PREDICTING STORM RUNOFF FROM SMALL GRASSLAND WATERSHEDS WITH THE USDAHL HYDROLOGIC MODEL

By

RICHARD LEE BENGTSON

Bachelor of Science
University of Wyoming
Laramie, Wyoming
1966

Master of Science
University of Illinois
Urbana, Illinois
1967

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1980

PREDICTING STORM RUNOFF FROM SMALL

GRASSLAND WATERSHEDS WITH THE

USDAHL HYDROLOGIC MODEL

Thesis Approved:

Frank R. Crow
Thesis Adviser

Myron D. Paine

Richard N. DeVries

Charles E. King

James E. Garton

Norman N. Durham
Dean of the Graduate College

PREFACE

This study is concerned with calibrating the USDAHL model and testing the calibrations on three separate watersheds. It was financed by the Oklahoma State University Agricultural Experiment Station under Regional Project No. RR-1632 "Development of Hydrologic and Water Quality Models for Agriucltural and Forestry." I am very grateful to the Agricultural Engineering Department for providing financial support for the study and for providing me with a research assistantship as well.

The author wishes to express his thanks and deep appreciation to his major adviser, Professor Frank R. Crow, for his guidance and assistance throughout this study. Appreciation is also extended to the other committee members, Dr. Richard N. DeVries, Dr. James E. Garton, Dr. Myron D. Paine, and Dr. Charles E. Rice, for their suggestions and cooperation.

Appreciation is extended to Dr. Arlin D. Nicks, Agricultural Engineer for the USDA SEA-AR Southern Plains Watershed and Water Quality Laboratory, for his guidance and cooperation in providing watershed information. Thanks are also extended to Mr. Jack I. Fryrear, draftsman of the Agricultural Engineering Department, and to Darlene Richardson for the typing of this thesis.

Finally, heartfelt appreciation is expressed to my wife, Jean, and our son, Robert, for their understanding, encouragement, and many sacrifices.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

Statement of the Problem

The ever increasing demand for dependable water supplies and flood control in the United States requires the construction of increasingly expensive supply and control systems. These systems which may include municipal water supply systems; flood control, recreation, or water storage reservoirs; channels; bridges and culverts; and irrigation systems require potential flow to be included in the design. It is common for designers to devote a short time to determining the magnitude of storm runoff for which a structure should be designed. Far too frequently, all that is done is to apply a few convenient formulas and then add 25 or 30 percent as a safety factor. On the other hand, months may be spent on structural design. A full realization of the magnitude of the costs involved in the solution of water resource problems should impress those in charge of these designs with a deep sense of responsibility and inspire them to obtain the most reliable results possible.

Estimating peak runoff and water yield is difficult especially for small watersheds. The flow is influenced by such factors as watershed soil and crop characteristics, antecedent soil moisture conditions and rainfall intensity. Change in land use may either increase or decrease the runoff. Also small watersheds are usually ungaged and there is not any history of past runoff with which to establish a design flow. A poor estimate of storm runoff can lead to underdesigned structures with a high risk of system failure or overdesign with tremendous unnecessary additional expense. Predicting storm runoff for small ungaged watersheds presently is a guess at best.

However, abundant rainfall data is available. One method for generating more precise estimations of storm runoff from ungaged watersheds synthetically is by entering the rainfall data into a continuous simulation hydrologic model. This would produce simulated runoff data from which to compute a design flow. Also the model could be used to evaluate land use change. The model would be applied to the watershed incorporating the new land use plan. Then the plan could be evaluated for its environmental effects, including hydrology and water quality. Consequently, the feasibility and expense of the new land use plan could be determined before large amounts of money were spent installing the new land uses.

The United States Department of Agriculture Hydrograph Laboratory (USDAHL) model (Holtan et al., 1975) is an accounting system that apportions precipitation to surface runoff, infiltration, evaporation, transpiration, lateral subflow, and groundwater recharge. It continuously simulates soil moisture and therefore has an available foundation on which to compute storm runoff when given rainfall data. The input parameters are derived from readily available soil survey records, land use patterns, topography, and general climatic conditions. This model was selected for this project because:

(1) It used easily compiled watershed input parameters.

(2) It continuously simulates soil moisture and therefore can use readily available historical precipitation data without requiring the usually unavailable soil moisture data.

(3) It easily accepts changes in land use.

All of the above factors make the USDAHL model applicable for use by the non-research community.

Previous research has shown that the USDAHL model will simulate runoff if it is properly calibrated. If this model can be calibrated for a gaged watershed and then successfully transferred to an ungaged watershed, it will provide the designer with a tool for predicting storm runoff and the effects of land use change on ungaged watersheds.

Objectives

The objectives of this study were:

1. To calibrate the USDAHL model to find those hydrologic parameters which best simulate the observed runoff.
2. To test the transferability of the model by applying it to three watersheds using the hydrologic parameters and comparing the observed runoff against the simulated runoff.
3. To identify any components of the USDAHL model that require improvement.

General Procedure for Accomplishing the Objectives

To accomplish objective 1, the USDAHL model was applied to the 6.3 ha Guthrie W-V Watershed which is located 7 km southeast of Guthrie, Oklahoma. The hydrologic parameters used by the model were varied until an optimum fit between observed and simulated runoff was achieved.

After completion of objective 1, the model's transferability was examined by transferring the hydrologic parameter values from objective 1 to the 7.8 ha Chickasha R-7 Watershed located 14 km northeast of Chickasha, Oklahoma. This tested the model's capability of being transferred to a similar watershed. Then the model was likewise applied to the 83.4 ha Stillwater W-4 Watershed and the 57.5 ha Stillwater Environmental Watershed. They are located 24 km north and 15 km west of Stillwater, Oklahoma, respectively. This tested the model's capability of being transferred to larger watersheds with varied soil characteristics.

CHAPTER II

REVIEW OF LITERATURE

Description of the USDAHL Model

The United States Department of Agriculture Hydrograph Laboratory (USDAHL) model of watershed hydrology was developed by an interdisciplinary team of scientists using a 6.14 square kilometer experimental watershed at Coshocton, Ohio. The model is an attempt to express watershed hydrology as a continuum and is described by Holtan et al. (1977). It is designed to serve the purposes of agricultural watershed engineering which normally pertains to field size watersheds and includes meteorology, climate, soils, vegetation, hydraulics, hydrogeology, and watershed hydrologic systems. Developmental considerations included the utilization of readily available input data to account for the dispersion of precipitation to evapotranspiration, soil moisture storage, groundwater recharge, and surface and subsurface movements to streamflow.

Evapotranspiration is estimated by coefficients applied to pan evaporation data using the equation:

$$ET = GI\ k\ Ep\ (S\text{-}SA/AWC)^{x} \qquad (1)$$

where

ET = Evapotranspiration potential

GI = Growth index of crop in percent of maturity

Ep = Pan evaporation

k = Ratio of GI to Ep, usually 1.0 - 1.2 for short grasses, 1.2 - 1.6 for crops up to shoulder height, and 1.6 - 2.0 for forest

S = Total soil porosity

SA = Available porosity

AWC = Porosity drainable only by ET

x = Set equal to AWC/G (G = gravity or free water).

ET is limited by the available water in the root zone and can range from a maximum at field capacity to zero at the wilting point. Water lost by evaporation from depression storage and free water in the soil is not included in the evapotranspiration process. This evaporation is computed as a function of pan evaporation and is programmed to increase from zero at field capacity to a value equal to pan evaporation at soil saturation.

The infiltration capacity is expressed by Holtan (1961 and 1965) as a decaying differential equation convergent upon a constant rate of infiltration. The infiltration rate is computed by:

$$f = (GI)\ (a)\ (Sa)^{1.4} + fc \qquad (2)$$

where

f = Infiltration rate

a = Index of surface-connected porosity

Sa = Available storage in surface layer

fc = Constant rate of infiltration after prolonged wetting.

Musgrave (1955) gave estimates of fc based upon hydrologic classes of soil in mm per hour as A = 11.43 - 7.62; B = 7.62 - 3.81; C = 3.81 - 1.27; and D = 1.27 - 0.0.

Rainfall in excess of infiltration is routed across each soil zone and cascaded, subject to further infiltration, across subsequent soil zones enroute to the channel. As expressed by England and Holtan (1969), the overland flow is computed by an adaption of the continuity equation:

$$Pe - qo = \Delta D \tag{3}$$

and

$$qo = (ova)\ D^{1.67} \tag{4}$$

where

Pe = Rate of rainfall in excess of infiltration and depression storage

qo = Rate of overland flow

Δ = Increment

D = Average depth of flow

ova = Coefficient dependent on roughness and length and degree of slope.

Channel flows and subsurface return flows are routed by simultaneous solutions of the continuity equation and a storage function. Storage coefficients are obtained by integration of the flow recession curve for a given watershed.

Downward percolation and lateral flow are supplied by free water and estimates of maximum seepage rate (C) and free-water capacity (G). The maximum seepage rate is computed by:

$$C = q_{L+1} + gr \tag{5}$$

where

q_{L+1} = Maximum rate of flow in regime

L = Regime number

gr = Maximum rate of groundwater recharge.

Increments of downward seepage (Subput) to the next regime are computed as a function of free water present:

$$\text{Subput}_{L+1} = \Delta t \; C \; (G-SA)/G \qquad (6)$$

where

Δt = Time increments in hours

SA = Air space in length equivalent of water.

Input Parameters

Input parameters to the model describe the following: (1) watershed, (2) zones, (3) soils, (4) routing (channel and subsurface), (5) cascading, and (6) land use. Holtan et al. (1975) and Holtan and Yaramanoglu (1977) describe the formats for the input parameters in detail.

Previous Research on the USDAHL Model

England and Coates (1971) showed that the model was applicable to moisture accounting on areas as small as a 2.5 m by 5.0 m lysimeter. In their study, they adjusted the various parameters to achieve a reasonable fit to records of evapotranspiration and percolation from a four year rotation of corn-wheat-meadow-meadow. The model was then applied to the subsequent four years of records in the same rotation. Comparisons between observed and computed monthly values of evapotranspiration and percolation during this period were good.

England (1975a) determined that one of the key values controlling the rates of processes, such as infiltration, evapotranspiration, vertical seepage, and lateral flows, is the moisture status of the soil profile at any given time. The model continuously keeps record of the amount of water-filled porosity in the soil layers 1 and 2, and conversely, the unfilled porosity (Sa), to control the rates of these processes. England concluded that the model was sensitive to the estimated root depth parameter and that the model could be used for many purposes other than streamflow prediction. After varying parameters, the results showed the model overpredicted soil moisture during wet periods and underpredicted soil moisture during dry periods.

England (1975b) emphasized that the kind, amount, distribution, and activity of roots produced by a given plant species is characteristic of that species. The soil and environmental factors act only as modifiers of these basic traits. Generally, roots will proliferate to the limit of their genetic potential or to the limit of the effective volume of the soil in which they are grown. This is determined vertically by the depth to rock, to a water table, to a restricting layer, or to a dry soil. England applied the model to a 2.4 m deep lysimeter containing continuously cropped bromegrass alfalfa. All of the soil and vegetation parameters were kept constant except root depth. As root depth increased to the limit of the lysimeter depth (2.4 m), computed evapotranspiration and percolation came closer to that actually observed. The results illustrated the adaptability of the model to soil moisture accounting and its sensitivity to the root depth parameter.

England (1977) also applied the model to a post oak-shortleaf pine watershed in east Texas. He found that the input parameters could usually be estimated from data or inferred from general knowledge of the behavior of specific soil-plant-water systems. However, sometimes these parameters could only be obtained by trial and error applications of the model, varying the parameters progressively stepwise in sequence, or in combination, until a satisfactory fit between observed and computed values of the dependent variables was achieved. Comer and Henson (1976) have shown that these parameters could be estimated by a computerized direct search optimization procedure. In England's (1977) study, the vegetative index (A), pan evaporation coefficient (ET/EP), surface storage volume (VD), and the groundwater recharge value (GR) were chosen from best fit values obtained by trial and error. His final values were VD = 6.4 mm, ET/EP = 1.20, GR = 0.01 mm/hr and A = 1.00. The ET/EP ratio of 1.20 was an indication that water return to the atmosphere was potentially 20% greater than pan evaporation. The A value of 1.00 was interpreted to mean that under this forest, the upper soil layer was entirely permeated by plant roots which allowed 100% of the surface horizons porosity to be receptive to incoming rainwater. The above adjusted parameters resulted in reasonable agreement between observed and computed daily soil moisture volumes.

Langford and McGuinness (1976) compared the USDAHL model with standard statistical methods for a 17.6 ha watershed at the USDA North Appalachian Experimental Watershed Research Center, Coshocton, Ohio. The model predicted flow for a 16 year period with a standard error of 38.4 mm and a correlation coefficient of 0.936. The statistical model predicted flow for the same period with a standard error of 33.3 mm or 15% less than the USDAHL model and a correlation coefficient of 0.956. They concluded the performance of the USDAHL model in detecting the effects of hydrologic change due to reforestation and partial cutting on annual streamflow was quite satisfactory, and that modeling was a viable alternative to standard statistical methods in detecting the magnitude and significance of hydrological change. Economy of data requirements makes modeling an attractive alternative to the regression methods.

James et al. (1977) examined the accuracy, precision, sensitivity, and limitations of the model on four 0.25 ha plots. They discovered that by increasing soil depths and root depths, runoff increased and evapotranspiration (ET) decreased. Also, that increasing the vegetative parameter (A) increases evaporation and decreases runoff and ET. Increasing the ET/EP ratio significantly increases ET and decreases runoff and evaporation. The simulated runoff for one plot agreed with the observed runoff. However, the simulated runoff for three other plots ranged from 44% to 48% greater than observed runoff.

Fisher et al. (1977) applied the model to three Maryland watersheds. Their objectives were to test the applicability of the model in different physiographic provinces and to investigate the usefulness of the model in evaluating land use plans for their impact on hydrology and water quality. The runoff simulated by the model was 1.1% and 1.8% larger than observed for the Coastal Plain and the Piedmont watersheds, respectively. For the Appalachian Plateau watershed, an error of +15.6% occurred. The reason for the poor results on the Appalachian Plateau watershed seemed to be in accounting for snowmelt. They calculated the peak flow versus probability curve for the Western Branch near Largo, Maryland. The simulated 100 year runoff flow was 2235 cfs as compared with the observed 100 year flow of 1950 cfs for an error of +14.6%. They concluded that it is necessary to obtain good documentation of land use change to obtain good results in hydrologic modeling. The model is a valuable tool for studying the effects of land use change and evaluating land use plans. Also since all hydraulic design is related to frequency of flooding, the model is applicable to determining design discharges because it can predict large amounts of streamflow information to which many hydrologic analysis techniques can be applied.

Molnau and Yoo (1977) evaluated the model on a 7020 ha watershed that originated north of Moscow, Idaho. Simulated runoff for a three year period was 324 mm as compared with an observed runoff of 265 mm for an error of +22.3%. The model's results for October through January were poor. Monthly, daily and most events were simulated to a reasonable degree, but overland flow and frozen ground events needed to be refined.

Nicks et al. (1977) applied the model to 12 central Oklahoma watersheds ranging in size from 5 ha to 48,192 ha. Their approach was to test the hydrologic model on a wide variety of watersheds varying in size, geometry, land use, and soils. Using a range in watershed size allowed the evaluation of model performance on large watersheds as compared with performance on small watersheds for which it was developed. The model was applied without any optimization of parameters. The model underpredicted the monthly and yearly water yields on six watersheds from 3 to 55 percent. It overpredicted on the other six watersheds by 190 to 390 percent. The most significant observation of these statistics was that the overestimates were much larger than the underestimates. However, the results did not indicate that larger watershed size with a greater number of soils and land uses caused larger errors or a trend to either overestimation or underestimation.

Hanson (1977) studied the results from the model on an 83 ha arid rangeland watershed in southwest Idaho. This watershed represented arid rangelands with limited precipitation (about 254 mm/yr), transient snow cover, and infrequent runoff. He discovered that varying the value for deep groundwater recharge over a very wide range had a very small effect on soil water, except during times when there was high precipitation input. The value used for the ET/EP ratio had considerable bearing on the amount of water used in evapotranspiration. Increasing the ratio increased evapotranspiration and decreased evaporation, with the total water used generally greater as the ratio increased. A value of 1.00 for the ET/EP ratio was selected as the most representative of the grasses grown on the watershed. Total observed and simulated runoff for 1967 to 1969 were 4.13 mm and 1.42 mm, respectively, for an error of 65.6%. Any model would have to be very sensitive and very finely tuned to simulate these small runoff amounts, which made it very difficult to assess the adequacy of the runoff simulation. The author decided that the watershed responded to larger amounts of daily precipitation at lower intensities whereas the model responded to higher intensity precipitation. Finally, the model estimated soil water adequately, except during late summer and fall. During late summer, the model allocated too much water for evapotranspiration, if water was available, and then did not allocate water for evapotranspiration at a fast enough rate during the fall.

Crow et al. (1977) experimented with the model on a 37 ha grassland watershed in central Oklahoma. They calibrated the model using data for 1970 to 1972. For this period, the simulated runoff was 332 mm. This compared with an observed runoff of 325 mm for an error of +2.1% and a correlation coefficient of 0.94. They also determined percent reduction in ET due to grazing factors for each of the following hydrologic cover conditions: poor, poor to fair, fair to good, and good. Then the period 1956 to 1959 was selected to give an independent test of the model. For this period, the simulated runoff was 1059 mm. This compares with an observed runoff of 917 mm for an error of +15.5% and a correlation coefficient of 0.94. The correlation between simulated and measured runoff was good for the spring months when rainfall was high, but the model overestimated runoff during the cool season months. Small discrepancies, always on the side of overestimation, occurred in months with little or no measured runoff.

