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A rainfall–runoff probabilistic simulation program: 1. Synthetic data generation

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Abstract

A computer program is described that generates synthetic rainfall data and catchment response data. These synthetic data are variable with respect to several parameters, and can be used for the evaluation of rainfall–runoff response sensitivity. Published by Elsevier Science Ltd.

Keywords: Rainfall; runoff; probabilistic; simulation

Software availability

Program title:	RRSIM
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First available:	June 1996
Hardware:	IBM PC
Source language:	FORTRAN
Availability:	Public domain

1. Introduction

The ability to perform thorough analysis of the reaction of a watershed to rainfall events is difficult due to the inability to have any real control over the system (e.g. Hromadka and Whitley, 1989). The storms have many parameters that are of interest, but few that can be measured with any great degree of accuracy. Likewise, the watershed has a number of factors that affect its reaction to the storm. Some of these are stable for a watershed but difficult to generalize, and others vary from day to day or are changed by the storm itself.

Program *Storm* is designed to model the reaction of a small watershed to simulated rainfall events. Certain arameters affecting the storm and watershed behavior are modifiable so that the individual effect of a particular parameter may be observed (see Hromadka, 1996). The data produced by the model consists of rain gauge measurements for each square mile of the watershed, along with the stream gauge measurement for the watershed system. The data can be written to disk and are formatted for acceptance by the companion program *Rain* which can then perform analysis on the data. All rainfall–runoff data are 'measured' exactly for this analysis, since both the storm and watershed are simulated, providing a clearer picture of the watershed reaction to changes in system parameters.

2. The program

The program consists of a Simscript executable file and a collection of data files. Since Simscript is a self-documenting language, the program is easily read and modified. The data files describe the various storms and the watershed. These are detailed below and are also easily read and modified. The Simscript programming language was chosen because it is a language designed for simulation and modeling and so has many handy built-in functions for statistical distributions and event handling.

Storm is run under the Simscript environment Simlab. The program is menu driven so the user interface is straightforward. If desired, the user may select the default (described below) for the changeable parameters by simply selecting the RUN button without entering any other data at the menu. By modifying any of the fields in the menu, the user forces those values to be used for the corresponding parameter.

Each time the program is executed, new watershed parameters are constructed based on the assumptions given below or as the user has selected from the initial menu. For each simulation, a new storm is generated based on the storm distribution described later. Except for the antecedent moisture condition, the watershed is always initialized back to the initial values for each new simulation.

3. Watershed

The simulated watershed, depicted in Fig. 1, is 40 square miles in area and is broken up into 40 one-square-mile grids. Each grid is connected to the stream gauge through a sequence of channels. There are three types of channels: regional, secondary, and other. Each channel type carries runoff at different rates as shown in Fig. 1. The distance from each grid, and total time for runoff to reach the stream gauge, are shown in Table 1.

One grid of the watershed is selected as the location of the rain gauge. The watershed configuration is described by data files so it can be easily modified.

4. Storms

There are 19 sizes of simulated storms for the model to select from, ranging in size from 10 to 100 square miles in area. A storm is made up of several square mile grids forming a larger rectangle. These different storms are depicted in Fig. 2.

The intensity of the storm varies over the storm area so that the center has the most intense rainfall with the outer edges having the least intense rainfall. These intensity factors are stable through the life of the storm. See Fig. 2 for the intensity distribution for each storm.

Storm size is selected based upon the event type the sample storm represents. A 2-yr-event storm is selected from storms 1–9 (see Fig. 2), a 10-yr-event storm is selected from storms 3–12, a 25-yr-event storm is

