IMPACT OF PARAMETER UNCERTAINTY IN HYDROLOGIC MODELING ON THE DESIGN OF SMALL FLOOD WATER RETARDING STRUCTURES

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PREFACE

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CHAPTER I

INTRODUCTION

For reasons of water supply, crop production, communication, and industrial purposes, man has always looked for plains located on river banks. As a consequence his lifestyle has always been susceptible to flood damage. Nowadays human being's need for food, water, and arable lands is increasing and so is his awareness of hydrologic events whose magnitude and frequency of occurrence are of every day importance all over the world. Therefore divers techniques and hydrologic models dealing with frequency analysis and flood routing have been developed. Most of these hydrologic models require input parameters that are defined in terms of watershed characteristics and rainfall data. These models simulate rainfall excess volumes and their time distribution which are of major importance for hydrologic design and planning such as dam construction, mineral resources utilization, and construction of large scale facilities.

Problem Statement

In hydrologic models, input parameters are represented by average values. However, there is a great deal of uncertainty as to the accuracy of the average set of parameters used. Because of the randomness of hydrologic events, one would naturally think about dealing with the random variability of the various model parameters so that their uncertain behavior may be characterized through probability distributions. Primary among these random variations are the precipitation and watershed characteristics as well as the soil moisture conditions.

In this study the Soil Conservation Service (SCS) hydrologic model is used, however, the techniques used are not limited to a particular model nor to any particular probability distribution. The Soil Conservation Service model (1972) is one of the widely used models in water resources planning and design. This model uses an important parameter called curve number (CN) which is a function of land cover, soil type, and antecedent soil moisture conditions. The SCS method is very sensitive to the CN (Hawkins, 1975), therefore, it is important to use estimates of the CN that accurately reflect the runoff potential of a watershed.

The SCS model estimates runoff volume as

$$Q = \frac{(R - 0.2\,S)^2}{(R + 0.8\,S)} \qquad R >= 0.2\,S$$

where Q is the runoff volume, R is the rainfall depth and S is a retention parameter. The factors 0.2 and 0.8 result from assumptions relating initial abstractions to potential infiltration used to develop the equation. The parameter S is stated as

$$S = \frac{1000}{CN} - 10$$

where CN is the runoff curve number.

Curve numbers for watershed complexes are generally found in tabular form. CN values in these tables represent average values and can not account for natural variability that exists from storm to storm. Thus, for any given storm, the actual value of S that corresponds to the observed rainfall and runoff may vary considerably from the value that might be computed from tables. For a particular watershed, S behaves as a random variable and in fact has been described using the lognormal distribution (Hjelemfelt et al., 1981; Haan and Schulze, 1987; and others). Rainfall is also a random variable generally described by the extreme value type I distribution for extreme rainfalls (Hershfield, 1961; Haan and Wilson, 1986; Haan and Edwards, 1987). Thus Q is the result of two random variables, R and S, making it necessary to consider the joint probability behavior of R and S. According to the SCS equation, the relation between Q and R and S is not linear so that the expected value of Q is not necessarily equal to Q calculated based on the expected values of R and S. What is more, the probabilistic behavior of Q depends on the probabilistic behavior of R and S (Haan and Edwards, 1987). To calculate Q for some return period T, the joint probability behavior of R and S should be considered.

Objectives

The purpose of this study was to investigate the impact of the probabilistic behavior of rainfall and the SCS model parameter, S, on the design of certain aspects of small flood water retarding structures. Such designs are usually based on flows of some specified return period. The flows are commonly estimated by assuming that the return period of a flow is equal to the return period of rainfall producing that flow unaware of the prevailing watershed conditions which are, certainly, variable from storm to storm.

Scope of Study

A hypothetical watershed was defined and a conservation detention structure was designed. The goal was to determine the flood storage height, f, needed for detention to control runoff due to a 10-year return period rainfall. The SCS runoff model with average-valued parameters along with a reservoir routing procedure based on the continuity equation was used and f was determined. A model that considered the probabilistic behavior of the SCS runoff equation parameters was developed. The model proceeded by:

1) Generating the parameters, S and R, from the lognormal and the extreme value type I probability distributions, respectively.

runoff model and reservoir routing calculations to determine the corresponding value of flood storage height.

The model resulted in a sample of N flood storage heights. A frequency analysis was conducted on these values and the value of flood storage height equaled or exceeded by 10 % of the sample observations was determined and compared with f. According to this comparison, a modified average value of the parameter S, S*, was determined so that f calculated using the 10-year rainfall and S* would equal the 10 % value of f determined from the simulations.

3) The procedure was generalized over a range of watershed and reservoir characteristics and a calibration scheme was proposed.

CHAPTER II

LITERATURE REVIEW

Introduction

Surface runoff or overland flow are general terms for surface water movement. Estimates of storm runoff volumes and peak rates of discharge are of special importance to hydrologists. Often stream flow data are not available for small watersheds and runoff must be estimated. Hence, several methods for estimating surface runoff from ungaged watersheds have been developed. Ideally these methods should be both simple and accurate. The accuracy with which surface runoff is modeled has been the subject of several recent investigations (Singh and Buapeng, 1977; Fouroud and Brougton, 1981; Kumar and Jain, 1982).

Rainfall-Runoff Modeling

Most of the hydrologic models developed to simulate runoff on ungaged watersheds converge to a unique definition of runoff volumes, that is rainfall minus losses. Losses or rainfall abstractions include losses due to interception, evaporation, infiltration, surface storage, and surface detention (Barfield, Warner, and Haan, 1981). The estimation of rainfall abstraction rates is subject to different approaches and methods expressed in different runoff models. Inputs of these models vary in the type of variable input and in the time scale of the required data. The difference in inputs can be explained partly by the original purpose of the model, the location or region for which it was developed and the ease of estimating input parameters. Presented below is a brief citation of some of the commonly used hydrologic models. Emphasis is placed on runoff estimation sections of the models.

<u>Stanford Model</u>

The Stanford watershed simulation model was developed by Crawford and Linsley (1966) at a time when the computer revolution increased the interest in digital simulation studies. A relatively complex calculation is involved to calculate runoff from rainfall as

$$q = \frac{64{,}200\ S^{1/2}}{n\ L} (D/L)^{5/3} (1 + 0.6(D/D_e)^3)^{5/3}$$

where q is the overland flow discharge, S and L are the slope and the length of basin surface respectively, n is Manning's coefficient, D_e is the surface detention depth at equilibrium, and D is the current detention storage depth

Output from the model consists of monthly summaries of soil moisture conditions, interflow discharge, actual evapotranspiration, complete hydrographs for all storms, and mean daily flows for each flow point. The model is used throughout the United States with many modified versions available. Modifications of the model have been made by James (1970), Shanholtz et al. (1972), and others. The optimization routines were modified by Liou (1970), and Ross (1970).

<u>USDA Hydrograph Loboratory Model</u>

This model was developed by Holton and Lopez (1971) to study hydrologic processes on small watersheds. A revised version of the model (Holton et al., 1975) requires as input data a continuous record of weighted rainfall, potential evapotranspiration based on weekly pan evaporation, weekly mean air temperature, and watershed characteristics such as basin zones, soils, type of crops and tillage procedure. The model is heavily dependent on infiltration and storage capacities. The Holton model for infiltration is

$$f = a\ GI\ S_a^{1.4} + f_c$$

where f is the infiltration rate, f_c is the final infiltration rate, S_a is the available soil water storage, a is the maximum infiltration capacity, and GI is the growth crop index in percent of maturity. GI and a are available in graphical and tabular forms, respectively.

Runoff rates are determined by the equations

$$P_e - Q_o = t\ D$$

and

$$q_o = a\ D^n$$

where P_e is the value of rainfall excess per unit time, Q_o is the value of outflow per unit time, q_o is the overland flow, D is the average depth of flow in inches, t is the time in hours, and a and n are coefficients.

The output of the model consists of accumulated rainfall, surface and subsurface runoff, rates of outflow in inches per hour, and stream flow in cubic feet per second.

Kentucky Model

This model was developed by Haan (1975) to simulate monthly runoff and water yield from watersheds in Kentucky. The method of determining runoff is related to infiltration theory. When precipitation, P, is greater than the maximum infiltration rate, f_{max}, the infiltration, f, is equal to f_{max}. Accordingly , f is set equal to P when the precipitation is less than the maximum potential infiltration, and equal to zero when the soil is saturated. Therefore, the model estimates runoff as

$$V_s = (P - f)\ t \qquad P > f$$

and

$$V_s = 0 \qquad P <= f$$

where V_s is the volume of surface runoff in inches and t is the time increment. The model estimates losses due to evapotranspiration by use of the Thornthwaite (1948) method. Water that does not appear as streamflow or evapotranspiration is assigned to deep seepage and later a portion of it may reappear as base flow.

Four parameters of this model must be estimated. The best set is obtained by minimizing the sum of squares of deviation between simulated and observed flows. The model has been used to simulate flows and calculate water yields on several watersheds in different states.

SSARR Model

The Streamflow Simulation and Reservoir Regulation (SSARR) model was developed by the U. S. Corps of Engineers (Rockwood, 1958, 1964). The model was developed for use in simulating small to large watershed flows. It consists of a watershed model, a river system model, and a reservoir regulation model (U. S. Army Corps of Engineers, 1975). The model uses an antecedent moisture index for surface runoff determination given as

$$Q = ROP * P_w$$

where Q is the generated runoff in inches, ROP is the runoff percent for soil moisture, and P_w is the weighted precipitation. More details on the different tasks of the model, the operating procedure, and the input-output components of the model may be found in Haan, Johnson, and Brakensiek (1982).

The SCS Model

Originally the SCS model was developed for predicting total runoff volumes from watersheds where only total precipitation data were available. At present it is the procedure most frequently used to estimate direct runoff from ungaged watersheds. The most important parameter in the model is the curve number, CN, whose value integrates the watershed characteristics and the hydrologic conditions. The Soil Conservation Service defined three different antecedent soil moisture conditions (AMC I, AMC II, and AMC III), to adjust the curve number to the antecedent conditions of the watershed. The antecedent moisture condition II corresponds to average flood conditions, the antecedent moisture condition I corresponds to conditions drier than the average, and antecedent moisture condition III corresponds to conditions wetter than the average. These definitions loose some of their significance when estimates of design flows that may occur in the future are desired, because the actual future antecedent moisture condition will be practically unknown.

Several investigators worried about the reliability of the model regarding the spectrum of hydrologic problems it is currently applied to. Rallison and Miller (1981), reported that the curve number procedure has increasingly been applied to hydrologic problems it was not originally intended to solve.

Aron et al. (1977), tested the SCS model against experimental data and found good agreement for uniform rainfalls. They reported that a initial abstraction, I_a, equal to 0.2 S performs well for large storms, but underestimates runoff for small or medium storms. They concluded by suggesting an I_a of 0.1 S for small and medium storms, but they neither redefined the curve numbers to adjust to their new formulation of the total abstraction nor quantitatively distinguished between small, medium, and large storms.

Accuracy of CN Estimates

The accuracy of CN values has been studied by many investigators (Ragan and Jackson, 1980; Haan and Wilson, 1986; and others). Smith (1978), and Hawkins (1978b), found that infiltration relationships, when calculated by the curve number procedure vary with storm intensity.

Hawkins (1975), studied the effect of inaccurate CN estimates on runoff. He stated that an accurate estimate of curve number was the weak input link for the method. Hawkins presented an error analysis of the SCS method by performing the sensitivity analysis of estimated runoff volumes with respect to errors in precipitation and curve number. He assumed a 10 % error in either of these quantities and used a wide range of precipitation and curve number values. The resulting errors in runoff estimates were determined. Hawkins concluded that, for a considerable range of precipitation, an accurate curve number is more important to the estimation of runoff volume than is an accurate estimation of basin rainfall.

Bondelid, McCuen, and Jackson (1982) proposed another approach to evaluate the sensitivity of the SCS model to errors in CN estimates. Based on the SCS method presented in TR-55 (Soil Conservation Service, 1975), they derived the equations expressing the sensitivities of runoff and peak rate of discharge to changes in CN. By analyzing these equations, they concluded that runoff estimates are sensitive to the accuracy of CN estimates and that the effects of variation in CN decreases as rainfall depth increases.

Kumar and Jain (1982), used the SCS equation to show that, for a given soil, the infiltration rate is a function of rainfall intensity, therefore, the minimum infiltration rate required by the SCS method may not be reached for low intensities. Further, they proposed a calibration of the SCS model after comparison of the antecedent moisture conditions, the minimum infiltration rates, and the curve numbers determined using, 1) The SCS standard guidelines, 2) a least square analysis, and 3) a trial and error procedure. They concluded that the index of estimating antecedent moisture conditions and their corresponding number of divisions should be improved.

Bales and Betson (1981), analyzed 585 storm events from 36 watersheds. They adopted the SCS procedure and determined 1) curve numbers from the SCS approach assuming AMC II conditions and modifying them for the AMC III conditions and 2) optimized curve numbers and median observed curve numbers from observed rainfall-runoff data. They found that the AMC III curve numbers agreed much more closely with the optimized and median curve numbers than the AMC II curve numbers, but both AMC conditions underpredicted runoff volumes.

Hope and Schulze (1981) evoked the problem of curve number estimation accuracy by describing and testing an alternative procedure proposed by Hawkins (1978a,b). The procedure aimed to eliminate the weakness of the standard curve number approach related to the definitions of the antecedent moisture conditions. Hope and Schulze concluded that the Hawkins procedure of the CN adjustment produced more accurate storm flow estimates than the standard SCS procedure. They proposed testing the procedure with different watershed data.

Randomness of the SCS Model Parameters

Hjelmfelt, Kramer, and Burwell (1981), proposed a method to interpret curve numbers determined from observed rainfall and runoff data. The observed curve numbers were transformed to observed retention factors which were treated as random variables. Values of S were assumed lognormally distributed with expected value corresponding to the SCS antecedent moisture condition AMC II. The study used maximum annual event runoff and associated rainfall volumes from twelve fields from Missouri, Illinois, and North Carolina. They concluded that extreme values of S at 10 % and 90 % lead to CN values comparable to SCS conditions AMC I and AMC III respectively. This study showed that the CN methodology could be used as an effective transformation from rainfall to runoff frequency distributions.

Haan and Wilson (1986), presented a procedure that consisted of combining the joint probabilistic behavior of rainfall and antecedent soil water conditions to estimate the magnitude of flow events for given return periods. They used the extreme value type I distribution to determine rainfall probabilities and the lognormal probability distribution to represent the SCS retention parameter variability. They derived a univariate probability density function of runoff events. They found that, for equal return periods, the probabilistic approach resulted in flow magnitude estimates greater than those estimates obtained by the standard SCS procedure. They concluded that flow volumes estimated by the probabilistic approach made a reasonable approximation to the observed runoff data which they used in their study.

Haan and Schulze (1987), examined the relationship between the return period of a flow volume and the return period of the rainfall producing that flow. In this study the rainfall of a given return period was assumed constant and the SCS retention parameter, S, was taken as a random variable characterized by the lognormal probability distribution. Transformation theory and the SCS equation were used to derive a probability density function of runoff volumes from that of the retention parameter. Haan and Schulze expressed the need to treat hydrologic model parameters as random variables making it possible to characterize their uncertain behavior through probability distributions.

Haan and Edwards (1987) extended the work of Haan and Schulze (1986) using a methodology similar to that used by Haan and Wilson (1986). They estimated runoff return period through a procedure that combined rainfall and antecedent soil condition probabilities. They showed the possibility of developing flow frequency curves by the use of existing estimation techniques and consideration of the joint probabilistic behavior of rainfall and antecedent conditions.

The last three studies agree that the recurrence interval of a flow is not necessarily equal to that of the rainfall producing that flow.

CHAPTER III

DATA AND MODEL SITE DEVELOPMENT

Introduction

This chapter is mainly concerned with describing a model of a small water retarding structure. Considered briefly are the watershed characteristics and the design criteria of the structure such as shape, slope, capacity, and the hydraulic and construction features of the spillway system.

Average values of retention parameter, S, and rainfall intensity, R, are used through the SCS model to route an inflow hydrograph for the considered watershed and rainfall data. This hydrograph is routed through the defined reservoir and the flood storage height, f, is determined. Computations are done using a computer package called SWAMP that integrates both the SCS model and the reservoir routing technique (Haan, 1987).

Watershed Characteristics

It might be more realistic to work with a real watershed, but, since neither a real structure design, nor actual flow rates are required to meet the objectives of this study, there is no practical necessity to use a site defined specific watershed. Therefore, a hypothetical watershed with reasonable characteristics reflecting similarities to real watersheds was used. A watershed with an area of 200 acres, a rectangular shape as shown in figure 1, and a slope of 6% was arbitrarily chosen. The maximum flow length is approximated as the diagonal of the watershed and is determined by

$$A = (2w)(1w) = 2w^2$$

$$L^2 = (2w)^2 + (1w)^2$$

$$L^2 = 5w^2$$

then

$$L = \sqrt{(5/2) \times \text{Area} \times 43560}$$

where A is the watershed area in acres and L is the maximum flow length in feet. With A equal to 200 acres, L is found to be 4667 feet.

Retention Parameter S

In reservoir design, a value of S corresponding to average watershed conditions is generally used. Since one of the purposes of this study was to evaluate the impact of variability in S on design, the average value that was selected was the mean of the lognormal distribution. Haan and Edwards (1987) have previously shown the lognormal distribution to approximate the S distribution. Further relying on the work of Haan and Edwards, the mean and standard deviation of observed S data for a Stillwater, OK, gaging station was used. They found the mean, S_m, and standard deviation, S_s, of S to be

S_m = 5 inches

S_s = 4 inches

The computer program used to compute the inflow hydrograph requires a value of the watershed curve number, CN, as the watershed response input parameter instead of the retention parameter S. The S value is transformed to a curve number parameter through the SCS equation

$$CN = 1000 / (S + 10)$$

which estimates the average CN as 67.

Rainfall Data

A flood control structure is assumed to be designed to control a 10-year, 24-hour rainfall. Rainfall data for the United States for different return periods and durations are available in Atlases. TP40 (Hershfield, 1961) shows for Stillwater a 10-year, 24-hour rainfall of 6 inches.

Inflow Hydrograph

The inflow hydrograph is determined using the watershed characteristics and the rainfall data defined above.

Computations are done following the SCS procedure. An example computer output composed of the calculated watershed hydrologic properties and the inflow hydrograph data is shown in Tables 1 and 2.

Structure Design

Many flood control structures are built every year in rural areas for the purpose of reducing flood flows from watersheds. These structures are designed for conservation and land protection such as reducing soil erosion and restoring the ground water level. They provide a source of water supply for crops, livestock, and recreational purposes. Generally these control and conservation structures are earth embankments in the form of dikes, levees, detention dams or reservoirs. In practical cases the effectiveness and safety of these structures require that they should be accurately designed by integrating the principals of soil physics and soil mechanics with construction principles. The bigger the structure, the more thorough the precautions for handling overflow should be. A typical detention structure is shown in figure 2.