Crow et al. (1976) made an analysis to determine the sensitivity of the model to changes in six different soil and land use parameters, using the same 37 ha watershed previously cited. The model was highly sensitive to the parameters of: the ratio of maximum evapotranspiration amount to maximum pan evaporation for a year (ET/EP), percent reduction in evapotranspiration attributable to grazing (GZ), and root depth of vegetation. The model was moderately sensitive to: percent volume of soil cracks, and basal area of vegetation (A). The model was slightly sensitive to depression storage (VD). An increase in ET/EP ratio, VD, and percent volume of soil cracks decreased simulated runoff. An increase in GZ increased runoff. Selecting too small a root depth increased runoff but selecting one too large had no effect.

Crow et al. (1978) calibrated the model on the 37 ha watershed for a six year period and then evaluated it for an 18 year test period.

After this, the parameters were transferred to 83 ha and 55 ha watersheds. For the calibration period of 1952 to 1957, the simulated runoff was 957 mm as compared with an observed runoff of 893 mm for an error of +7.1%, a correlation coefficient of 0.95 and a standard deviation of 12.2 mm. For the test period of 1958 to 1976, the simulated runoff was 2418 mm as compared with an observed runoff of 2729 mm for an error of -11.4%, an correlation coefficient of 0.93 and a standard deviation of 8.3 mm. During the test period of 1952 to 1972, the simulated runoff from the 83 ha watershed was 2762 mm as compared with an observed 2199 mm for an error of +25.6%, a correlation coefficient of 0.95 and a standard deviation of 8.0 mm. For the 55 ha watershed, the test was limited to four events in 1977. The simulated runoff was 112.5 mm as compared with an observed runoff of 64.7 mm for an error of +73.9%.

Engman (1978) evaluated the model based on research at four independent SEA locations. He concluded that the model did a good job in predicting monthly and annual water yields. However, it seemed to overestimate in wet years and underestimate in dry years. Prediction of daily and event runoff was poor and the model would not be recommended for simulating storm hydrographs. The prediction of soil water storage was good. The results were generally better for small watersheds than for larger ones, presumably because it is more difficult to properly zone large complex areas and to estimate input parameters with large numbers of soils and land uses. He listed the models strengths as:

(1) The model can be used to study the effects of land use changes.

(2) Input data for the model can be derived from data which are presently available to SCS.

(3) Use of MIAD computer files to obtain the necessary land use and soils parameters significantly reduces the time required to estimate the parameters.

(4) All parameters and data can be derived from readily available information.

He listed these areas as conceptual weaknesses:

(1) Snowmelt and infiltration into frozen ground.

(2) Plant growth and soil water utilization by plants.

(3) Subsurface flow routing procedure.

(4) The required overland flow length was found not be a measurable parameter.

(5) The soil profile crack storage.

(6) Timing of flow routing.

Ghermazien (1978) extended the work by Crow et al. (1976) on defining the factors for the percent reduction in evapotranspiration due to grazing pertaining to hydrologic cover condition (GRAZ). He determined the percent reduction in evapotranspiration due to grazing factors to be 45, 50, 55, 60, and 65 for vegetative cover conditions of good, good to fair, fair, fair to poor, and poor, respectively. He calibrated the model on the previously cited 37 ha grassland watershed for the 24 year period from 1952 to 1976. He determined that a depression storage of 15.24 mm, index of surface connected porosity of 0.10, ET/EP ratio of 0.88, root depth of 1270 mm, upper temperature of 26.7^{o} C and lower temperature of 0^{o} C were the optimum hydrologic parameters. Ghermazien transferred the optimum hydrologic parameter values to a

83.4 ha watershed and concluded that the model performed better in simulating runoff from a watershed for which it was calibrated than from a watershed for which no calibration was made.

CHAPTER III

INPUT DATA DETERMINATION

Watershed Parameters

Before the model can be applied to a watershed, the user must understand the procedures used to determine the measurable watershed parameter values. The purpose of this chapter is to explain these procedures.

Hydrologic Zones

The purpose of dividing a watershed into zones is to create areas of homogeneity for purposes of computation (Holtan and Yaramanoglu, 1977). This enables a more accurate computation of infiltration, evapotranspiration, and overland flow.

The zones must be sequential from the edge of the watershed to the main channel. In this study, the watersheds are divided according to surface slope. Zone I is the upland zone consisting of the hilltops with small slopes of zero to three percent usually at the edge of the watershed. Zone II is the hillside zone consisting of the intermediate ground with steep slopes. Zone III is the lowland zone consisting of the flood plain land near and including the main channel with small slopes of zero to three percent.

Areas

The areas of the total watershed and each zone are measured from topographic maps by a planimeter as described by Lind (1979). The area of each type of soil is measured by a planimeter from soil maps. The land use areas are measured by a planimeter from land use or topographic maps.

Climatological Data

Temperature

The daily maximum and minimum temperatures are taken from the records of the operating agency or recorded from a hygrothermograph. The model requires 52 average weekly temperatures. To calculate one average weekly temperature, the maximum and minimum temperatures for each day of the seven days in a week are added and the sum is divided by 14.

Pan Evaporation

The model requires 52 average weekly pan evaporation values. The daily pan evaporation values are recorded from the records of the operating agency. Then the seven values for one week are averaged to calculate the average weekly pan evaporation value.

For the Stillwater Environmental Watershed, the daily pan evaporation values were determined by the Oklahoma Agricultural Experiment Station Agronomy Farm. These data were not available for November, December, January, February, March, and April. Kohler et al. (1955) developed an empirical relation for estimating pan evaporation from pertinent meteorological factors. Kohler et al. (1959) later refined the above empirical equation into a nomograph to estimate pan evaporation from meteorological factors. This nomograph required mean daily air temperature, solar radiation, mean daily dew point temperature and daily wind movement. Since these data were either collected as part of the Environmental Watershed project or could be calculated from data collected, the nomograph was used to estimate the missing daily pan evaporation values. Then the values were averaged to calculate average weekly pan evaporation values as described above.

Precipitation

Precipitation values are taken from the records of the operating agency or from universal recording rain gages. These data are compiled from the records or rain gage charts at breakpoints and then translated into the Holtan format (Holtan et al., 1975) for use as input to the model.

Recession Analysis

Barnes (1939) described the components of storm discharge of streams as surface flow, subsurface flow, and base flow. The total runoff of either of these components does not bear a fixed relationship to the others. The surface flow is affected by the duration and intensity of rainfall and the channel storage characteristics of the watershed. The subsurface flow depends upon the soil characteristics of the region. Base flow is the discharge into the stream from groundwater storage. The equation of the combined recession curve is:

$$q(t) = q(o)\ e^{-t/m} \tag{7}$$

where

$q(t)$ = Rate of flow at time increment (t)

$q(o)$ = Rate of flow at start of period

t = Time increments in hours

m = Absolute value of $t/\Delta \ln q$ and is constant for each straight line segment of recession curve on semi-logarithmic scale.

The model uses equation (7) to route recession hydrographs (Holtan et al., 1975). The values of m derived for each linear segment of the recession curve on semi-logarithmic plotting are assumed to represent successive flow regimes, starting with mc for channel flow and proceeding through a series (m1, m2, m3, and m4) for successively deeper or more devious regimes or subsurface flow. For those watersheds not having any return flow, only mc needs to be defined. Also the model permits input of recession coefficients (m1 to m4) obtained from downstream gaging sites of an encompassing watershed.

Output includes "onsite" return flow of volumes that passed through the soils of one or more zones to become part of the runoff at the weir. Output also lists "offsite" return flow for comparison with regional information downstream.

The m values are calculated by selecting hydrographs with continually falling recession curves and plotting the recession portions of the hydrograph versus time from start of flow on semilogarithmic paper. The curves are drawn as a series of straight lines. The value of m is determined as the number of hours required for the recession segment to cross one log cycle divided by 2.3. The first straight segment is mc, the second straight segment is m1, and the point where the two segments meet is q1. The maximum rate of flow associated with each linear segment of the recession curve is defined as q. The next straight segments, if applicable, are m1, m2, and q2 and so forth through m4 and q4. The m values for each storm are averaged to calculate an average m value for each segment. The same procedure applies to the q values.

To compute the calculation interval for channel routing (Δt), the mc is divided by five and then the quotient is adjusted to a value that will divide evenly into 24.0.

Zone Parameters

Overland Flow Length

The different hydrologic zones are outlined on a tracing of the watershed from a topographic map. The zones are then divided into subzones with each minute watershed containing its channels outlined as a separate subzone. The remaining areas without channels are also considered subzones. In the subzones with channels, the total length of all the channels as indicated by contours are measured by a cartometer. The area of the subzone is measured by a planimeter. The average length of flow can be calculated by the equation:

$$Lo = \frac{\text{Area}}{(2)(\text{Channel length})} \tag{8}$$

Equidistant lines are drawn perpendicular to the contour lines across the subzones with no channels. The average length of these lines is assumed to be the average length of flow from the subzone. The average length of flow for each hydrologic zone is calculated by the equation

$$Lo = \sum_{n=1}^{n} \left(\frac{Area(n)}{Area}\right)(Lo(n)) \qquad (9)$$

where Lo(n) is the average length of flow for subzone n.

Average Zonal Slope

The average percent slope of each zone is required by the model. This is used to compute the overland flow coefficient (ova) for equation (4) (Holtan et al., 1975).

To calculate the average slope, equidistant lines are drawn perpendicular to the contour lines. The slope of each line in the zone is calculated and then averaged to determine the average zonal slope.

Soil Parameters

Soil Depths

The soil types for each zone are identified from soil maps. Then the depths of the A horizon and the total aerated well-drained soil including topsoil (A and B horizons) are determined from SCS soil surveys based on soil type. From this data, a weighted average for each depth is calculated for each zone.

Hydrologic Soil Capacities

The average moisture drained by gravity (G) and moisture drained by vegetation (AWC) for both topsoil and lower layer are required by the model. The values depend on soil type, and are listed in Table I. This table was adapted from England (1970) and modified by Nance (1977). From this data, a weighted average G and AWC are calculated for the upper and lower soil layers in each zone.

TABLE I

HYDROLOGIC CAPACITIES OF SOIL TEXTURE CLASSES

Texture Class	S %	G %	AWC %
Coarse Sand	24.4	17.7	3.0
Coarse Sandy Loam	24.5	15.8	8.7
Sand	32.3	19.0	4.0
Loamy Sand	37.0	26.9	7.0
Loamy Fine Sand	32.6	27.2	8.0
Sandy Loam	30.9	18.6	12.3
Fine Sandy Loam	36.6	23.5	13.1
Very Fine Sandy Loam	32.7	21.0	14.0
Loam	30.0	14.4	15.6
Silt Loam	31.3	11.4	19.9
Sandy Clay Loam	25.3	13.4	14.0
Clay Loam	25.7	13.0	16.0
Silty Clay Loam	23.3	8.4	18.0
Sandy Clay	19.4	11.6	11.0
Silty Clay	21.4	9.1	12.3
Clay	18.8	7.3	11.5

S = Total moisture storage capacity.
G = Moisture drained by gravity.
AWC = Moisture drained by vegetation.

Final Infiltration Rate

The constant rate of infiltration after prolonged wetting, (fc) in equation (2), is used by the model to calculate infiltration rate. Musgrave (1955) gave associated rates of fc based on the hydrologic classes of the soil types in mm per hr as A = 11.43 - 7.62, B = 7.62 - 3.81, C = 3.81 - 1.27, and D = 1.27 - 0.0. The texture and density of the topsoil gives a clue to the selection of fc within a group. If the topsoil approaches clay, fc is near the lower limit of its group. For sand, fc is near the upper limit, and for loams fc is near the midpoint. The appropriate fc is identified for each soil type and then a weighted average is calculated for the zone.

Cracking Volumes

Certain soils such as montmorillonite clays form deep cracks on drying. Cracking is estimated for a given horizon from the ratio of bulk density at field capacity in g/cm^3 (BDW) to bulk density when air-dry in g/cm^3 (BDD) by the equation:

$$\text{Percent Cracks} = 100\left[\left(\frac{BDW}{BDD}\right)^{1/3} - \frac{BDW}{BDD}\right] \qquad (10)$$

This equation was developed from the work of Grossman et al. (1968). The model calculates the volume of cracks at any given time as a linear function of soil moisture present and is limited to AWC. Cracks are at a maximum within the root zone at wilting point and disappear at field capacity (Holtan et al., 1975).

In this study, the percent of soil depths subject to cracking is calculated from data provided by Nance (1977). The wet and dry bulk densities based on soil type shown in Table II were substituted into

TABLE II

BULK DENSITIES AND CRACKING VOLUMES FOR SPECIFIC SOIL TYPES

Soil Type	Bulk Density Wet, g/cm^3	Bulk Density Dry, g/cm^3	% Cracks
Aydelotte Loam	1.45	1.85	13.8
Darnell FSL	1.36	1.38	1.0
Grainola Loam	1.44	1.86	14.4
Lucien SL	1.39	1.41	0.9
Renfrow Loam	1.40	1.86	15.7
Stephenville SL	1.36	1.44	3.7
Stoneburg Loam	1.39	1.58	7.8
Zaneis Loam	1.40	1.62	8.8

equation (10) to calculate values of percent cracks. Then a weighted average is calculated for each layer in each zone for input into the model.

Land Use

GRAZ

The model requires the yearly percent reduction in evapotranspiration attributable to grazing (GRAZ) for pastured grassland. The vegetative cover conditions of good, fair, and poor were established by Ree et al. (1977). Crow et al. (1976) assigned values to the vegetative conditions. Ghermazien (1978) modified the values and listed them as 45, 50, 55, 60, and 65 for vegetative conditions of good, good to fair, fair, fair to poor, and poor, respectively. Ghermazien's modified values are used by this study. The yearly average vegetative cover is identified from the watershed records. Then the corresponding percent reduction is used as input into the model.

Tillage Practices

Holtan et al. (1975) listed the tillage practices as turnplow, plant, harvest, and cultivation. The model uses these practices to modify the growth index of the crop (GI). These practices are entered as the date of the event as determined from watershed records.

TU and TL

The temperature above which the crop's ET is impaired (TU) and the temperature below which the crops ET does not function (TL) were taken from previous test with the model by Ghermazien (1978). Values of 26.7^{o} C and 0.0^{o} C are used for TU and TL, respectively.

CHAPTER IV

WATERSHED DESCRIPTIONS

Guthrie W-V Watershed

The Guthrie W-V Watershed was operated by the USDA-ARS Red Plains Watershed Research Center from January, 1942, to December, 1953, and is described by USDA-ARS (1956). It is located 7 km southeast of Guthrie, Logan County, Oklahoma, in the Cimarron River Basin. It is rectangular in shape, contains 6.3 ha, and is approximately 490 m long by 140 m wide. The topography is rolling with Zaneis loam soil and ephemeral flow. The vegetative cover was moderately grazed native grass which was mowed every spring. The precipitation and climatic input are from the USDA-ARS Red Plains Watershed Research Center records and are shown in Appendix A. The data on hydrologic zones, overland flow lengths, and land slope were determined from a topographic map provided by Nicks (1978). The hydrologic zones and topography are shown in Figure 1. The soils data were from USDA-SCS (1960). The hydrologic and soil parameters are shown in Table III.

A channel routing coefficient (mc) of 0.307 and a channel routing delta time (Δt) of 0.06 hour were calculated from existing flood hydrographs. Figure 2 shows the semi-log plots of the recession curves. Table IV shows the calculations of mc and Δt. Because the runoff from this watershed occurs only during and shortly after precipitation, the routing coefficients associated with subsurface flow were set to zero.

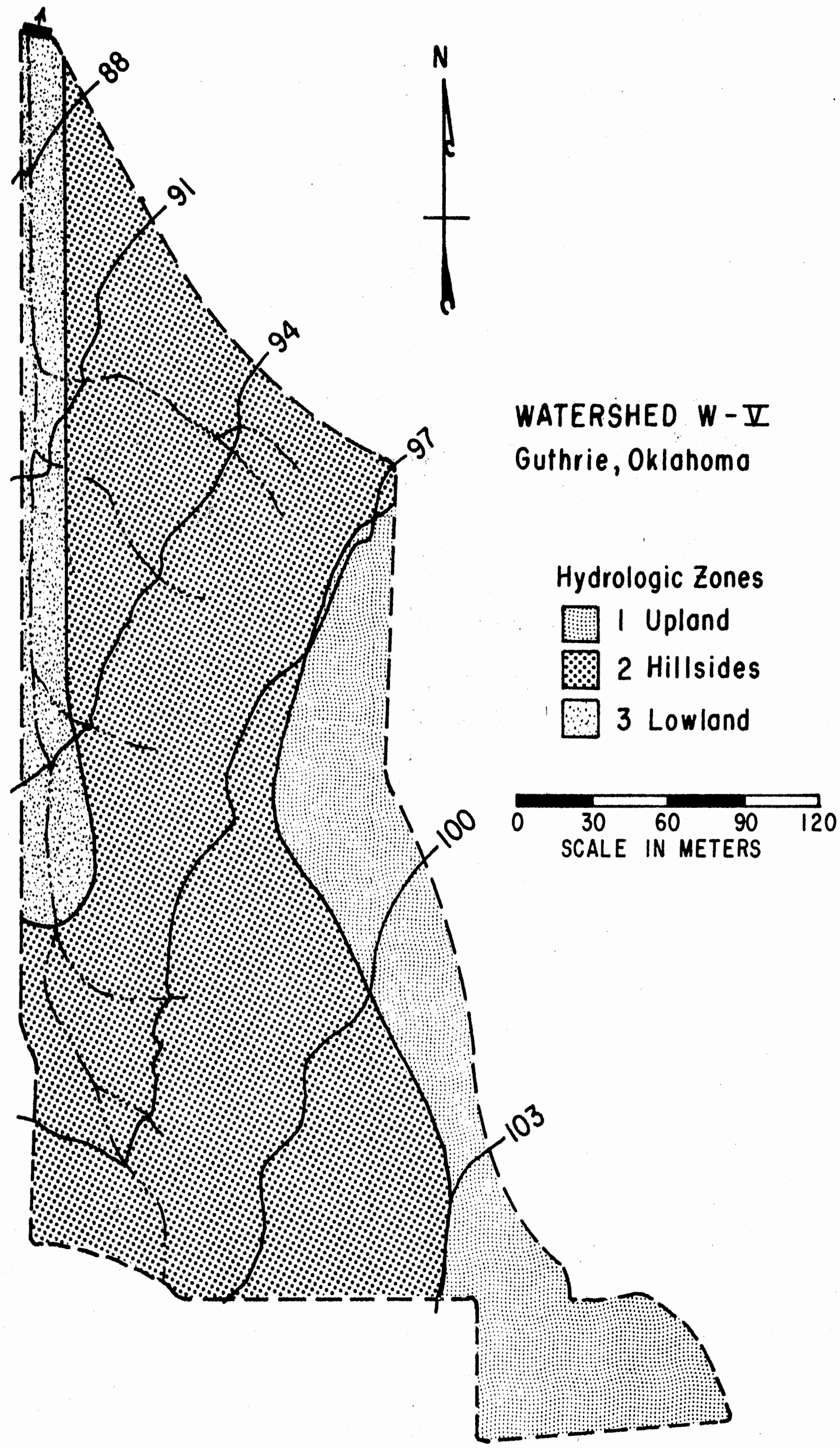

Figure 1. Topographic Map and Hydrologic Zones for Guthrie W-V Watershed

TABLE III

HYDROLOGIC ZONE AND SOIL PARAMETERS FOR GUTHRIE W-V WATERSHED (6.3 ha)

	Zone 1	Zone 2	Zone 3
Zone Area, %	20.0	70.4	9.6
Average Slope, %	2.6	4.5	2.5
Overland Flow Length, m	37	35	9
Principal Soil Series	Zaneis	Zaneis	Zaneis
Soil Texture	loam	loam	loam
Final Infilt. Rate, mm/hr	5.70	5.70	5.70
Depth, Upper layer, cm	30	23	23
Depth, Lower layer, cm	53	53	53
G*, Upper layer, %	14.4	14.4	14.4
G*, Lower layer, %	9.7	9.7	9.7
AWC+, Upper layer, %	15.6	15.6	15.6
AWC+, Lower layer, %	17.4	17.4	17.4
Cracks[xx], Upper layer, %	5.9	5.9	5.9
Cracks[xx], Lower layer, %	11.7	11.7	11.7
Root Depth, cm	83	76	76

*Percent of soil depth drained by gravity.
+Percent of soil depth drained by plants.
xxPercent of soil depth subject to cracking.

