28	:50	1.74	.28
4-28	1.09	.65	9:14	.24	1.34	:56	1.66	.45
4-29	.06	.04	:38	.20	1.42	9:00	1.50	.56
4-30	.01	T	:52	.26	1.48	:06	1.13	.69
5-1	.37	T	10:10	.20	1.54	:12	.763	.78
5-2	0	T	:20	.24	1.58	:18	.574	.85
5-3	.84	.48	:37	.14	1.62	:24	.451	.90
[illegible]	0	.01				:29	.381	.94
5-[illegible]	.02	T				:44	.266	1.02
5-9	.89	.02				10:12	.214	1.13
5-10	0	.01				:36	.178	1.21
5-11	3.92	3.11				:59	.115	1.27
5-12	0	.06				11:19	.0687	1.30
5-13	0	T 2/				:37	.0444	1.31
						12:05p	.0255	1.33
Watershed Conditions: 100% Bermuda grass pasture with grass and weeds 12" high, dense growth.						:40	.0156	1.34
						2:15	.0046	1.35
						3:05	.0023	1.36

Notes: To convert runoff in in/hr to cfs, multiply by 3.014. 1/ Precipitation prior to 2:32p. 2/Runoff prior to 8:24a. 3/ Rainfall ended 9:07p. 4/ Runoff prior to 9:42p.

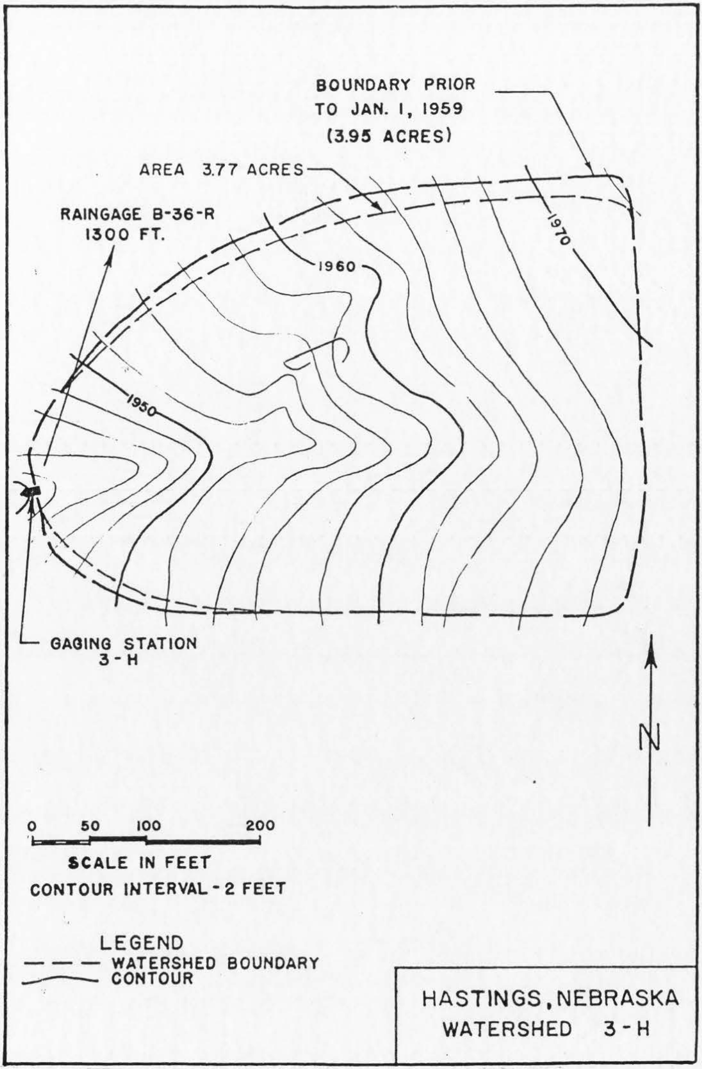
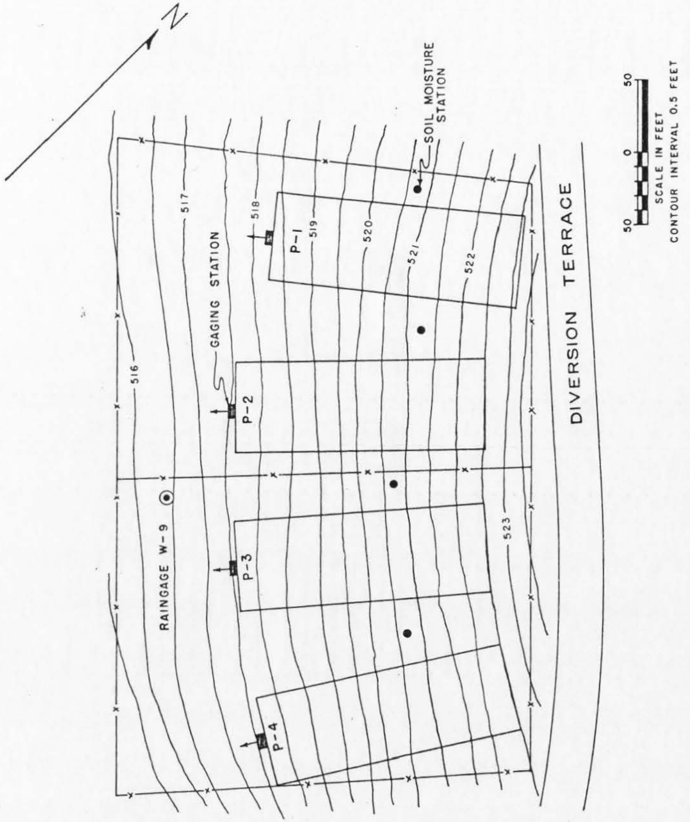