The intent of this study is to make some preliminary decisions on the shape, capacity, and design features of the spillway system for a flood control structure planned for the 200 acre watershed defined above. To evaluate a range of watershed and basin characteristics, many combinations of watershed characteristics and detention features

TABLE 1

WATERSHED HYDROLOGIC
PROPERTIES

Watershed area = 200 acres
Land slope = 6 %
Maximum flow length = 4667 feet
Curve number for flow time calculation = 67

Based on these characteristics, the following properties relative to a unit hydrograph are determined:

Time increment = 15 minutes
Lag time = 39 minutes
Time to peak = 45 minutes
Time of concentration = 64 minutes
Peak flow = 202 cfs

SCS Curvilinear Unit Hydrograph

Rainfall has been computed based on an approximation to the SCS type II rainfall curve

The 24-hour rainfall is 6 inches

Rainfall starting time = 9.5
Rainfall stopping time = 24

Abstractions from rainfall are based on the SCS curve number technique with a CN of 67

TABLE 2

INFLOW HYDROGRAPH

Time	Rain	Rain Excess	UH	RO Hydro
9.50	0.97	0.00	0.00	0.00
9.75	1.02	0.00	39.92	0.00
10.00	1.08	0.00	153.87	0.01
10.25	1.14	0.00	201.67	0.10
10.50	1.21	0.01	169.94	0.40
10.75	1.29	0.01	112.42	1.03
11.00	1.39	0.01	63.81	2.04
11.25	1.51	0.02	32.59	3.53
11.50	1.66	0.03	15.41	5.69
11.75	1.90	0.06	6.86	8.98
12.00	3.00	0.44	2.92	14.74
12.25	4.10	0.62	1.20	39.00
12.50	4.34	0.15	0.00	113.90
12.75	4.49	0.10	0.00	206.46
13.00	4.61	0.08	0.00	237.54
13.25	4.71	0.06	0.00	209.87
13.50	4.79	0.06	0.00	161.39
13.75	4.86	0.05	0.00	117.24
14.00	4.92	0.04	0.00	85.21
14.25	4.98	0.04	0.00	64.26
14.50	5.03	0.04	0.00	51.03
14.75	5.08	0.03	0.00	42.60
15.00	5.13	0.03	0.00	36.82
15.25	5.17	0.03	0.00	32.73
15.50	5.21	0.03	0.00	29.96
15.75	5.25	0.03	0.00	27.74
16.00	5.29	0.03	0.00	25.90
16.25	5.32	0.02	0.00	24.35
16.50	5.35	0.02	0.00	23.00
16.75	5.39	0.02	0.00	21.83
17.00	5.42	0.02	0.00	20.80
17.25	5.45	0.02	0.00	19.87
17.50	5.47	0.02	0.00	19.05
17.75	5.50	0.02	0.00	18.30
18.00	5.53	0.02	0.00	17.62
18.25	5.55	0.02	0.00	17.00
18.50	5.58	0.02	0.00	16.43
18.75	5.60	0.02	0.00	15.90
19.00	5.63	0.02	0.00	15.41
19.25	5.65	0.02	0.00	14.96
19.50	5.67	0.02	0.00	14.54
19.75	5.69	0.02	0.00	14.15
20.00	5.71	0.02	0.00	13.78
20.25	5.74	0.02	0.00	13.43
20.50	5.76	0.01	0.00	13.11
20.75	5.78	0.01	0.00	12.80

TABLE 2 (Continued)

Time	Rain	Rain Excess	UH	RO Hydro
21.00	5.79	0.01	0.00	12.51
21.25	5.81	0.01	0.00	12.23
21.50	5.83	0.01	0.00	11.97
21.75	5.85	0.01	0.00	11.72
22.00	5.87	0.01	0.00	11.49
22.25	5.89	0.01	0.00	11.26
22.50	5.90	0.01	0.00	11.05
22.75	5.92	0.01	0.00	10.85
23.00	5.94	0.01	0.00	10.65
23.25	5.95	0.01	0.00	10.46
23.50	5.97	0.01	0.00	10.28
23.75	5.98	0.01	0.00	10.11
24.00	0.00	0.00	0.00	9.95
24.25	0.00	0.00	0.00	9.32
24.50	0.00	0.00	0.00	7.37
24.75	0.00	0.00	0.00	4.90
25.00	0.00	0.00	0.00	2.84
25.25	0.00	0.00	0.00	1.48
25.50	0.00	0.00	0.00	0.71
25.75	0.00	0.00	0.00	0.32
26.00	0.00	0.00	0.00	0.13
26.25	0.00	0.00	0.00	0.05
26.50	0.00	0.00	0.00	0.01
26.75	0.00	0.00	0.00	0.00
Volume (in)	5.02	2.52	0.99	2.50

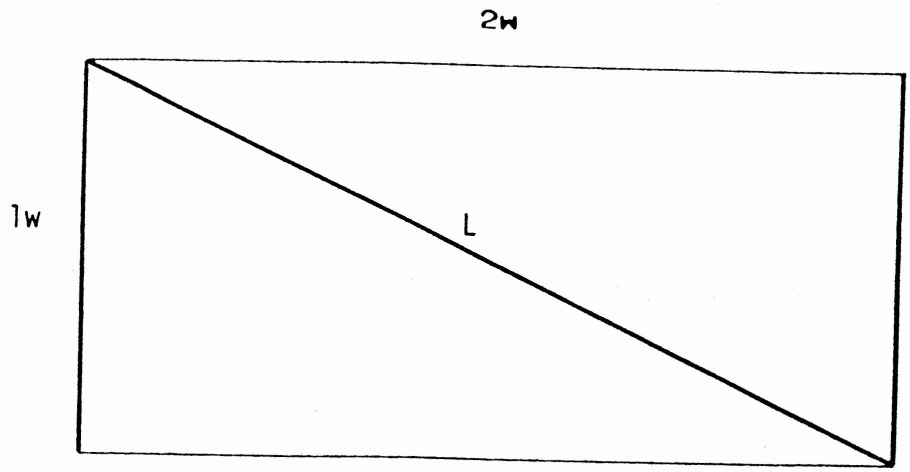

Figure 1. Hypothetical Watershed

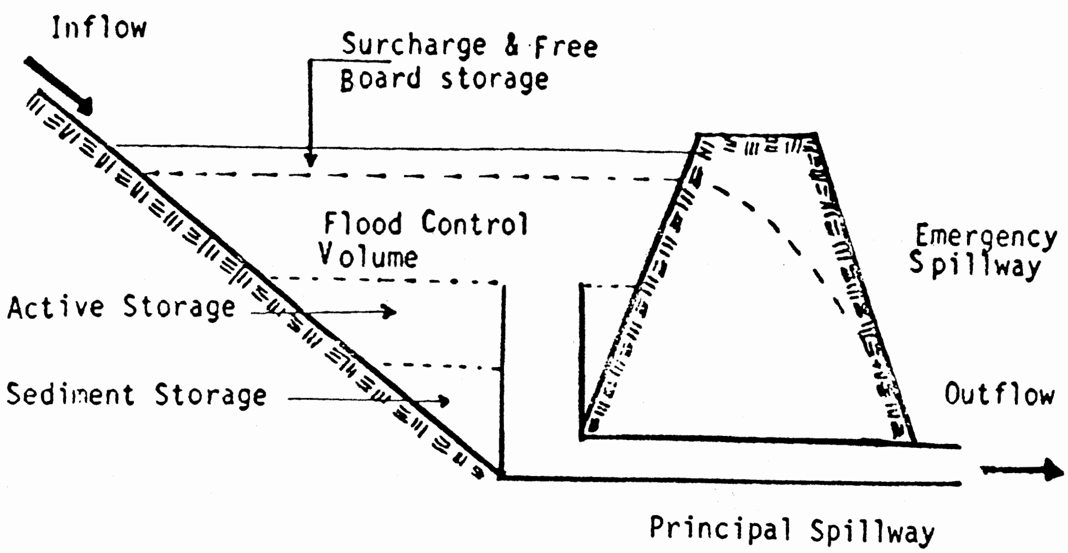

Figure 2. Schematic of a Small Flood Water Retarding Structure

were used.

Shape and Available Storage

Since the primary function of a reservoir is to provide storage, their most important physical characteristic is storage capacity. The capacity of a reservoir on a natural site is generally determined from topographic surveys. However the capacity of a reservoir of regular shape may be computed by the formulas for the volumes of solids. The reservoir to be used in this study is of triangular shape with a lateral side slope Z1 and an upstream slope Z2. A schematic drawing of the reservoir is shown in figure 3.

To determine the relation between stage and storage needed to develop a stage-storage curve, consider a horizontal cross section of the reservoir as shown in figure 4. The incremental volume is defined as:

$$dV = A(h)\,dh$$

where A(h) is the cross sectional area corresponding to depth h and dh is the variation of the water level in the reservoir. The total volume up to the level h is then calculated by integration of the above differential equation between levels 0 and h.

$$V(h) = \int_0^h dV$$

$$V(h) = \int_0^h A(h)\, dh$$

The area A(h) can be expressed in terms of h as

$$A(h) = 2 \ [\ 1/2 \ (Z_1 h) (Z_2 h)\ ]$$

$$A(h) = Z_1 Z_2 h^2$$

This form shows that the capacity is not only a function of the water level in the reservoir but also a function of the lateral sides slope Z_1, and the reservoir base slope Z_2.

$$V(h,Z_1,Z_2) = \int_0^h Z_1 Z_2 h^2 \, dh = \frac{Z_1 Z_2}{3} h^3$$

If slopes of 10 to 1 and 45 to 1 are assigned to Z_1 and Z_2 respectively, the computational form of the stage-storage relationship would be

$$V(h,10,45) = 150 h^3$$

where V is the storage in cubic feet and h is the stage in feet. This equation defines the stage-storage relationship for the hypothetical reservoir (Table 3).

<u>Discharge Through the Spillway System</u>

Obviously any headwater flood control structure must be equipped with a principal spillway and/or an emergency spillway to handle normal overflow and prevent overtopping. The goal here is to decide on the design features of

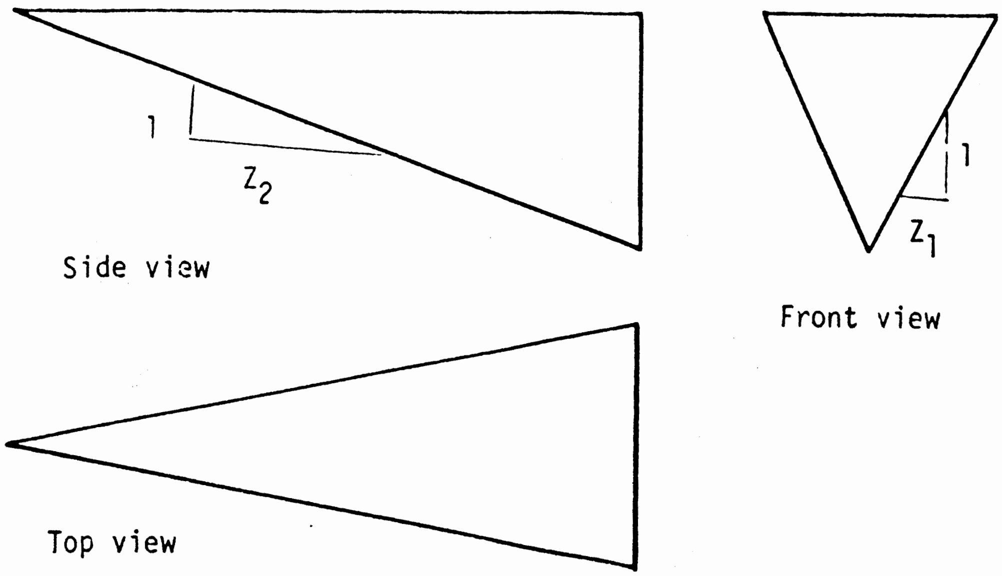

Figure 3. Schematic Drawing of a Triangular reservoir

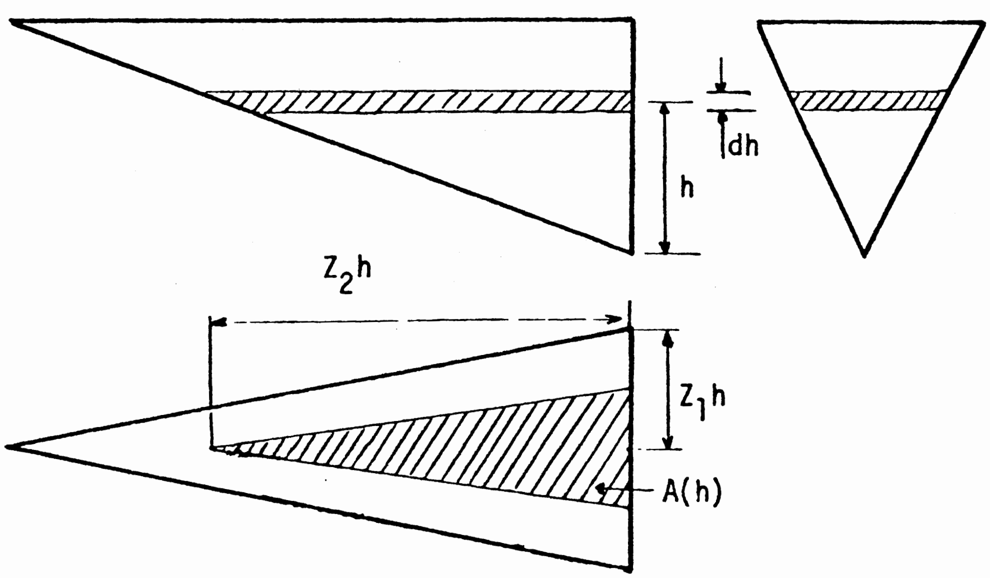

Figure 4. Horizontal Cross Section of the Reservoir

TABLE 3

STAGE-STORAGE CURVE

Stage (feet)	Depth (feet)	Storage (acre-feet)
1000.00	.00	.00
1002.00	2.00	.03
1004.00	4.00	.22
1006.00	6.00	.74
1008.00	8.00	1.76
1010.00	10.00	3.44
1012.00	12.00	5.95
1014.00	14.00	9.45
1016.00	16.00	14.10
1018.00	18.00	20.08
1020.00	20.00	27.55
1020.40	20.40	29.23
1020.80	20.80	30.99
1021.00	21.00	31.89
1021.40	21.40	33.75
1021.80	21.80	35.68
1022.00	22.00	36.67
1022.40	22.40	38.70
1022.80	22.80	40.81
1023.00	23.00	41.90
1023.40	23.40	44.12
1023.80	23.80	46.42
1024.00	24.00	47.60
1024.40	24.40	50.02
1024.80	24.80	52.52
1025.00	25.00	53.81
1025.40	25.40	56.43
1025.80	25.80	59.14
1026.00	26.00	60.52
1026.40	26.40	63.36
1026.80	26.80	66.28
1027.00	27.00	67.78
1027.40	27.40	70.84
1027.80	27.80	73.98
1028.00	28.00	75.59
1028.40	28.40	78.88
1028.80	28.80	82.26
1029.00	29.00	83.98

the spillway system which allows developing the stage-discharge curve needed for routing computations.

<u>Design of the Principal Spillway</u>

The principal spillway is designed to control the rate of outflow during normal overflow. Standard designs are available from references of the Soil Conservation Service (1969) and the U.S. Bureau of Reclamation (1977). According to these references, a structure designed to control runoff from a 200 acre watershed should have the following characteristics:

1) The height of the crest of the principal spillway is 15 to 20 feet.

2) The flood storage height should not exceed 3 to 4 feet.

3) The maximum depth of flow in the emergency spillway should not exceed 1 foot.

4) A net freeboard of 1 to 2 feet should be reserved in the emergency spillway.

5) It is preferable that the diameter of the riser of the principal spillway be 1.5 to 2 times as large as the diameter of the barrel. A summary of these criteria are shown in figure 5.

In order to meet the above defined criteria, many combinations of riser and barrel diameters, height of principal spillway crest, and reservoir side slopes were tried. The design selected was:

-- Height of the principal spillway crest = 20 feet

-- Diameter of riser = 45 inches

-- Diameter of barrel = 30 inches

The top of dam was taken as 1029 feet which represents a height of 9 feet above the crest of the principal spillway. This would not normally be necessary for a 10-year rainfall and average watershed characteristics. However, it was done because later in this study, higher rainfall intensities and different watershed conditions were used that can result in flood storage heights well in excess of that produced under average conditions.

Stage-Discharge Curve

The rate of discharge from the principal spillway is controlled by the hydraulic head above the crest of the principal spillway (Barfield, Warner and Haan, 1981). Three flow conditions may be present- weir flow, orifice flow, or pipe flow.

Weir Flow. At a very low head, the riser crest acts like a weir and the flow is computed from

$$Q_w = C_w L H^{3/2}$$

where Q_w is the discharge in cfs, C_w is a weir coefficient typically taken equal to 3.0, L is the weir length in feet, in this case it is equal to the circumference of the inlet, and H is the water head above the riser crest. The computational form of the weir equation is:

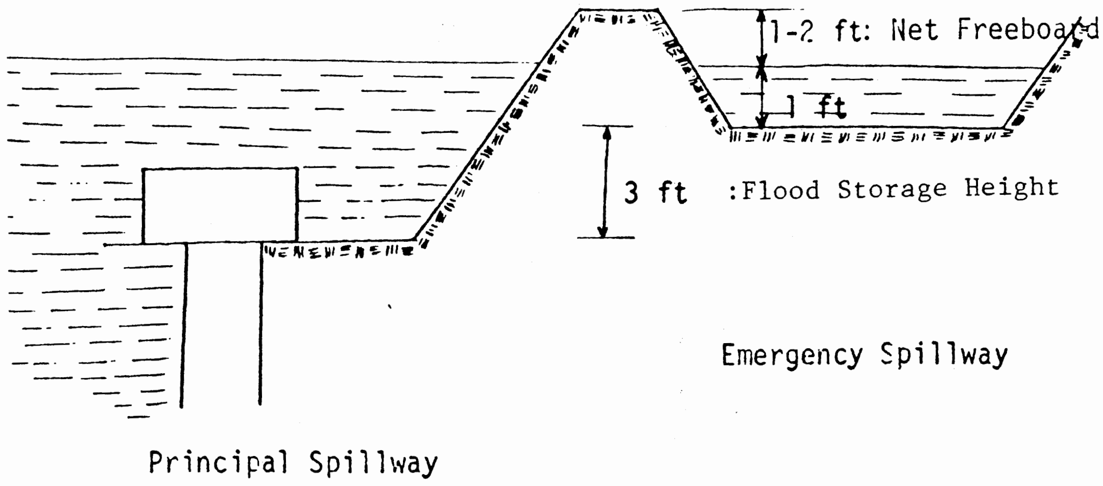

Figure 5. Standard Dimension of a Detention Structure After Schwab et al., 1981.

$$Q_w = 3.0\ \pi\ (D_r/12)\ h^{3/2}$$

D_r = 45 inches, then

$$Q_w = 35.34\ H^{3/2}$$

<u>Orifice</u> <u>Flow.</u> When the hydraulic head above the riser crest increases, the inlet starts acting like an orifice and the flow is described by the equation

$$Q_o = C_o\ A\ (2\ g\ H)^{1/2}$$

where Q_o is the orifice flow in cfs, C_o is an orifice coefficient generally taken equal to 0.6, A is the area of the riser cross section in square feet, and H is the hydraulic head in feet. The computational form of the equation would be

$$Q_o = 0.6\ \pi/4\ (D_r/12)^2\ (2\ g\ H)^{1/2}$$

D_r = 45 inches, then

$$Q_o = 53.18\ H^{1/2}$$

<u>Pipe</u> <u>Flow.</u> Eventually when the head is high enough, the outlet flows full and the flow becomes pipe controlled. The flow is described by an equation that integrates the entrance head loss, bend head loss, friction head loss, and velocity head loss (Barfield, Warner and Haan, 1981).

$$Q_p = \frac{A\ [\ 2\ g\ (H_d + H)]^{1/2}}{[\ 1 + K_e + K_b + K_c L\ ]^{1/2}}$$

where Q_p is the pipe flow in cfs, H_d is the distance from the riser crest to a point 0.6 D_b above the invert of the barrel (D_b is the barrel diameter), H is the hydraulic head above the riser crest in feet, A is the cross sectional area of the barrel in square feet, L is the length of the barrel in feet, K_e is the entrance loss coefficient taken equal to 1, K_b is the bend loss coefficient taken equal to 0.5, K_c is the friction loss coefficient calculated by the equation

$$K_c = \frac{5087\ n^2}{D_b^{4/3}}$$

where n is Manning's coefficient selected from tables as .025 (Barfield, Warner and Haan, 1981), and D_b is the diameter of the barrel in inches.

The barrel was selected to be 40 feet long and have a diameter of 30 inches. The computational form of the pipe flow equation is

$$Q_p = 20.06\ (H + 18.5)^{1/2}$$

Finally the stage discharge curve is computed. For a given head, the discharge is determined using the three outflow equations mentioned above. Among the three values found for a given stage, the minimum is chosen to be the design flow (Wilson, 1987). The stage-discharge curve computations are shown in Table 4.

Reservoir Routing and Flood Storage Height Determination

Reservoir routing is the process of determining the stage and outflow rate variations within a given reservoir and for a particular inflow hydrograph. The process is based on the continuity equation:

$$I - O = \frac{\Delta S}{\Delta t}$$

where I is the inflow, O is the outflow, ΔS is the variation in storage, and Δt is the time increment.

The inflow hydrograph is routed through reservoir using the SWAMP computer package (Haan, 1987). Table 5 shows an outflow hydrograph due to the inflow hydrograph shown in table 1 and from the above defined reservoir whose stage-storage and stage-discharge curves are shown in tables 3 and 4 respectively. The outflow volume is less than the inflow volume because the routing was stopped before all of the flow had been routed. The reservoir effect represented by the peak flow reduction may be seen in Figure 6 which shows a plot of the inflow and outflow hydrographs. From reservoir routing, the objective was to determine the flood storage height, f, which is the difference between the stage that corresponds to the maximum rate of discharge, MS, and the stage that corresponds to the crest of the principal spillway, CS. Table 5 shows that MS has the value of 23.04 feet. CS was designed to be equal to 20 feet, therefore

$$f = MS - CS$$

$$f = 23.04 - 20$$

$$f = 3.04 \text{ feet.}$$

It is at this height above the crest of the principal spillway that the emergency spillway should be designed when average values of the different parameters involved in the SCS procedure are used.