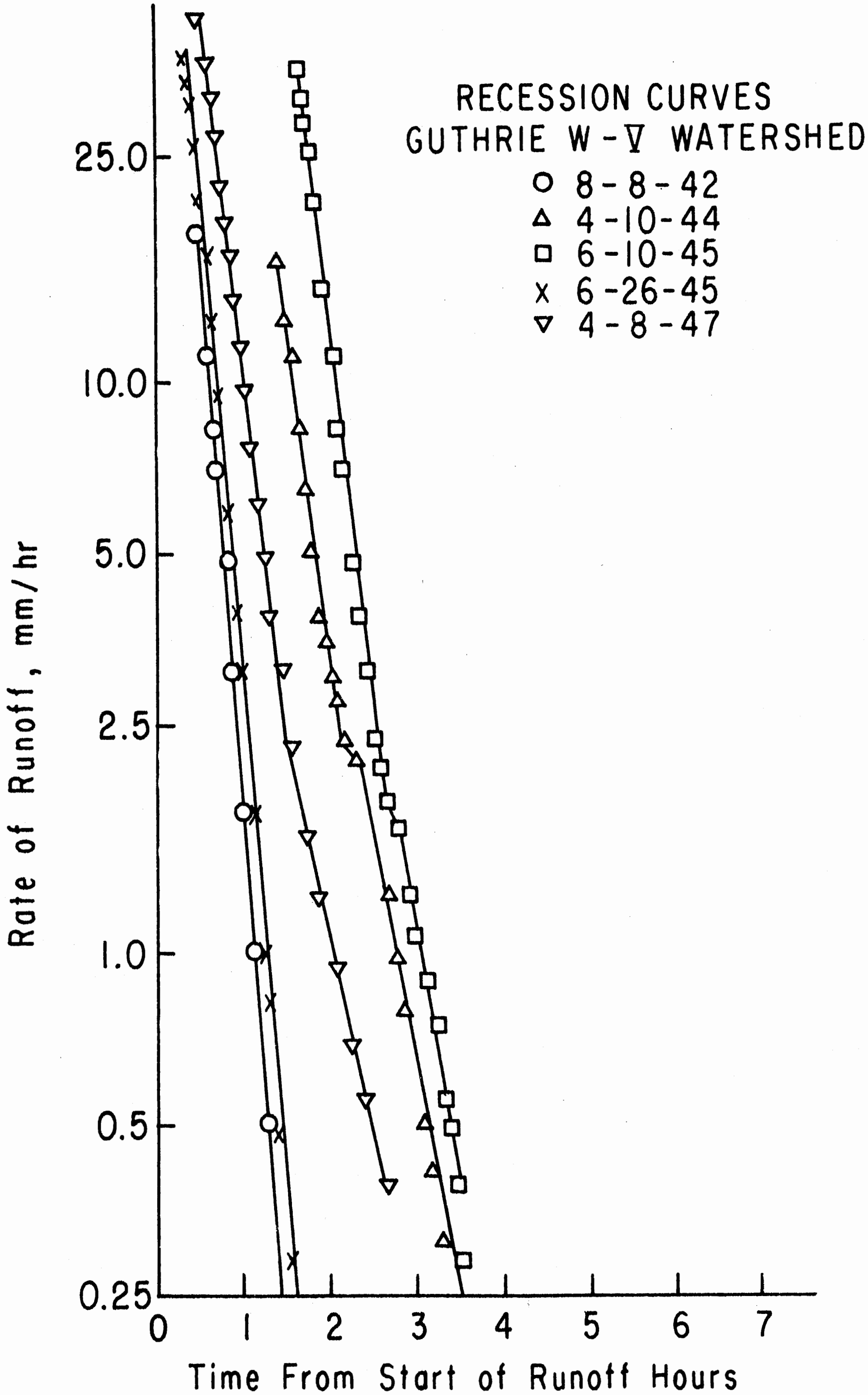

Figure 2. Graph of Recession Curves for Guthrie W-V Watershed

TABLE IV

CALCULATION OF CHANNEL ROUTING COEFFICIENT, mc
FOR GUTHRIE W-V WATERSHED

Date of Storm	Hours Per Log Cycle	mc
4-08-42	0.544	0.23652
4-10-44	0.864	0.37565
6-10-45	0.776	0.33739
6-26-45	0.600	0.26087
4-08-47	0.752	0.32696
AVG		0.30747

Use mc = 0.307

Δt should be less than or equal to 1/5th of the channel routing coefficient and must divide evenly into 24.0.

$$\frac{0.307}{5} = 0.0614 \qquad \frac{24.0}{0.06} = 400$$

Use $\Delta t = 0.06$

The vegetative cover on this watershed had been kept in excellent condition. For this reason a GRAZ factor of 35 was selected.

Chickasha R-7 Watershed

The Chickasha R-7 Watershed is operated by the USDA-SEA Southern Plains Watershed and Water Quality Laboratory, Chickasha, Oklahoma, and is described by USDA-ARS (1972). It is located 14 km northeast of Chickasha, Grady County, Oklahoma, in the Washita River Basin and 79 km southeast of the Guthrie watershed. It is circular in shape, contains 7.8 ha, and has a principal waterway, 415 m long, with ephemeral flow. The geology is composed of a heterogeneous mixture of sandstones, shales, siltstones and siltstone conglomerates. The rocks of any given bed may exhibit an abrupt change in composition and texture. The formation is relatively impermeable and yields only moderate quantities of groundwater to wells. USDA-SCS (1978) describes the soils as 38% Kingfisher silt loam, 39% Renfrow silt loam, and 23% Kingfisher-Lucien complex. A soils map is shown in Figure 3 and the soil classifications are in Table V.

The entire watershed was cultivated from 1907 until about 1935. Severe erosion occurred during the latter years the watershed was in cultivation. The area was changed to pasture without the establishment of a grass cover. A fair cover of little bluestem grass has become established on 69% of the area. The rest of the area supports a cover consisting mainly of annual threeawn grass. The watershed is continuously grazed by beef cattle. Because it had fair to poor vegetative cover for the test period, a GRAZ factor of 60 was selected for the USDAHL model tests.

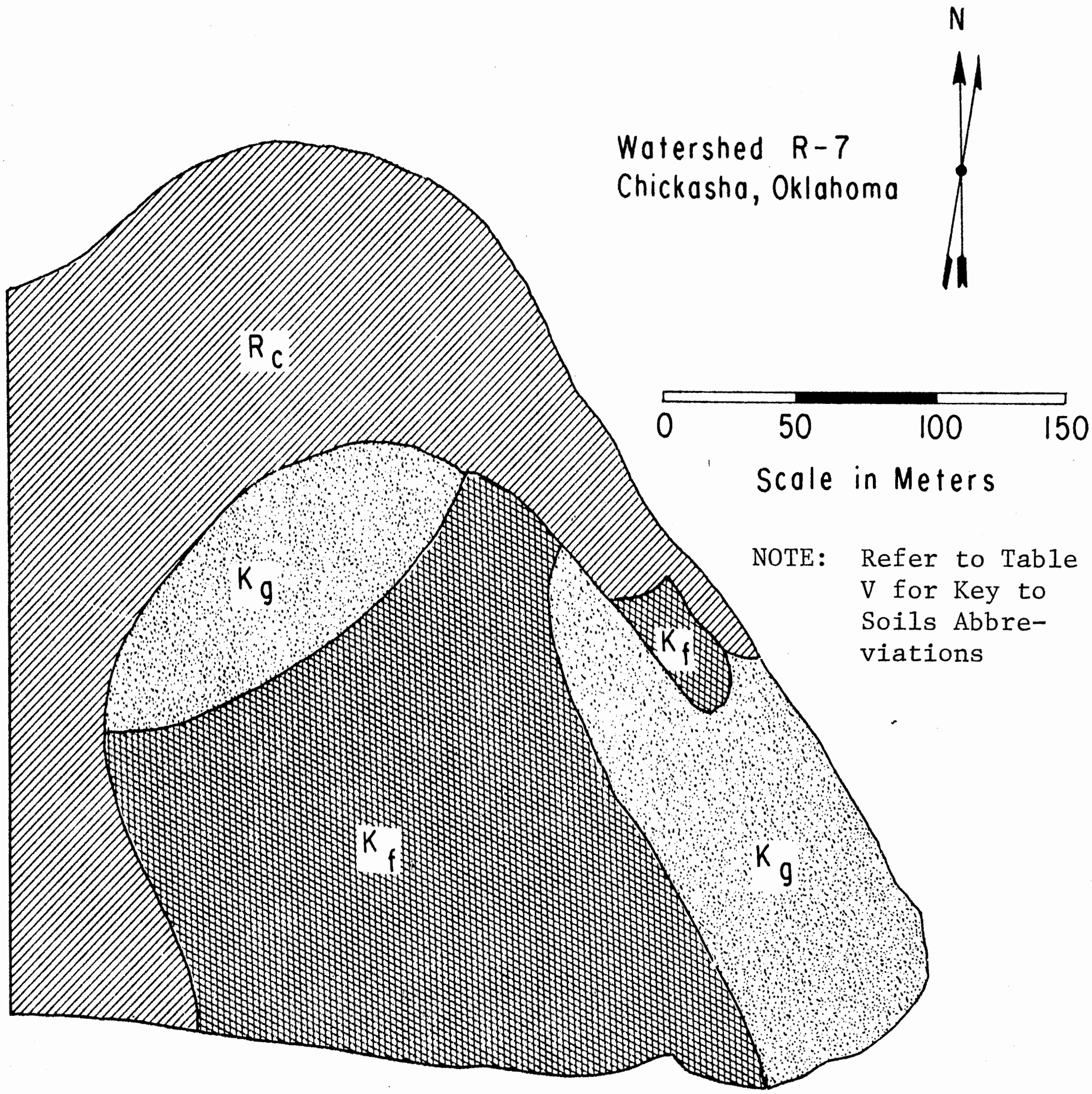

Figure 3. Soils Map for Chickasha R-7 Watershed

TABLE V

SOIL CLASSIFICATIONS FOR CHICKASHA R-7 WATERSHED

Zone	Soil Type	Percent Zone Area	Area m^2	Topsoil Depth, cm	Total Soil Depth, cm	Final Infil. Rate, mm/hr
1	Kingfisher Silt Loam (Kf)	3.7	648	36	96	5.72
	Kingfisher-Lucien Complex (Kg)	25.0	12,342	23	41	3.81
	Renfrow Silt Loam (Rc)	71.3	4,330	23	160	0.64
	TOTAL	100.0	17,320	24	128	1.62
2	Kingfisher Silt Loam (Kf)	20.9	7,325	36	96	5.72
	Kingfisher-Lucien Complex (Kg)	27.7	9,712	23	41	3.81
	Renfrow Silt Loam (Rc)	51.4	18,008	23	160	0.64
	TOTAL	100.0	35,045	26	114	2.58
3	Kingfisher Silt Loam (Kf)	84.0	21,288	36	96	5.72
	Kingfisher-Lucien Complex (Kg)	16.0	4,047	23	41	3.81
	TOTAL	100.0	25,335	34	87	5.41
TOTAL			77,700			

The period for the precipitation and climatic data is from January, 1967, to December, 1974. These data are from the USDA-SEA Southern Plains Watershed and Water Quality Laboratory records and are shown in Appendix B. The hydrologic zones and topography are shown in Figure 4. The hydrologic and soil parameters are shown in Table VI.

Stillwater W-4 Watershed

The Stillwater W-4 Watershed was operated by the USDA-ARS Water Conservation Structures Laboratory until 1974. It is presently operated by the Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma, and is described by USDA-ARS (1956). The area is a natural watershed with a highway embankment forming the east boundary and is part of the Black Bear Creek drainage of the Arkansas River Basin. It is located 70 km northeast of the Guthrie watershed and 24 km north of Stillwater, Oklahoma, in Noble County. The watershed has an area of 83.4 ha and is rectangular in shape, 1480 m long by 615 m wide. The principal waterway has ephemeral flow and is 2030 m in length. It has a drainage density of 7.2 km per km^2 and three ponds with a total drainage area of 16.6 ha and total storage of 2700 m^3.

This watershed represents the grasslands of the Reddish Prairies of Oklahoma, Kansas, and Texas, which have slow to moderate internal drainage and good surface drainage. USDA-SCS (1956) describes the soils as 42.9% Vernon clay loam, 13.8% Lucien very fine sandy loam, 13.6% Albion loam, 11.3% Renfrow silt loam, 10.1% Gowen silt loam, 3.7% Kirkland silt loam, 2.0% Renfrow silty clay loam, 1.4% Lucien loam, and 1.2% Norge silt loam. A soils map is shown in Figure 5 and the soil classifications in Table VII. The vegetative cover is pasture

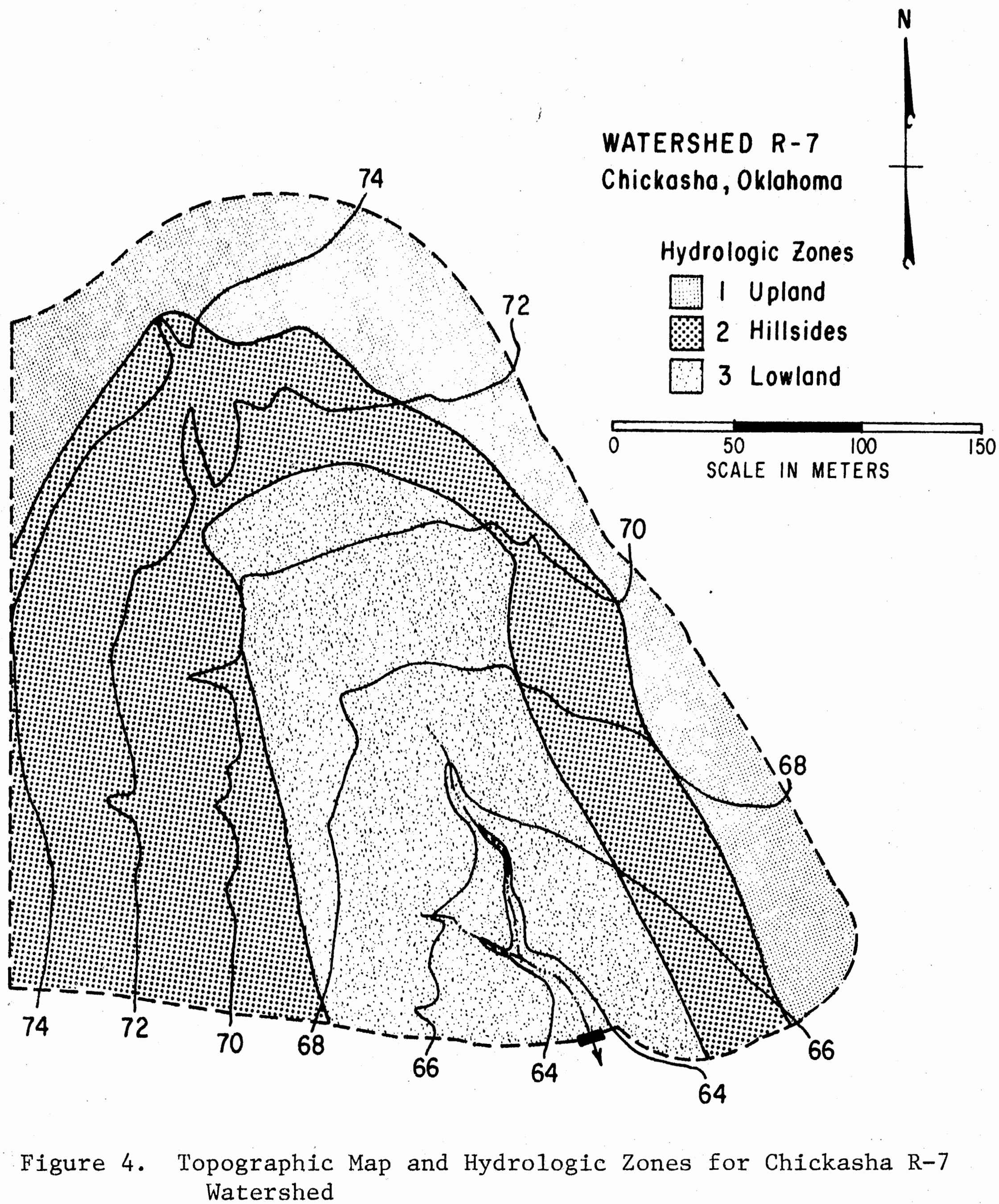

Figure 4. Topographic Map and Hydrologic Zones for Chickasha R-7 Watershed

TABLE VI

HYDROLOGIC ZONE AND SOIL PARAMETERS FOR CHICKASHA R-7 WATERSHED (7.8 ha)

	Zone 1	Zone 2	Zone 3
Zone Area, %	22.3	45.1	32.6
Average Slope, %	2.8	4.5	3.6
Overland Flow Length, m	44	28	16
Principal Soil Series	Renfrow	Renfrow	Renfrow
Soil Texture	silt loam	silt loam	silt loam
Final Infilt. Rate, mm/hr	1.62	2.58	5.41
Depth, Upper layer, cm	24	26	34
Depth, Lower layer, cm	104	88	53
G*, Upper layer, %	11.4	11.4	11.4
G*, Lower layer, %	10.0	10.0	10.0
AWC+, Upper layer, %	19.9	19.9	19.9
AWC+, Lower layer, %	13.7	14.8	17.7
Cracks[xx], Upper layer, %	8.0	8.0	8.0
Cracks[xx], Lower layer, %	15.7	15.7	15.7
Root Depth, cm	128	114	87

*Percent of soil depth drained by gravity.
+Percent of soil depth drained by plants.
xxPercent of soil depth subject to cracking.