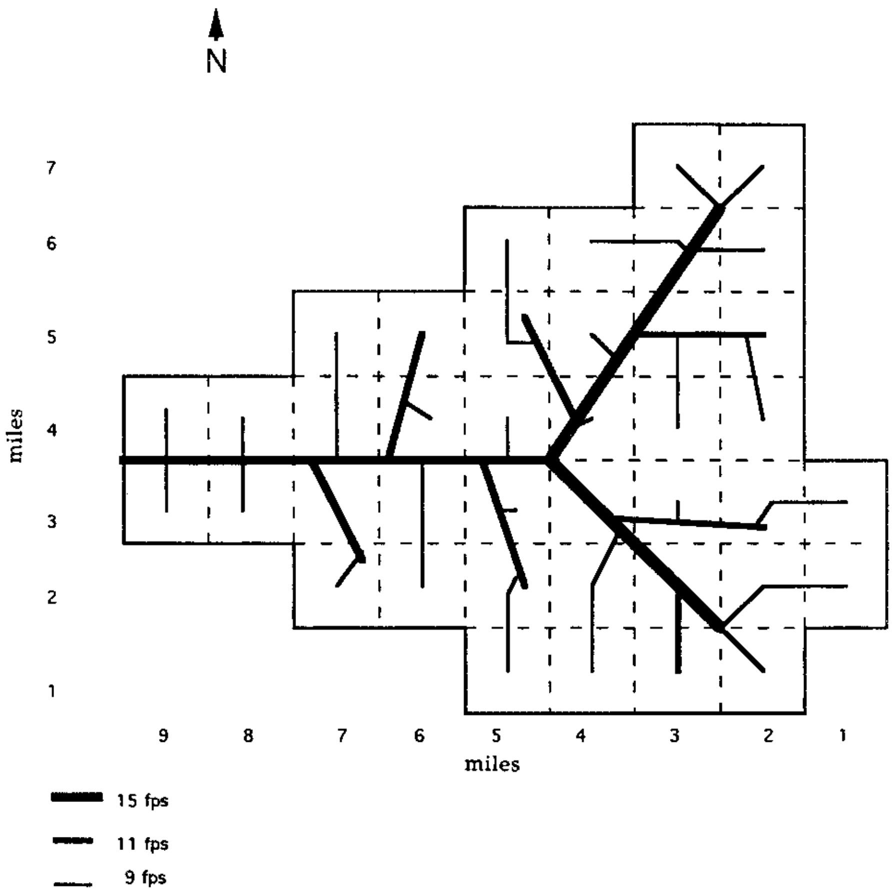

Fig. 1. Watershed.

Table 1
Watershed subarea time to stream gauge

Grid X	Y	Regional distance (15 fps)	Secondary distance (11 fps)	Other distance (9 fps)	Flow travel time (min)
1	2	8.0	0.0	1.7	64
1	3	6.0	1.5	1.6	63
2	1	8.0	0.0	0.7	54
2	2	8.0	0.0	0.7	54
2	3	6.0	1.5	0.6	53
2	4	6.6	1.7	1.1	63
2	5	6.6	1.7	0.0	52
2	6	8.2	0.0	0.8	56
2	7	8.8	0.0	0.7	58
3	1	7.3	1.0	0.0	51
3	2	7.3	0.0	0.0	43
3	3	6.0	0.8	0.3	45
3	4	6.6	0.7	1.0	54
3	5	6.6	0.7	0.0	44
3	6	8.0	0.0	0.3	50
3	7	8.8	0.0	0.7	58
4	1	6.5	0.0	1.5	53
4	2	6.5	0.0	0.5	43
4	3	5.8	0.0	0.0	34
4	4	5.8	0.0	0.3	37
4	5	6.7	0.0	0.5	44
4	6	8.0	0.0	1.3	60
5	1	4.1	1.5	1.3	49
5	2	4.1	1.5	0.3	39
5	3	4.1	0.5	0.2	30
5	4	4.5	0.0	0.5	31
5	5	5.6	1.0	0.5	46
	6	5.6	1.0	1.5	56
6	2	3.6	0.0	1.5	36
6	3	3.6	0.0	0.5	26
6	4	3.0	0.7	0.3	26
6	5	3.0	1.7	0.0	31
7	2	2.3	1.3	0.5	29
7	3	2.3	0.6	0.0	18
7	4	2.5	0.0	0.5	20
7	5	2.5	0.0	1.5	29
8	3	1.5	0.0	0.5	14
8	4	1.5	0.0	0.5	14
9	3	0.5	0.0	0.5	8
9	4	0.5	0.0	0.5	8

selected from storms 6–16, and a 100-yr-event storm is selected from storms 9–19. For a particular event class storm, its areal extent is selected randomly from the associated range.

5. Storm parameters

5.1. Duration

The duration, measured as the period of time from the moment the storm touches the edges of the watershed until it dissipates, is assumed to be uniformly distributed. Table 2 shows the distribution intervals for the storms of each frequency used in the model.

5.2. Intensity

The intensity of rainfall, $I(t)$, is assumed to be a triangular function as shown in Fig. 3. The time at which the storm reaches its peak intensity, T_p, is assumed to be related to the storm duration by the multiplication of duration with a random sample from a uniform distribution with range [0.2, 0.8], or U[0.2, 0.8], given by

$$T_p = \text{duration} * U[0.2, 0.8] \qquad (1)$$

By assuming that the peak 1-h time period of rainfall is symmetric about T_p (see Fig. 3), the peak intensity is found by integrating the intensity function over the peak 1-h time period and setting it equal to the 1-h intensity (see Table 2). So

$$I_p = I_h/(1-D/(8*T_p*(D-T_p))) \qquad (2)$$

where I_p is the peak intensity, D is the duration, I_h is the 1-h intensity, and T_p is the peak intensity time.