TABLE 4

STAGE-DISCHARGE CURVE

Stage (feet)	Depth (feet)	Weir Flow (cfs)	Orifice Flow (cfs)	Pipe Flow (cfs)	design Flow (cfs)
1000.00	.00	.00	.00	86.28	.00
1002.00	.00	.00	.00	86.28	.00
1004.00	.00	.00	.00	86.28	.00
1006.00	.00	.00	.00	86.28	.00
1008.00	.00	.00	.00	86.28	.00
1010.00	.00	.00	.00	86.28	.00
1012.00	.00	.00	.00	86.28	.00
1014.00	.00	.00	.00	86.28	.00
1016.00	.00	.00	.00	86.28	.00
1018.00	.00	.00	.00	86.28	.00
1020.00	.00	.00	.00	86.28	.00
1020.40	.40	8.94	33.63	87.21	8.94
1020.80	.80	25.29	47.57	88.13	25.29
1021.00	1.00	35.34	53.18	88.58	35.34
1021.40	1.40	58.55	62.92	89.49	58.55
1021.80	1.80	85.35	71.35	90.38	71.35
1022.00	2.00	99.97	75.21	90.83	75.21
1022.40	2.40	131.41	82.39	91.71	82.39
1022.80	2.80	165.59	88.99	92.58	88.99
1023.00	3.00	183.65	92.11	93.01	92.11
1023.40	3.40	221.58	98.06	93.88	93.88
1023.80	3.80	261.81	103.67	94.73	94.73
1024.00	4.00	282.74	106.36	95.15	95.15
1024.40	4.40	326.20	111.55	96.00	96.00
1024.80	4.80	371.68	116.51	96.83	96.83
1025.00	5.00	395.15	118.91	97.24	97.24
1025.40	5.40	443.50	123.58	98.07	98.07
1025.80	5.80	493.68	128.07	98.89	98.89
1026.00	6.00	519.43	130.26	99.29	99.29
1026.40	6.40	572.23	134.54	100.10	100.10
1026.80	6.80	626.71	138.68	100.90	100.90
1027.00	7.00	654.56	140.70	101.30	101.30
1027.40	7.40	711.46	144.67	102.09	102.09
1027.80	7.80	769.92	148.52	102.87	102.87
1028.00	8.00	799.72	150.42	103.27	103.27
1028.40	8.40	860.44	154.13	104.04	104.04
1028.80	8.80	922.63	157.76	104.81	104.81
1029.00	9.00	954.26	159.54	105.20	105.20

TABLE 5

ROUTED HYDROGRAPH

Time (hours)	Inflow (cfs)	Stage (feet)	Outflow (cfs)
9.50	0.00	1020.00	0.00
9.70	0.00	1020.00	0.00
9.90	0.01	1020.00	0.00
10.10	0.04	1020.00	0.00
10.30	0.16	1020.00	0.01
10.50	0.40	1020.00	0.03
10.70	0.90	1020.00	0.08
10.90	1.64	1020.01	0.18
11.10	2.64	1020.02	0.35
11.30	3.97	1020.03	0.60
11.50	5.69	1020.04	0.95
11.70	8.32	1020.07	1.46
11.90	12.43	1020.10	2.22
12.10	24.44	1020.16	3.58
12.30	53.98	1020.29	6.58
12.50	113.90	1020.57	15.98
12.70	187.95	1021.03	37.22
12.90	225.11	1021.58	64.29
13.10	226.48	1022.10	77.01
13.30	200.18	1022.53	84.49
13.50	161.39	1022.82	89.32
13.70	126.07	1022.98	91.84
13.90	98.03	1023.04	92.30
14.10	76.83	1023.03	92.23
14.30	61.61	1022.96	91.48
14.50	51.03	1022.85	89.85
14.70	44.29	1022.73	87.79
14.90	39.14	1022.59	85.47
15.10	35.19	1022.44	83.03
15.30	32.18	1022.28	80.30
15.50	29.96	1022.13	77.50
15.70	28.18	1021.97	74.69
15.90	26.64	1021.82	71.74
16.10	25.28	1021.67	67.24
16.30	24.08	1021.53	62.82
16.50	23.00	1021.41	58.75
16.70	22.07	1021.29	52.14
16.90	21.21	1021.19	46.44
17.10	20.43	1021.11	41.64
17.30	19.71	1021.04	37.61

Inflow volume = 41.61 acre feet
Outflow volume = 29.24 acre feet

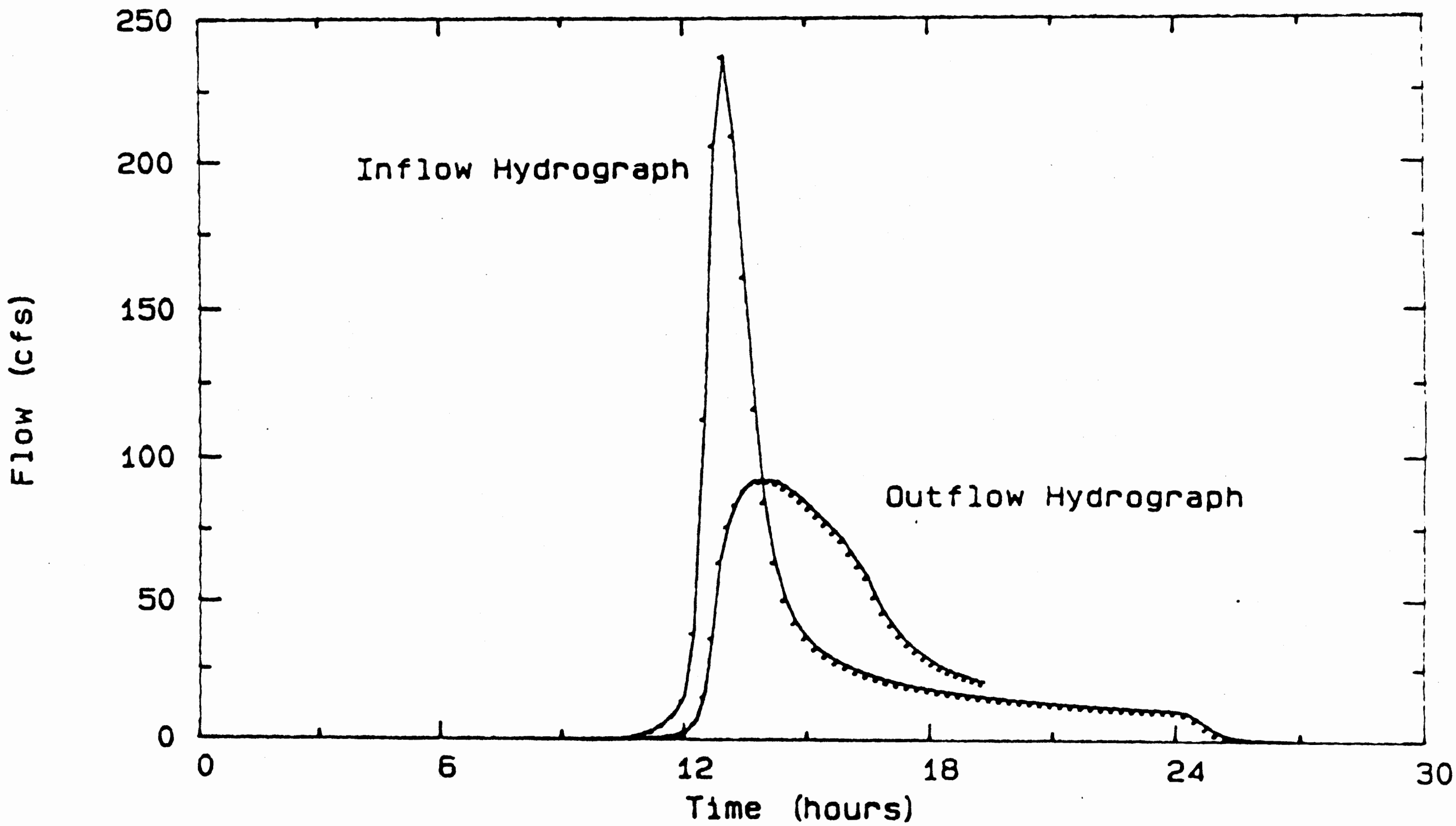

Figure 6. Inflow and Outflow Hydrographs

CHAPTER IV

PROBABILISTIC MODEL DEVELOPMENT

Introduction

This section involves the development of a simulation model that considers the probabilistic behavior of the SCS model parameters. The simulation process starts with generating random values for S and R. The generation procedure supposes that S and R are totally independent so that separate univariate generators are used. This assumption is supported by Haan and Schulze (1986) and Haan and Edwards (1987). Each couple of R and S is used by the SCS model to determine a runoff hydrograph. The hydrograph is routed through a reservoir and the flood storage height is determined. This routine is repeated N times to result in a sample of N flood storage heights. Presented in this chapter are the details of the development of the simulation computer code. Subroutines for the inflow hydrograph and reservoir routing computations are adopted from SWAMP (Haan, 1987) with slight modifications. The SWAMP computer program is based on SCS procedures as detailed in Barfield, Warner and Haan (1981).

Input Parameters

The simulation procedure requires different types of input data. Some of the data are considered as constants. This includes the watershed area, land slope, length of the main channel, and reservoir characteristics describing the stage-storage and stage-discharge characteristics. Two inputs, the SCS curve number and storm rainfall, are random variables and change from simulation to simulation. The sample size used can be varied from 10 to 1000. In general, as the sample size increases, the stability of the results improves and the computation time increases.

<u>S Data Generation</u>

It was stated in the literature review that S is a function of many variables and that this variability can be described by the lognormal probability distribution

$$p_S(s) = \frac{1}{s\sqrt{2\pi\sigma^2}} \exp\left[\frac{-(\text{Log } s - \mu)^2}{2\sigma^2}\right], \; s > 0$$

where μ and σ^2 are, respectively, the mean and the variance of the log transformed data. It was stated previously that Haan and Edwards (1987) computed observed S values from observed rainfall and runoff data for different watersheds. The mean and standard deviation they found for the Stillwater station are used to simulate S values from the lognormal distribution. The generation of an observation, x, from a given distribution is generally done by integrating the probability density function of that distribution between $-\infty$ and x, set it equal to a random number generated from the uniform distribution in the interval (0, 1), and solve for x. For some cases, like the present one, an analytic integration of the probability density functions is not possible and numerical methods are used instead. The algorithm used for generating lognormal data is explained in Haan (1977). This algorithm is based on a numerical method developed for normal deviate generation whose computer subroutine is presented in Wolfe (1983). This subroutine was used for lognormal data generation by using a special property of the lognormal distribution, namely, that if Y is normally distributed with mean μ_1 and variance σ_1^2 then e^Y is lognormally distributed with mean μ and variance σ^2. The generation procedure consists of:

1) Generate a random number, RN, from the standard normal distribution in the interval $(-\infty,\infty)$ using the procedure of Wolfe (1983).

2) Generate a normal observation from the relationship

$$Y = \sigma \, RN + \mu$$

where μ and σ are the mean and standard deviation of the logarithmically transformed data estimated from the mean and standard deviation of the untransformed data using the relations from Chow (1954).

$$\mu = \frac{1}{2} \text{Log}[S_m^2/(C_v^2 + 1)]$$

$$\sigma = \text{Log}(C_v^2 + 1)$$

where S_m is the mean of the untransformed data, and C_v is the coefficient of variation of the untransformed data.

3) The last step is to transform Y to S from the equation

$$S = \text{EXP}(Y)$$

where S is the SCS retention parameter.

Rainfall Data Generation

It is quite common to describe rainfall events by the extreme value type I distribution (Hershfield, 1961; Haan, 1977).

$$p_R(r) = \frac{1}{\alpha} \exp\left[\frac{-(r-\beta)}{\alpha} - \exp\left[\frac{-(r-\beta)}{\alpha} \right]\right]$$

where α and β are the distribution parameters. They are function of the mean and the standard deviation of the representative set of data. In this study α and β are estimated from (Haan and Wilson, 1986)

$$\alpha = 0.236\ (R_{100} - R_2)$$

$$\beta = R_{100} - 1.086\ (R_{100} - R_2)$$

where R_{100} and R_2 are the 100-year and the 2-year, 24-hour rainfalls respectively.

The rainfall data generation procedure is

1) Generate a random number, RND, from the uniform distribution in the interval (0, 1).

2) Set $\int_{-\infty}^{R} p_R(r)\, dr$ equal to RND

and solve for R. That is

$$P_R(R) = \int_{-\infty}^{R} \frac{1}{\alpha} \exp\left[\frac{-(r-\beta)}{\alpha} - \exp\left[\frac{-(r-\beta)}{\alpha}\right]\right] dr = RND$$

Use a change of variable to simplify this integration

$$y = \frac{1}{\alpha}(r-\beta)$$

The integration limits become

a) $y = -\infty$ for $r = -\infty$

b) $y = \frac{1}{\alpha}(R-\beta)$ for $r = R$

Since $y = \frac{1}{\alpha}(r-\beta)$ then $dr = \alpha dy$. The integral becomes

$$P_R(R) = P_Y(Y) = \int_{-\infty}^{Y} \exp(-y)\exp(-\exp(-y))\, dy$$

Set v equal to $-\exp(-y)$. Then dv equals $\exp(-y)\, dy$ and the integration limits become

a) $v = -\infty$ for $y = -\infty$

b) $v = -\exp(-y)$ for $y = Y$

Therefore

$$P_Y(Y) = \int_{-\infty}^{-\exp(-Y)} \exp(v)\, dv$$

which solves for

$$P_Y(Y) = \exp(-\exp(-Y)) = RND$$

then

$$\text{Log } RND = -\exp(-Y)$$

and

$$-\text{Log}(-\text{Log}(RND)) = Y$$

Solving for R

$$-\text{Log}(-\text{Log}(RND)) = \frac{1}{\alpha}(R - \beta)$$

then

$$R = \beta - \alpha \text{Log}(-\text{Log}(RND))$$

Inflow Hydrograph Development

The inflow hydrograph is defined as the plot of flow rate passing a particular point versus time. Computations are done following the SCS procedure which considers both precipitation and watershed characteristics. It consists of simulating a rainfall pattern, deriving a rainfall excess pattern, defining a unit hydrograph, and using a convolution process to translate the rainfall excess into a runoff hydrograph.

Unit Hydrograph

This model adopts the SCS model unit hydrograph. McCuen (1982) defines a unit hydrograph as " the hydrograph that results from one inch of precipitation excess generated uniformly over the watershed at a uniform rate during a specified period of time". Unit hydrograph computations integrate an estimate of unit hydrograph timing parameters, an estimate of the unit hydrograph peak flow rate, and use of an approximating equation (Barfield, Warner and Haan, 1981).

Timing Parameters. The unit hydrograph timing parameters as defined and estimated by the SCS and stated in Barfield, Warner and Haan (1981), are

__ Lag time

$$LAGT = \frac{(FLENGTH)^{0.8}\ (SFLO)^{0.7}}{1900\ (SLOPE)^{0.5}}$$

where FLENGTH is the maximum flow length in feet, SFLO is the SCS retention parameter in inches, SLOPE is the average land slope in percent and LAGT is the lag time in hours.

__ Time of concentration

$$TC = \frac{LAGT}{0.6}$$

__ Time increment

$$DT = \frac{LAGT}{3}$$

__ Time to peak

$$TP = LAGT + \frac{DT}{2}$$

In the computer code DT and TP are rounded off to nearest integer.

<u>Peak Flow.</u> The equation derived by the SCS for the peak flow of a unit hydrograph is

$$QP = \frac{484 \ AREA}{640 \ TP/60}$$

where AREA is the area of the watershed in acres, TP is the time to peak in minutes, and QP is the peak flow in cfs.

<u>Approximating Equation.</u> The equation used to approximate the SCS curvilinear unit hydrograph is that proposed by Haan (1970).

$$\frac{q(t)}{QP} = \left[\frac{t}{TP} \exp(1 - \frac{t}{TP}) \right]^{C3TP}$$

where q(t) is the unit hydrograph ordinate at time t, and C3TP is a curve parameter which, for the SCS unit hydrograph, is equal to 3.75. The computer subroutine using this equation estimates the unit hydrograph base time as 4 times the time to peak. The number of unit hydrograph points created is

$$NUHO = 4\ TP/DT$$

Finally the unit hydrograph points are determined by use of the above formula as

$$UH_i = QP[C_i \exp(1 - C_i)]^{3.75}$$

and

$$t_i = (i - 1)\ DT$$

where C_i is equal to $(i - 1)\ DT/TP$, and i varies from 1 to NUHO.

Rainfall Pattern

There are different types of storm patterns available such as historic storms, Huff's curves, and synthetic patterns (Barfield, Warner and Haan, 1981). Synthetic patterns are derived by two different methods; the Intensity-Duration-Frequency method and the SCS method. This model adopts the SCS (Soil Conservation Service, 1975) method which presents two types of storm patterns- type I and type II- applicable for different geographic regions of the United States. Using the same rainfall intensity used in part one, a 24-hour rainfall pattern is developed based on the type II curve whose shape is approximated by the equation

$$\frac{P(t)}{P_{24}} = 0.5 + \frac{T}{24}\left[\frac{24.04}{2\,|T| + 0.04}\right]^{0.755}$$

where P(t) is the synthetic rainfall depth in inches at time t, P_{24} is the 24-hour rainfall depth of a given return period in inches, and T is equal to t - 12 in hours, and t is the time. The computer code starts by solving for the starting time of the rainfall pattern. The SCS runoff equation shows that 0.2 S inches of rain must occur before any runoff starts. Therefore, the starting time, T1, is determined by solving the rainfall pattern equation for T with P is taken equal to 0.2 S. A numerical solution procedure is presented.

1) For a given S, the entity 0.2 S/24 is computed and set equal to PP24.

2) Then a starting time of 1 is given to T and an increment of 0.25 is used.

3) A variable RHS is set equal to

$$12 + (T - 12)\left[\frac{24.04}{2\,|T - 12| + 0.04}\right]^{0.755}$$

At each step, RHS is tested against 24*PP24.

4) The process goes on until a value of T that gives RHS > 24*PP24 is reached. This value is set equal to T1. The stopping time, T_2, is taken equal to 24 hours. Finally the total number of rainfall data points is computed as

$$NTR = 60(T2 - T1)/DT$$

and rainfall data is determined as

$$t_i = T1 + (i - 1)DT/60$$

and

$$R_i = P_{24}\left[0.5 + \frac{t_i - 12}{24}\left[\frac{24.04}{2\left|t_i - 12\right| + 0.04}\right]^{0.755}\right]$$

where i varies from 1 to NTR.

Rainfall Excess

Rainfall excess is defined as rainfall minus losses due to interception, infiltration, evapotranspiration and depressional storage. The rainfall excess pattern is estimated by the SCS equation

$$CRE_i = \frac{(R_i - 0.2\,S)^2}{R_i + 0.8\,S} \qquad , R_i > 0.2\,S$$

$$CRE_i = 0 \qquad , R_i <= 0.2\,S$$

where i varies from 1 to NTR.

Finally the rainfall excess pattern is used to compute rainfall excess bursts

$$RE_i = CRE_i - CRE_{i-1} \qquad , CRE_i > CRE_{i-1}$$

$$RE_i = 0 \qquad , \text{otherwise}$$

Convolution and Inflow Hydrograph Computations

So far unit hydrograph and rainfall excess patterns have been generated. The next step is to use a convolution process to translate the precipitation excess into a runoff hydrograph. Conceptually the convolution approach integrates a process of multiplication, translation with time, and addition. The mechanism is that, given a rainfall excess pattern of NTR bursts and a unit hydrograph of NUHO points, the first burst of rainfall excess of duration DT is multiplied by the ordinates of the unit hydrograph. The unit hydrograph is then translated in time by DT and the next burst of rainfall excess is used. The process goes on until the unit hydrograph is translated for all rainfall excess bursts. The results of multiplications are summed for each time interval and the result is a runoff hydrograph composed of NTR+NUHO - 1 data points. In the computer code, data points of the inflow hydrograph are computed by the equations

$$IH_j = \sum_{i=1}^{j} UH_i \, RE_{j-i+1} \;; \; j = 1, 2, \ldots, NTR+NUHO - 1$$

$$t_j = T1 + (j - 1)DT$$

where IH_j is the runoff hydrograph ordinate at time t_j, RE and UH are as defined above with the exception

$RE_i = 0$ for $i > NTR$

$UH_i = 0$ for $i > NUHO$

Reservoir Routing

Reservoir routing is used to determine the outflow hydrograph from a reservoir for a given inflow hydrograph and for known stage-storage and stage-discharge curves of that reservoir. The reservoir routing subroutine is based on the storage equation

$$I - O = \frac{\Delta S}{\Delta t}$$

where I is the inflow, O is the outflow, Δt is the routing time interval and ΔS is the change of storage that occurs during the time interval Δt. This equation is rearranged and numerically solved to have the form

$$\Delta t\left(\frac{I_{i+1} - I_i}{2}\right) - \Delta t\left(\frac{O_{i+1} - O_i}{2}\right) = S_{i+1} - S_i$$

where subscripts i+1 and i indicate times $t+\Delta t$ and t respectively. The inflow hydrograph values are known at any time i. The outflow and storage values are known at time i-1, but unknown at time i. Using this information, the above equation is rearranged so that the unknown parameters are set on the left hand side and the known ones are set on the right hand side.

$$S_{i+1} + \frac{\Delta t}{2} O_{i+1} = \frac{\Delta t}{2}(I_{i+1} + I_i) + S_i - \frac{\Delta t}{2} O_i$$

This results in one equation with two unknowns for which there is no direct analytic solution. Although, for this case a combined (analytic, graphical) procedure known as the storage indication method is available, the reservoir routing subroutine of this model proceeds numerically to solve the reservoir routing equation. The process consists of:

1) Δt is set equal to 0.2 hr. If Δt is different from the inflow hydrograph time interval, an adjustment of the time scale is made and new inflow hydrograph ordinates are determined from the old ones by linear interpolation.

2) An elevation variable, H, is initialized equal to the stage level of the principal spillway, ELPSP, and a storage function subroutine is called to determine the value of corresponding storage (S1), by linear interpolation among the stage-storage curve values. For the same H, a discharge function subroutine is called to determine the corresponding discharge value (O1), by linear interpolation among the stage-discharge data points.

3) S1 and O1 values are used along with the values of UH1 and UH2 of the inflow hydrograph to compute the right hand side of the routing equation, RHS1. S1 and O1 are also used to compute the left hand side of the equation, LHS1. The absolute value of (LHS1 - RHS1) is tested against a tolerance value equal to CV * RHS1; CV = 0.0001

If the test was positive (ABS(LHS1 - RHS1) > CV * RHS), then an entity of 0.2 SIGN(LHS1 - RHS1) is subtracted from H and the process restarts. The loop goes on until an H value that gives a negative test is reached. This H value and the corresponding outflow and storage are recorded as H1, S1, and O1; values of the stage, storage, and discharge at time t1. To compute the records at time t2, H is set equal to H1. In general, when the time index is i, H is set equal to H_{i-1} and the process restarts from step 2.

Flood Storage Height Determination

The reservoir routing subroutine objective is to determine the maximum stage value resulting from an inflow hydrograph. Then a data point of the desired flood storage height sample is obtained by subtracting the principal spillway stage value from the above determined maximum stage. The program determines the flood storage height using each of the randomly generated S, R pairs. Thus N values of flood storage height were generated. A listing of the model computer code is shown in Appendix A.