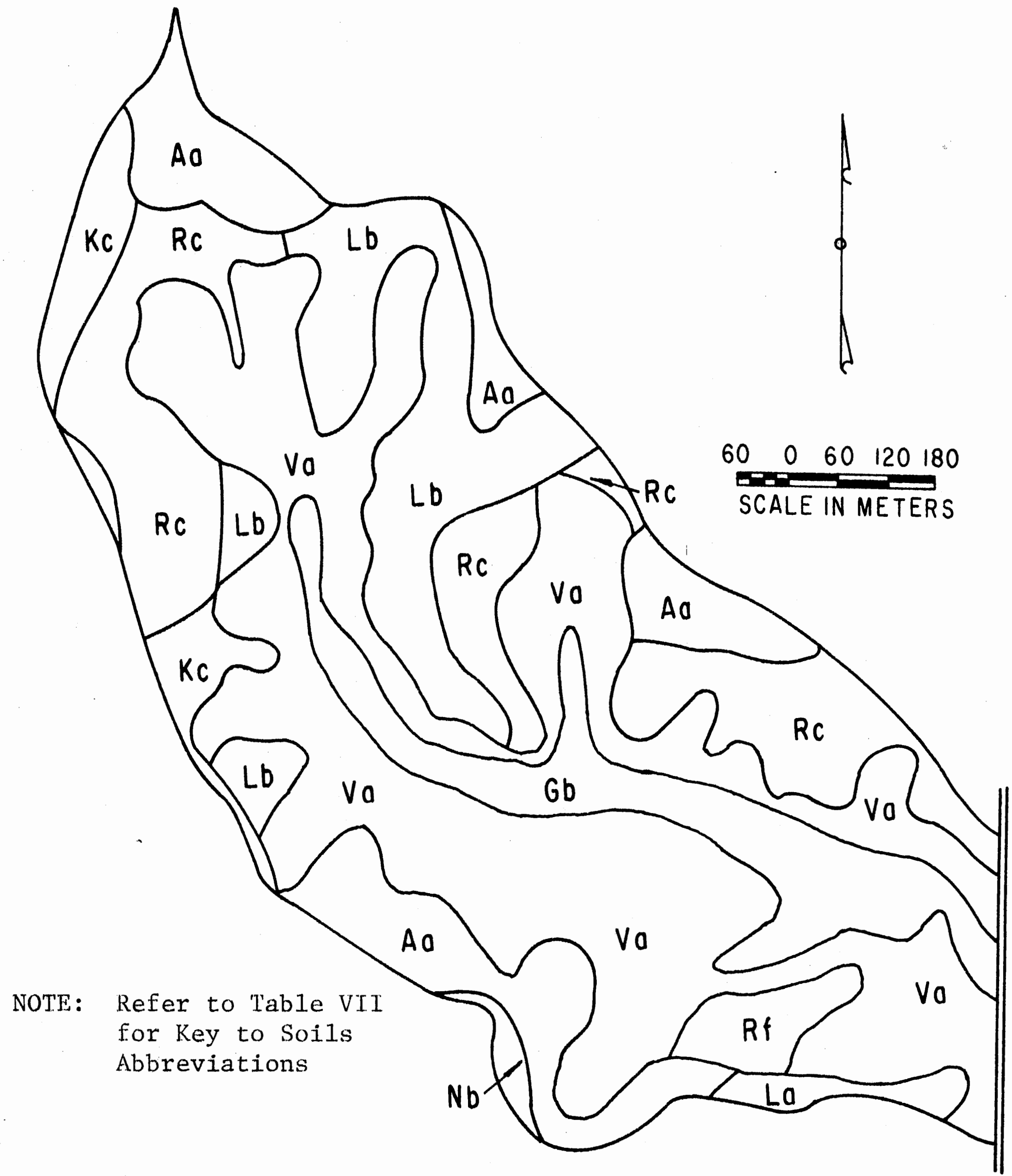

Figure 5. Soils Map for Stillwater W-4 Watershed

TABLE VII

SOIL CLASSIFICATIONS FOR STILLWATER W-4 WATERSHED

Zone	Soil Type	Percent Zone Area	Area m^2	Topsoil Depth, cm	Total Depth, cm	Final Infil. Rate, mm/hr
1	Albion Loam (Aa)	38.3	113,096	25	117	5.72
	Kirkland Silt Loam (Kc)	10.6	31,289	25	102	0.64
	Lucien Very Fine Sandy Loam (Lb)	5.6	16,655	18	56	3.81
	Norge Silt Loam (Nb)	3.5	10,296	30	183	5.72
	Renfrow Silt Loam (Rs)	31.9	94,032	25	158	0.64
	Renfrow Silty Clay Loam (Rf)	5.7	16,806	25	158	0.25
	Vernon Clay Loam (Va)	4.4	12,869	15	69	0.25
	TOTAL	100.0	295,042	24	128	2.90
2	Lucien Loam (La)	2.7	11,927	8	25	2.54
	Lucien Very Fine Sandy Loam (Lb)	22.3	98,238	18	56	3.81
	Vernon Clay Loam (Va)	75.0	329,865	15	69	0.25
	TOTAL	100.0	440,030	16	65	1.10
3	Gowen Silty Clay Loam (Gb)	85.7	84,429	46	152	5.72
	Vernon Clay Loam (Va)	14.3	14,124	15	69	0.25
	TOTAL	100.0	98,553	41	140	4.94
TOTAL			833,625			

consisting of 30% short perennial grass, 50% tall perennial grass, and 20% annual grass. Table VIII shows the vegetative cover conditions and percent reduction due to grazing (GRAZ) used for the model tests.

The period for the precipitation and climatic data is from January, 1953, to December, 1972. These data are from the Oklahoma Agricultural Experiment Station and are shown in Appendix C. Figure 6 shows the hydrologic zones and topography. The hydrologic and soil parameters are shown in Table IX.

Stillwater Environmental Watershed

The Stillwater Environmental Watershed is operated by the Oklahoma Agricultural Experiment Station. This area is located 40 km northeast of the Guthrie watershed and 15 km west of Stillwater, Oklahoma, in Noble County and is part of the Lake Carl Blackwell drainage of the Cimarron River Basin. The watershed has an area of 57.5 ha and is 1040 m long by 550 m wide with a principal waterway, 1100 m long, which has ephemeral flow. It has a drainage density of 8.7 km per km^2, a bifurcation ratio of 6.5, and a stream frequency of 59 km^{-2} which shows this to be a highly dissected and well drained watershed that would be expected to produce flood hydrographs with high peak rates of flow and short duration. One stock water pond with a drainage area of 6.9 ha and a storage of 5000 m^3 is located on the watershed.

Gray and Nance (1978) described the soils as 28.6% Stoneburg loam, 19.3% Grainola loam, 17.9% Stoneburg-Channel complex, 9.5% Lucien loam, 6.9% Zaneis loam, 5.9% Aydelotte loam, 5.4% Darnell fine sandy loam, 2.4% Lucien sandy loam, 2.4% Stephenville sandy loam, and 1.6% Renfrow loam (Table X). A soils map is shown in Figure 7.

TABLE VIII

VEGETATIVE COVER CONDITIONS AND PERCENT REDUCTION IN ET DUE TO GRAZING FOR STILLWATER W-4 WATERSHED

Year	Vegetative Cover Conditions	Percent Reduction In ET
1953	Good	45
1954	Fair	55
1955	Fair	55
1956	Poor	65
1957	Fair-Poor	60
1958	Fair	55
1959	Fair	55
1960	Fair	55
1961	Fair	55
1962	Poor	65
1963	Fair	55
1964	Fair-Poor	60
1965	Fair-Poor	60
1966	Poor	65
1967	Good-Fair	50
1968	Fair-Poor	60
1969	Fair	55
1970	Poor	65
1971	Poor	65
1972	Poor	65

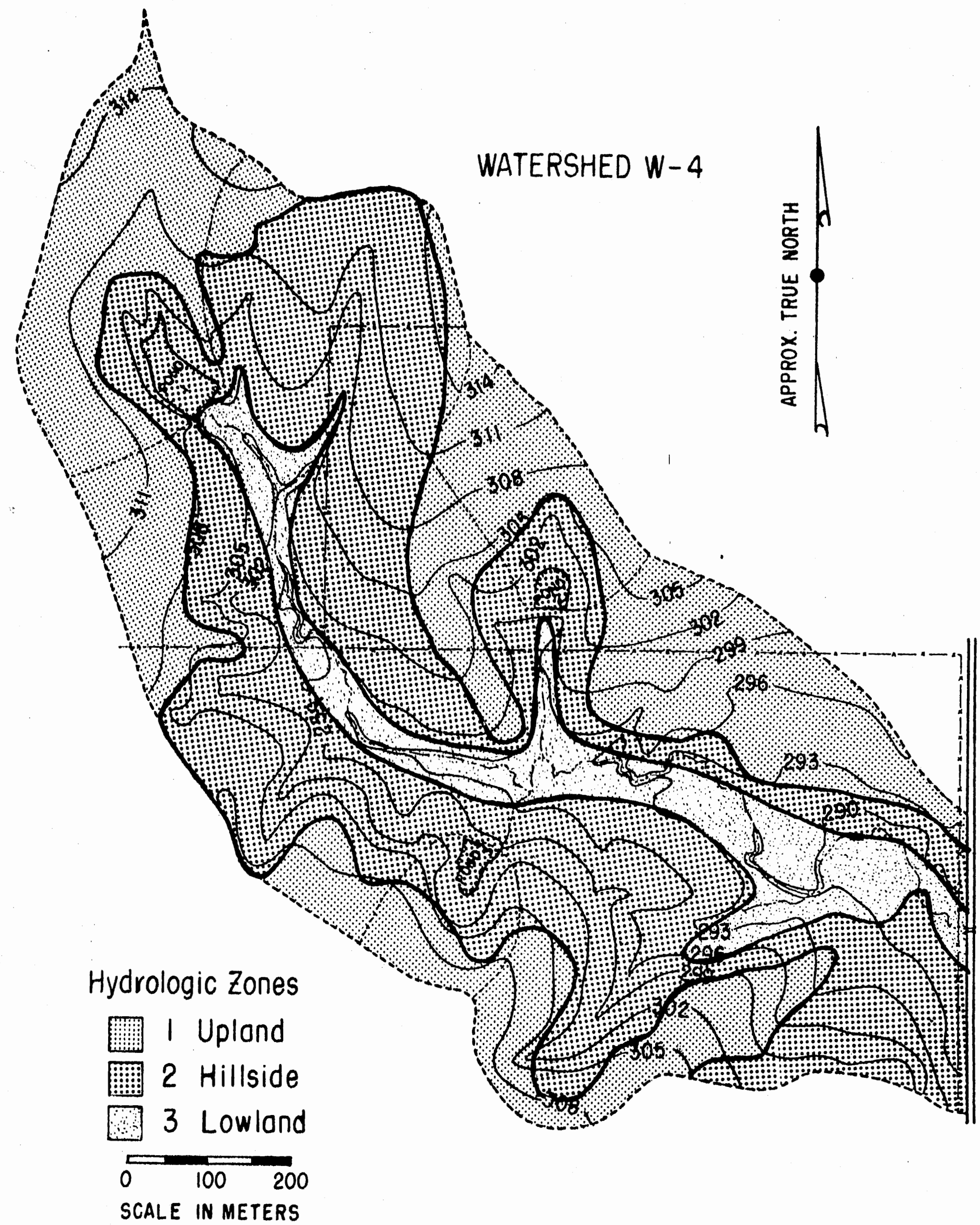

Figure 6. Topographic Map and Hydrologic Zones for Stillwater W-4 Watershed

TABLE IX

HYDROLOGIC ZONE AND SOIL PARAMETERS FOR STILLWATER W-4 WATERSHED (83.4 ha)

	Zone 1	Zone 2	Zone 3
Zone Area, %	35.4	52.8	11.8
Average Slope, %	4.7	6.3	4.7
Overland Flow Length, m	119	122	25
Principal Soil Series	Renfrow	Vernon	Gowen
Soil Texture	Silt Loam	Clay Loam	Silt Loam
Final Infilt. Rate, mm/hr	2.90	1.10	4.94
Depth, Upper layer, cm	24	16	41
Depth, Lower layer, cm	104	49	99
G*, Upper layer, %	14.3	14.8	11.6
G*, Lower layer, %	14.6	10.5	10.8
AWC+, Upper layer, %	16.1	15.5	19.3
AWC+, Lower layer, %	13.7	12.2	18.7
Cracksxx, Upper layer, %	12.0	12.0	7.4
Cracksxx, Lower layer, %	8.9	12.0	7.4
Root Depth, cm	128	65	140

*Percent of soil depth drained by gravity.
+Percent of soil depth drained by plants.
xxPercent of soil depth subject to cracking.

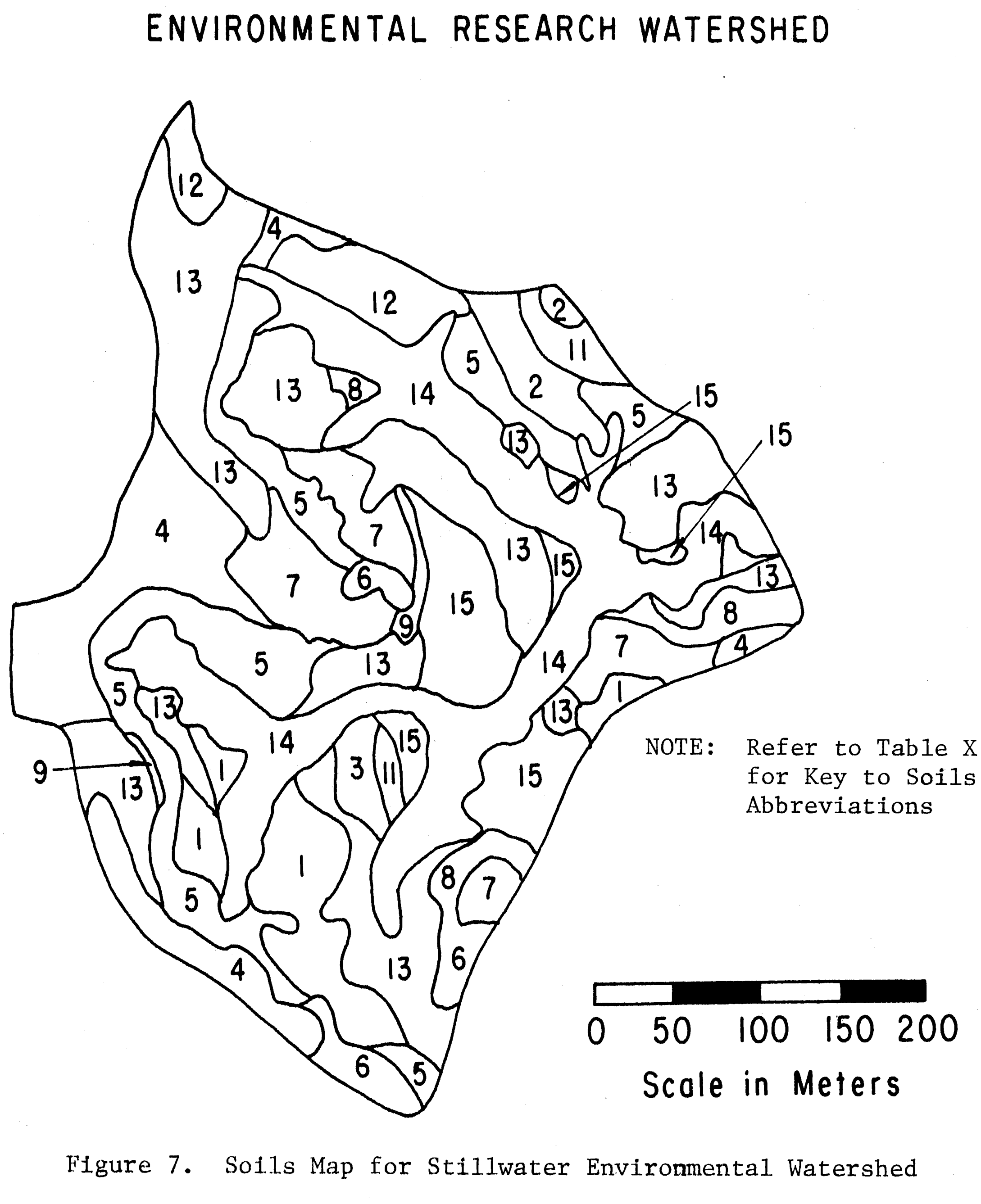

Figure 7. Soils Map for Stillwater Environmental Watershed

TABLE X

SOIL CLASSIFICATIONS FOR STILLWATER ENVIRONMENTAL WATERSHED

Zone	Soil Type	Percent Zone Area	Area m^2	Topsoil Depth, cm	Total Depth, cm	Final Infil. Rate, mm/hr
1	Grainola Loam (4)	38.1	53,639	7	61	0.64
	Lucien Sandy Loam (6)	9.8	13,797	8	38	3.81
	Lucien Loam (7)	13.0	18,302	12	33	2.54
	Stoneburg Loam (12)	39.1	55,047	15	62	5.72
	TOTAL	100.0	140,785	11	55	3.18
2	Aydelotte Loam (1)	11.0	34,512	13	152	0.64
	Darnell Fine Sandy Loam (2)	7.6	23,845	12	51	3.81
	Grainola Loam (5)	18.2	57,103	12	86	0.64
	Lucien Loam (8)	10.0	31,375	12	33	2.54
	Lucien Rock Outcrop (9)	1.5	4,706	7	15	2.54
	Renfrow Loam (10)	2.9	9,099	38	158	0.64
	Stephenville Sandy Loam (11)	3.6	11,295	30	58	6.60
	Stoneburg Loam (13)	34.8	109,185	15	64	5.72
	Zanies Loam (15)	10.4	32,630	23	147	5.72
	TOTAL	100.0	313,750	16	84	3.61
3	Darnell Rock Outcrop (3)	5.8	6,966	15	15	3.81
	Stephenville Sandy Loam (11)	2.3	2,762	30	58	6.60
	Stoneburg-Channel Complex (14)	85.9	103,165	10	84	0.76
	Zanies Loam (15)	6.0	7,206	23	147	5.72
	TOTAL	100.0	120,099	12	83	1.37
TOTAL			574,634			