Once the duration, peak intensity and the peak intensity time are known, the intensity function is given by

$$I(t) = \begin{cases} (t/T_p) * I_p & \text{if } t < T_p \\ [(D-t)/(D-T_p)] * I_p & \text{if } t > T_p \end{cases} \qquad (3)$$

5.3. Velocity and movement

The northerly position of the storm is initially chosen and then held constant while the storm moves in the easterly direction (see Fig. 4). The initial position of the storm is found by allowing the vertical coordinate of the center of the storm to vary uniformly along the width of the watershed. Once the initial position of the storm is established, the storm moves easterly 1 mile every $1/v$ hours, where the velocity, v, is assumed to be uniformly distributed between 5 and 10 miles per hour. The initial movement of the storm occurs, however, at $1/(2v)$ hours. This half-time span is used to approximate the continuous movement of a storm by the model.

6. Watershed parameters

6.1. Loss function

Two types of loss function are used by the model. One of the loss functions is the Horton loss function (Hromadka *et al.*, 1987).

$$f(t) = f_c + (f_o + f_c) * e^{-bt} \qquad (4)$$

where f_o is the initial loss rate, f_c is the ultimate loss rate, and b is a calibration constant. The ultimate loss

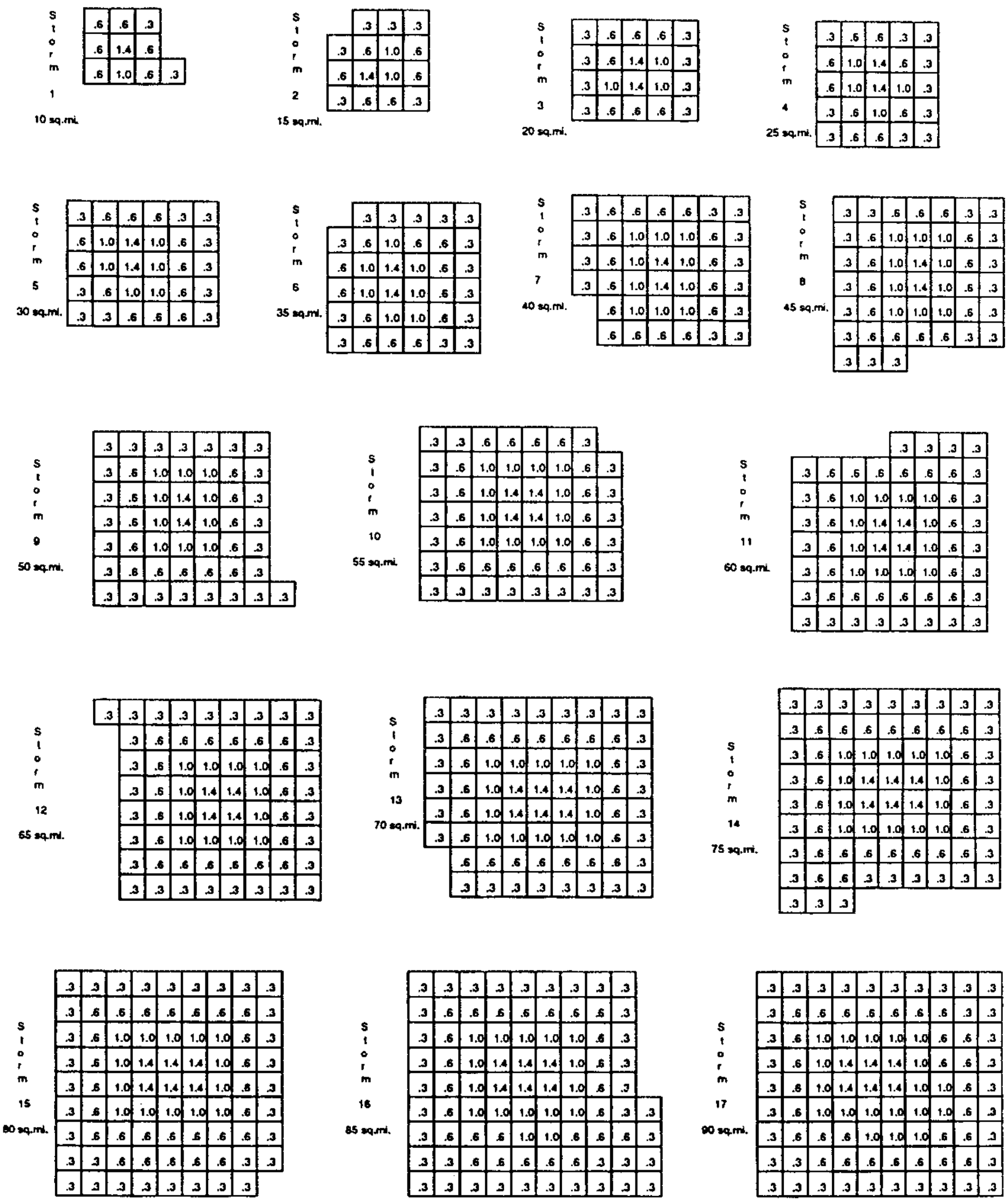

Fig. 2. Storm patterns (values inside squares are relative proportion of rainfall intensity).