Figure 32. Map of Watershed 3-H, Hastings, Nebraska



NOTE: EACH WATERSHED AREA IS 0.243 ACRES.

RIESEL (WACO), TEXAS

WATERSHEDS

P-1
P-2
P-3
P-4

Figure 33. Map of watersheds P1, P2, P3 and P4, Waco, Texas

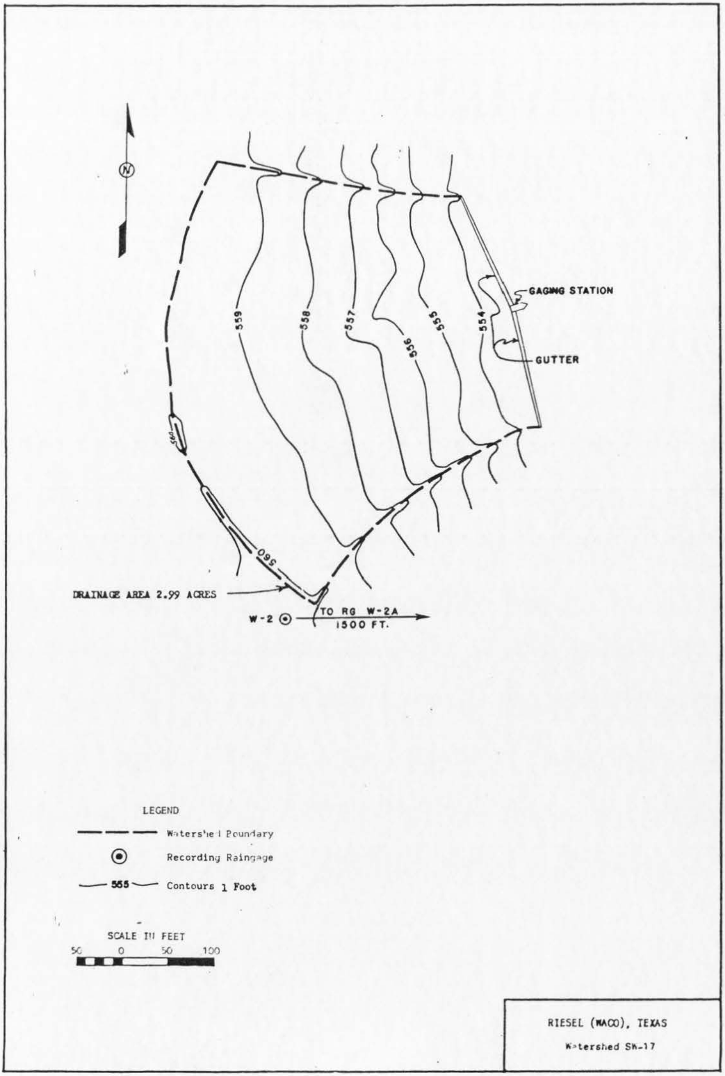
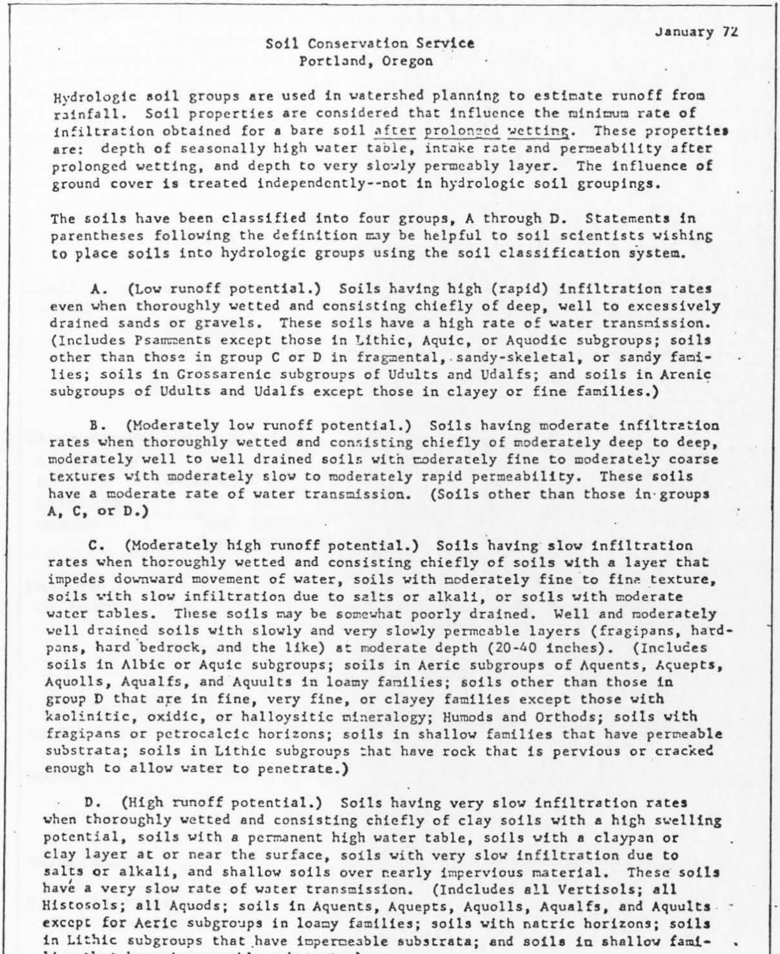


Figure 34. Map of Watershed SW-17, Waco, Texas

Appendix D



January 72

Soil Conservation Service
Portland, Oregon

Hydrologic soil groups are used in watershed planning to estimate runoff from rainfall. Soil properties are considered that influence the minimum rate of infiltration obtained for a bare soil after prolonged wetting. These properties are: depth of seasonally high water table, intake rate and permeability after prolonged wetting, and depth to very slowly permeably layer. The influence of ground cover is treated independently--not in hydrologic soil groupings.

The soils have been classified into four groups, A through D. Statements in parentheses following the definition may be helpful to soil scientists wishing to place soils into hydrologic groups using the soil classification system.