Land use consists of 6% wheat, 5% woods, and 89% pasture. Baker (1976) described the pasture as tallgrass prairie. The vegetation consists of Little Bluestem, Indiangrass, Western Ragweed, Annual Threeawn, and Scribner's Panicum. The vegetation is moderately grazed. Table XI shows the vegetative cover conditions and GRAZ factors used for the model tests.

The period for the precipitation and climatic data is from January, 1977, to October, 1979. These data are from the Oklahoma Agricultural Experiment Station and are shown in Appendix D. Figure 8 shows the hydrologic zones and topography. The hydrologic and soil parameters are shown in Table XII.

TABLE XI

VEGETATIVE COVER CONDITIONS AND PERCENT REDUCTION IN ET DUE TO GRAZING FOR STILLWATER ENVIRONMENTAL WATERSHED

Year	Vegetative Cover Conditions	Percent Reduction in ET
1977	Fair	55
1978	Fair	55
1979	Excellent	40

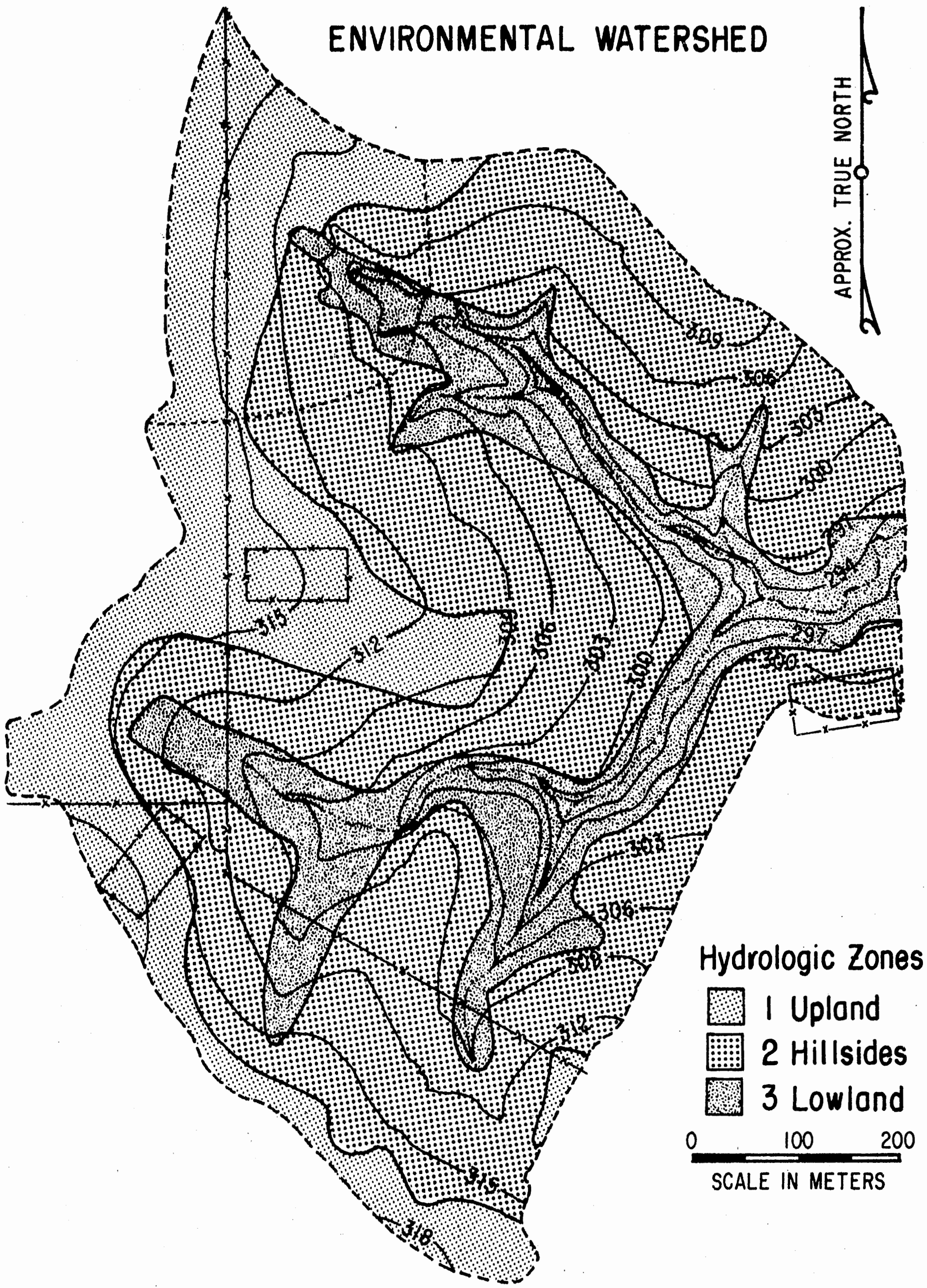

Figure 8. Topographic Map and Hydrologic Zones for Stillwater Environmental Watershed

TABLE XII

HYDROLOGIC ZONE AND SOIL PARAMETERS FOR STILLWATER ENVIRONMENTAL WATERSHED (57.5 ha)

	Zone 1	Zone 2	Zone 3
Zone Area, %	24.5	54.6	20.9
Average Slope, %	3.6	5.3	9.0
Overland Flow Length, m	67	85	20
Principal Soil Series	Stoneburg	Stoneburg	Stoneburg
Soil Texture	Loam	Loam	Clay Loam
Final Infilt. Rate, mm/hr	3.18	3.61	1.37
Depth, Upper layer, cm	11	16	12
Depth, Lower layer, cm	44	68	71
G*, Upper layer, %	14.8	15.5	18.4
G*, Lower layer, %	12.3	13.4	13.4
AWC+, Upper layer, %	15.3	15.2	12.5
AWC+, Lower layer, %	14.2	15.6	14.0
Cracks[xx], Upper layer, %	8.7	8.4	7.8
Cracks[xx], Lower layer, %	8.7	8.4	7.8
Root Depth, cm	55	84	83

*Percent of soil depth drained by gravity.
+Percent of soil depth drained by plants.
xxPercent of soil depth subject to cracking.

CHAPTER V

CALIBRATING THE USDAHL MODEL

Types of Calibrations

The model was calibrated using three different sets of criteria which are described below. These criteria were based on situations that would potentially make the model responsive to ungaged watersheds.

The Type I calibration was based on the coincidence of the regression line between observed and simulated monthly runoff with the plotted equal-value line.

The Type II calibration was based on the equality of the total simulated and observed runoff for the calibration period and the monthly values regression line being as close to the plotted equal-value line as the condition of equal runoff would allow. The monthly simulated runoff from the model was plotted versus the monthly observed runoff. A regression equation was calculated for the points and compared with an equal-value line. The hydrologic parameters used by the model were varied until the calibration conditions were satisfied.

Both Type I and Type II calibrations considered the watershed as a bounded system as shown in Figure 9. The precipitation supplied water to the budget and it left by either evapotranspiration, surface runoff, or groundwater recharge. Because central Oklahoma grassland watersheds normally have runoff only during and shortly after storms the lateral subflow was ignored for these two calibrations.

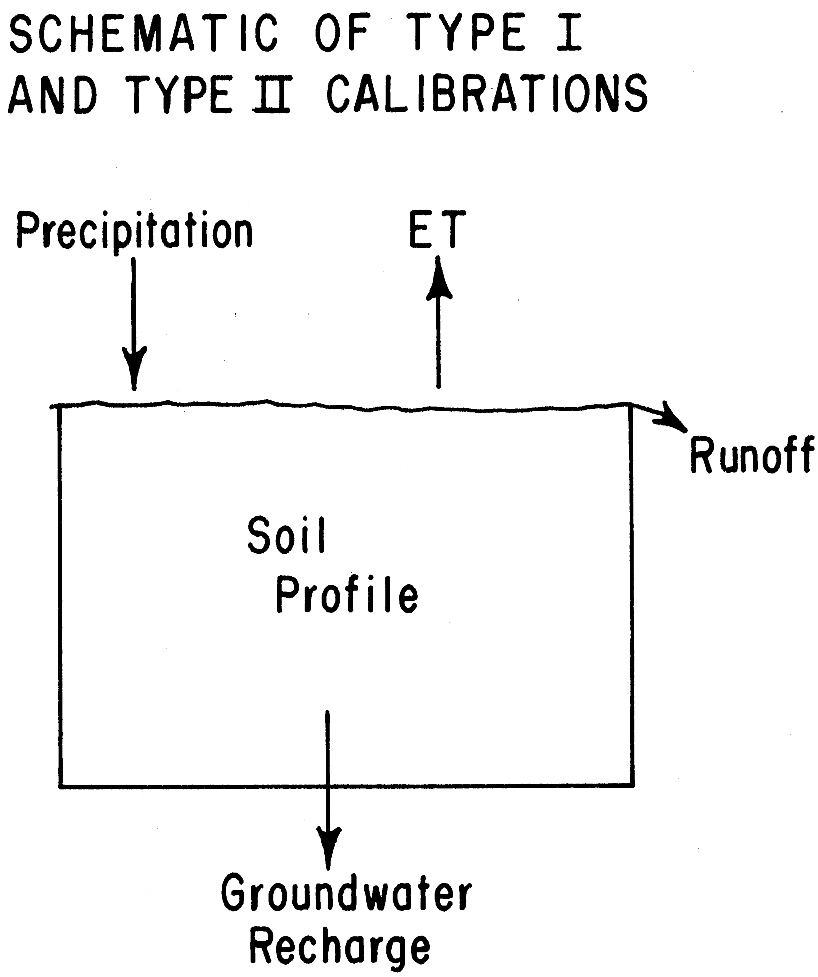

Figure 9. Schematic of the Water Budget Components for Type I and II Calibrations

The Type III was developed to consider the case of lateral subflow (offsite flow). Routing coefficients for the runoff recession curve downstream from the watershed were calculated and entered into the model. This added another component, offsite flow, to the system as shown in Figure 10. The varying of the parameters was continued until the total simulated runoff equaled the total observed runoff for the calibration period and the monthly values regression line was as close to the plotted equal-value line as the condition of equal runoffs would allow.

Pertinent Parameters

One rule used to calibrate this model was that the parameters described in Chapter III which were easily measured from topography, soil, or land use, were measured and then held constant during the calibration process.

The variables listed below were identified as parameters to be varied because they are difficult to measure. They are, in fact, measured by calibration. England (1977) also identified these same variables when he calibrated the model on a Post Oak-Shortleaf Pine watershed:

VD   Depression Storage Parameter - the volume of depressions that would store rainfall until it infiltrated.

A   Vegetative Parameter - the infiltration capacity in depth per hour per depth$^{1.4}$ of available storage from the Holtan infiltration equation $f = A \cdot S_a^{1.4} + f_c$ (Holtan, 1965). It is an index of surface-connected porosity and is land use related.

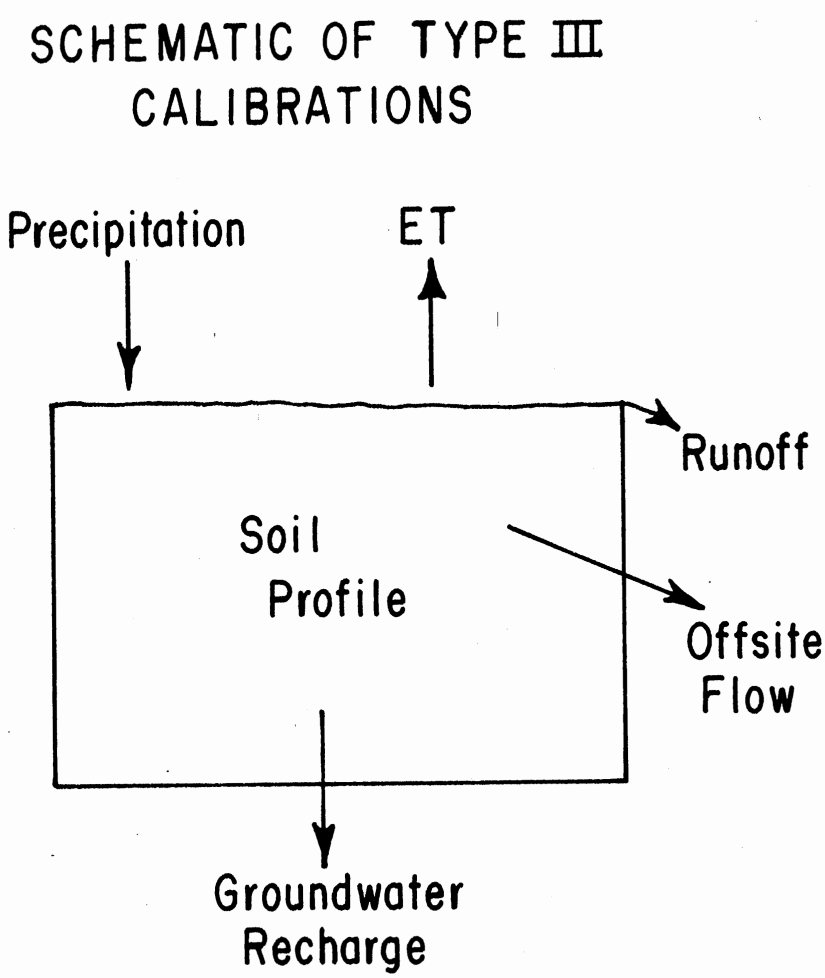

Figure 10. Schematic of the Water Budget Components for Type III Calibration

ET/EP <u>Evapotranspiration Parameter</u> - the ratio of maximum evapotranspiration to maximum pan evaporation for a year.

GR <u>Deep Groundwater Recharge Parameter</u> - deep percolation rate that does not show up in the recession curve.

Initial Parameter Values

Vegetative Parameter

The literature was researched for starting values of the pertinent parameters. Holtan et al. (1975) stated that values for the vegetative parameter, A, can range from 0.10 to 1.00 depending on the type of vegetation. Specific values used by previous researchers for grass pasture were 0.8 (Nicks et al., 1977), 0.7 (Holtan et al., 1975), 0.2 (Hanson, 1977), and 0.1 (Ghermazien, 1978). The median value, 0.7, was selected for this study.

Depression Storage Parameter

The values for the parameter, VD, ranged from 25.4 mm to 1.27 mm and depended on watershed topography. The value, 15.24 mm, was selected because Crow et al. (1978) had used this value for the Stillwater Environmental Watershed which was the watershed nearest the Guthrie watershed.

Evapotranspiration Parameter

The values for the parameter, ET/EP, for grass watersheds, used by previous researchers were 1.20, 1.02, 1.00, and 0.88. Lysimeter studies conducted by Blad and Rosenberg (1974) gave average daily evapotranspiration rates for the months of July and August as 7 and 5 mm/day, respectively. The maximum rate was slightly greater than 9 mm/day. Myers (1976) listed the average pan evaporation values for July and August for Stillwater, Oklahoma, as 9.2 and 8.4 mm/day, respectively. This resulted in average ET/EP ratios for July and August of 0.76 and 0.60, respectively, with maximum ratios of 0.98 and 1.07. Doorenbos and Pruitt (1977) gave an ET/EP ratio range from 0.50 to 0.94 for grass. They listed an ET/EP ratio of 0.85 for relative humidities greater than 70% and 0.82 for relative humidities from 40% to 70% from a lysimeter study conducted at Davis, California. In summary, the ET/EP ratios for grass depended on the temperatures, winds, solar radiation, and relative humidities of the watershed and had a range of 0.50 to 1.07. For this study, the value, 0.82, from the Davis, California, lysimeter study was selected and rounded down to 0.80. It was selected because it was specific data from conditions that approximated those of central Oklahoma.