rate, f_c, is found by using a triangular distribution with a minimum value of 0.2, a maximum value of 0.6, and a mean of 0.3 inches. Once f_c is found, the initial loss rate, f_o, is found by

$$f_o = k * f_c \qquad (5)$$

where k is uniformly distributed between 2 and 5.

In order to find b, the calibration constant, we assume that the time, T, such that

$$f_o - f(T) = 0.9 * (f_o - f_c) \qquad (6)$$

is uniformly distributed between one-third and two thirds of an hour. Hence, b is given by

$$b = -\ln(0.1)/T \qquad (7)$$

Table 2
Storm distributions

·equency (years)	Probability[a]	Area (sq. miles)	Duration (h)	1-h intensity[c] (depth inches)
2	50%	U [10, 50][b]	U [3, 5]	0.60
10	90%	U [20, 65][b]	U [3.4, 6.8]	0.75
25	96%	U [30, 80][b]	U [3.6, 7.2]	1.00
100	99%	U [50,100][b]	U [4, 8]	1.50

[a]Represents the probability of this frequency or smaller storm occurring within a year.
[b]U [*, **] represents uniform distribution with a Lower Board of * and an Upper Board **.
[c]1-h intensity, the amount of rainfall that falls during the peak 1-h period of the storm.

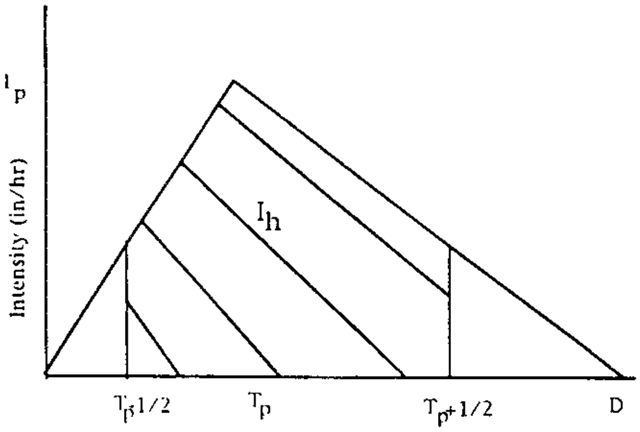

Fig. 3. Storm intensity function.

The other function used by the model is the phi index loss function (Hromadka *et al.*, 1987). Unlike the Horton loss function, which is different for each square mile of the watershed, the phi index loss function uses the same phi value for every section.

6.2. *Initial abstraction (IA)*

Each square mile of the watershed has a different initial abstraction, which is assumed, for parameter distribution purposes, to be uniformly distributed between 0.2 and 0.8 inches. Once chosen, the initial abstraction remains constant for every storm.

6.3. *Antecedent moisture condition (AMC)*

Like IA, every square mile of the watershed has a different antecedent moisture condition, AMC, which is assumed to be uniformly distributed between 0 and 1 inch. A new value for the AMC is selected for each storm.

6.4. *Time of concentration*

The time of concentration, T_c, is assumed to be a linear function, in the algebraic sense, of the initial abstractions, IA. For each square mile of the watershed we have

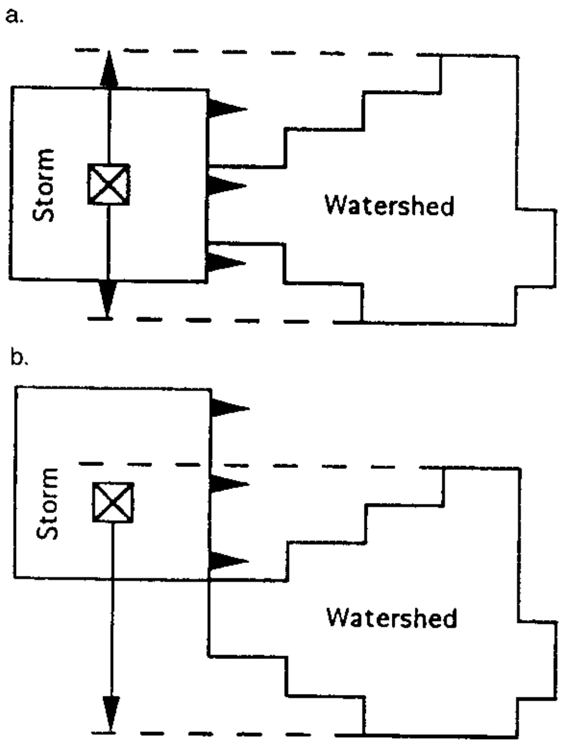

Fig. 4. Storm movement.