CHAPTER V

RESULTS AND ANALYSIS

Selection of Sample Size

It was necessary to select a sample size , N, that results in relatively small variation in the estimated mean flood storage height yet is not so large as to require an unreasonable amount of computer time. Different sample sizes were used. For each sample size, the program was run 10 times resulting in 10 samples of flood storage heights. Frequency analyses were done and a value of f_{10} determined for each sample. Summary statistics of f_{10} values for the different sample sizes are shown in Table 6. Based on these results, a sample size of 1000 was chosen.

Generated S data

The computer output of the simulated S data is shown in Appendix A. The results of the frequency analysis of S data, mainly the summary statistics and the approximation by the lognormal probability distribution, are shown in Table 7 and Table 8. The fit of the lognormal distribution to the simulated S data is shown in Figure 7. For this plot, as well as for all the following probability plots, only every tenth point is plotted.

TABLE 6

STATISTICS OF f_{10} FOR DIFFERENT SIMULATION SIZES

Simulation Size	Mean	Standard Deviation
100	4.54	.89
200	4.58	.33
300	4.36	.31
400	4.53	.29
500	4.49	.22
600	4.38	.18
1000	4.44	.16

TABLE 7

SUMMARY STATISTICS OF S DATA

GEN. S VAL.

BASED ON 1000 OBSERVATIONS

ORIGINAL DATA

MEAN	4.834806
VARIANCE	14.261910
STD DEV	3.776495
COEF VAR	0.781105
SKEW COEF	2.523713

LOGS OF DATA

MEAN	1.320412
VARIANCE	0.531440
STD DEV	0.728999
COEF VAR	0.552100
SKEW COEF	-0.151885

TABLE 8

APPROXIMATION OF S DATA BY THE
LOGNORMAL DISTRIBUTION

RET PERIOD	PROBABILITY	VALUE
1.01	99	.68
1.25	80	2.03
1.42	70	2.54
1.66	60	3.05
2.00	50	3.74
2.32	43	4.27
3.33	30	5.47
5.00	20	6.90
6.66	15	7.87
10.00	10	9.52
14.28	7	11.17
20.00	5	12.42
25.00	4	13.41
50.00	2	16.69
100.00	1	20.42
500.00	.2	30.56
1000.00	.1	35.62

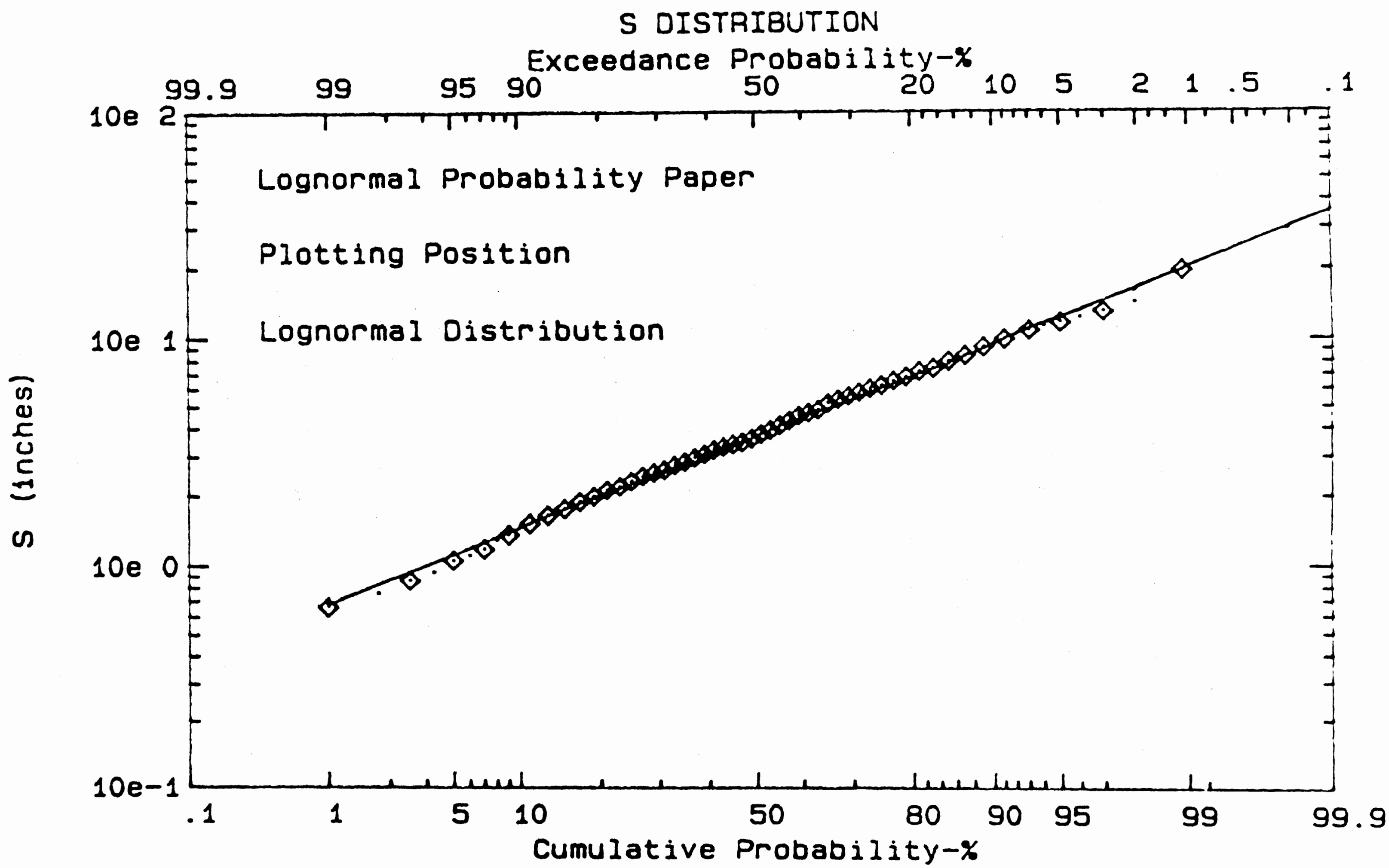

Figure 7. Lognormal fit to the S data

The summary statistics show that the simulated mean and variance of S are close to the original values of 5 and 4, respectively. Figure 7 shows the generated data are in fact lognormally distributed.

Generated Rainfall Data

The computer output of the simulated rainfall data is shown in Appendix B. The results of the frequency analysis of simulated rainfall data, as approximated by the extreme value type I distribution, is shown in Table 9 as well as in Fig 8. The plotted data shows the extreme value type I probability distribution fit the exceedence probability plot very well showing that the simulated rainfall is from the extreme value type I distribution.

Simulated Flood Storage Heights

The resulting sample of flood storage heights is presented in appendix B. This set of data was subject to a frequency analysis as follows:

1) The data was analyzed and plotted in terms of exceedence probability. The computer output of the plotting position analysis (the first 200 points) is shown in Appendix C. The exceedence probability plot of data is shown in Figure 9.

2) Looking for an approximating analytic probability distribution, the data was treated by the normal and the extreme value type I distributions. Application of the

TABLE 9

EXTREME VALUE TYPE I APPROXIMATION
TO RAINFALL DATA

RET PERIOD	PROBABILITY	VALUE
1.01	99	.96
1.25	80	2.31
1.42	70	2.68
1.66	60	3.03
2.00	50	3.39
2.32	43	3.65
3.33	30	4.24
5.00	20	4.84
6.66	15	5.25
10.00	10	5.80
14.28	7	6.28
20.00	5	6.72
25.00	4	7.02
50.00	2	7.92
100.00	1	8.81
500.00	.2	10.88
1000.00	.1	11.77

ALPHA = 1.28192
BETA = 2.92123

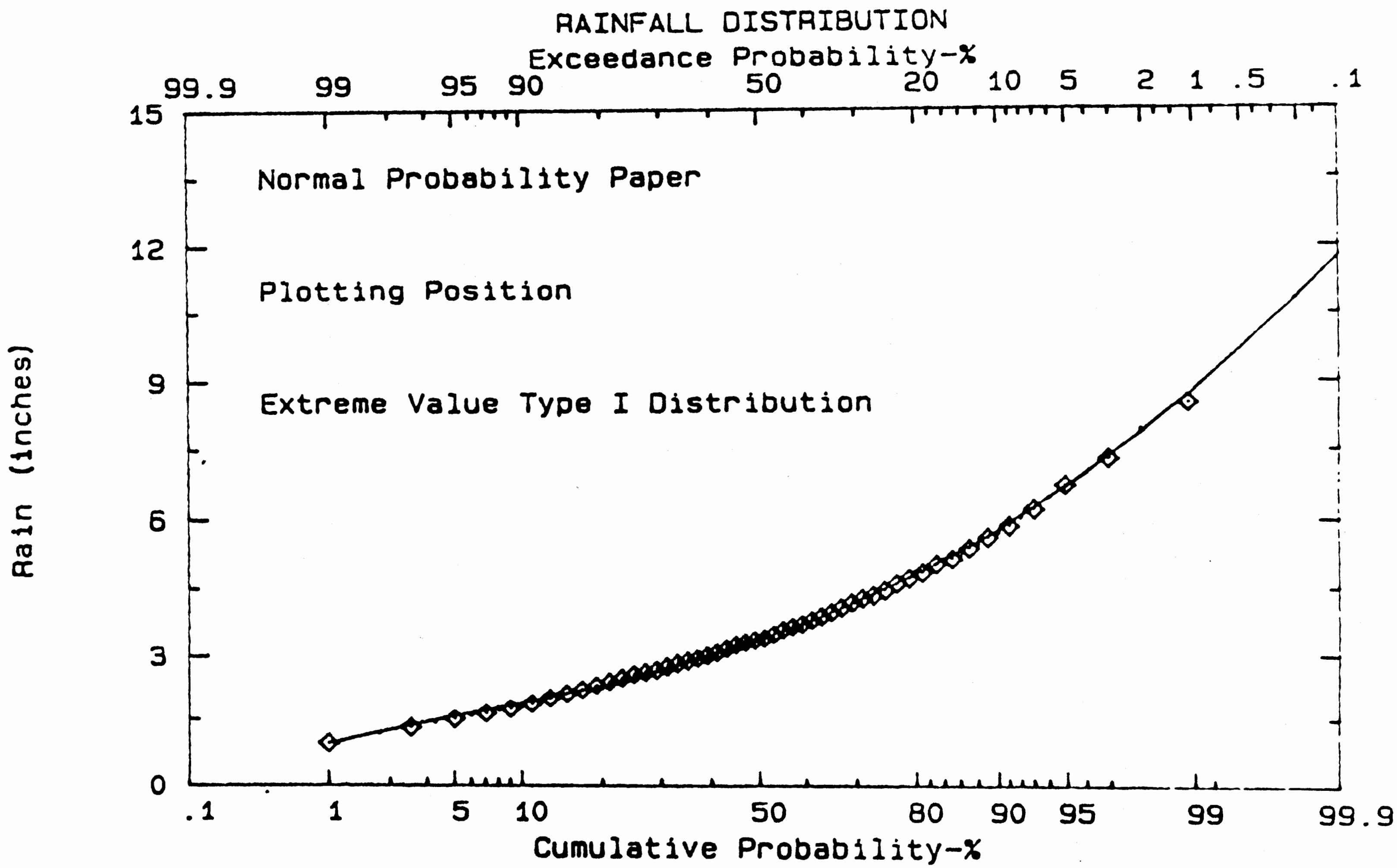

Figure 8. Fit of the Extreme Value Type I Distribution
to Rainfall Data

lognormal and the log Pearson distributions was not possible because of the presence of zero values. Tables 10 and 11 show output of the frequency analysis of data using the normal distribution and the extreme value type I distribution, respectively. Figures 10 and 11 show the fit of these distributions to the exceedence probability plot of data. Figure 10 shows that the normal distribution is not a good representative of the flood storage height data. However, based on figure 11, one could accept the extreme value type I distribution to represent the flood storage height data. Seeking for a stronger evidence, the Chi-square goodness of fit test was used and the hypothesis stating that the data is from the extreme value type I distribution was rejected.

Another approach that was tried consisted of eliminating all zero flood storage height values and analyzing the remaining data. The frequency analysis of the nonzero data showed that among some of the most commonly used distributions, the Log Pearson Type III appeared to fit the data. Summary statistics and the Log Pearson Type III approximation to the modified data are shown in Tables 12 and 13, respectively. The goodness of fit was not upheld by the Chi-square goodness of fit test (Appendix D shows the calculations involved in the Chi-square test). Therefore, the decision made was to use the empirical exceedence probability analysis based on the plotting position scheme to determine flood storage heights

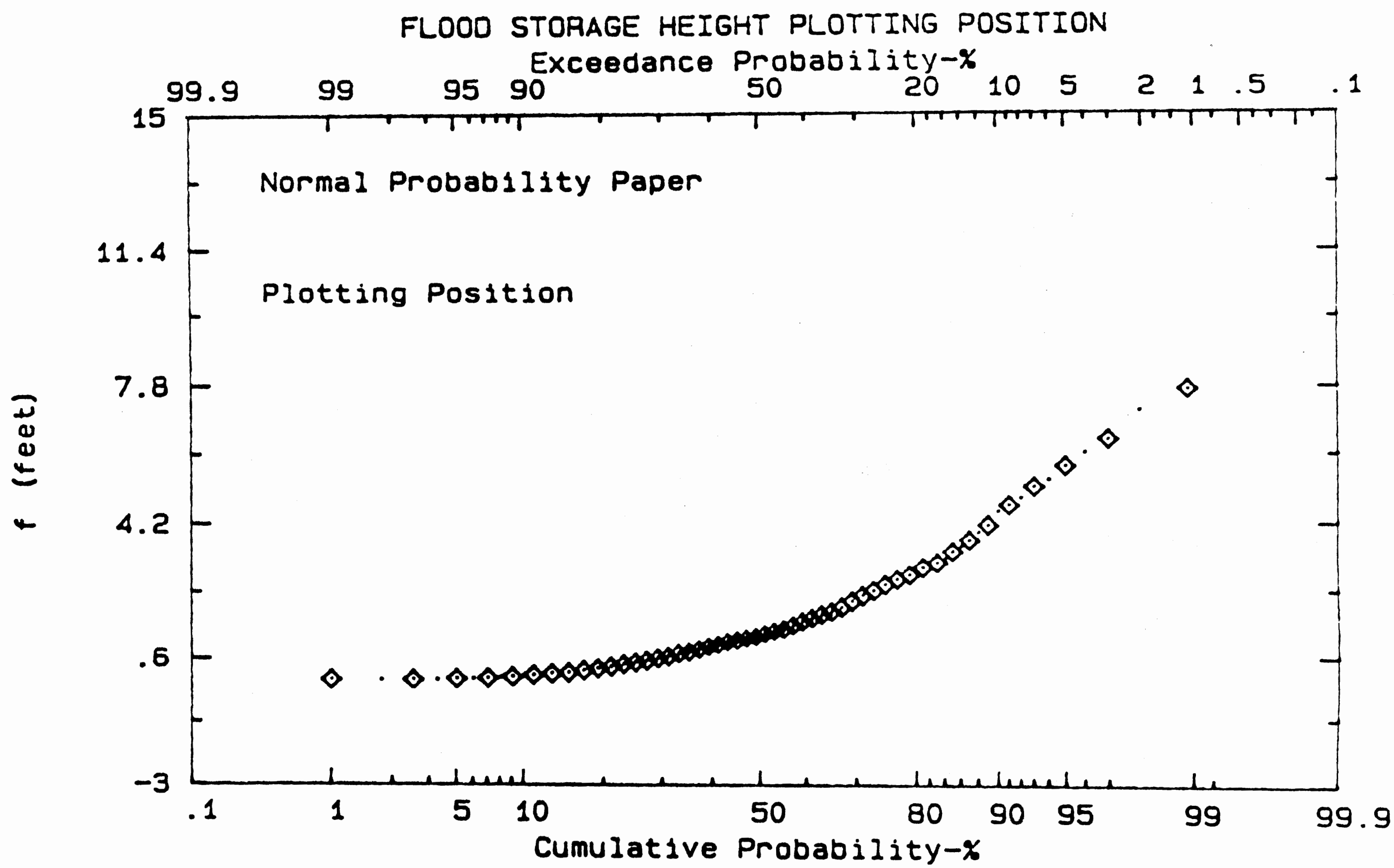

Figure 9. Exceedence Probability Plot of the Generated Flood Storage Height Data

TABLE 10

NORMAL APPROXIMATION TO f DATA

RET PERIOD	PROBABILITY	VALUE
1.01	99	- 2.43
1.25	80	.27
1.42	70	.84
1.66	60	1.29
2.00	50	1.80
2.32	43	2.13
3.33	30	2.74
5.00	20	3.32
6.66	15	3.65
10.00	10	4.12
14.28	7	4.52
20.00	5	4.79
25.00	4	4.98
50.00	2	5.52
100.00	1	6.03
500.00	.2	7.03
1000.00	.1	7.41

MEAN VALUE = 1.803824
STAND. DEV = 1.816765
VARIANCE = 3.300635

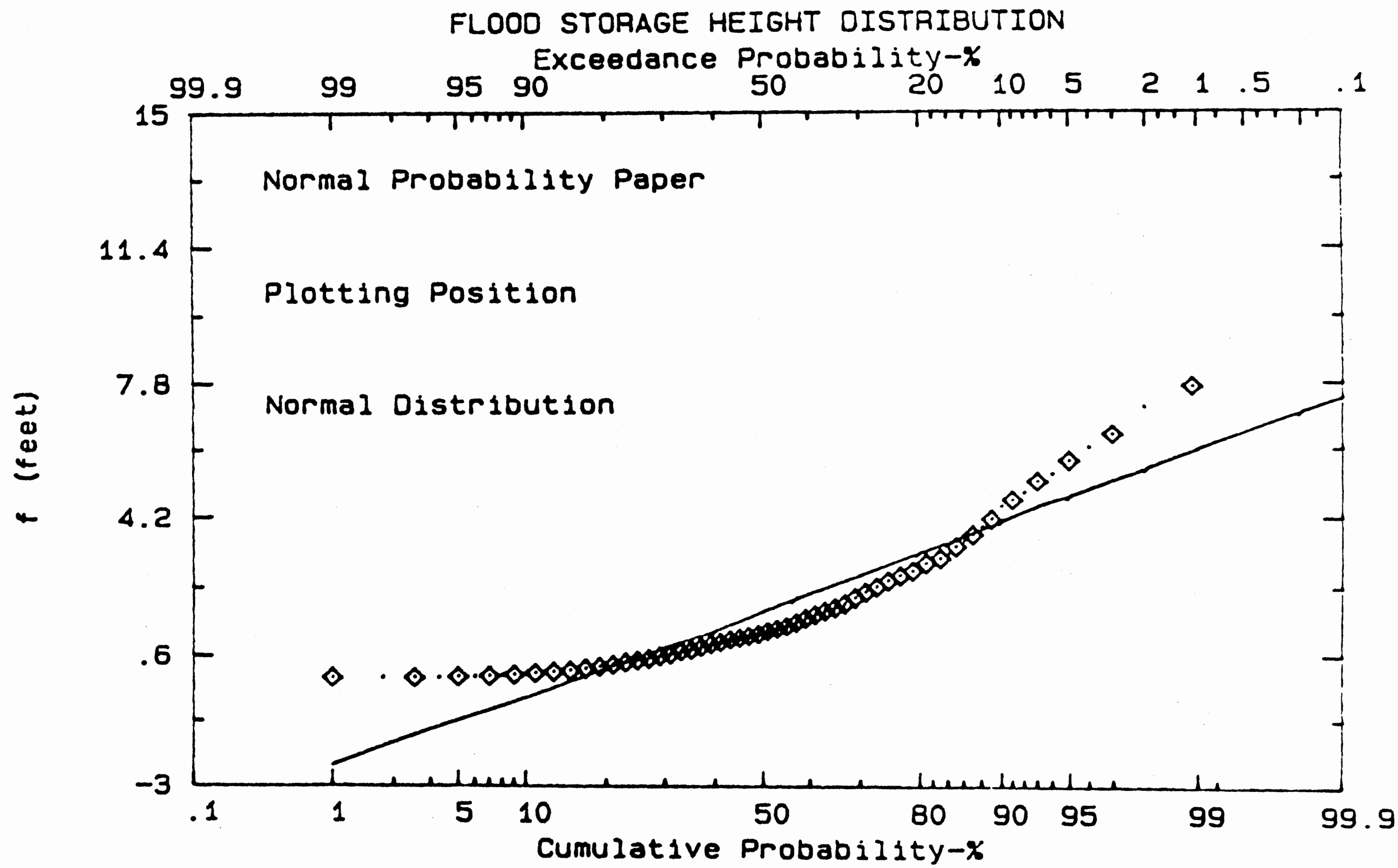

Figure 10. Fit of the Normal Distribution to the Flood Storage Height Data

TABLE 11

EXTREME VALUE TYPE I APPROXIMATION
TO f DATA

RET PERIOD	PROBABILITY	VALUE
1.01	99	- 1.18
1.25	80	.31
1.42	70	.72
1.66	60	1.11
2.00	50	1.50
2.32	43	1.80
3.33	30	2.44
5.00	20	3.11
6.66	15	3.56
10.00	10	4.17
14.28	7	4.70
20.00	5	5.19
25.00	4	5.51
50.00	2	6.51
100.00	1	7.50
500.00	.2	9.78
1000.00	.1	10.77