Groundwater Recharge Parameter

Very little data have been provided by previous researchers with the model. Therefore, as an initial value for this study, the value of 0.0033 mm/hr used by Ghermazien (1978) for a central Oklahoma watershed was selected.

Watershed Selection

The USDAHL model was applied to the Guthrie W-V Watershed to determine the parameter values which best simulated monthly runoff. The watershed is described in Chapter IV. It was selected because it was small with grass pasture as the only land use, which made it easier to calculate the effect of land use on the parameter values. It had a smooth, well maintained, soil surface and grass cover. This meant that a single VD value could be applied to the entire watershed and that the investigator would not be working with an average VD calculated from several values. Also, the operating agency had collected precise precipitation, runoff, topographies, climatic, and soils records.

Calibration Procedure

Initial Trial

Monthly simulated runoff was calculated using the selected initial parameters. The observed and simulated monthly runoff values were plotted and a linear regression equation was calculated (Figure 11). This equation was

$$Q_s = -1.75 + 0.97\ Q_o \qquad (11)$$

with r = 0.94 and S.D. = 7.08 mm. The total simulated runoff was 25% less than the total observed runoff because the initial value of VD was too large which caused the model to underpredict the small runoff events (Table XIII). Table XIV shows the observed and the initial trial simulated monthly runoff values.

Type I

The model was run again after decreasing VD from 15.24 mm to 2.54 mm which caused the simulated runoff to be increased by 41.3%. It now underpredicted small events and overpredicted large events. The regression equation was

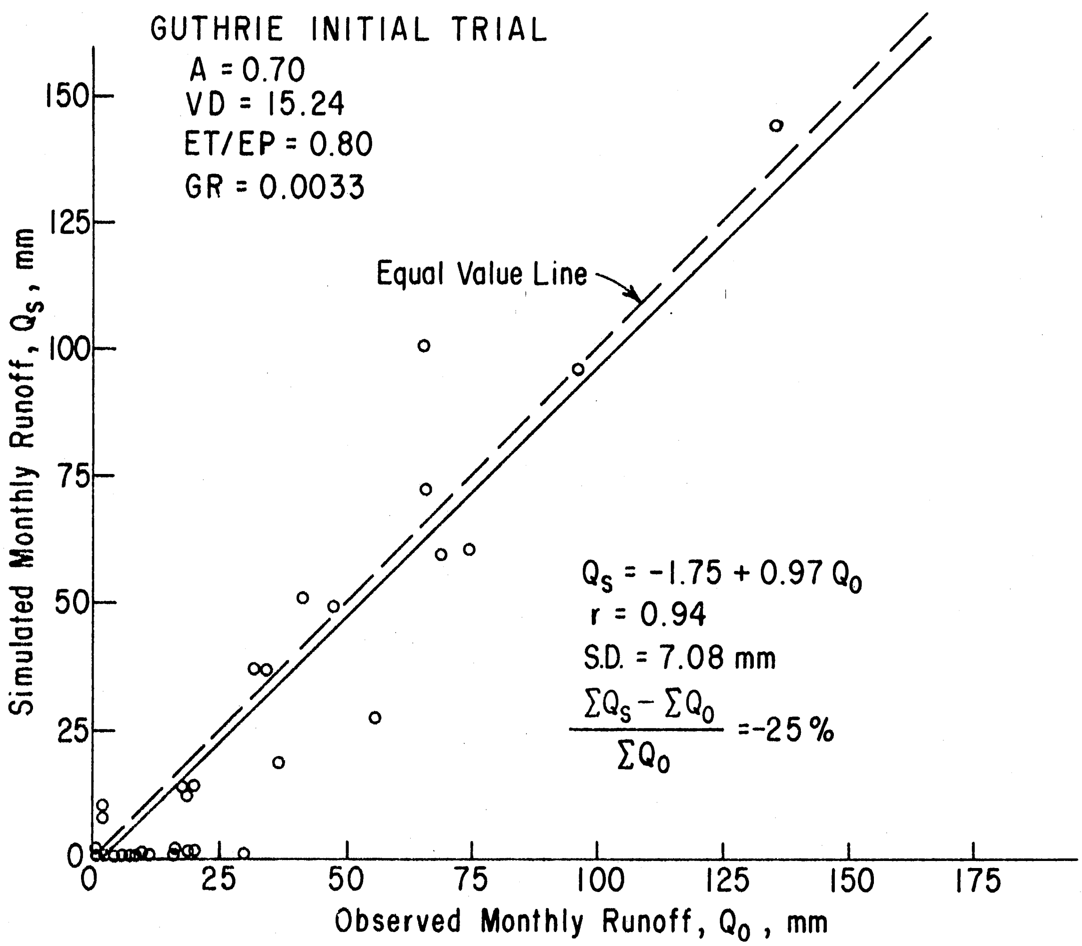

Figure 11. Monthly Runoff for Initial Trial for Guthrie W-V Watershed from 1942 to 1953

TABLE XIII

ANNUAL SUMMARY OF INITIAL TRIAL WATER BALANCE FOR GUTHRIE W-V WATERSHED FROM 1942 TO 1953

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi-ration mm	Soil Evap mm	Ground-water Recharge mm	Chg Soil Moisture mm
1942	790	87	59	410	303	22	-4
1943	567	83	71	350	180	11	-45
1944	784	71	28	439	254	17	+46
1945	811	123	99	309	432	24	-53
1946	678	39	0	433	200	17	+28
1947	650	140	149	338	219	11	-67
1948	581	79	27	412	149	8	-15
1949	1052	239	247	372	346	20	+67
1950	677	86	116	374	229	15	-57
1951	820	116	51	441	255	13	+60
1952	483	22	0	417	128	10	-72
1953	809	52	1	508	192	14	+94
TOTAL	8702	1137	848	4803	2887	182	-18
MEAN	725	95	71	400	240	15	-1.5

Offsite Flow = 0.0

TABLE XIV

OBSERVED AND INITIAL TRIAL SIMULATED MONTHLY RUNOFF FOR GUTHRIE W-V WATERSHED, mm

Year	/ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1942	O	0	0.5	0	69.6	3.3	0.8	0	1.8	10.7	0.5	0	0.2	87.4
	S	0	0	0	59.3	0	0	0	0	0	0	0	0	59.3
1943	O	0	0	0	0	74.9	2.0	0	0	0	5.6	0	0	82.5
	S	0	0	0	0	60.4	10.2	0	0	0	0	0	0	70.6
1944	O	0	0	6.4	17.8	18.8	3.0	0	0	1.0	16.5	0.3	6.8	70.6
	S	0	0	0	13.8	12.1	0	0	0	0	1.8	0	0	27.7
1945	O	0	0.3	1.0	15.7	0	66.5	2.3	0	37.0	0	0	0	122.8
	S	0	0	0	0	0	72.2	7.8	0	18.7	0.4	0	0	99.1
1946	O	0.5	1.0	0.3	0	11.7	2.8	0	5.6	0	5.3	11.4	0	38.6
	S	0	0	0	0	0	0	0	0	0	0	0	0	0
1947	O	0	0	0	96.8	41.9	0	1.5	0	0	0	0	0	140.2
	S	0	0	0	96.0	50.8	2.1	0	0	0	0	0	0	148.9
1948	O	0	0	4.3	18.0	0.3	56.1	0	0	0	0	0	0	78.7
	S	0	0	0	0	0	27.4	0	0	0	0	0	0	27.4
1949	O	6.4	0.5	0	0	136.5	66.0	20.1	0	9.6	0.3	0	0	239.4
	S	0	0	0	0	144.0	100.3	1.5	0	1.2	0	0	0	247.0
1950	O	0	0	0	0	3.3	34.8	48.0	0	0	0	0	0	86.1
	S	0	0	0	0	0	36.6	49.1	30.7	0	0	0	0	116.4

TABLE XIV (Continued)

Year / Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1951	O	0	3.5	0	11.2	30.0	32.2	7.1	20.1	9.4	0	3.0	0	116.5
	S	0	0	0	0	0	37.0	0	14.1	0	0	0	0	51.1
1952	O	0	0.3	11.2	0.3	8.1	0	0.3	2.0	0	0	0	0	22.2
	S	0	0	0	0	0	0	0	0	0	0	0	0	0
1953	O	0	0	7.1	1.3	1.8	0	3.0	18.8	3.6	7.4	4.8	3.8	51.6
	S	0	0	0	0	0	0	0	1.0	0	0	0	0	1.0
TOTAL	O	6.9	6.1	30.3	230.7	330.6	264.2	82.3	48.3	71.3	35.6	19.5	10.8	1136.6
	S	0	0	0	169.1	267.3	285.8	58.4	45.8	19.9	2.2	0	0	848.5
MEAN		0.6	0.5	2.5	19.2	27.5	22.0	6.8	4.0	5.9	3.0	1.6	0.9	94.7
		0	0	0	14.1	22.3	23.8	4.9	3.8	1.6	0.2	0	0	70.7

O - Observed Runoff.
S - Simulated Runoff - Initial Trial.

$$Q_s = -0.48 + 1.12\ Q_o \tag{12}$$

with r = 0.96 and S.D. = 6.59 mm.

For the next run, the ET/EP ratio was increased from 0.80 to 0.88 the value used by Ghermazien (1978). The total runoff simulated by this run was 1.35% less than the total observed runoff. The regression equation was

$$Q_s = -0.68 + 1.07\ Q_o \tag{13}$$

with r = 0.95 and S.D. = 6.92 mm. This run also underpredicted small events and overpredicted large events.

At this time, several parameter variations were tried in an attempt to reach a Type I calibration. It was not until the groundwater recharge (GR) was increased, that the regression line moved toward the equal-value line. Then it was discovered that by varying both A and GR at the same time, the slope of the regression line could be changed without causing the line to move away from the equal-value line. By varying A and GR, the calibration was fine tuned and after a total of eight trials, a Type I calibration was achieved.

As shown in Figure 12, the regression line nearly coincided with the equal-value line. Also, the small runoff events were now simulated. The regression equation was

$$Q_s = -0.51 + 1.01\ Q_o \tag{14}$$

with r = 0.93 and S.D. = 7.57 mm. The monthly simulated and observed runoff values and the water budget are shown in Tables XV and XVI. Figure 13 is a double mass plot which shows that yearly simulated and observed runoff values were nearly equal until 1951 when the simulated runoff became less than the observed. For the entire calibration period of 1942 to 1953, the total simulated runoff was 5.4% less than

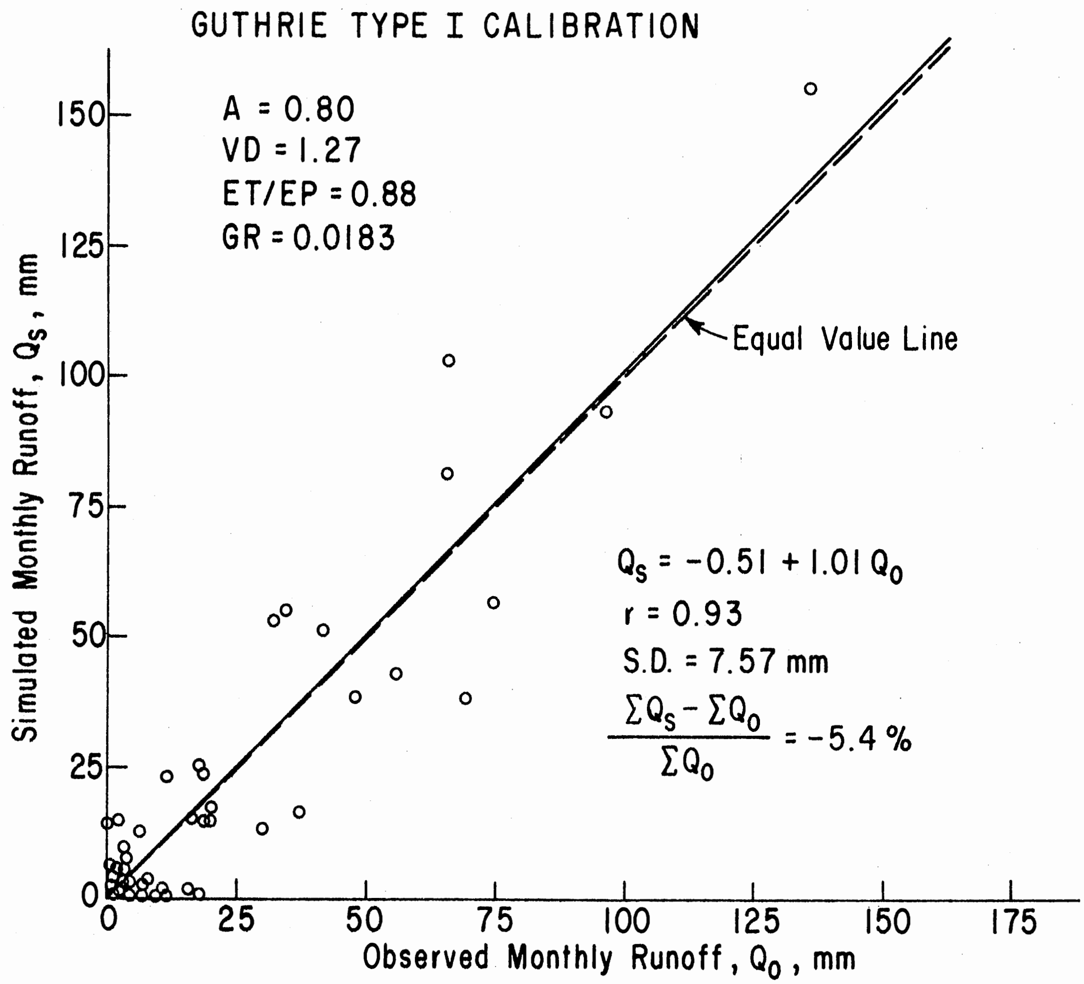

Figure 12. Monthly Runoff for Type I Calibration for Guthrie W-V Watershed from 1942 to 1953

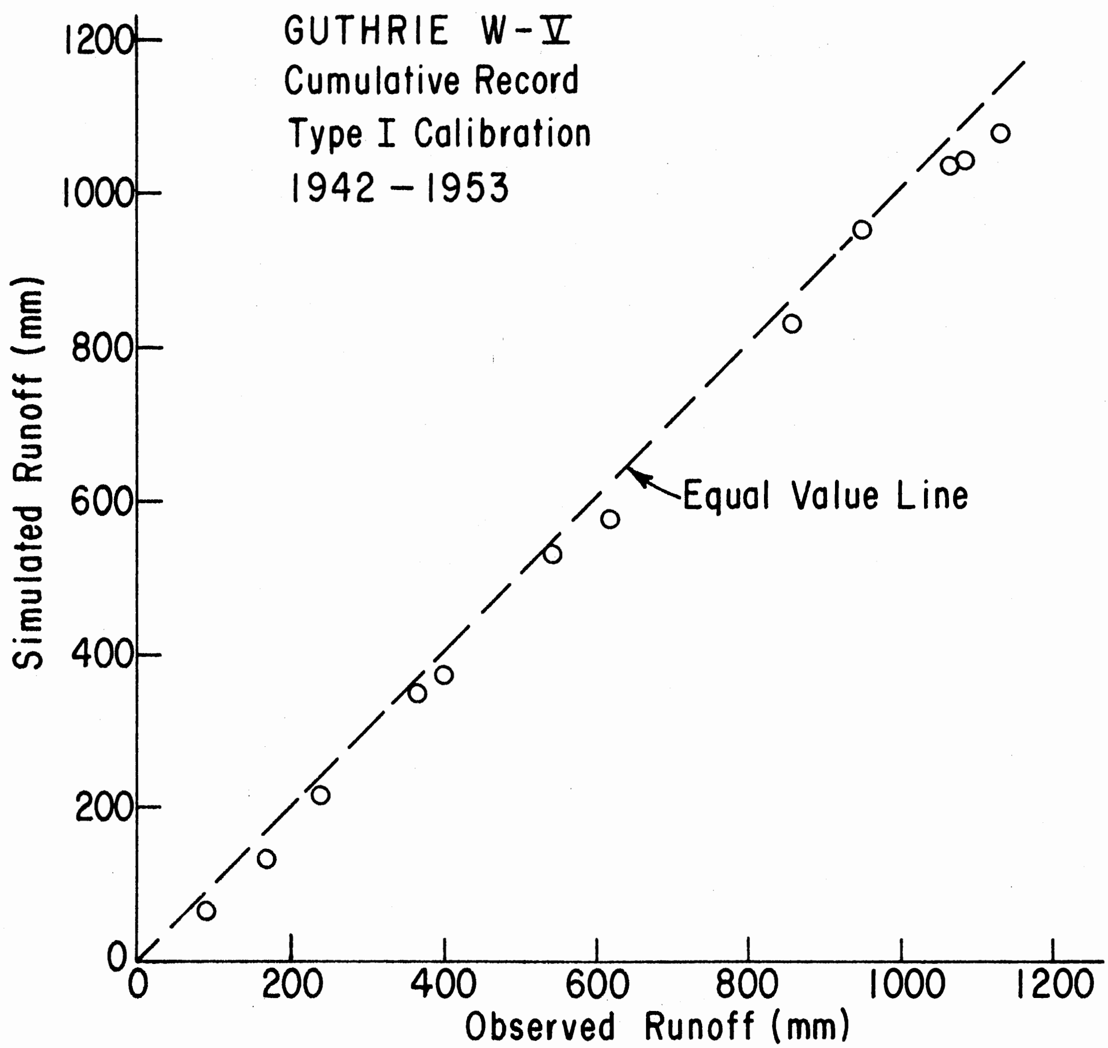

Figure 13. Type I Calibration Double Mass Plot for Guthrie W-V Watershed from 1942 to 1953

TABLE XV

ANNUAL SUMMARY OF TYPE I CALIBRATION
WATER BALANCE FOR GUTHRIE W-V
WATERSHED FROM 1942 TO 1953

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi-ration mm	Soil Evap mm	Ground-water Recharge mm	Chg Soil Moisture mm
1942	790	87	62	471	179	73	+5
1943	567	83	72	388	110	34	-37
1944	784	71	79	470	137	62	+36
1945	811	123	131	411	234	89	-54
1946	678	39	24	469	94	56	+35
1947	650	140	159	378	138	36	-61
1948	581	79	47	478	56	22	-22
1949	1052	239	255	463	206	63	+65
1950	677	86	122	425	144	45	-59
1951	820	116	86	525	115	34	+60
1952	483	22	4	435	73	31	-60
1953	809	52	34	583	74	42	+76
TOTAL	8702	1137	1075	5496	1560	587	-16
MEAN	725	95	90	458	130	49	-1.3

Offsite Flow = 0.0

TABLE XVI

TYPE I CALIBRATION MONTHLY SIMULATED RUNOFF
FOR GUTHRIE W-V WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1942	0	3.5	0	38.2	9.5	6.0	0	0	2.0	3.0	0	0	62.3
1943	0	0.1	0	0	56.6	14.8	0	0	0	0	0	0	71.5
1944	1.4	0.6	12.7	25.1	23.6	0.1	0	0	0	15.2	0	0	78.7
1945	0	0.5	4.2	1.8	0	103.1	5.6	0	16.0	0	0	0	131.2
1946	0	0	0	0	23.2	0	0	0	0	0	0.7	0	23.9
1947	0	0	0	93.4	51.3	14.4	0	0	0	0	0	0	159.1
1948	0	0	3.0	0.8	0	43.0	0.2	0	0	0	0	0	47.0
1949	0	0	0	0	155.4	81.5	17.3	0	0.7	0	0	0	254.9
1950	0	0.9	0	0	1.7	55.1	38.4	26.2	0.6	0	0	0	122.9
1951	0	0	0	0	13.2	53.1	2.5	14.8	0	0	3.0	0	86.5
1952	0	0	0	0.2	3.4	0	0	0	0	0	0	0	3.6
1953	0	0	0	0	3.2	0	0	14.7	5.2	2.8	0	7.7	33.6
TOTAL	1.4	5.6	19.9	159.5	341.1	371.1	64.0	55.7	24.5	21.0	3.7	7.7	1075.2
MEAN	0.1	0.5	1.6	13.3	28.4	30.9	5.3	4.6	2.0	1.8	0.3	0.6	89.6

the total observed runoff. The final hydrologic parameters were A = 0.80, VD = 1.27 mm, ET/EP = 0.88, and GR = 0.0183 mm/hr.