A. (Low runoff potential.) Soils having high (rapid) infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission. (Includes Psamments except those in Lithic, Aquic, or Aquodic subgroups; soils other than those in group C or D in fragmental, sandy-skeletal, or sandy families; soils in Grossarenic subgroups of Udults and Udalfs; and soils in Arenic subgroups of Udults and Udalfs except those in clayey or fine families.)

B. (Moderately low runoff potential.) Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures with moderately slow to moderately rapid permeability. These soils have a moderate rate of water transmission. (Soils other than those in groups A, C, or D.)

C. (Moderately high runoff potential.) Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, soils with moderately fine to fine texture, soils with slow infiltration due to salts or alkali, or soils with moderate water tables. These soils may be somewhat poorly drained. Well and moderately well drained soils with slowly and very slowly permeable layers (fragipans, hardpans, hard bedrock, and the like) at moderate depth (20-40 inches). (Includes soils in Albic or Aquic subgroups; soils in Aeric subgroups of Aquents, Aquepts, Aquolls, Aqualfs, and Aquults in loamy families; soils other than those in group D that are in fine, very fine, or clayey families except those with kaolinitic, oxidic, or halloysitic mineralogy; Humods and Orthods; soils with fragipans or petrocalcic horizons; soils in shallow families that have permeable substrata; soils in Lithic subgroups that have rock that is pervious or cracked enough to allow water to penetrate.)

D. (High runoff potential.) Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, soils with very slow infiltration due to salts or alkali, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission. (Indcludes all Vertisols; all Histosols; all Aquods; soils in Aquents, Aquepts, Aquolls, Aqualfs, and Aquults except for Aeric subgroups in loamy families; soils with natric horizons; soils in Lithic subgroups that have impermeable substrata; and soils in shallow families that have impermeable substrata.)

Figure 35. Soil Conservation Service hydrologic soil groups

Table 16. Runoff curve numbers for hydrologic soil-cover complexes.

(Antecedent moisture condition II, and $I_a = 0.2 S$)

Land use	Cover		Hydrologic soil group			
	Treatment or practice	Hydrologic condition	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 legumes 1/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	"and terraced	Poor	63	73	80	83
	"and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		---	74	84	90	92

1/ Close-drilled or broadcast.
2/ Including right-of-way.

Table 17. 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		S values*	Curve* starts where P =	CN for condition II	CN for conditions		S values*	Curve* starts where P =
	I	III				I	III		
			(inches)	(inches)				(inches)	(inch
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	inf.
62	42	79	6.13	1.23					
61	41	78	6.39	1.28					

*For CN in column 1.

Table 18. Modification of AMC (antecedent moisture conditions) to include 24-hour antecedent precipitation

Antecedent 24-hour precip.	Antecedent 5-day precipitation		
	< 1.4	1.4-2.1	> 2.1
(in)			
0.00 - 0.39	I	II	III
.40 - 0.74	+I	+II	III
.75 - 1.1	II	+II	III
> 1.1	+II	III	III

Note: Based on the case that if all antecedent precipitation falls on the first day and an average of .2 in/day evaporation occurs; the value of AMC for the 5th day will be 2.1 - 1.0 = 11 inches for AMC III,
1.4 - 1.0 = .4 inches for AMC II

Table 19. Infiltration characteristics of different soil hydrological classes. No cover (S1)

Infiltration Characteristics		Hydrologic Soil Class[1]						
		A	+B	B	+C	C	+D	D
Constant infiltration fc (iph)[2]		.30-.45 (.35)	(.30)	.15-.30 (.23)	(.16)	.05-.15 (.10)	(.06)	0-.0
	AMC[3]							
	I	6.95	5.38	3.89	3.25	2.50	2.20	1.76
	+I	4.97	3.83	2.76	2.28	1.75	1.51	1.20
S1	II	2.99	2.27	1.63	1.30	0.99	0.81	0.64
	+II	2.12	1.57	1.14	0.89	0.65	0.54	0.44
	III	1.24	0.87	0.64	0.47	0.31	0.26	0.21

[1] US SCS (3) Classification, modified by Chiang (26).

[2] From C. B. England (54)

[3] From Table D-4.

VITA

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