ALPHA = 1.416526
BETA = 0.9862794

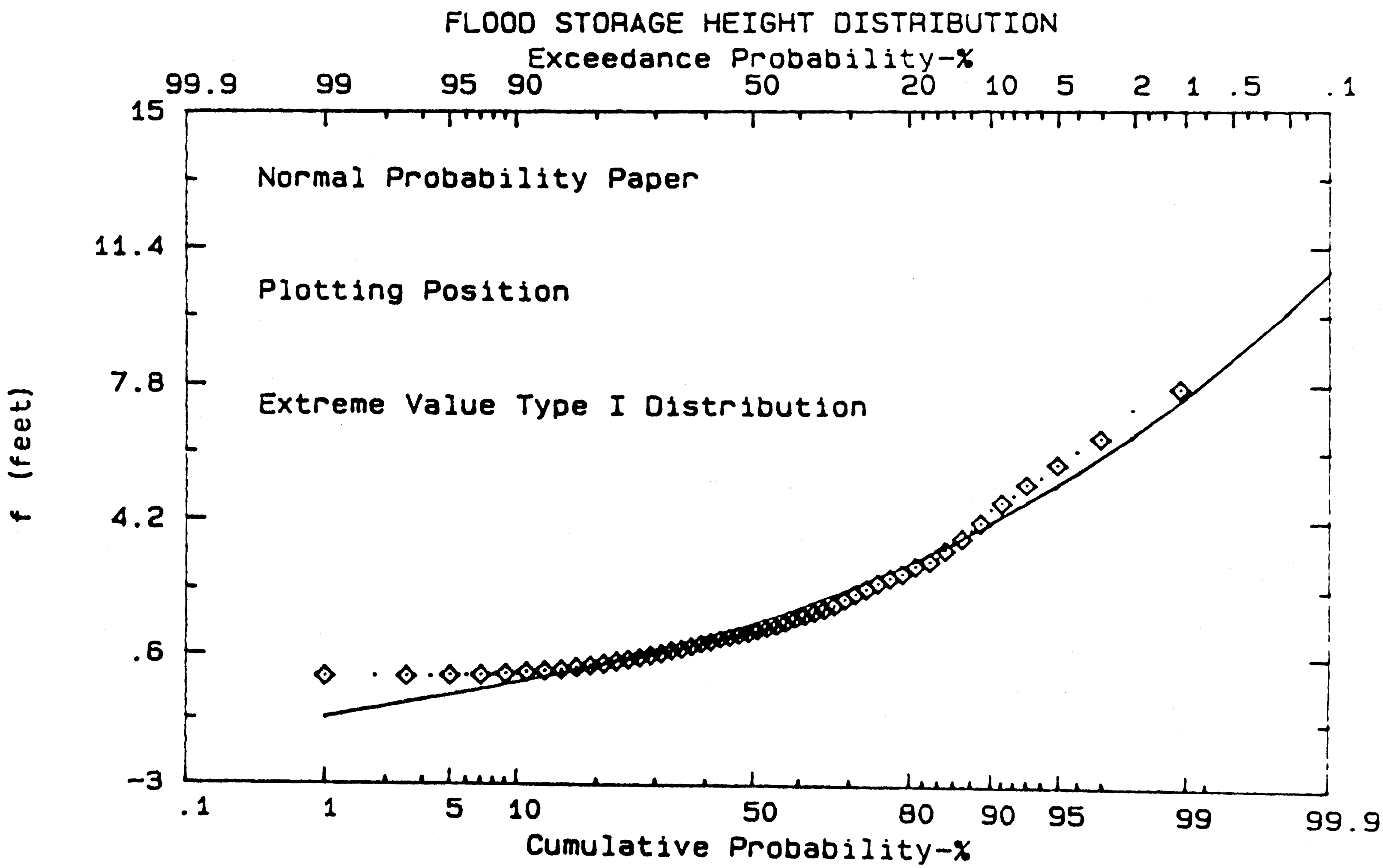

Figure 11. Fit of the Extreme Value Type I Distribution to the Flood Storage Height Data

of different return periods and abandon the search for an analytic expression for the probability distribution.

Determination of f_{10} by the Probabilistic Approach

The value of flood storage height equaled or exceeded by 10 % of the observations read directly from the plotting position output (Appendix C) was found to be

f_{10} = 4.49 feet

Note that the data in appendix C is based on 1000 observations 39 of which are zero.

Discussion

The detention design flood storage height, f, computed using average values of S and R was found to be 3 feet. By comparison between f and f_{10}, it is clearly inferred that the detention volume is underdesigned. That is the SCS model underpredicted the 10-year overflow. In fact the data of Appendix C shows that an f of 3 feet is exceeded 19 percent of the time or about once every 5 years. This underprediction demonstrates that the 10-year rainfall and the average retention parameter don't necessarily produce the 10-year runoff hydrograph or flood storage height.

Calibration Based on the Rainfall Parameter

In order to come up with a flood storage height equal

TABLE 12

SUMMARY STATISTICS OF THE NONZERO f DATA

FLOOD STORAGE HEIGHT

BASED ON 961 OBSERVATIONS

ORIGINAL DATA

MEAN	1.877028
VARIANCE	3.297175
STD DEV	1.815812
COEF VAR	.967387
SKEW COEF	1.635570

LOGS OF DATA

MEAN	5.840177
VARIANCE	1.599648
STD DEV	1.264772
COEF VAR	21.656400
SKEW COEF	- .9224073

TABLE 13

LOG PEARSON TYPE III APPROXIMATION
TO THE NON ZERO f DATA

RET PERIOD	PROBABILITY	VALUE
1.01	99	.02
1.25	80	.40
1.42	70	.64
1.66	60	.90
2.00	50	1.28
2.32	43	1.58
3.33	30	2.28
5.00	20	3.10
6.66	15	3.63
10.00	10	4.48
14.28	7	5.27
20.00	5	5.82
25.00	4	6.23
50.00	2	7.44
100.00	1	8.59
500.00	.2	10.84
1000.00	.1	11.64

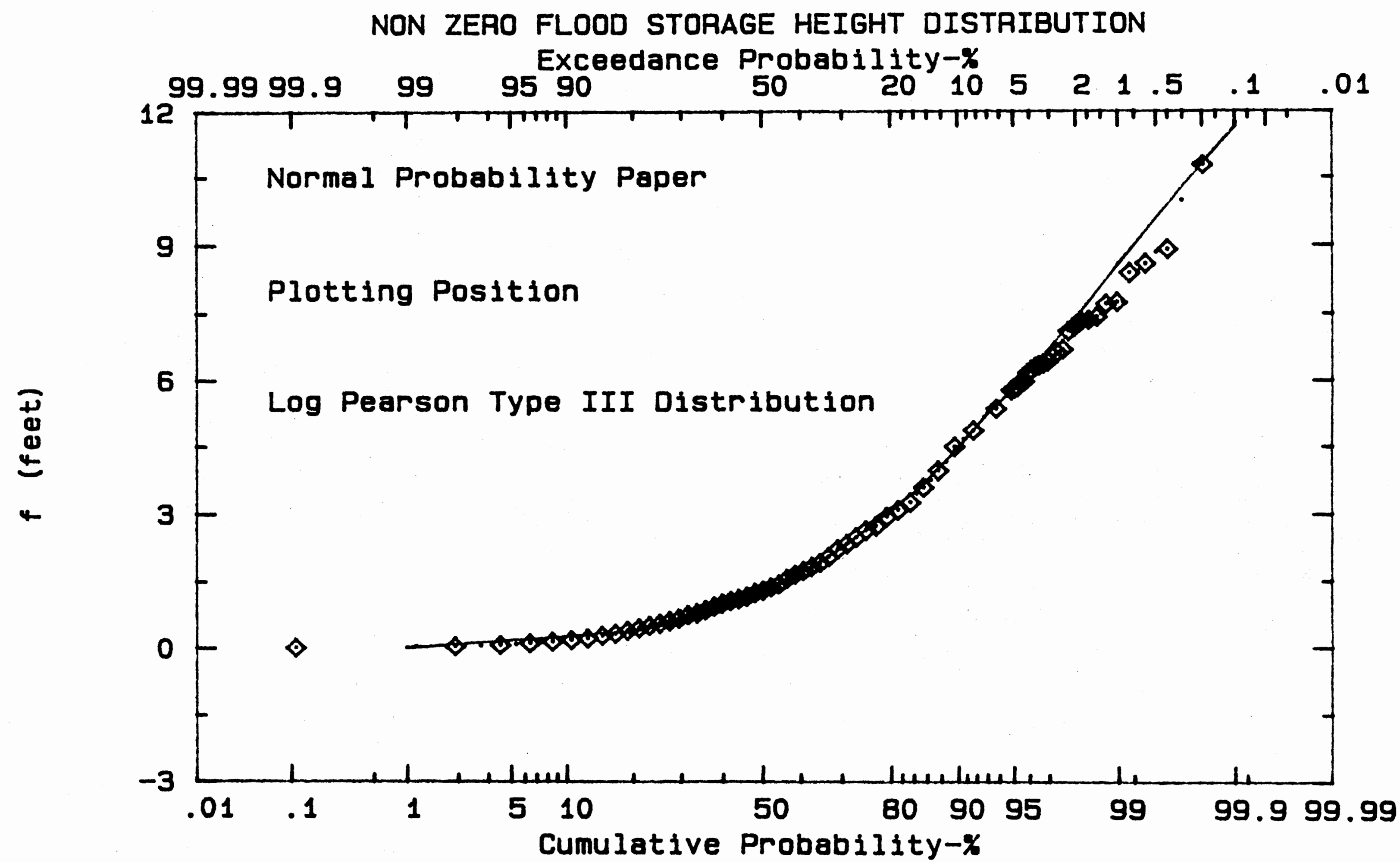

Figure 12. Fit of the Log Pearson Type III Distribution to the Nonzero Flood Storage Height Data

to that determined by the probabilistic approach while using the SCS average-valued model, it is possible to use a rainfall intensity of return period different than the return period of flow used to design the structure. This approach consisted of using a trial and error process that kept the retention parameter constantly equal the average value, S_m, and used different 24-hour rainfall depth values. The rainfall depth that resulted in a flood storage height equal to f_{10} was found to be

$$R^* = 7.3 \text{ inches}$$

the return period of this rainfall is determined by use of the extreme value type I distribution

$$T^* = 1/(1 - (\exp(-\exp(\beta - R^*)/\alpha)))$$

α and β are as defined previously.

$$T^* = 27 \text{ years}$$

From this result, it may be concluded that the use of a T-year rainfall to design for a T-year flow may be in error if average hydrograph model parameters are used.

This approach would not be easily accepted by most hydrologists. Therefore, it is not recommended as an option for use with the SCS model for design purposes. It is proposed only to show the falsity of the assumption of equality between return period rainfall and resulting flow where average model parameters are used.

Calibration Based on the Retention Parameter

Unlike rainfall, explaining the underprediction of the design flood storage height as a consequence of using non suitable S values might be accepted by most hydrologists. The underprediction of the design flood storage height is to be avoided by using an S value different than the average. It is obvious that the flood storage height is an increasing function of the runoff volume. It also known from the SCS model that runoff volume is a decreasing function of S values. Since f is smaller than f_{10}, then the S value which, if used by the SCS standard model, would result in an f value equal to f_{10}, is smaller than the average S. This value, denoted by S*, was determined by trial and error to be

$$S^* = 3.30 \text{ inches.}$$

The corresponding curve number is

$$CN^* = 75.2.$$

The curve number used in the average-valued approach was equal to 67, therefore, an immediate suggestion is to increase the curve number corresponding to average conditions by about 12 %. This suggestion concerns the assumed reservoir and watershed characteristics, and rainfall intensity.

The detention structure considered in this study was designed to control 10-year return period flows. Therefore a 10-year return period rainfall and a range of watershed average condition curve numbers and reservoir characteristics are considered to determine a set of correction factors suggested to be applied on the average condition curve numbers for the design of small flood water retarding structures. The range of curve numbers, the corresponding average S values and their assumed statistics are shown in Table 14.

The calculations are made assuming constant watershed geometric characteristics and a constant coefficient of variation of the S values. The different reservoir characteristics, mainly the equations defining the stage-storage and the stage-discharge relationships are shown in Tables 15 and 16, respectively. These relationships defined the reservoir characteristics for the associated CN used in all subsequent analyses. For every case, f, f_{10}, S*, and CN* were determined similarly to the previous example (CN = 67). A summary of the calculation results is shown in Table 17. Using the range of CN and their corresponding CN* values, a set of conversion factors was determined (Table 18). This set may be referred as the factors of converting average condition curve numbers to consider the probabilistic variations.

Generalization of the Calibration Approach for Different Return Period Rainfalls

In this section the calibration approach is

TABLE 14

SUMMARY STATISTICS RELATIVE TO THE RANGE OF CURVE NUMBERS USED

CN	S_m (inch)	Standard Deviation (inch)	Coefficient of Variation
50	10.00	8.00	0.8
60	6.67	5.34	0.8
70	4.28	3.43	0.8
80	2.50	2.00	0.8
90	1.11	0.89	0.8

TABLE 15

STAGE-STORAGE RELATIONSHIP EQUATIONS FOR THE DIFFERENT RESERVOIR CASES

CN (AMC II)	Z_1 (%)	Z_2 (%)	Storage(1) (acre-feet)
50	10.00	4.63	$72\ h^3/43560$
60	10.00	2.90	$115\ h^3/43560$
70	8.33	2.10	$192\ h^3/43560$
80	8.33	2.00	$200\ h^3/43560$
90	8.33	1.43	$280\ h^3/43560$

(1) h is the water level in the reservoir.

TABLE 16

STAGE-DISCHARGE RELATIONSHIP EQUATIONS FOR THE DIFFERENT RESERVOIR CASES

CN (AMC II)	Diameter[1] of Spillway (inch)	Discharge[2] Weir Flow (cfs)	Discharge[2] Orifice Flow (cfs)	Discharge[2] Pipe Flow (cfs)
50	15	$17.67\ h^{3/2}$	$13.30\ h^{1/2}$	$4.04(h+19.25)^{1/2}$
60	24	$28.30\ h^{3/2}$	$34.04\ h^{1/2}$	$12.11(h+18.80)^{1/2}$
70	30	$35.34\ h^{3/2}$	$53.18\ h^{1/2}$	$20.06(h+18.50)^{1/2}$
80	48	$56.55\ h^{3/2}$	$136.14\ h^{1/2}$	$56.12(h+17.60)^{1/2}$
90	60	$70.68\ h^{3/2}$	$212.72\ h^{1/2}$	$90.35(h+17.00)^{1/2}$

(1) Diameter values are those of th barrel of the principal spillway. The diameter of the riser is taken equal to one and one half times the diameter of the barrel.

(2) - The design discharge is taken equal to the minimum of flows.
- h is the head above the riser of the principal spillway.

TABLE 17

SUMMARY OF CALCULATION RESULTS FOR THE CONSIDERED RANGE OF CURVE NUMBERS

Return period = 10 years
Rainfall = 6 inches

CN	S_m (inch)	f (feet)	f_{10} (feet)	S* (inch)	CN*
50	10.00	3.03	6.73	6.26	61.5
60	6.67	3.02	5.50	3.97	71.6
70	4.29	3.04	4.24	2.80	78.1
80	2.50	3.02	3.62	1.75	85.1
90	1.11	3.03	3.21	0.85	92.2

TABLE 18

FACTORS OF CONVERTING AVERAGE CONDITION CURVE NUMBERS TO PROBABILISTIC CONDITIONS

Curve Number (AMC II)	Factor of Conversion
50	1.230
60	1.193
70	1.123
80	1.064
90	1.024

generalized by considering a range of rainfall return periods. A summary of the calculation results is presented in Table 19. Similarly to the previous examples, f values are determined by using average condition curve numbers, f_T values are read from the plotting position outputs of the different simulations, and S* values are determined by trial and error. The resulting set of conversion factors is presented in table 20.

In real cases the 2-year and 5-year return period flows are controlled by small structures such as ponds and levees whose construction features are different from those of small reservoirs considered in this study. The 25-year return period flows are controlled by bigger reservoirs or dams having more complex design features. Therefore, the above set of conversion factors are not recommended for use for design purposes as much as considered to draw conclusions about the validity of the average-valued approach as a prediction procedure.

By examining the set of conversion factors and the summary of calculation results, it may be concluded that

1) for all rainfall return periods and curve number cases, the average-valued approach underpredicted and conversion factors greater than unity are needed.

2) The magnitude of conversion factors increases with increasing rainfall return periods, therefore, the underprediction is worst for higher return period rainfalls.

3) Within a given return period, the conversion factors decrease with increasing curve number values, therefore, the underprediction is less serious for higher curve number values for which the standard SCS procedure approaches the probabilistic procedure.

TABLE 19

SUMMARY OF THE CALCULATION RESULTS
FOR RANGE OF RETURN PERIODS
AND CN VALUES

Return Period (years)	Rainfall (inch)	CN	S_m (in)	f (ft)	f_T (ft)	S* (in)	CN*
2	3.5	50	10.00	0.34	0.67	8.05	55.4
		60	6.67	0.71	1.11	5.15	65.8
		70	4.29	1.04	1.32	2.95	77.2
		80	2.5	1.49	1.72	2.02	83.2
		90	1.11	1.79	1.91	0.85	92.2
5	5	50	10.00	1.46	3.95	6.69	59.9
		60	6.67	1.84	3.79	4.01	71.4
		70	4.29	2.12	3.00	2.95	77.2
		80	2.5	2.33	2.91	1.66	85.8
		90	1.11	2.56	2.72	0.80	92.6
10	6	50	10.00	3.03	6.73	6.26	61.5
		60	6.67	3.02	5.49	3.97	71.6
		70	4.29	3.03	4.24	2.80	78.1
		80	2.50	3.02	3.62	1.75	85.1
		90	1.11	3.03	3.21	0.73	93.2
25	7	50	10.00	5.07	x	x	x
		60	6.67	4.46	7.82	3.37	71.6
		70	4.29	4.05	5.41	2.72	78.6
		80	2.50	3.84	4.51	1.71	85.4
		90	1.11	3.54	3.85	0.66	93.8

(X) f_T exceeded 9 feet

TABLE 20

FACTORS OF CONVERTING AVERAGE CONDITION CURVE NUMBERS TO PROBABILISTIC CONDITIONS FOR DIFFERENT RETURN PERIOD RAINFALLS

Return Period / Curve Number	2	5	10	25
50	1.11	1.20	1.23	x
60	1.10	1.19	1.20	1.25
70	1.06	1.10	1.12	1.22
80	1.04	1.07	1.06	1.07
90	1.02	1.03	1.02	1.04

(x) f_T exceeded 9 feet

CHAPTER VI

SUMMARY AND CONCLUSIONS

Most of hydrologic models define their input parameters as average values neglecting the uncertainty that may be caused by their random variability inherited from the nature of the hydrologic phenomena. The objective of this study was to show the necessity of considering the probabilistic behavior of hydrologic model parameters. This was done by examining the design of certain aspect of a hypothetical detention structure planned for the protection of a hypothetical watershed. The SCS runoff model was used and a simulation model that treated the SCS model parameters, S and R, as random variables, was developed. The procedure was to determine the design flood storage height of a hypothetically defined reservoir. This was done by use of both the SCS standard approach and the simulation model that accounted for the joint probabilistic behavior of the SCS parameters. By comparing the results, it was possible to conclude:

1) Compared with the probabilistic approach, the SCS standard approach underpredicted the design flood storage height.

2) The assumption stating that the return period of a

flow is equal to the return period of the rainfall producing that flow, may be in error if the flow is predicted based on average model parameters.

3) The uncertainty in hydrologic modeling may be treated and alleviated by use of stochastic processes.

4) Average-valued hydrologic models would be more reliable if some parameter calibration schemes such as conversion factors are made available.

The presented calibration scheme may be criticized as the result of some theoretical assumptions. In order to come up with more realistic and practical solutions that account for the actual variability of the parameters, it is suggested to

1) Use actual watersheds for which actual rainfall and runoff data was or may be collected.

2) Select the above watersheds to be protected by actual detention structure for which flooding events were or may be recorded.

3) Conduct analyses that relate rainfall data and the retention parameter data, derived from the observed rainfall and runoff records, to the frequency of overflows.