Type II

For the Type II calibration, the primary consideration was that the total simulated and total observed runoff must be equal for the entire calibration period, while obtaining the best possible fit of the monthly and observed runoff, as determined by the positions of the regression line and the equal-value line. Again after four trials, it was discovered that the best way of achieving a Type II calibration was by varying A and GR. After eight trials, the Type II calibration was achieved with the results being shown in Figure 14 and Tables XVII and XVIII. The total simulated runoff was equal to the total observed runoff. The regression equation was

$$Q_s = -0.23 + 1.03\ Q_o \tag{15}$$

with r = 0.92 and S.D. = 8.35 mm.

The double mass plot of yearly simulated and observed runoff (Figure 15) reveals that all of the points are located near the equal-value line. The parameter values for VD and ET/EP were the same as for the Type I calibration. The parameter, A, was decreased from 0.8 to 0.6 which increased runoff as compared to the Type I calibration. The parameter, GR, was increased from 0.0183 mm/hr to 0.0229 mm/hr which decreased runoff. The overall result was that simulated runoff increased 5.6%, simulated evapotranspiration increased 0.7%, simulated soil evaporation decreased 12%, and groundwater recharge increased 14.8%. The model now simulated small and large events equally well with

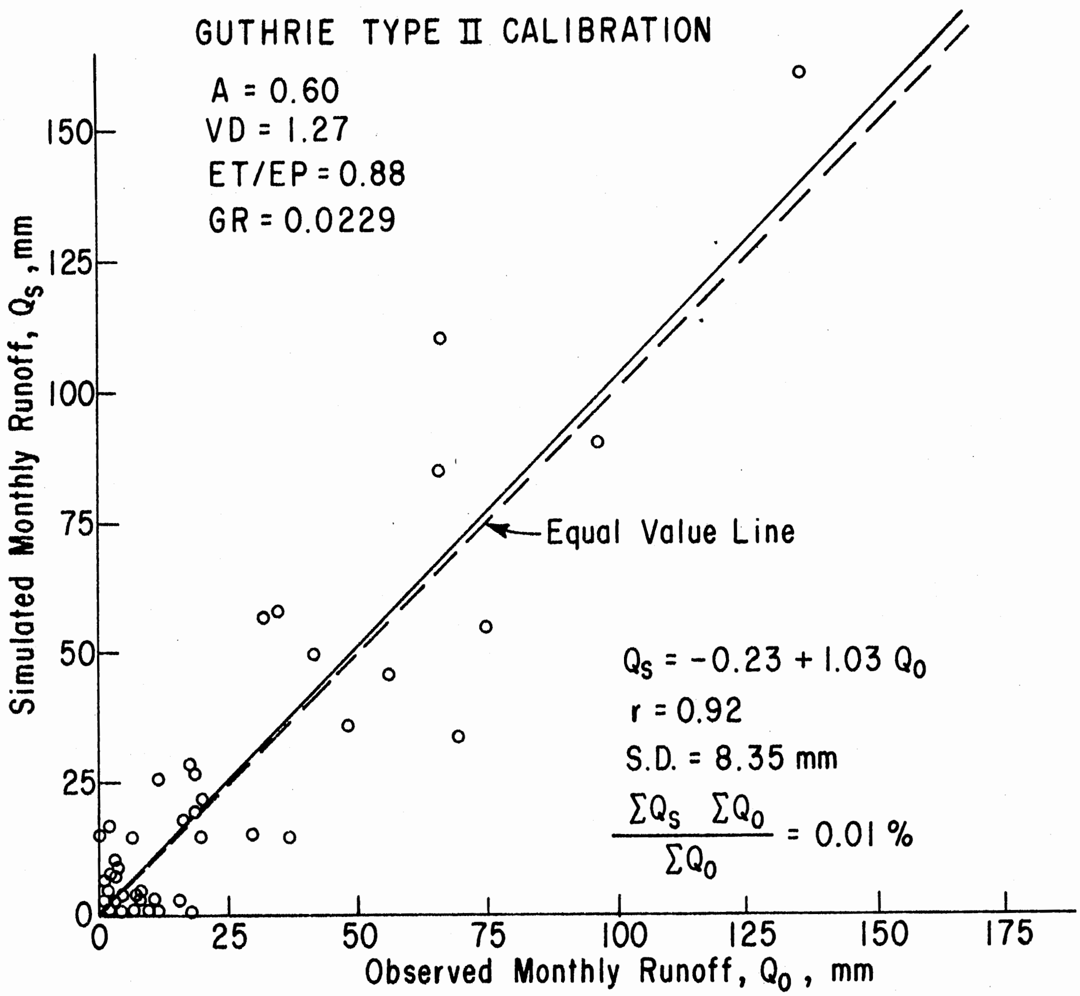

Figure 14. Monthly Runoff for Type II Calibration for Guthrie W-V Watershed from 1942 to 1953

TABLE XVII

ANNUAL SUMMARY OF TYPE II CALIBRATION
WATER BALANCE FOR GUTHRIE W-V
WATERSHED FROM 1942 TO 1953

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi-ration mm	Soil Evap mm	Ground-water Recharge mm	Chg Soil Moisture mm
1942	790	87	62	474	164	85	+5
1943	567	83	72	388	101	39	-33
1944	784	71	91	473	117	71	+32
1945	811	123	142	416	202	103	-52
1946	678	39	27	470	81	65	+35
1947	650	140	155	379	132	43	-59
1948	581	79	52	480	47	25	-23
1949	1052	239	270	476	172	72	+62
1950	677	86	122	430	132	51	-58
1951	820	116	95	528	100	39	+58
1952	483	22	5	435	65	36	-58
1953	809	52	44	587	59	45	+74
TOTAL	8702	1137	1137	5536	1372	674	-17
MEAN	725	95	95	461	114	56	-1.4

Offsite flow = 0.0

TABLE XVIII

TYPE II CALIBRATION MONTHLY SIMULATED RUNOFF
FOR GUTHRIE W-V WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1942	0	4.6	0	33.7	10.6	6.9	0	0	2.9	3.7	0	0.1	62.5
1943	0	0.1	0	0	54.9	16.7	0	0	0	0	0	0	71.7
1944	1.8	0.9	14.8	28.3	26.6	0.9	0	0	0	18.0	0	0.1	91.4
1945	0	1.0	5.8	2.7	0	110.3	7.4	0	14.5	0	0	0	141.7
1946	0	0	0	0.3	25.6	0.6	0	0	0	0	0.9	0	27.4
1947	0	0	0	90.4	49.6	15.2	0	0	0	0	0	0	155.2
1948	0	0	4.0	0.5	0.3	45.7	1.4	0	0	0	0	0	51.9
1949	0	0	0	0	161.2	85.3	22.1	0	0.8	0	0	0	269.4
1950	0	1.4	0	0	2.3	58.0	36.0	24.2	0.1	0	0	0	122.0
1951	0	0	0	0	15.2	56.8	4.1	14.7	0	0	3.5	0	94.3
1952	0	0	0	0.4	4.6	0	0	0	0	0	0	0	5.0
1953	0	0	0	0	5.0	0	0	19.5	7.2	3.4	0	8.9	44.0
TOTAL	1.8	8.0	24.0	156.3	355.9	396.4	71.0	58.4	25.5	25.1	4.4	9.1	1136.5
MEAN	0.1	0.7	2.0	13.0	29.6	33.0	5.9	4.9	2.1	2.1	0.4	0.8	94.7

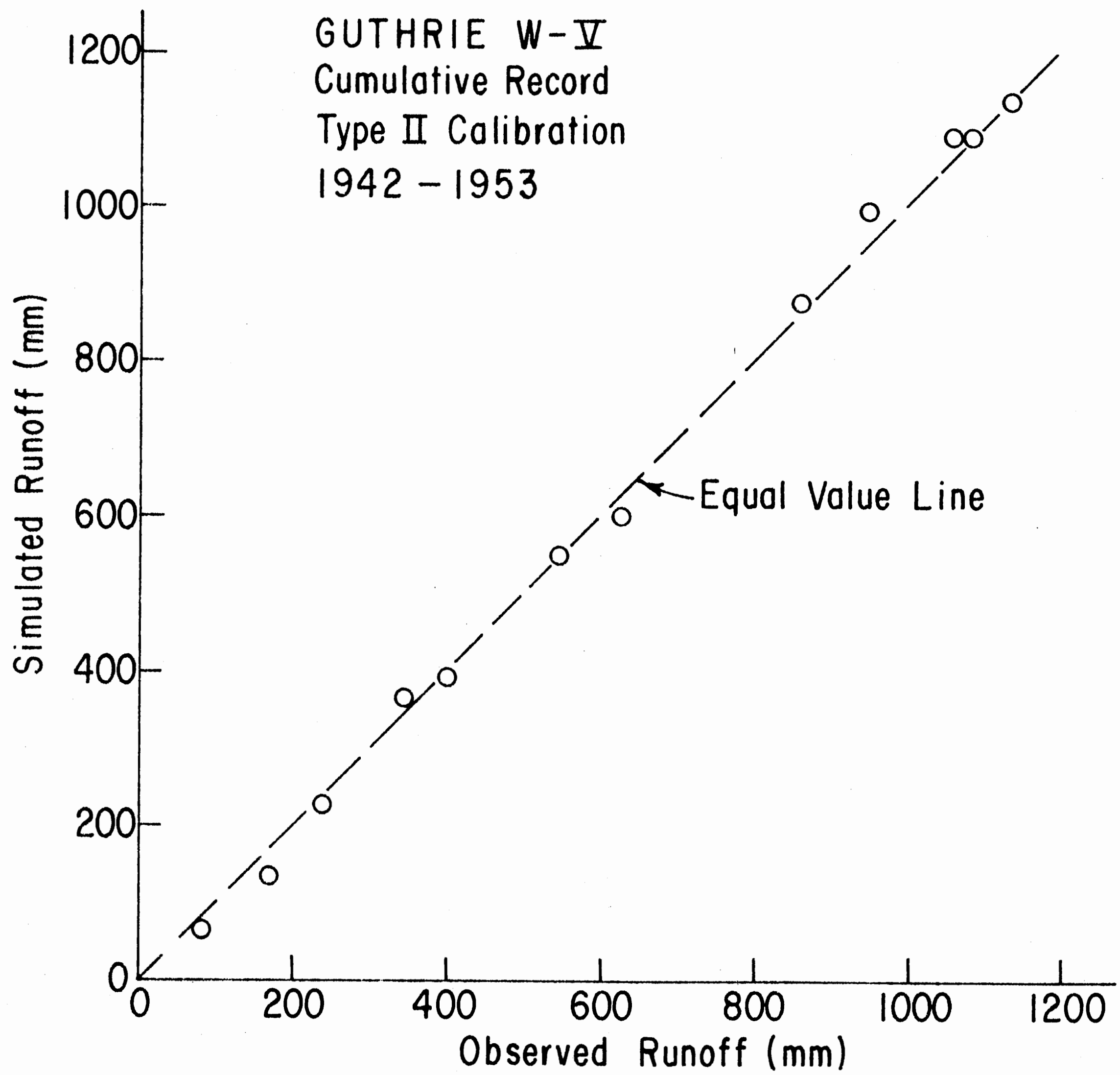

Figure 15. Type II Calibration Double Mass Plot for Guthrie W-V Watershed from 1942 to 1953

a balanced number of points on both sides of the equal-value line (Figure 14).

Type III

For the Type III calibration, the routing coefficients and maximum rates of flow associated with each of the four linear segments of the runoff recession curve downstream were calculated and entered into the model. The coefficients were calculated from hydrographs recorded by the U.S. Geological Survey at a gaging point 54 km northeast of the Guthrie watershed. This station, Council Creek, was the nearest continuous recorded data available. Figure 16 shows the linear segments and the maximum rates of flow associated with each.

The addition of the downstream routing coefficients caused the model to decrease the amount of simulated runoff. For the first trial using the Type II parameter values with the addition of the routing coefficients, the total simulated runoff was decreased 54.4% from 1137 mm to 518 mm. The regression equation was

$$Q_s = -1.26 + 0.62\ Q_o \qquad (16)$$

with r = 0.74 and S.D. = 10.81 mm. These results revealed that the parameters had to be adjusted to increase simulated runoff. For the next trial, A was decreased to 0.2 and GR to 0.0033 mm/hr which produced an error of -35.5%. These results meant that the ET/EP ratio of 0.88 would have to be decreased because further decreasing of A, VD, and GR would not sufficiently increase the simulated runoff to equal observed runoff.

The next trial used an ET/EP ratio of 0.50, which was chosen because it was at the lower end of the ET/EP ratio range given by

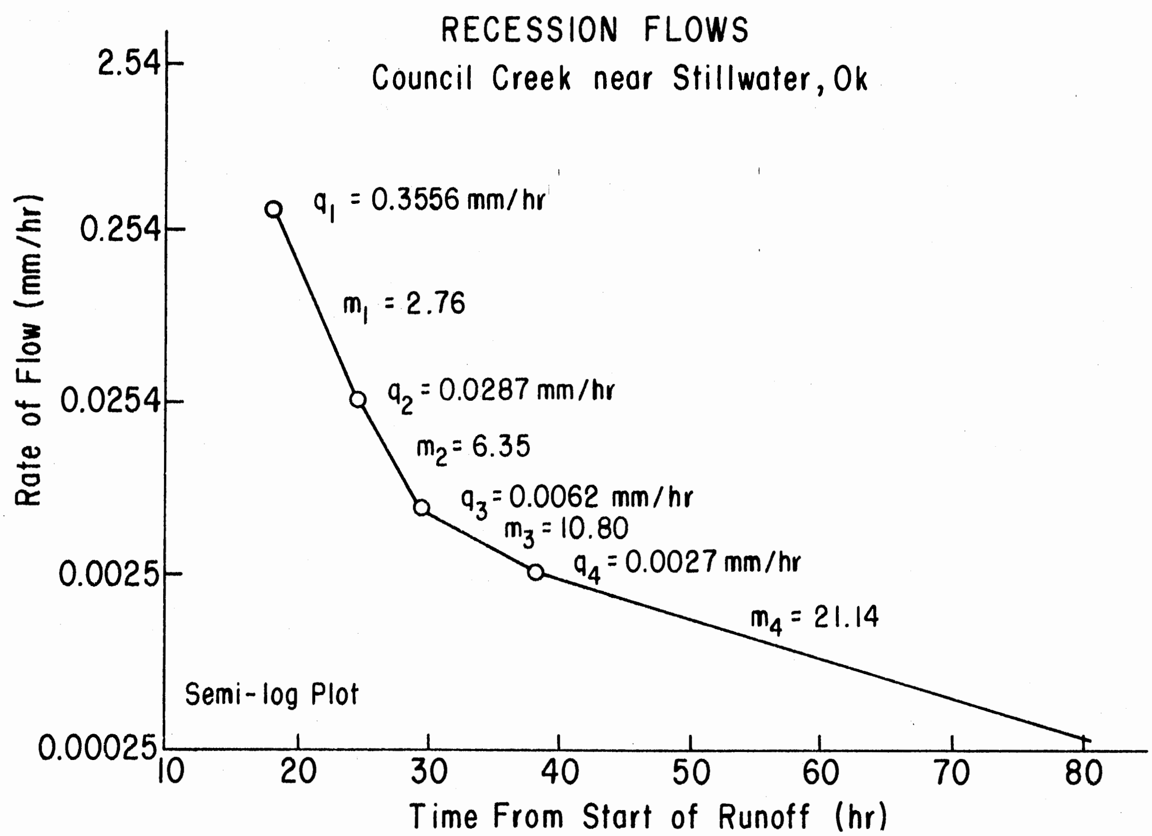

Figure 16. Separation of Council Creek Flow Regimes for the Type III Calibration

Doorenbos and Pruitt (1977). An error of +13.3% resulted with an equation of

$$Q_S = 0.03 + 1.05\ Q_O \quad (17)$$

with r = 0.86 and S.D. = 12.1 mm. The parameter A was then varied using a bracketing technique until the total simulated runoff was equal to the total observed runoff.