$$T_c = 5/9 * (\text{IA} + 1)$$

since the minimum and maximum values of T_c are assumed to be two-thirds of an hour and 1 h, respectively.

7. Test cases

The watershed rainfall–runoff model can now be used to evaluate performance sensitivity to each of the parameter types described in the previous section. For each test case, the program runs 200 different storms. In each case one parameter is changed from the base case as follows.

Test 1: The initial abstraction for every section of the watershed is set at 0.5 inches.

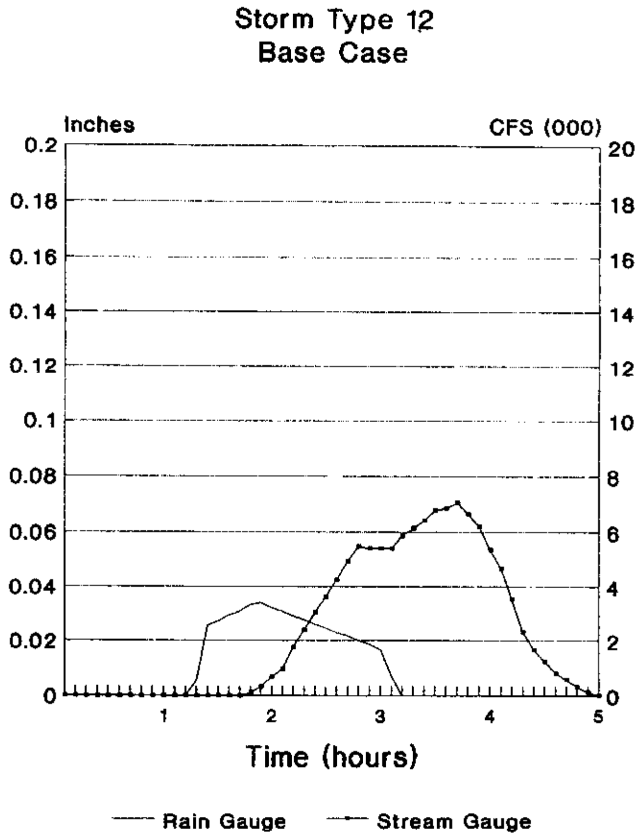

Fig. 5. (a) Storm type 12 — base case.

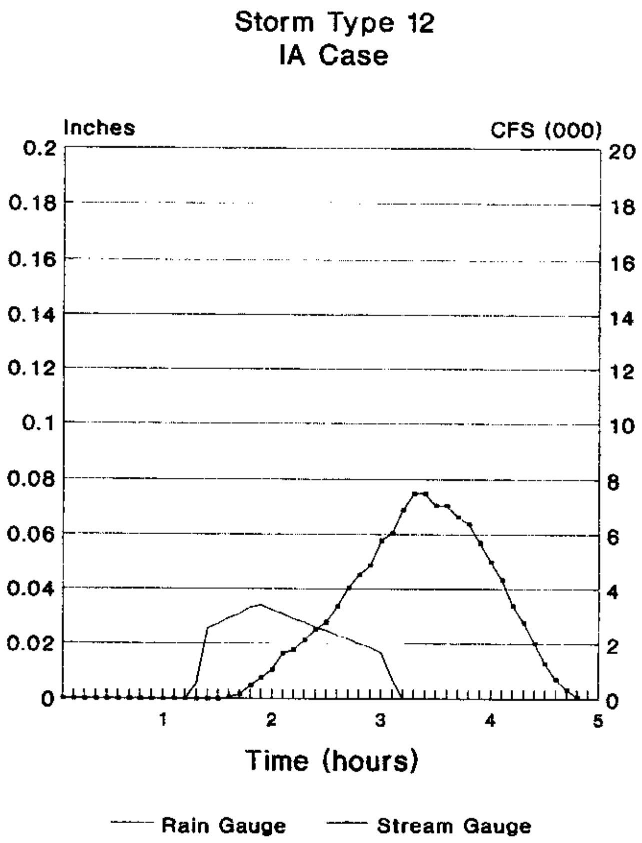

Fig. 5. (b) Storm type 12 — 1A case.