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APPENDIXES

APPENDIX A

COMPUTER CODE OF THE PROBABILISTIC MODEL

```
10 CLS
20 DIM V(50,10),U(50,10),GESVAL(1000),GERVAL(1000),FSH(1000),O(500),UH(300)
30 DIM T(500),R(300),CRE(300),RE(300),H(500),TI(300),QI(300),Q(500)
40 DIM HS(50),S(50),HQ(50),QD(50),IH(500),T1(300),TT(300),N$(20)
50 DIM MSH(1000)
60 PRINT "This program computes a sample of flood storage "
70 PRINT "heights for a given reservoir. The computations"
80 PRINT "are based on the SCS model. Values of the SCS "
90 PRINT "retention parameter are simulated from the log-"
100 PRINT "normal distribution and rainfall data is simulated"
110 PRINT "from the extreme value type I distribution"
120 PRINT
130 INPUT "Enter Simulation size in the range [10,1000]";N:PRINT
140 PRINT "Enter data related to routing an inflow hydrograph":PRINT
150 INPUT "Watershed Area(acres)";AREA:PRINT
160 INPUT "Maximum Flow Length(feet)";FLENGTH:PRINT
170 INPUT "Land Slope (in %)";LSLOPE:PRINT
180 PRINT "Enter data related to Reservoir Routing":PRINT
190 INPUT "Elevation of the Principal Spillway(feet)";ELPSP:PRINT
200 INPUT "name of the file containing the Stage-Storage curve data";SSF$
210 OPEN "I",#1,SSF$
220 INPUT #1,SNV,NO
230 FOR I = 1 TO SNV:INPUT #1,N$(I):NEXT
240 FOR I = 1 TO NO
250 FOR J = 1 TO SNV
260 INPUT #1 ,V(I,J)
270 NEXT J,I
280 CLOSE #1:PRINT
290 INPUT "Name of the file containing the stage-discharge curve data";SDF$
300 OPEN "i",#1,SDF$
310 INPUT #1,DNV,NO
320 FOR I = 1 TO DNV:INPUT #1,N$(I):NEXT
330 FOR I = 1 TO NO
340 FOR  J = 1 TO DNV
350 INPUT #1,U(I,J)
360 NEXT J,I
370 CLOSE #1:PRINT
380 INPUT "file name for output";OUTP$
390 OPEN "o",#5,OUTP$
400 REM***************SCS PARAMETER DATA GENERATION******************************
410 PRINT "Data Generation":PRINT
420 PRINT "Data generation of the SCS parameter S"
430 PRINT "Done using the Lognormal prob.dist":PRINT
440 INPUT "Mean of data to be generated(inch)";M:PRINT
450 INPUT "Standard deviation of data to be generated(inch)";SD:PRINT
460 YM = .5 * LOG((M^2)/((SD/M)^2 +1))
470 YSD = SQR(LOG((SD/M)^2+1)):PRINT
```

```
480 RANDOMIZE TIMER
490 SGV = 0
500 SGVS = 0
510 FOR I = 1 TO N
520 GOSUB 760
530 SGV = SGV + GESVAL(I)
540 SGVS = SGVS + (GESVAL(I))^2
550 NEXT I
560 PRINT #5," Simulated Values of S":PRINT #5,
570 PRINT #5, N;" Observations":PRINT #5,
580 FOR I = 0 TO N - 10 STEP 10
590 PRINT #5, USING "  ##.##";GESVAL(I+1);GESVAL(I+2);GESVAL(I+3);GESVAL(I+4);GE
SVAL(I+5);GESVAL(I+6);GESVAL(I+7);GESVAL(I+8);GESVAL(I+9);GESVAL(I+10)
600 NEXT I :PRINT #5,
610 PRINT #5,"Statistics: ":PRINT #5,
620 PRINT #5,"                    Mean      Standard deviation":PRINT #5,
630 PRINT #5,"Original";
640 PRINT #5, USING "           ##.##";M;SD
650 PRINT #5, "Simulated  ";
660 PRINT #5, USING "        ###.## ";SGV/N;SQR((SGVS-((SGV^2)/N))/(N-1)):PRINT
 #5,
670 GSV$ = "NETPAR.DAT"
680 OPEN "O",#3,GSV$
690 PRINT #3,1;N:PRINT #3,"GEN. S VAL."
700 FOR I = 1 TO N
710 PRINT #3,GESVAL(I)
720 NEXT I
730 CLOSE #3
740 PRINT
750 GOTO 900
760 REM--subroutine for lognormal data generation--
770 IF NRN = 1 THEN 870
780 R1 = 2 * RND - 1
790 R2 = 2 * RND - 1
800 S = R1^2 + R2^2
810 IF S >= 1 THEN 780
820 RN1 = R1 * SQR((-2*LOG(S))/S)
830 RN2 = R2 * SQR((-2*LOG(S))/S)
840 GESVAL(I) = EXP(YM + YSD*RN1)
850 NRN = NRN + 1
860 RETURN
870 GESVAL(I) = EXP(YM + YSD*RN2)
880 NRN = 0
890 RETURN
900 PRINT
910 REM****************RAINFALL DATA GENERATION*************************************
920 PRINT "Generation of rainfall data done using the "
```

```
930 PRINT "extreme value type I prob.Dist.":PRINT
940 INPUT "The 2-year 24-hour rainfall(inch)";R2:PRINT
950 INPUT "the100-year 24-hour rainfall(inch)";R100:PRINT
960 A = .236 * (R100 - R2):B = R100 - 1.086 * (R100 - R2)
970 RANDOMIZE TIMER
980 FOR I = 1 TO N
990 GERVAL(I) = B - A * LOG(-LOG(RND))
1000 NEXT I
1010 PRINT #5," Simulated Rainfall":PRINT #5,:PRINT #5, N;" Observations":PRINT
#5,
1020 FOR I = 0 TO N - 10 STEP 10
1030 PRINT #5, USING "  ##.##";GERVAL(I+1);GERVAL(I+2);GERVAL(I+3);GERVAL(I+4);G
ERVAL(I+5);GERVAL(I+6);GERVAL(I+7);GERVAL(I+8);GERVAL(I+9);GERVAL(I+10)
1040 NEXT I
1050 PRINT #5, :PRINT #5, "Statistics: ":PRINT #5,
1060 PRINT #5, " R 2-24        R 100-24       Alpha        Beta"
1070 PRINT #5, USING "  ##.##         ##.##         ##.##        ##.## ";R2;R100;A;B

1080 PRINT #5, :GRV$="RAINFA.DAT"
1090 OPEN "O",#3,GRV$
1100 PRINT #3,1;N
1110 PRINT #3,"RAINFALL"
1120 FOR I = 1 TO N
1130 PRINT #3,GERVAL(I)
1140 NEXT I
1150 CLOSE #3
1160 PRINT
1170 REM**************FLOOD STORAGE HEIGHT DETERMINATION************************
1180 FOR K = 1 TO N
1190 GOSUB 2820:PRINT
1200 PRINT "PROCESSING FOR ";K;"TH PAIR (S= ";GESVAL(K);", R= ";GERVAL(K);")"
1210 REM******************SCS CURVILINEAR UNIT HYDROGRAPH*******************
1220 SFLO = GESVAL(K)
1230 LAGT = 60*((FLENGTH^.8)*(SFLO+1)^.7)/1900/SQR(LSLOPE)
1240 TC = LAGT/.6
1250 DT = LAGT/3
1260 TP = LAGT + DT/2
1270 DT = 5 * INT(DT/5 + .5):IF DT < 5 THEN DT = 5
1280 TP = 5 * INT(TP/5):IF TP < 5 THEN TP = 5
1290 QP = 484 * AREA/640/TP*60
1300 NUNO = INT(TP*4/DT) :C1=DT/TP
1310 FOR J = 1 TO NUNO
1320 C2 = (J-1)*C1
1330 UH(J) = QP*(C2*EXP(1-C2))^3.75
1340 NEXT J
1350 REM*****************RAINFALL SECTION***************************************
1360 T2 = 24
```

```
1370 P24 = GENVAL(K)
1380 RS = GESVAL(K):PP24 = .2*RS/P24
1390 T = 1
1400 T = T + .25
1410 IF T >= 24 THEN FSH(K) = 0! :GOTO 2190
1420 RNS = 12 + (T - 12)*(24.04/(2*ABS(T-12) + .04))^.755
1430 IF RNS < 24*PP24 THEN 1400
1440 IF PP24 > .5 THEN T1 = T - .5:GOTO 1460
1450 T1 = T - .25
1460 NTR = INT(60*(T2-T1)/DT)
1470 FOR I = 1 TO NTR
1480 T(I) = T1 +(I - 1)*DT/60
1490 T = T(I) - 12
1500 C1 = (24.04/(2*ABS(T)+.04))^.755
1510 R(I) = P24*(.5+T*C1/24)
1520 NEXT I
1530 REM******************ABSTRUCTIONS VIA SCS EQUATION**********************
1540 S = GESVAL(K)
1550 FOR I = 1 TO NTR
1560 IF R(I) < .2 * S THEN CRE(I) = 0:GOTO 1580
1570 CRE(I) = (R(I)-.2*S)^2/(R(I) + .8*S)
1580 NEXT I
1590 REM******************RON COMPUTATION*************************************
1600 NNO = NUNO + NTR
1610 RE(1) = 0
1620 FOR I = 2 TO NTR
1630 RE(I) = CRE(I) - CRE(I-1)
1640 IF RE(I) < 0 THEN RE(I) = 0
1650 NEXT I
1660 FOR J = 1 TO NNO
1670 SMM = 0
1680 FOR I = 1 TO J
1690 SMM = SMM + UN(I)*RE(J-I+1)
1700 NEXT I
1710 IN(J) = SMM:IF IN(J) < 0 THEN IN(J) = 0
1720 TT(J) =T(1) + (J-1)*DT/60
1730 NEXT J
1740 REM********************RESERVOIR ROUTING*********************************
1750 FOR I = 1 TO NNO:TI(I)=TT(I):QI(I)=IN(I):NEXT I
1760 NIN = NNO
1770 RDT = .2
1780 J = 0:T1(1)=TI(1):Q(1)=QI(1):INVOL = Q(1)
1790 J=1
1800 NIN = INT((TI(NIN)-T1(1))/RDT)+1
1810 FOR I = 2 TO NIN
1820 T1(I) = T1(I-1)+RDT:T1(I)=INT(100*(T1(I)+.005))/100
1830 IF T1(I) <= TI(J) THEN GOTO 1850
```

```
1840 J = J+1:GOTO 1830
1850 Q(I) = QI(J-1)+(QI(J)-QI(J-1))*(TI(I)-TI(J-1))/(TI(J)-TI(J-1))
1860 INVOL = INVOL + Q(I)
1870 NEXT I
1880 IF INVOL <= 2 THEN FSH(K) = 0:GOTO 2190
1890 FOR I = 1 TO NO:BS(I)=V(I,1):S(I)=V(I,SNV):NEXT I
1900 FOR I = 1 TO NO:BQ(I)=W(I,1):QD(I)=W(I,DNV):NEXT I
1910 REM*************************ROUTING COMPUTATIONS***************************
1920 CV = .0001
1930 DTS = RDT*3600
1940 H1 = ELPSP
1950 H = H1:GOSUB 2650
1960 GOSUB 2730
1970 S1 = STOR:O1 = DISCH
1980 H21=H1:S21=S1:O21=O1
1990 RHS = S1 - O1 * DTS/2 + (Q(1) + Q(2))*DTS/2
2000 LHS1 = S21 + O21 * DTS/2
2010 IF ABS(LHS1 - RHS)<CV*RHS THEN S22=S1:LHS2=LHS1:O22=O1:H22=H1:GOTO 2130
2020 H22 = H21 - .2 * SGN(LHS1-RHS)
2030 H=H22:GOSUB 2650
2040 GOSUB 2730
2050 S22 = STOR:O22=DISCH
2060 LHS2=S22+O22*DTS/2
2070 IF ABS(LHS2-RHS)<CV*RHS THEN 2130
2080 DX = LHS2-LHS1:DY=H22-H21
2090 H21=H22:LHS1=LHS2
2100 IF DX = 0 THEN 2130
2110 H22 = H22 - (LHS2 -RHS)*DY/DX
2120 GOTO 2030
2130 IO = IO +1:H(IO)=H22:O(IO)=O22
2140 IF H(IO) < H(IO-1) THEN FSH(K) = H(IO-1) - ELPSP:GOTO 2190
2150 IF IO >= NIN THEN T(IO+1)=T(IO)+RDT:Q(IO+1)=0
2160 S1=S22:O1=O22:RHS=S1-O1*DTS/2+(Q(IO+1)+Q(IO))*DTS/2
2170 H21=H22:S22=S21:O22=O21:LHS1=LHS2
2180 GOTO 2020
2190 IO = 0 :NEXT K
2200 PRINT #5,
2210 PRINT #5, "SAMPLE OF FLOOD STORAGE HEIGTS:":PRINT #5,
2220 PRINT #5, N;" Observations":PRINT #5,
2230 FOR I = 0 TO N-10 STEP 10
2240 PRINT #5, USING "  ##.##";FSH(I+1);FSH(I+2);FSH(I+3);FSH(I+4);FSH(I+5);FSH(
I+6);FSH(I+7);FSH(I+8);FSH(I+9);FSH(I+10)
2250 NEXT I:PRINT #5,
2260 NAM$ = "FLSTHT.DAT"
2270 OPEN "O",#3,NAM$
2280 PRINT #3,1,N
2290 PRINT #3,"Flood Storage Height"
```

```
2300 FOR I = 1 TO N
2310 PRINT #3,FSH(I)
2320 NEXT I
2330 CLOSE #3:PRINT
2340 REM -----COUNT AND ELIMINATE ZERO VALUES-----
2350 NZ = 0
2360 FOR I = 1 TO N
2370 IF FSH(I) > 0 THEN NZ = NZ +1:MSH(NZ) = FSH(I)
2380 NEXT I
2390 NO=N-NZ:ENZ=10*INT(NZ/10):ONZ=NZ-ENZ
2400 PRINT #5, "Number of observations equal to 0: ";NO:PRINT #5,
2410 PRINT #5,"Modified Sample of Flood Storage Heights": PRINT #5,
2420 PRINT #5, NZ;" Observations":PRINT #5,
2430 FOR I = 0 TO ENZ - 10 STEP 10
2440 PRINT #5, USING "  ##.##";MSH(I+1);MSH(I+2);MSH(I+3);MSH(I+4);MSH(I+5);MSH(
I+6);MSH(I+7);MSH(I+8);MSH(I+9);MSH(I+10)
2450 NEXT I
2460 FOR I = 1 TO ONZ
2470 PRINT #5, USING "  ##.##";MSH(ENZ+I);
2480 NEXT I:PRINT #5,
2490 MNAM$ = "MFLSTH.DAT"
2500 OPEN "o",#3,MNAM$
2510 PRINT #3,1;NZ
2520 PRINT #3,"FLOOD STORAGE HEIGHT"
2530 FOR I = 1 TO NZ
2540 PRINT #3,MSH(I)
2550 NEXT I
2560 CLOSE #3
2570 CLOSE #5
2580 PRINT "RESULTS OF THIS RUN ARE IN FILES:":PRINT
2590 PRINT:PRINT "PRINT OUT OF RESULTS                : ";OUTP$
2600 PRINT "S DATA                              : ";GSV$
2610 PRINT "R DATA                              : ";GRV$
2620 PRINT "FLOOD STORAGE HEIGHT DATA          :";NAM$
2630 PRINT "NON ZERO FLOOD STORAGE HEIGHT DATA :";MNAM$
2640 END
2650 REM************************STORAGE AS A FUNCTION OF STAGE****************
2660 IF H <= HS(1) THEN STOR = 43560!*S(1):GOTO 2720
2670 IF H >= HS(NO) THEN STOR = 43560!*S(NO):GOTO 2720
2680 FOR IZ = 1 TO NO
2690 IF H <= HS(IZ) THEN 2710
2700 NEXT IZ
2710 STOR=43560!*(S(IZ-1)+(H-HS(IZ-1))*(S(IZ)-S(IZ-1))/(HS(IZ)-HS(IZ-1)))
2720 RETURN
2730 REM************************DISCHARGE AS A FUNCTION OF STAGE****************
2740 IF H <= HQ(1) THEN DISCH = QD(1):GOTO 2800
2750 IF H >= HQ(NO) THEN DISCH = QD(NO):GOTO 2800
```

```
2760 FOR IZ = 1 TO NO
2770 IF H <= HQ(IZ) THEN 2790
2780 NEXT IZ
2790 DISCH=QD(IZ-1)+(H-HQ(IZ-1))*(QD(IZ)-QD(IZ-1))/(HQ(IZ)-HQ(IZ-1))
2800 RETURN
2810 REM**************SCREEN MESSAGE*********************************************
2820 CLS
2830 PRINT "COMPUTING...":PRINT
2840 PRINT "for inflow hydrograph routing:":PRINT
2850 PRINT "** The SCS curvilinear Unit Hydrograph is used. This program"
2860 PRINT "   approximates this hydrograph with a continuous function."
2870 PRINT
2880 PRINT "** The rainstorm pattern used is computed using the SCS "
2890 PRINT "   type II method."
2900 PRINT
2910 PRINT "** Runoff and total abstraction computations are based on the SCS"
2920 PRINT "   Curve Number approach. The SCS curve number equation is:"
2930 PRINT "   Q = (R - 0.2S)^2/(R + 0.8S), for R > 0.2s"
2940 PRINT "   where S = (1000/CN) - 10"
2950 PRINT
2960 PRINT "** Reservoir routing is based on the continuity equation principal"
2970 PRINT "   I - O = DS/DT"
2980 PRINT
2990 PRINT " STAND BY!!!"
3000 RETURN
```

APPENDIX B

SIMULATED S, RAINFALL, AND FLOOD STORAGE HEIGHT DATA

Simulated Values of S

1000 Observations

8.83	2.66	11.76	5.00	7.87	1.76	1.99	0.89	4.58	3.29
4.25	4.77	1.80	8.46	4.06	2.24	2.04	3.55	39.83	3.43
3.21	8.63	3.57	3.73	1.06	4.24	6.78	0.94	11.11	1.69
3.26	4.81	7.97	9.24	3.51	21.38	1.65	2.85	1.14	1.26
22.34	4.44	6.02	3.48	3.29	3.29	2.80	1.65	6.81	6.60
4.12	1.93	1.43	1.33	4.13	5.80	1.81	3.66	5.79	2.17
11.56	10.44	12.56	7.52	4.56	3.48	3.64	14.33	7.43	6.91
6.02	3.94	5.47	3.48	3.47	7.48	22.77	5.63	3.58	11.48
8.55	5.30	2.49	2.00	1.20	2.67	5.97	7.41	2.51	5.41
10.93	3.25	9.89	2.81	4.72	6.89	4.35	3.05	3.46	3.04
5.85	3.94	5.78	4.76	3.86	2.12	2.21	5.44	2.37	4.32
2.34	2.80	1.72	3.47	10.89	7.68	1.95	1.51	3.47	2.54
3.69	0.91	6.53	3.92	3.43	6.04	1.65	1.91	10.40	1.81
2.97	0.76	11.66	3.37	14.25	5.56	2.36	11.58	4.61	1.95
3.60	5.97	9.47	2.61	3.03	3.58	5.42	5.46	6.04	2.29
2.30	20.20	2.88	7.28	6.39	1.10	1.09	9.22	1.70	2.78
9.45	3.98	1.74	0.57	19.95	4.69	3.68	6.17	1.74	7.24
5.30	0.85	6.51	6.56	1.69	1.06	2.06	2.16	3.42	2.26
4.18	7.55	2.99	4.49	3.34	1.12	5.00	3.52	9.77	11.32
4.58	5.72	2.68	3.58	2.58	0.65	2.15	2.39	4.98	3.56
4.01	1.65	1.16	0.42	3.32	2.06	2.01	3.42	1.61	1.70
4.70	7.29	1.65	5.59	2.97	4.36	0.06	4.17	6.97	2.92
6.78	6.93	1.77	1.69	7.55	2.21	0.45	3.01	7.97	1.72
1.96	1.52	4.20	14.14	1.02	1.93	9.60	19.00	1.95	3.32
1.81	6.85	5.37	17.18	6.06	2.80	6.09	3.86	3.76	2.48
5.39	2.82	10.74	8.43	2.67	0.59	4.04	1.71	0.10	1.39
1.42	3.84	5.00	6.22	3.33	1.55	7.43	11.87	10.09	2.32
4.78	0.88	2.17	18.56	6.22	29.87	6.74	1.46	5.55	2.16
15.10	5.79	3.36	8.99	3.39	5.40	2.44	6.51	9.74	8.83
3.41	5.54	4.54	4.83	10.02	4.03	1.00	8.93	4.72	3.30
7.31	2.98	1.59	9.91	7.99	2.55	1.00	3.06	5.29	1.98
4.29	1.36	5.11	1.86	5.35	8.58	1.19	9.35	5.56	7.85
1.44	2.14	2.02	2.84	5.57	2.60	6.51	7.55	4.34	2.60
1.77	4.59	3.19	3.27	5.49	3.16	6.51	3.37	12.29	3.65
1.79	1.54	8.59	2.51	2.27	3.35	0.55	3.37	2.31	3.01
4.38	3.48	9.94	0.73	1.19	4.45	3.76	6.76	4.92	1.92
4.70	2.34	1.47	3.10	2.92	3.34	1.49	1.04	3.39	3.16
2.47	6.63	0.70	1.67	19.98	5.77	7.73	3.45	3.36	1.79
8.61	10.53	6.19	2.64	2.13	6.61	1.35	3.95	3.06	5.46
5.50	1.71	10.26	2.98	7.68	1.45	1.53	1.52	2.31	1.02
2.56	7.31	3.03	10.43	2.40	3.44	0.99	2.54	3.27	6.19
10.71	2.67	7.33	3.20	3.70	2.61	5.13	2.97	2.47	5.70
1.64	5.40	9.45	3.21	5.31	4.56	2.50	3.86	9.76	2.17
3.20	3.91	5.63	1.05	2.09	3.55	2.67	0.92	0.60	13.01