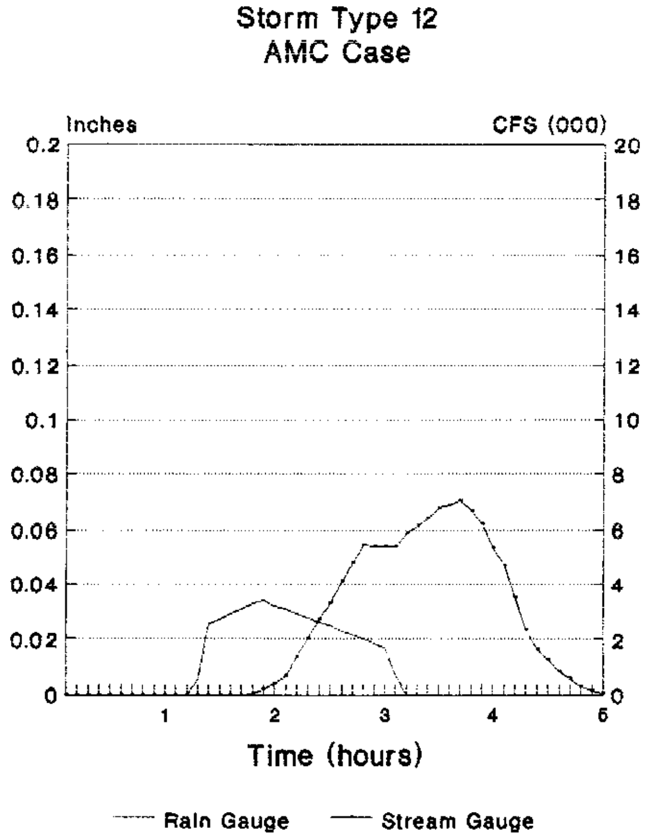

Fig. 5. (c) Storm type 12 — AMC case.

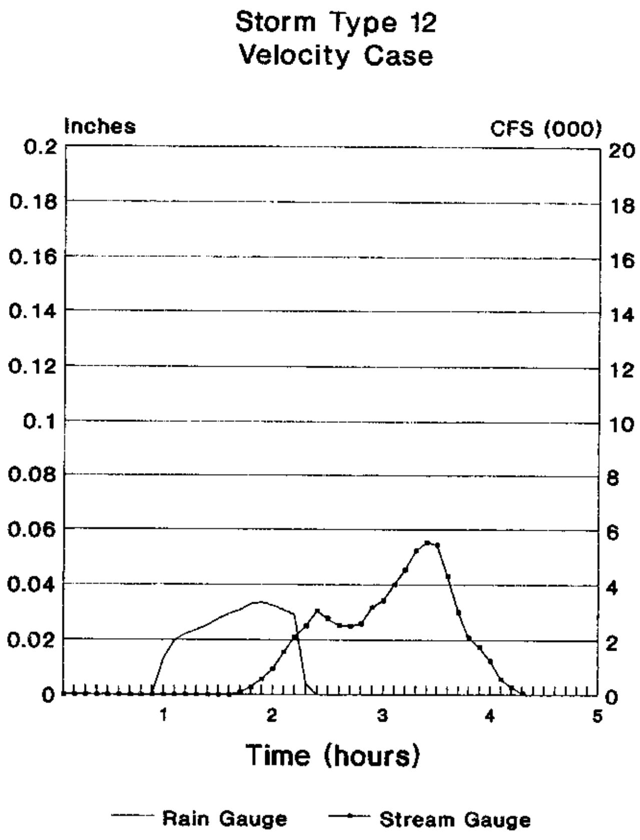

Fig. 5. (d) Storm type 12 — velocity case.