11.09	0.93	7.25	4.76	2.14	11.93	3.15	5.75	11.83	5.84
3.84	5.92	5.29	3.24	4.61	4.58	8.49	2.51	8.53	4.67
4.84	1.36	6.81	3.77	13.75	5.80	6.21	3.91	5.66	1.11
3.26	6.23	2.61	6.74	3.10	2.90	4.72	2.04	10.98	14.02
6.20	2.34	2.89	2.57	3.11	9.85	0.94	5.28	4.01	8.22
3.61	4.66	6.21	2.79	1.90	2.05	3.41	4.30	1.51	2.41
2.64	4.68	2.41	11.09	0.94	3.07	1.33	2.65	4.60	3.33
8.09	2.22	11.30	6.88	4.94	3.39	4.77	2.58	2.66	12.24
5.14	4.63	6.76	5.19	1.66	2.69	5.05	2.47	6.58	3.24
4.09	15.73	1.08	1.34	1.14	2.98	2.99	4.36	3.61	12.09
2.79	20.01	0.55	3.01	1.22	6.40	7.48	0.42	1.08	2.02
3.04	6.16	2.91	6.18	1.24	3.79	7.46	11.28	4.66	1.94
6.03	7.51	3.11	1.88	3.07	6.30	4.54	0.73	5.21	10.61
1.80	5.67	7.10	3.62	10.98	13.05	1.61	2.05	3.21	1.98
1.87	5.15	5.84	2.49	3.08	2.34	10.92	2.97	3.57	4.94
2.76	1.55	3.45	8.03	8.08	0.68	3.49	3.56	6.81	3.73
3.34	26.03	0.77	2.17	5.62	7.30	0.91	8.13	3.35	6.58
5.49	6.38	9.39	2.62	4.05	2.43	5.27	7.29	2.44	2.52
1.10	2.43	9.97	2.82	3.90	5.85	1.64	7.12	6.96	4.69
1.59	3.79	2.56	5.35	8.56	3.48	3.23	7.59	2.96	5.37
3.39	2.29	7.60	1.18	5.71	3.45	1.98	10.41	1.20	2.14
2.20	0.81	5.48	2.09	3.51	5.81	4.30	19.63	1.52	3.00
8.56	2.84	5.32	6.37	0.50	3.94	7.67	6.39	2.15	10.61
7.84	4.84	6.30	2.25	4.05	2.67	1.30	9.82	0.92	2.08
2.30	5.91	2.28	4.71	7.38	0.80	0.90	2.78	6.22	2.76
12.03	6.49	3.78	2.60	2.50	6.10	4.15	1.85	3.61	7.30
3.18	3.42	3.69	3.72	6.50	2.67	0.69	4.16	12.99	5.60
9.48	1.46	1.51	4.38	6.65	2.34	6.02	2.29	4.24	3.46
6.28	3.23	7.31	2.47	4.16	3.41	14.60	4.77	13.90	1.26
10.70	3.12	2.63	5.86	5.21	7.25	2.59	3.37	2.01	4.55
9.17	2.71	4.28	7.30	2.15	5.72	1.53	1.46	4.61	2.29
1.62	3.48	8.21	2.46	2.77	6.75	1.30	5.48	6.61	4.33
2.30	1.00	5.01	2.77	14.32	18.20	5.62	1.26	2.54	9.55
4.46	4.81	2.44	5.08	3.35	1.03	14.18	1.82	1.50	0.42
8.33	6.15	2.11	4.75	2.20	1.16	4.33	10.82	4.87	5.99
1.79	6.74	1.67	6.22	1.91	2.54	2.34	2.23	1.02	2.73
1.33	2.90	6.58	1.53	5.79	1.34	4.05	4.46	0.86	1.97
3.97	3.56	0.54	4.80	3.25	3.20	2.80	6.53	4.01	2.03
8.09	12.10	1.89	4.33	4.34	4.88	8.43	6.90	5.32	9.30
1.10	6.16	12.02	4.06	6.96	5.70	3.87	7.43	8.42	2.91
13.54	1.58	4.22	3.66	1.60	6.54	10.47	6.76	3.02	5.87
2.20	7.18	7.07	5.77	7.24	2.56	5.36	4.79	2.63	5.73
9.44	0.70	3.99	2.03	2.64	6.50	5.29	2.61	11.00	3.33
8.21	6.03	1.14	2.49	1.89	3.19	2.45	1.49	11.63	4.38
3.80	3.93	7.73	8.33	1.60	3.88	5.30	3.00	9.66	6.67
3.41	0.67	4.15	4.60	2.60	4.60	8.88	1.90	4.44	3.61
2.84	1.97	11.37	1.11	3.84	12.23	2.00	3.90	2.15	6.51

1.95	3.20	8.13	2.87	3.02	4.79	2.69	5.23	5.14	4.53
1.31	4.60	3.77	13.00	10.96	3.88	1.98	2.46	3.67	3.11
10.15	2.73	6.32	2.19	6.19	2.02	14.27	4.98	4.14	11.52
1.65	11.29	5.75	1.08	15.13	2.77	1.45	1.76	0.13	2.73
2.52	2.65	4.54	3.09	2.10	10.02	0.84	4.08	0.86	2.01
1.72	4.14	0.83	5.55	7.10	12.41	1.39	2.97	0.11	2.51
7.67	7.19	4.58	2.07	0.83	7.24	12.44	2.42	3.32	3.64
0.94	1.41	1.36	3.19	7.13	5.85	3.32	0.66	3.16	12.94
0.70	8.67	2.20	1.14	3.64	1.88	8.13	2.20	14.31	9.97

Statistics:

	Mean	Standard deviation
Original	4.92	3.99
Simulated	4.83	3.70

Simulated Rainfall

1000 Observations

3.84	1.66	7.20	7.80	4.34	3.24	0.09	4.74	1.41	3.71
3.36	0.82	3.60	4.33	3.28	2.17	2.11	1.51	2.13	1.84
3.39	5.05	4.49	5.59	4.40	3.74	2.93	4.15	4.37	4.82
2.97	5.90	3.13	4.30	5.66	5.02	3.36	2.98	3.67	1.71
2.31	10.07	3.52	4.71	3.81	3.76	4.46	3.93	5.37	3.83
3.27	3.08	6.99	2.43	0.65	4.11	3.66	3.74	5.27	4.27
1.75	2.89	4.50	4.37	2.45	3.73	2.86	2.79	3.44	4.69
6.23	2.29	2.17	2.47	3.36	1.43	2.91	3.83	5.11	5.43
3.35	4.34	2.73	2.79	5.25	4.15	3.00	3.27	3.85	2.28
4.71	4.25	4.84	1.94	4.29	9.65	5.05	2.88	2.88	3.03
1.55	4.95	4.07	3.48	4.46	5.62	3.01	4.51	1.78	5.93
2.68	2.77	4.59	1.42	4.39	4.60	3.12	2.86	2.88	4.09
4.04	1.49	2.17	3.68	2.04	2.60	4.73	2.33	7.78	4.10
6.28	6.12	3.23	4.02	2.56	3.27	4.25	3.99	2.55	4.64
1.80	4.21	3.93	2.90	3.44	2.60	4.54	3.96	6.18	2.99
3.27	4.24	3.33	5.20	1.17	2.40	3.00	6.45	3.47	4.22
3.45	2.31	2.15	5.28	6.02	3.16	2.57	3.17	5.01	2.04
2.02	0.96	4.02	1.62	3.00	3.05	3.36	0.86	3.13	5.14
4.25	6.19	2.49	6.61	5.22	2.39	3.17	3.65	4.89	2.80
3.15	5.55	2.08	3.78	1.08	1.63	4.76	2.74	2.35	5.08
5.70	1.26	1.38	3.16	0.84	2.42	1.67	5.18	3.34	6.99
4.55	2.68	7.26	2.23	2.44	5.28	3.69	4.95	2.97	3.40
4.29	3.58	1.30	2.31	4.24	3.45	3.77	3.37	2.77	3.24
3.90	1.68	4.29	8.24	1.06	5.39	3.47	2.70	2.55	1.92
2.62	4.66	4.76	5.59	1.61	2.56	6.44	4.84	3.09	2.73
5.71	6.03	2.90	4.59	5.79	0.92	6.17	3.02	5.29	7.95
4.74	8.47	1.16	3.70	0.46	4.17	1.90	2.60	3.02	3.26
3.22	3.84	4.04	1.66	3.64	3.59	2.51	2.83	6.25	2.30
2.08	2.85	1.31	4.62	0.98	2.05	3.61	4.72	4.02	3.54
5.40	3.50	3.37	2.03	7.25	4.34	3.94	4.44	2.00	3.53
6.16	5.16	2.18	4.41	3.04	3.60	1.73	2.15	4.74	3.65
4.41	3.21	3.69	3.71	5.06	5.93	10.21	5.07	3.40	5.38
3.86	6.44	4.16	6.51	4.20	7.75	7.70	5.93	2.75	4.95
4.25	3.62	3.19	3.93	6.74	5.52	2.63	5.05	3.11	3.99
6.96	1.75	5.16	6.45	3.26	4.11	2.70	2.68	3.00	7.95
2.62	4.24	3.86	3.49	2.66	2.37	4.16	4.46	3.01	3.76
5.18	3.75	2.57	2.52	2.18	6.67	2.95	3.36	1.74	3.78
3.65	5.67	1.76	1.72	4.99	1.99	3.76	2.62	3.32	4.76
1.43	4.76	3.16	4.11	3.16	5.54	4.45	2.30	4.48	3.52
2.83	1.98	12.21	4.23	1.41	3.51	3.12	8.11	5.69	6.06
3.83	3.37	3.68	5.07	3.13	4.26	2.29	3.00	4.50	1.41
3.01	2.77	4.09	2.94	3.34	2.20	5.11	4.33	1.47	4.09
2.12	3.45	4.37	6.32	3.85	4.85	1.79	2.65	3.28	5.70

1.82	3.93	3.84	2.16	3.28	2.91	2.47	1.75	3.37	1.91
4.32	4.05	1.57	4.73	4.32	5.47	6.59	4.11	3.94	4.06
2.65	6.71	2.32	5.15	2.71	3.23	3.06	3.68	3.16	3.19
3.74	4.96	3.41	7.49	5.47	2.66	2.62	2.96	5.02	3.11
2.46	4.44	2.59	4.48	3.63	1.78	3.35	3.39	3.07	3.47
3.73	2.98	3.22	3.67	2.13	4.21	3.81	1.18	2.17	3.98
1.64	5.48	1.53	5.83	3.89	3.12	2.33	3.45	1.22	4.72
3.33	4.98	6.74	4.02	2.29	6.77	5.40	2.12	2.50	2.90
2.85	1.97	3.31	3.49	3.68	3.49	2.75	2.33	2.09	1.96
4.23	4.16	1.62	3.54	2.25	2.83	8.21	2.77	2.91	3.30
4.73	3.43	3.26	3.34	2.38	2.57	2.60	7.39	1.46	5.40
2.67	3.91	2.71	5.86	1.69	4.50	4.22	4.40	6.21	3.57
3.35	1.91	4.61	2.87	3.24	2.68	2.42	2.50	2.22	1.79
1.95	5.45	3.59	3.18	1.39	3.54	3.47	7.18	2.64	3.27
2.02	2.11	5.65	3.28	4.96	2.66	2.31	4.33	5.15	1.83
2.80	5.22	1.98	3.11	2.14	2.66	2.48	1.58	3.31	4.80
4.12	2.14	2.64	2.84	2.88	3.35	3.59	2.06	3.03	2.37
8.29	1.20	2.05	5.70	2.88	10.26	3.15	4.00	3.80	1.67
1.45	3.60	4.51	2.71	3.88	3.16	4.07	2.18	3.32	4.62
2.30	2.08	10.72	5.88	3.88	3.51	2.42	3.61	2.40	3.31
2.98	2.93	2.42	3.00	1.05	0.85	5.96	3.25	4.01	3.06
1.52	3.41	2.92	6.85	3.39	1.26	3.37	3.66	1.31	3.97
2.22	2.68	4.20	3.25	4.52	4.64	5.70	1.73	2.36	3.61
2.90	4.08	8.49	5.07	4.36	2.07	1.50	3.10	5.71	5.92
11.46	6.50	2.98	3.91	4.72	2.62	5.08	2.44	2.56	2.43
1.00	2.92	3.02	3.63	2.43	5.30	3.05	1.99	6.10	4.21
2.83	3.02	2.43	5.51	4.09	1.20	2.61	7.30	1.13	0.80
3.69	3.71	1.62	4.35	2.77	1.92	2.93	2.96	1.52	13.61
3.32	4.98	3.80	7.20	2.01	3.27	1.76	3.64	3.39	3.06
3.37	7.39	3.91	6.72	1.97	2.66	2.77	2.99	4.10	3.64
1.51	4.32	2.34	3.73	2.05	1.77	4.09	3.94	1.96	2.14
3.25	3.70	4.05	4.57	2.01	2.10	3.23	5.75	3.68	4.10
3.66	7.22	2.83	3.95	1.92	2.29	2.01	0.84	1.48	2.57
4.16	3.49	2.20	3.07	1.74	1.71	2.88	3.39	2.35	5.00
1.84	3.62	2.66	1.24	2.05	3.21	1.60	3.69	2.93	4.88
6.09	2.91	2.05	2.68	2.56	2.66	5.12	6.98	1.90	2.56
3.68	1.79	1.79	3.52	3.05	7.70	3.44	2.52	3.95	2.75
4.35	2.89	2.02	3.25	5.17	3.73	1.46	2.63	3.83	5.15
5.74	1.60	3.30	4.71	4.59	4.40	1.42	3.01	5.02	2.40
4.62	2.07	2.98	2.66	4.23	2.46	4.61	3.07	4.41	2.43
4.37	6.75	7.30	5.36	5.09	4.61	3.11	2.89	2.04	4.13
4.32	4.02	1.87	3.81	3.26	1.83	6.49	4.26	3.38	2.46
1.87	5.04	3.69	5.10	9.01	2.47	2.54	2.70	2.76	3.52
1.38	2.22	2.09	5.27	4.73	1.06	4.03	3.07	2.59	3.44
4.32	1.06	2.21	3.98	8.52	2.71	2.22	3.32	2.52	3.87
2.88	5.14	4.34	4.33	4.82	3.40	8.70	2.91	3.66	2.99
1.58	2.63	4.49	2.53	3.22	3.05	5.69	3.42	4.08	2.57

4.23	2.32	4.33	4.59	4.65	3.32	3.93	1.66	5.83	1.31
2.23	5.45	3.12	1.69	4.16	4.69	4.46	2.59	5.66	1.39
3.06	1.98	1.53	3.65	1.77	3.87	2.05	7.30	1.90	6.00
2.84	2.55	6.85	3.78	5.41	2.60	2.66	4.85	8.33	5.12
6.32	7.13	2.61	5.61	3.31	3.85	1.03	6.08	4.12	2.77
2.36	4.39	3.57	2.34	2.82	2.64	2.99	3.11	4.61	1.03
2.34	6.76	2.59	2.67	2.99	5.11	4.37	6.70	3.43	2.67
2.18	3.41	3.63	3.18	1.53	1.60	2.68	1.67	4.84	1.63
5.43	4.83	3.34	4.74	4.64	2.57	5.65	2.87	5.50	4.89
5.23	6.23	6.51	2.63	3.96	2.60	2.32	1.79	4.76	2.51

Statistics:

R 2-24	R 100-24	Alpha	Beta
3.50	9.00	1.30	3.03

SAMPLE OF FLOOD STORAGE HEIGTS:

1000 Observations

0.40	0.44	1.25	5.16	0.75	2.49	8.39	5.45	0.04	1.80
1.09	0.00	2.85	0.63	1.10	1.02	1.05	0.15	0.00	0.36
1.54	0.92	2.42	3.60	4.81	1.36	0.31	4.60	0.32	4.63
1.19	3.07	0.23	0.51	3.86	0.98	2.71	1.38	3.72	1.13
0.00	8.43	0.71	2.73	1.89	1.84	2.99	3.46	1.54	0.75
1.07	2.11	7.71	1.89	0.00	1.10	2.91	1.62	1.80	3.36
0.00	0.05	0.23	0.83	0.46	1.70	0.96	0.00	0.43	1.11
2.60	0.51	0.17	0.75	1.40	0.00	0.00	0.98	3.14	0.62
0.25	1.38	1.33	1.74	5.78	2.73	0.47	0.36	2.49	0.22
0.46	2.37	0.63	0.59	1.58	5.81	2.49	1.23	1.04	1.34
0.02	2.66	1.08	1.02	2.24	5.29	1.80	1.45	0.61	3.48
1.38	1.23	4.30	0.13	0.35	0.91	2.14	2.26	1.04	2.77
1.89	1.14	0.08	1.47	0.48	0.18	4.56	1.35	1.09	3.60
5.28	7.36	0.05	2.06	0.00	0.68	3.15	0.18	0.50	4.13
0.29	1.10	0.35	1.42	1.73	0.80	1.48	1.10	2.54	1.73
2.07	0.33	1.70	1.29	0.00	2.07	2.87	1.44	2.81	2.78
0.20	0.51	1.25	6.70	0.15	0.84	0.76	0.51	4.84	0.04
0.13	0.59	0.87	0.10	2.23	2.97	1.74	0.07	1.25	4.56
1.78	1.83	0.94	4.19	3.42	2.03	0.73	1.61	0.66	0.17
0.86	2.16	0.73	1.70	0.10	1.56	4.15	1.40	0.32	3.13
3.45	0.47	0.84	3.95	0.10	1.33	0.41	3.33	2.73	7.39
1.80	0.16	7.75	0.19	0.91	2.71	4.15	2.48	0.30	1.75
0.95	0.57	0.46	1.44	0.76	2.33	4.67	1.68	0.13	2.49
3.15	0.95	1.80	1.24	0.25	5.24	0.19	0.00	1.49	0.43
1.68	1.13	1.65	0.19	0.02	1.08	2.35	2.59	1.09	1.34
2.48	5.09	0.04	0.75	4.92	0.75	3.90	3.26	1.14	0.84
4.89	7.15	1.29	0.76	0.00	3.98	0.12	0.01	0.07	1.99
0.85	4.26	3.11	0.00	0.73	0.00	0.16	2.27	2.94	1.15
0.00	0.43	0.10	0.67	0.02	0.13	2.31	1.24	0.35	0.29
3.71	0.81	1.01	0.20	1.71	1.95	4.25	0.61	0.61	1.57
1.90	3.78	1.37	0.47	0.21	2.21	1.33	0.66	1.66	2.01
1.86	2.88	1.03	2.93	1.89	1.35	10.78	0.80	0.75	1.26
3.66	6.54	2.67	5.64	1.21	7.42	3.86	1.66	0.68	3.79
3.76	1.16	1.37	2.04	3.51	4.02	0.22	3.21	0.51	1.86
7.29	1.01	0.90	5.95	2.09	2.17	0.08	0.92	2.67	7.33
0.59	2.23	0.28	3.99	2.32	0.44	1.97	1.05	1.18	2.95
2.41	2.51	1.94	0.92	0.73	5.33	2.39	3.41	0.30	1.94
2.35	1.83	1.66	0.88	0.47	0.09	0.52	0.86	1.41	4.49
0.00	0.51	0.50	2.70	2.09	1.74	4.57	0.51	2.25	0.04
0.47	1.11	6.20	2.64	0.00	3.19	2.59	8.91	5.25	6.43
2.48	0.42	1.98	0.63	1.77	2.27	2.03	1.58	2.63	0.32
0.05	1.29	0.73	1.19	1.26	0.93	2.05	2.75	0.36	1.60
1.27	0.82	0.51	4.99	1.08	2.16	0.59	0.75	0.13	5.35
0.40	1.66	0.99	1.78	2.24	1.84	1.06	1.42	3.97	0.00

0.31	4.49	0.03	1.92	3.46	0.59	5.44	1.11	0.15	1.06
0.76	3.13	0.26	3.42	0.59	0.91	0.17	2.34	0.19	0.86
1.16	5.24	0.51	5.97	0.41	0.33	0.25	0.94	1.74	2.98
0.80	1.16	1.16	1.06	1.07	0.46	0.95	2.38	0.05	0.04
0.78	1.65	1.56	2.28	0.63	0.41	4.14	0.04	0.42	0.53
0.20	2.75	0.27	4.86	3.13	2.06	0.67	1.14	0.50	3.69
1.02	2.22	6.42	0.22	2.07	5.84	5.85	0.78	0.48	1.11
0.14	0.85	0.07	0.54	1.08	1.52	0.57	0.99	0.75	0.00
1.36	1.53	0.15	0.92	1.39	1.33	5.69	1.40	0.33	1.50
2.31	0.56	3.23	3.06	2.00	1.01	1.03	5.30	0.12	0.55
1.17	0.00	3.18	4.61	1.14	1.15	0.76	5.48	7.10	2.70
1.62	0.05	3.09	0.37	3.03	0.80	0.09	0.04	0.31	0.81
0.07	1.37	1.83	3.12	0.17	0.66	1.07	8.60	0.43	0.09
1.10	0.13	1.61	1.28	0.53	0.28	1.48	3.73	3.46	0.85
1.86	2.13	0.09	1.69	0.65	1.37	0.19	0.30	1.32	1.85
2.67	1.39	0.87	0.14	0.15	3.85	1.57	0.46	0.35	0.61
7.33	0.00	2.00	5.35	0.47	6.23	3.25	0.55	1.85	0.17
0.02	0.68	0.57	1.27	1.25	1.78	1.22	0.05	1.94	3.49
1.93	0.83	4.82	4.90	1.63	0.75	1.59	0.55	0.11	0.93
2.29	0.96	1.07	0.58	0.11	0.08	4.53	0.33	2.36	0.61
0.18	2.26	0.20	7.77	0.72	0.08	2.44	0.18	0.71	3.06
1.06	2.82	1.24	2.18	2.40	1.41	3.31	0.00	1.65	1.92
0.12	2.57	5.76	1.48	5.38	0.38	0.00	0.48	5.30	0.94
7.21	3.78	0.39	2.89	2.32	1.18	5.47	0.05	2.46	0.93
0.66	0.44	1.76	1.12	0.09	6.36	0.14	0.63	2.45	2.73
1.41	0.39	0.63	4.61	3.81	0.00	0.64	7.71	0.03	0.00
1.84	1.72	0.18	2.19	0.28	0.62	3.28	0.86	0.00	11.73
0.16	5.16	3.52	5.03	0.05	1.98	0.04	2.49	1.12	1.17
0.58	6.30	0.65	6.33	0.27	0.89	0.00	0.72	0.09	3.57
0.00	2.64	0.98	0.07	0.53	0.08	2.72	1.99	0.95	0.29
0.16	2.18	1.56	0.97	1.63	0.15	2.74	6.16	1.19	3.12
3.13	5.96	0.13	2.66	0.59	0.10	2.40	0.00	0.05	0.57
3.20	3.64	0.24	1.49	0.00	0.00	0.47	3.20	1.02	0.73
0.17	1.09	1.30	0.12	1.06	3.23	0.00	2.94	2.36	0.88
1.50	0.40	0.98	0.54	1.39	2.33	2.57	1.34	0.14	0.26
2.95	0.02	0.95	0.67	2.08	7.50	2.19	1.33	4.26	1.24
4.47	1.28	0.29	2.74	1.00	3.60	0.08	0.58	4.35	4.83
3.61	0.19	3.97	1.89	2.79	2.58	0.24	0.76	2.65	1.34
0.83	0.00	2.01	0.62	1.68	0.40	0.76	0.35	1.42	0.03
4.74	3.03	1.11	2.99	1.31	1.43	1.07	0.21	0.12	2.56
0.14	3.66	0.22	1.67	2.63	0.03	1.19	0.94	1.67	0.24
0.77	1.23	0.59	1.76	4.81	1.11	0.35	0.55	1.29	0.78
0.00	2.30	0.38	4.94	3.53	0.00	1.19	1.60	0.34	1.51
0.67	0.00	1.78	2.66	9.98	1.02	0.95	2.88	0.02	1.40
0.93	2.90	0.78	0.65	4.74	1.27	6.05	1.28	0.24	0.35
0.21	2.89	2.02	0.49	1.77	0.80	1.17	2.59	2.25	0.77
2.73	1.30	0.29	5.02	2.44	0.05	3.02	0.17	5.61	0.00