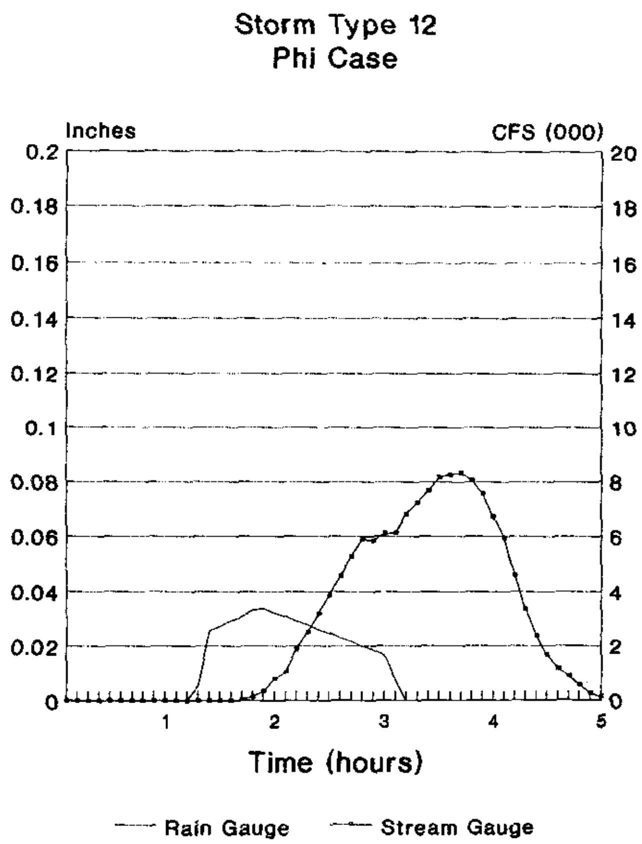

Fig. 5. (e) Storm type 12 — phi index case.

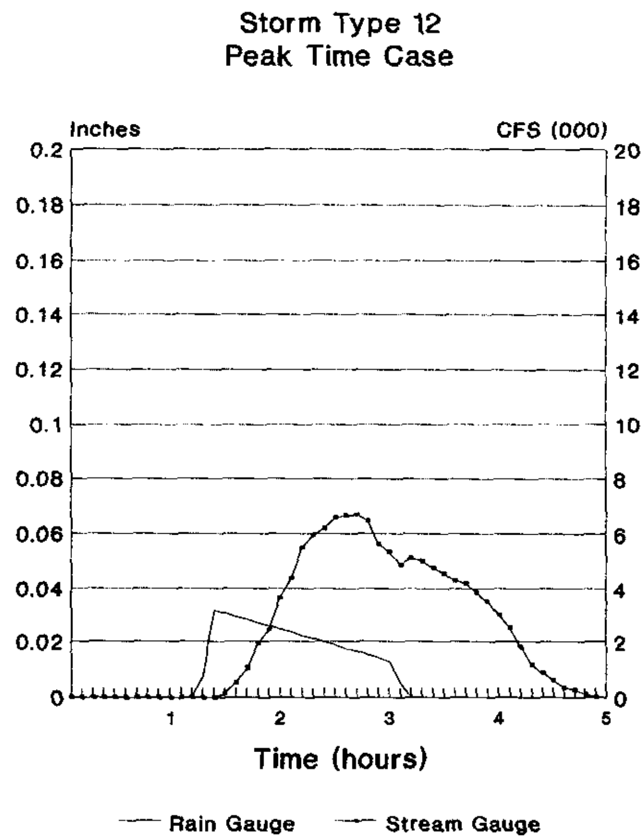

Fig. 5. (f) Storm type 12 — peak time case.

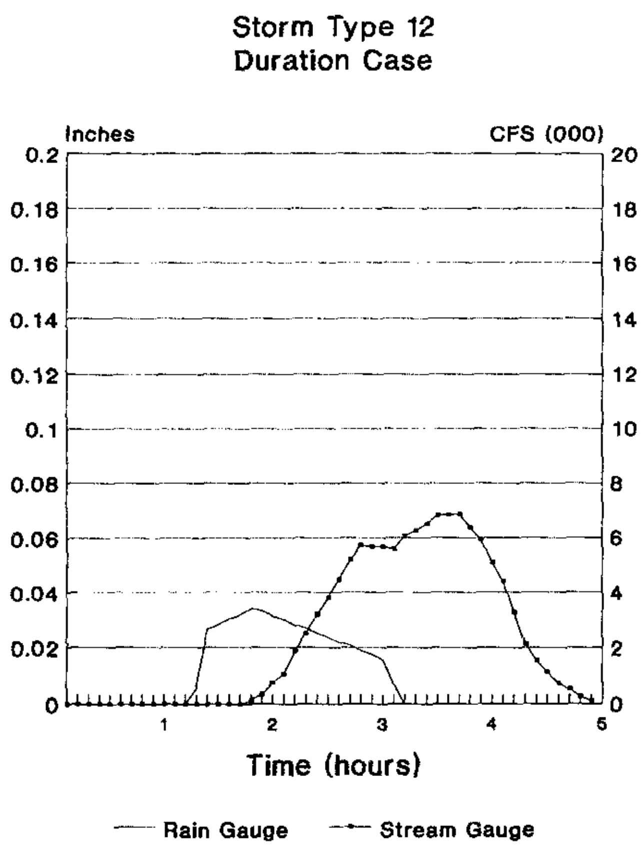

Fig. 5. (g) Storm type 12 — duration case.

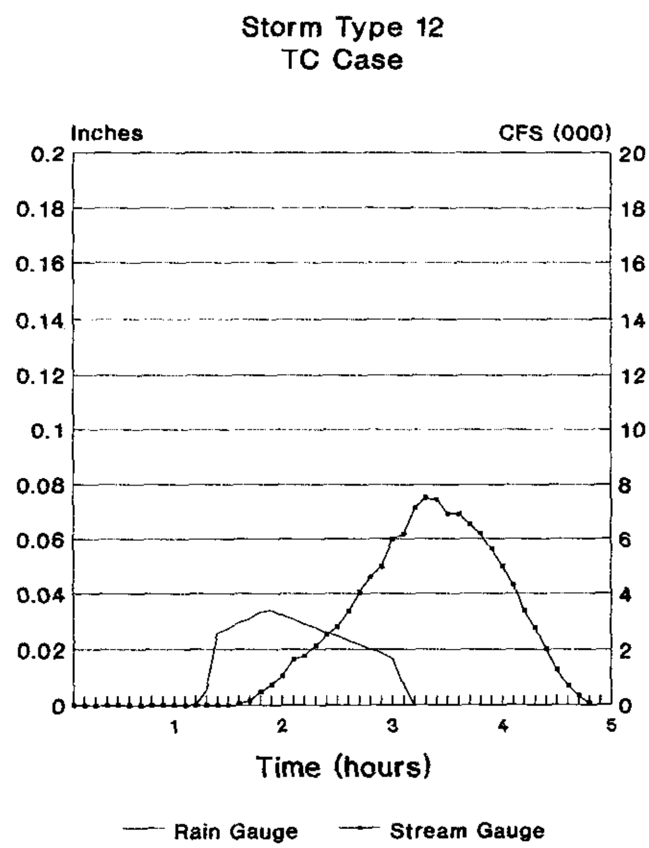

Fig. 5. (h) Storm type 12 — TC case.

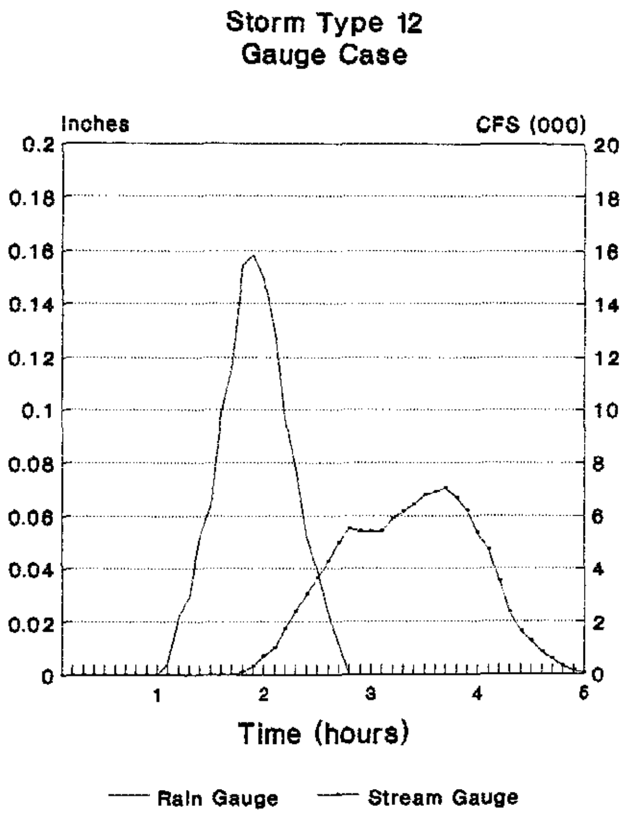

Fig. 5. (i) Storm type 12 – gauge case.

Test 2: The antecedent moisture condition is set to 0 for every section of the watershed.

Test 3: The storm velocity is held at 7 miles per hour for every storm generated.

Test 4: The phi index loss function is used with the phi value set at 0.3 inches for every section of the watershed.

Test 5: The peak time of rainfall for every storm is set at 0.5 h.

Test 6: The duration of the storm is fixed at 4 h for each storm.

Test 7: The time of concentration for every sectior of the watershed is set to 0.83 h.

Test 8: The position of the rain gauge is relocated to the centroid of the watershed.

Figure 5 shows graphed results from a storm type 12 event for each of the test cases. The graphs are time versus inches of rain measured by the rain gauge and the amount of runoff measured at the stream gauge in cubic feet per second.

8. Conclusions

A computer program is described that generates synthetic rainfall and runoff data. The program incorporates a variety of parameters for both storm development and runoff response. These synthetic data are useful in subsequent evaluation of calibration issues regarding sensitivity to specific parameters or modeling simplifications.

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