1.21	3.88	0.22	0.40	2.52	1.88	3.09	0.40	2.57	0.04
2.71	0.21	0.13	0.06	0.00	1.62	1.02	6.97	0.33	4.70
0.05	1.10	3.04	2.77	1.79	1.51	0.00	1.88	6.63	0.52
6.63	1.30	0.32	6.39	0.03	2.35	0.36	6.56	0.60	1.26
1.04	3.04	1.14	0.79	1.67	0.03	3.20	0.98	5.31	0.19
1.44	4.66	2.66	0.39	0.29	0.43	4.41	5.04	0.33	1.27
0.04	0.45	1.16	2.12	1.26	0.03	0.00	0.52	3.01	0.19
6.28	5.02	3.04	2.99	1.04	0.29	4.05	3.24	4.00	0.31
6.37	1.48	6.30	2.33	1.03	1.61	0.04	0.69	0.18	0.07

Number of observations equal to 0: 39

Modified Sample of Flood Storage Heights

961 Observations

0.40	0.44	1.25	5.16	0.75	2.49	8.39	5.45	0.04	1.80
1.09	2.85	0.63	1.10	1.02	1.05	0.15	0.36	1.54	0.92
2.42	3.60	4.81	1.36	0.31	4.60	0.32	4.63	1.19	3.07
0.23	0.51	3.06	0.98	2.71	1.38	3.72	1.13	8.43	0.71
2.73	1.89	1.04	2.99	3.46	1.54	0.75	1.07	2.11	7.71
1.09	1.10	2.91	1.62	1.88	3.36	0.05	0.23	0.83	0.46
1.70	0.96	0.43	1.11	2.60	0.51	0.17	0.75	1.40	0.98
3.14	0.62	0.25	1.38	1.33	1.74	5.70	2.73	0.47	0.36
2.49	0.22	0.46	2.37	0.63	0.59	1.58	5.01	2.49	1.23
1.04	1.34	0.02	2.66	1.08	1.02	2.24	5.29	1.00	1.45
0.61	3.48	1.38	1.23	4.30	0.13	0.35	0.91	2.14	2.26
1.04	2.77	1.09	1.14	0.08	1.47	0.48	0.10	4.56	1.35
1.09	3.60	5.28	7.36	0.05	2.06	0.68	3.15	0.18	0.50
4.13	0.29	1.10	0.35	1.42	1.73	0.00	1.48	1.10	2.54
1.73	2.07	0.33	1.70	1.29	2.07	2.07	1.44	2.01	2.70
0.20	0.51	1.25	6.70	0.15	0.84	0.76	0.51	4.84	0.04
0.13	0.59	0.87	0.10	2.23	2.97	1.74	0.07	1.25	4.56
1.78	1.83	0.94	4.19	3.42	2.03	0.73	1.61	0.66	0.17
0.86	2.16	0.73	1.70	0.10	1.56	4.15	1.40	0.32	3.13
3.45	0.47	0.84	3.95	0.10	1.33	0.41	3.33	2.73	7.39
1.80	0.16	7.75	0.19	0.91	2.71	4.15	2.48	0.30	1.75
0.95	0.57	0.46	1.44	0.76	2.33	4.67	1.68	0.13	2.49
3.15	0.95	1.00	1.24	0.25	5.24	0.19	1.49	0.43	1.68
1.13	1.65	0.19	0.02	1.08	2.35	2.59	1.09	1.34	2.48
5.09	0.04	0.75	4.92	0.75	3.98	3.26	1.14	8.84	4.89
7.15	1.29	0.76	3.98	0.12	0.01	0.07	1.99	0.85	4.26
3.11	0.73	0.16	2.27	2.94	1.15	0.43	0.10	0.67	0.02
0.13	2.31	1.24	0.35	0.29	3.71	0.81	1.01	0.20	1.71
1.95	4.25	0.61	0.61	1.57	1.90	3.78	1.37	0.47	0.21
2.21	1.33	0.66	1.66	2.81	1.86	2.08	1.03	2.93	1.89
1.35	10.78	0.00	0.75	1.26	3.66	6.54	2.67	5.64	1.21

7.42	3.86	1.66	0.68	3.79	3.76	1.16	1.37	2.04	3.51
4.02	0.22	3.21	0.51	1.86	7.29	1.01	0.98	5.95	2.09
2.17	0.08	0.92	2.67	7.33	0.59	2.23	0.28	3.99	2.32
0.44	1.97	1.05	1.18	2.95	2.41	2.51	1.94	0.92	0.73
5.33	2.39	3.41	0.30	1.94	2.35	1.03	1.66	0.00	0.47
0.09	0.52	0.86	1.41	4.49	0.51	0.50	2.70	2.09	1.74
4.57	0.51	2.25	0.84	0.47	1.11	6.20	2.64	3.19	2.59
8.91	5.25	6.43	2.48	0.42	1.98	0.63	1.77	2.27	2.03
1.58	2.63	0.32	0.05	1.29	0.73	1.19	1.26	0.93	2.05
2.75	0.36	1.60	1.27	0.82	0.51	4.99	1.08	2.16	0.59
0.75	0.13	5.35	0.40	1.66	0.99	1.78	2.24	1.04	1.06
1.42	3.97	0.31	4.49	0.03	1.92	3.46	0.59	5.44	1.11
0.15	1.06	0.76	3.13	0.26	3.42	0.59	0.91	0.17	2.34
0.19	0.86	1.16	5.24	0.51	5.97	0.41	0.33	0.25	0.94
1.74	2.98	0.00	1.16	1.16	1.06	1.07	0.46	0.95	2.38
0.05	0.04	0.78	1.65	1.56	2.28	0.63	0.41	4.14	0.04
0.42	0.53	0.20	2.75	0.27	4.86	3.13	2.06	0.67	1.14
0.50	3.69	1.82	2.22	6.42	0.22	2.07	5.84	5.05	0.78
0.40	1.11	0.14	0.85	0.07	0.54	1.08	1.52	0.57	0.99
0.75	1.36	1.53	0.15	0.92	1.39	1.33	5.69	1.40	0.33
1.50	2.31	0.56	3.23	3.06	2.00	1.01	1.03	5.30	0.12
0.55	1.17	3.18	4.61	1.14	1.15	0.76	5.48	7.10	2.70
1.62	0.05	3.09	0.37	3.03	0.00	0.09	0.04	0.31	0.01
0.07	1.37	1.03	3.12	0.17	0.66	1.07	8.60	0.43	0.09
1.10	0.13	1.61	1.28	0.53	0.28	1.48	3.73	3.46	0.05
1.06	2.13	0.09	1.69	0.65	1.37	0.19	0.30	1.32	1.05
2.67	1.39	0.07	0.14	0.15	3.85	1.57	0.46	0.35	0.61
7.33	2.00	5.35	0.47	6.23	3.25	0.55	1.85	0.17	0.02
0.68	0.57	1.27	1.25	1.78	1.22	0.05	1.94	3.49	1.93
0.83	4.82	4.90	1.63	0.75	1.59	0.55	0.11	0.93	2.29
0.96	1.07	0.58	0.11	0.08	4.53	0.33	2.36	0.61	0.18
2.26	0.20	7.77	0.72	0.08	2.44	0.18	0.71	3.06	1.06
2.82	1.24	2.18	2.48	1.41	3.31	1.65	1.92	0.12	2.57
5.76	1.48	5.38	0.38	0.48	5.38	0.94	7.21	3.70	0.39
2.09	2.32	1.18	5.47	0.05	2.46	0.93	0.66	0.44	1.76
1.12	0.09	6.36	0.14	0.63	2.45	2.73	1.41	0.39	0.63
4.61	3.81	0.64	7.71	0.03	1.84	1.72	0.18	2.19	0.28
0.62	3.28	0.86	11.73	0.16	5.16	3.52	5.03	0.05	1.98
0.04	2.49	1.12	1.17	0.58	6.30	0.65	6.33	0.27	0.09
0.72	0.09	3.57	2.64	0.98	0.87	0.53	0.08	2.72	1.99
0.95	0.29	0.16	2.18	1.56	0.97	1.63	0.15	2.74	6.16
1.19	3.12	3.13	5.96	0.13	2.66	0.59	0.10	2.40	0.05
0.57	3.20	3.64	0.24	1.49	0.47	3.20	1.02	0.73	0.17
1.09	1.30	0.12	1.06	3.23	2.94	2.36	0.88	1.50	0.40
0.98	0.54	1.39	2.33	2.57	1.34	0.14	0.26	2.95	0.02
0.95	0.67	2.08	7.50	2.19	1.33	4.26	1.24	4.47	1.20
0.29	2.74	1.80	3.60	0.08	0.58	4.35	4.83	3.61	0.19

3.97	1.09	2.79	2.58	0.24	0.76	2.65	1.34	0.83	2.01
0.62	1.68	0.40	0.76	0.35	1.42	0.03	4.74	3.03	1.11
2.99	1.31	1.43	1.07	0.21	0.12	2.56	0.14	3.66	0.22
1.67	2.63	0.03	1.19	0.94	1.67	0.24	0.77	1.23	0.59
1.76	4.01	1.11	0.35	0.55	1.29	0.78	2.30	0.38	4.94
3.53	1.19	1.60	0.34	1.51	0.67	1.78	2.66	9.98	1.02
0.95	2.88	0.02	1.40	0.93	2.90	0.78	0.65	4.74	1.27
6.05	1.28	0.24	0.35	0.21	2.89	2.02	0.49	1.77	0.80
1.17	2.59	2.25	0.77	2.73	1.30	0.29	5.02	2.44	0.05
3.02	0.17	5.61	1.21	3.88	0.22	0.40	2.52	1.08	3.09
0.40	2.57	0.04	2.71	0.21	0.13	0.06	1.62	1.02	6.97
0.33	4.70	0.05	1.10	3.04	2.77	1.79	1.51	1.88	6.63
0.52	6.63	1.30	0.32	6.39	0.03	2.35	0.36	6.56	0.60
1.26	1.04	3.04	1.14	0.79	1.67	0.03	3.28	0.98	5.31
0.19	1.44	4.66	2.66	0.39	0.29	0.43	4.41	5.84	0.33
1.27	0.04	0.45	1.16	2.12	1.26	0.03	0.00	0.52	3.01
0.19	6.28	5.02	3.04	2.99	1.04	0.29	4.05	3.24	4.00
0.31	6.37	1.48	6.30	2.33	1.83	1.61	0.04	0.69	0.18
0.07									

APPENDIX C

FLOOD STORAGE HEIGHT PLOTTING POSITION DATA

******** PLOTTING POSITION OF OBSERVED DATA ******

Flood Storage Height

RANK	VALUE	RET PERIOD	PLOT POS
1	11.731	1001.000	0.090
2	10.776	500.500	0.190
3	9.980	333.660	0.290
4	8.907	250.250	0.390
5	8.843	200.200	0.490
6	8.596	166.830	0.590
7	8.426	143.000	0.690
8	8.392	125.120	0.790
9	7.768	111.220	0.890
10	7.753	100.100	0.990
11	7.713	91.000	1.090
12	7.713	83.410	1.190
13	7.496	77.000	1.290
14	7.423	71.500	1.390
15	7.395	66.730	1.490
16	7.356	62.560	1.590
17	7.335	58.880	1.690
18	7.329	55.610	1.790
19	7.290	52.680	1.890
20	7.207	50.050	1.990
21	7.148	47.660	2.090
22	7.100	45.500	2.190
23	6.970	43.520	2.290
24	6.697	41.700	2.390
25	6.632	40.040	2.490
26	6.627	38.500	2.590
27	6.557	37.070	2.690
28	6.536	35.750	2.790
29	6.429	34.510	2.890
30	6.419	33.360	2.990
31	6.392	32.290	3.090
32	6.372	31.280	3.190
33	6.361	30.330	3.290
34	6.328	29.440	3.390
35	6.303	28.600	3.490
36	6.297	27.800	3.590
37	6.276	27.050	3.690
38	6.233	26.340	3.790
39	6.197	25.660	3.890
40	6.160	25.020	3.990
41	6.045	24.410	4.090
42	5.969	23.830	4.190

43	5.962	23.270	4.290
44	5.948	22.750	4.390
45	5.848	22.240	4.490
46	5.839	21.760	4.590
47	5.836	21.290	4.690
48	5.810	20.850	4.790
49	5.783	20.420	4.890
50	5.763	20.020	4.990
51	5.694	19.620	5.090
52	5.637	19.250	5.190
53	5.614	18.880	5.290
54	5.482	18.530	5.390
55	5.472	18.200	5.490
56	5.451	17.870	5.590
57	5.437	17.560	5.690
58	5.382	17.250	5.790
59	5.381	16.960	5.890
60	5.353	16.680	5.990
61	5.350	16.400	6.090
62	5.325	16.140	6.190
63	5.312	15.880	6.290
64	5.305	15.640	6.390
65	5.292	15.400	6.490
66	5.285	15.160	6.590
67	5.254	14.940	6.690
68	5.245	14.720	6.790
69	5.244	14.500	6.890
70	5.164	14.300	6.990
71	5.155	14.090	7.090
72	5.085	13.900	7.190
73	5.031	13.710	7.290
74	5.023	13.520	7.390
75	5.020	13.340	7.490
76	4.995	13.170	7.590
77	4.935	12.990	7.690
78	4.918	12.830	7.790
79	4.905	12.670	7.890
80	4.895	12.510	7.990
81	4.856	12.350	8.090
82	4.843	12.200	8.190
83	4.826	12.060	8.290
84	4.822	11.910	8.390
85	4.808	11.770	8.490
86	4.807	11.630	8.590
87	4.736	11.500	8.690
88	4.735	11.370	8.790
89	4.700	11.240	8.890
90	4.668	11.120	8.990
91	4.662	11.000	9.090

92	4.633	10.880	9.190
93	4.615	10.760	9.290
94	4.615	10.640	9.390
95	4.599	10.530	9.490
96	4.573	10.420	9.590
97	4.560	10.310	9.690
98	4.560	10.210	9.790
99	4.530	10.110	9.890
100	4.491	10.010	9.990
101	4.490	9.910	10.080
102	4.471	9.810	10.180
103	4.411	9.710	10.280
104	4.347	9.620	10.380
105	4.302	9.530	10.480
106	4.262	9.440	10.580
107	4.261	9.350	10.680
108	4.251	9.260	10.780
109	4.186	9.180	10.880
110	4.155	9.100	10.980
111	4.154	9.010	11.080
112	4.140	8.930	11.180
113	4.131	8.850	11.280
114	4.052	8.780	11.380
115	4.020	8.700	11.480
116	4.001	8.620	11.580
117	3.988	8.550	11.680
118	3.979	8.480	11.780
119	3.978	8.410	11.880
120	3.972	8.340	11.980
121	3.967	8.270	12.080
122	3.953	8.200	12.180
123	3.883	8.130	12.280
124	3.864	8.070	12.380
125	3.858	8.000	12.480
126	3.848	7.940	12.580
127	3.813	7.880	12.680
128	3.790	7.820	12.780
129	3.785	7.750	12.880
130	3.780	7.700	12.980
131	3.763	7.640	13.080
132	3.731	7.580	13.180
133	3.722	7.520	13.280
134	3.712	7.470	13.380
135	3.689	7.410	13.480
136	3.664	7.360	13.580
137	3.663	7.300	13.680
138	3.642	7.250	13.780
139	3.606	7.200	13.880
140	3.599	7.150	13.980

141	3.599	7.090	14.080
142	3.597	7.040	14.180
143	3.571	6.990	14.280
144	3.533	6.950	14.380
145	3.520	6.900	14.480
146	3.508	6.850	14.580
147	3.485	6.800	14.680
148	3.479	6.760	14.780
149	3.462	6.710	14.880
150	3.459	6.670	14.980
151	3.456	6.620	15.080
152	3.447	6.580	15.180
153	3.419	6.540	15.280
154	3.417	6.490	15.380
155	3.408	6.450	15.480
156	3.360	6.410	15.580
157	3.327	6.370	15.680
158	3.309	6.330	15.780
159	3.279	6.290	15.880
160	3.277	6.250	15.980
161	3.265	6.210	16.080
162	3.250	6.170	16.180
163	3.238	6.140	16.280
164	3.230	6.100	16.380
165	3.229	6.060	16.480
166	3.214	6.030	16.580
167	3.204	5.990	16.680
168	3.199	5.950	16.780
169	3.188	5.920	16.880
170	3.181	5.880	16.980
171	3.153	5.850	17.080
172	3.152	5.810	17.180
173	3.141	5.780	17.280
174	3.134	5.750	17.380
175	3.133	5.720	17.480
176	3.132	5.680	17.580
177	3.130	5.650	17.680
178	3.125	5.620	17.780
179	3.122	5.590	17.880
180	3.110	5.560	17.980
181	3.094	5.530	18.080
182	3.089	5.500	18.180
183	3.071	5.460	18.280
184	3.060	5.440	18.380
185	3.056	5.410	18.480
186	3.043	5.380	18.580
187	3.042	5.350	18.680
188	3.035	5.320	18.780
189	3.031	5.290	18.880

190	3.028	5.260	18.980
191	3.024	5.240	19.080
192	3.006	5.210	19.180
193	2.995	5.180	19.280
194	2.991	5.150	19.380
195	2.989	5.130	19.480
196	2.980	5.100	19.580
197	2.965	5.080	19.680
198	2.955	5.050	19.780
199	2.948	5.030	19.880
200	2.945	5.000	19.980
201	2.942	4.980	20.070
202	2.934	4.950	20.170
203	2.909	4.930	20.270
204	2.904	4.900	20.370
205	2.890	4.880	20.470
206	2.886	4.850	20.570
207	2.883	4.830	20.670
208	2.878	4.810	20.770
209	2.865	4.780	20.870
210	2.850	4.760	20.970
211	2.823	4.740	21.070
212	2.814	4.720	21.170
213	2.812	4.690	21.270
214	2.788	4.670	21.370
215	2.778	4.650	21.470
216	2.774	4.630	21.570
217	2.768	4.610	21.670
218	2.754	4.590	21.770
219	2.746	4.570	21.870
220	2.744	4.550	21.970
221	2.736	4.520	22.070
222	2.735	4.500	22.170
223	2.732	4.480	22.270
224	2.730	4.460	22.370
225	2.729	4.440	22.470
226	2.728	4.420	22.570
227	2.719	4.400	22.670
228	2.715	4.390	22.770
229	2.713	4.370	22.870
230	2.712	4.350	22.970
231	2.701	4.330	23.070
232	2.698	4.310	23.170
233	2.669	4.290	23.270
234	2.667	4.270	23.370
235	2.666	4.250	23.470
236	2.665	4.240	23.570
237	2.663	4.220	23.670
238	2.662	4.200	23.770

APPENDIX D

CHI-SQUARE GOODNESS OF FIT TEST OF THE LOG PEARSON TYPE III DISTRIBUTION FIT TO THE NONZERO FLOOD STORAGE HEIGHT DATA

Class Boundaries Lower	Upper	Observed Number	Expected Number	$\frac{(O - E)^2}{E}$
0.000	0.195	110	96.1	2.01
0.195	0.400	74	96.1	5.08
0.400	0.640	89	96.1	0.52
0.640	0.900	75	96.1	4.63
0.900	1.280	79	96.1	3.04
1.280	1.600	120	96.1	5.94
1.600	2.280	123	96.1	7.53
2.280	3.100	111	96.1	2.31
3.100	4.480	79	96.1	3.04
4.480	+ oo	101	96.1	0.25
	Total	961	961	34.35

$X_c^2 = 34.35$

$X_{.9,\ 7} = 12.02$ (from Chi-square table)

$X_c^2 > X_{.9,\ 7}$ therefore, for a 10 % level of confidence, the hypothesis that the log Pearson type III distribution describes the nonzero flood storage height data is rejected (Haan, 1977).

The class boundaries were determined by using the statistics of the log transformed data (Table 12) and the K value for Pearson type III distribution table (Wilson, 1987). Ten equal expected frequency class intervals are used. For a given cumulative probability value, P, the corresponding nonzero flood storage height, f_P, is determined from

$$f_P = \exp\ (Y_m + K_T * S_y)$$

where Y_m and S_y are the mean and standard deviation of the log transformed data, K_T is a function of the skewness coefficient of the log transformed data, C_s, and T is the return period determined as the inverse of the exceedence probability.

$$T = 1/(1-P)$$

Example of calculation:

$P = 0.1$ then $T = 1.11$

$C_s = -0.922$ then $K_{1.11} = -1.339$

$Y_m = 0.0584$ and $S_y = 1.265$

$f_{.1} = \exp(0.0584 - 1.339*1.265)$

$= 0.195$

For a given class interval, the Observed Number represents the number of nonzero flood storage height plotting position data points bounded by the interval limits and the Expected Number is the total number of observations divided by the number of class intervals.

VITA 2

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