Five trials were needed to complete the Type III calibration and achieve the results shown in Figure 17 and Tables XIX and XX.

The regression equation was

$$Q_s = 0.31 + 0.96\ Q_o \quad (18)$$

with r = 0.85 and S.D. = 11.78 mm. The simulated transpiration and soil evaporation decreased, 32% and 96%, respectively, from the Type II calibration. The groundwater recharge was insignificant but 43% of the water budget left the watershed as offsite flow. The points on the double mass curve shown in Figure 18 are below the equal-value line until 1950 and then follow the line. The final parameter values were A = 0.32, VD = 1.27 mm, ET/EP = 0.50, and GR = 0.0033 mm/hr.

Annual Peak Rates of Flow

To evaluate the model's capability to simulate annual peak rates of flow with a total yield calibration, the simulated 100 year return period rates of flow were compared with the observed. The 100 year return period rates of flow were calculated using the Log Pearson Type III method described by Hjelmfelt and Cassidy (1975) and Haan (1977). Table XXI shows the annual observed and simulated peak rates of flow from 1942 to 1953. The observed Log Pearson Type III 100 year peak rate of flow was 1.76 m^3/s (Table XXII). The Type I, II, and III

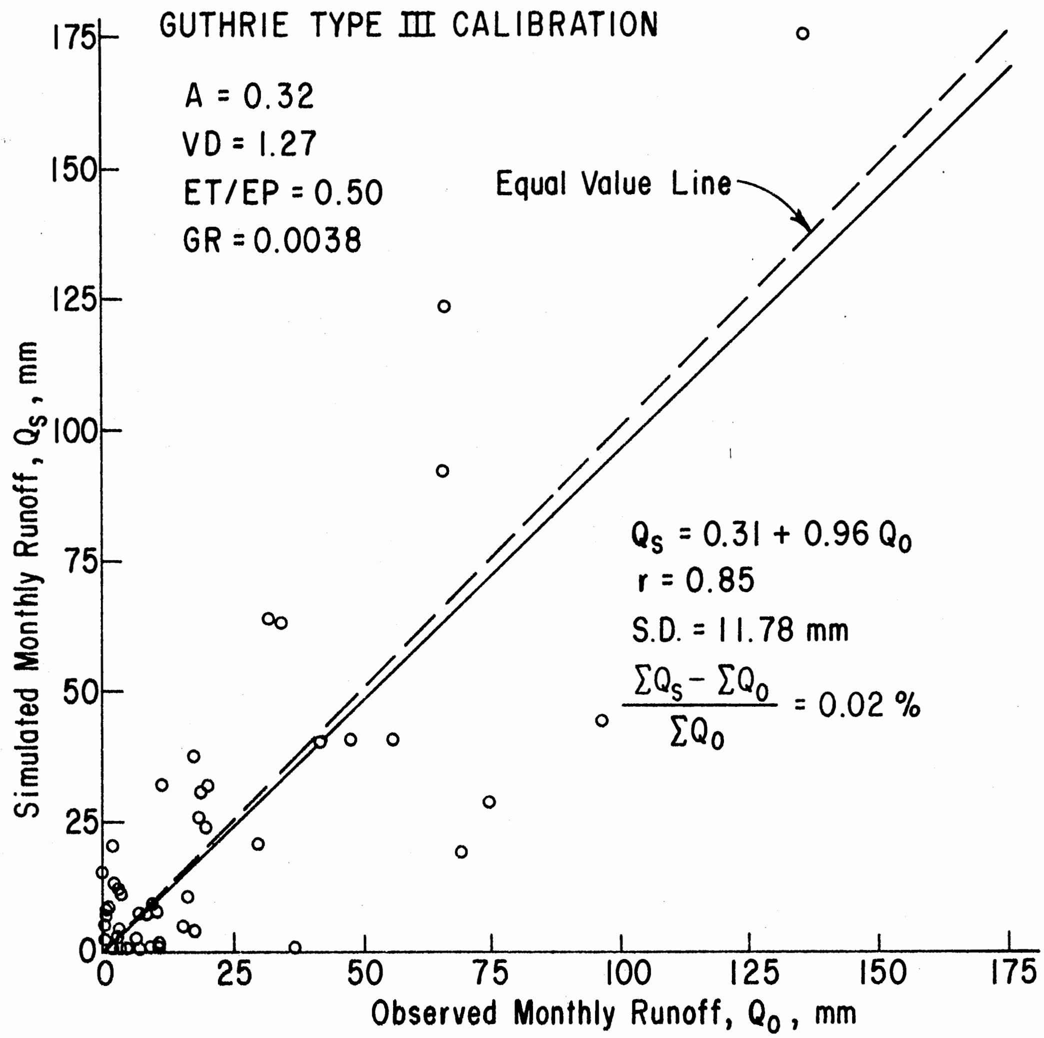

Figure 17. Monthly Runoff for Type III Calibration for Guthrie W-V Watershed from 1942 to 1953

TABLE XIX

ANNUAL SUMMARY OF TYPE III CALIBRATION WATER BALANCE FOR GUTHRIE W-V WATERSHED FROM 1942 TO 1953

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Offsite Flow mm	Chg Soil Moisture mm
1942	790	87	59	320	5	400	+6
1943	567	83	51	268	3	279	-34
1944	784	71	85	341	5	320	+33
1945	811	123	154	289	5	387	-24
1946	678	39	32	313	4	307	+22
1947	650	140	99	291	4	293	-37
1948	581	79	50	313	5	218	-5
1949	1052	239	308	315	7	379	+43
1950	677	86	112	292	4	304	-35
1951	820	116	119	338	6	326	+31
1952	483	22	10	318	2	195	-42
1953	809	52	58	371	5	330	+45
TOTAL	8702	1137	1137	3769	55	3738	+3
MEAN	725	95	95	314	5	312	+0.2

Groundwater Recharge = 0.0

TABLE XX

TYPE III CALIBRATION MONTHLY SIMULATED RUNOFF
FOR GUTHRIE W-V WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1942	0	6.4	0	18.9	12.0	7.8	0	0	7.5	5.4	0	0.6	58.6
1943	0	2.4	0	0	28.5	20.1	0	0	0	0	0	0	51.0
1944	0	0	2.4	37.4	30.3	4.4	0	0	0	10.5	0	0.2	85.2
1945	0	2.8	8.7	4.7	0	123.8	13.0	0	0.7	0	0	0	153.7
1946	0	0	0	0.3	31.8	0.2	0	0	0	0	0.1	0	32.4
1947	0	0	0	44.1	40.0	15.2	0.1	0	0	0	0	0	99.4
1948	0	0	0	3.8	0	40.5	5.4	0	0	0	0	0	49.7
1949	0	0	0.4	0	175.4	92.3	31.4	0	9.0	0	0	0	308.5
1950	0	2.3	0	0	4.1	63.1	40.4	2.0	0	0	0	0	111.9
1951	0	0	0	0	20.6	63.9	7.1	23.7	0	0	3.2	0	118.5
1952	0	0	1.4	0.6	7.2	0.2	0	0	0	0	0	0	9.4
1953	0	0	0	0	2.9	0	0	25.6	10.8	7.7	0	11.1	58.1
TOTAL	0	13.9	12.9	109.8	352.8	431.5	97.4	51.3	28.0	23.6	3.3	11.9	1136.4
MEAN	0	1.2	1.1	9.2	29.4	36.0	8.1	4.3	2.3	2.0	0.3	1.0	94.7

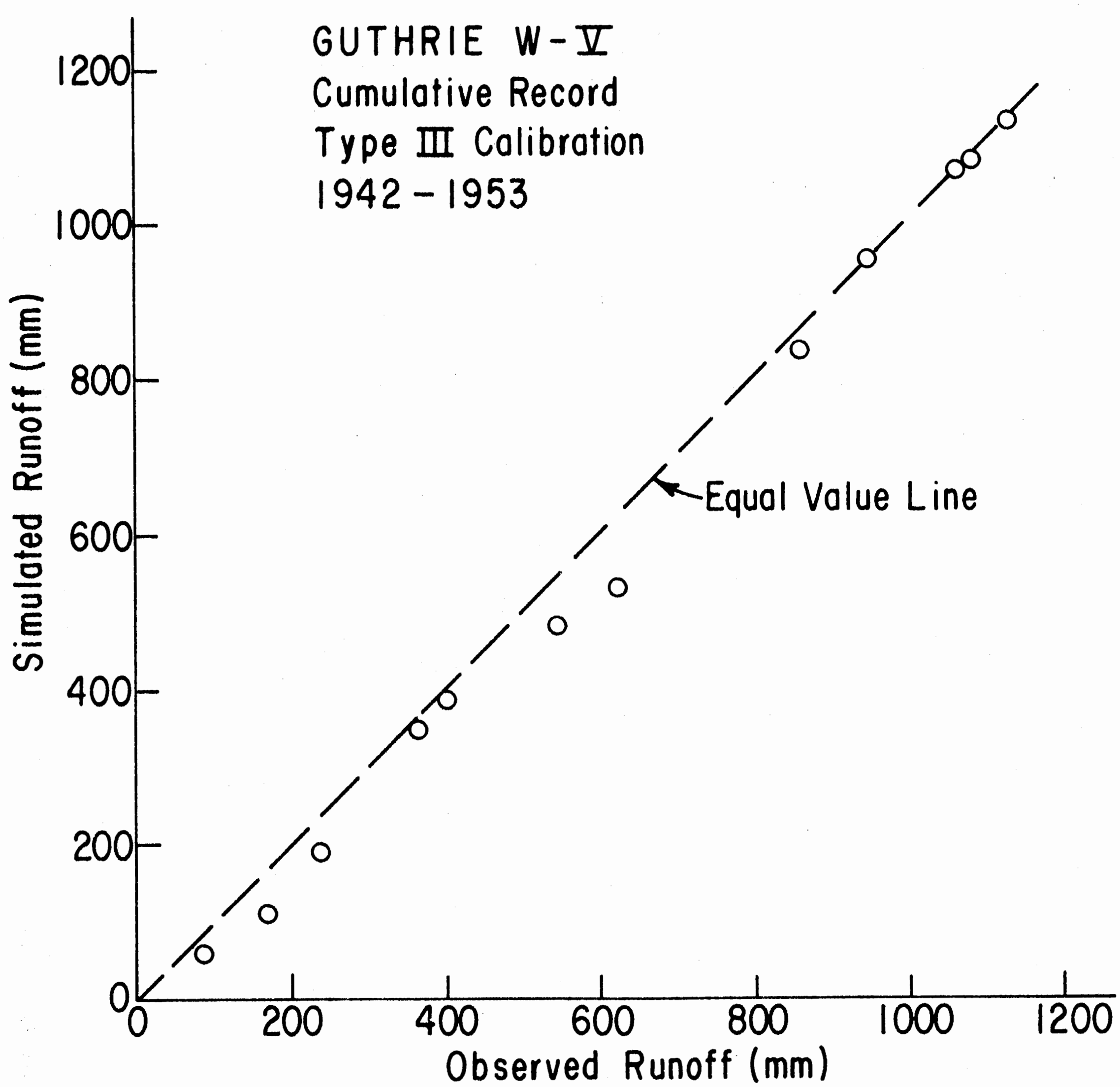

Figure 18. Type III Calibration Double Mass Plot for Guthrie W-V Watershed from 1942 to 1953

TABLE XXI

OBSERVED AND SIMULATED ANNUAL PEAK RATES
OF FLOW FOR GUTHRIE W-V WATERSHED
(mm/hr)

Year	Date	Observed	Date	SIM Type I	SIM Type II	SIM Type III
1942	4-18	35.6	4-18	37.8	32.8	28.4
1943	5-09	14.7	5-19	16.5	15.0	9.9
1944	5-26	20.3	4-10	50.5	45.0	44.4
1945	6-10	36.6	6-10	53.8	49.0	46.2
1946	5-06	20.6	5-06	53.6	46.0	46.2
1947	4-08	43.9	4-08	84.6	68.6	69.8
1948	6-23	26.2	6-23	29.5	24.1	23.4
1949	5-19	87.6	5-19	111.0	94.7	94.2
1950	7-21	27.7	6-10	57.2	52.3	52.1
1951	8-10	64.3	6-10	134.9	114.3	105.1
1952	5-23	5.1	5-23	13.7	14.2	19.5
1953	8-18	22.9	8-18	19.0	19.8	22.7

TABLE XXII

THE 100 YEAR RETURN PERIOD RATES OF RUNOFF FLOW FOR GUTHRIE W-V WATERSHED

Type	100 Year Return Period		% Error
	mm/hr	m^3/s	
Observed	100	1.76	——
SIM-I	220	3.88	120
SIM-II	183	3.23	83
SIM-III	160	2.83	60

simulated 100 year rates overpredicted the observed by 120%, 83%, and 60%, respectively.

Discussion of Calibration Results

The model underpredicted surface runoff in April and September and overpredicted in June (Figure 19). Generally, the first storms after dry periods were underpredicted, while storms occurring within two weeks after wet periods were overpredicted. These discrepancies suggested an incorrect simulation of the rate of soil moisture accretion or depletion. This may indicate a need for a more precise description of watershed soils. Over the long term, however, the model gave good predictions, even with the described shortcoming. The calibration parameter values and statistical results are shown in Tables XXIII and XXIV, respectively.

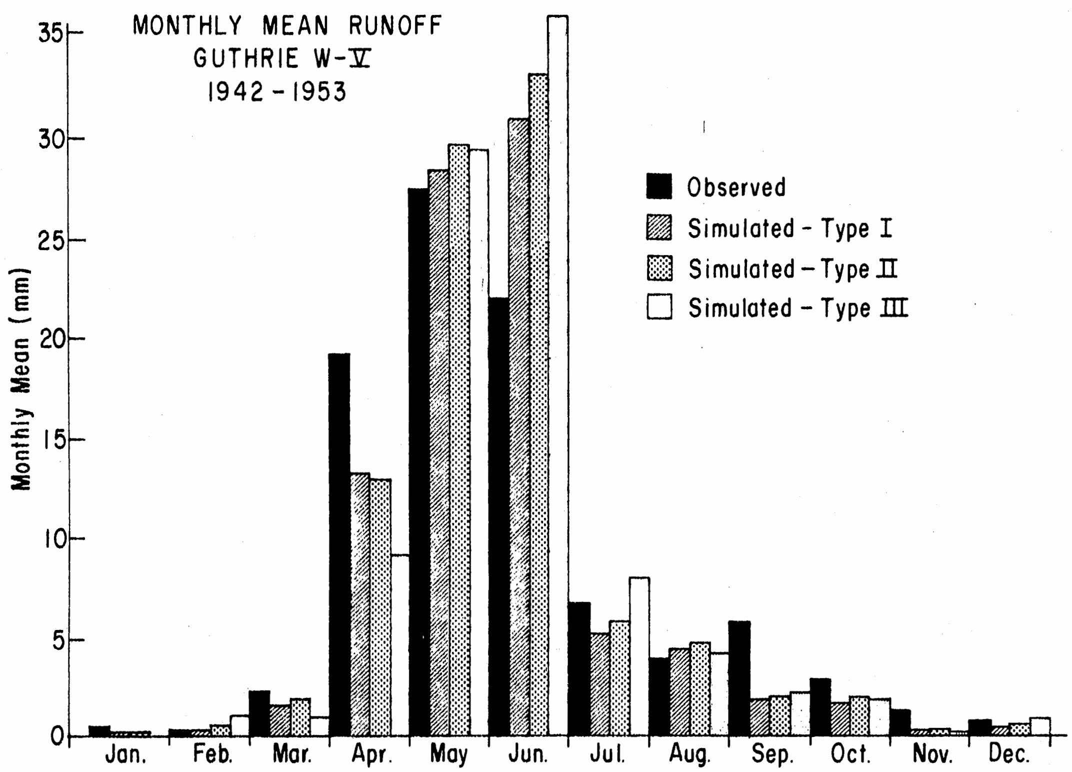

Figure 19. Comparison of Monthly Mean Runoff for Guthrie W-V Watershed

TABLE XXIII

PARAMETERS USED IN THE CALIBRATION
OF THE USDAHL MODEL

Calibration Type	A	VD, mm	ET/EP	TU°C	TL°C	GR, mm/hr	Flow Regimes
I	0.80	1.27	0.88	26.7	0.0	0.0183	No
II	0.60	1.27	0.88	26.7	0.0	0.0229	No
III	0.32	1.27	0.50	26.7	0.0	0.0038	Yes

TABLE XXIV

STATISTICAL RESULTS OF CALIBRATIONS AT
THE GUTHRIE W-V WATERSHED
(1942-1953)

Calibration Type	Reg Coef	r	S.D. mm	Error %
I	1.01	0.93	7.57	-5.4
II	1.03	0.92	8.35	0.0
III	0.96	0.85	11.78	0.0

The water balances for the Types I and II calibrations are more in agreement with independent research data than is the Type III water balance. An approximate mean annual evapotranspiration (ET) value of 650 mm for grass can be calculated from lysimeter studies by Blad and Rosenberg (1974). The mean ET values for the Type I, II, and III calibrations are 588, 575, and 319 mm and are 9%, 11%, and 51% smaller than the lysimeter value, respectively.

CHAPTER VI

EVALUATING THE CALIBRATION TYPES

One purpose of a hydrologic model is to predict runoff from ungaged watersheds. One method for accomplishing this would be to calibrate the USDAHL model for a gaged watershed and then transfer the parameter values to similar ungaged watersheds. Therefore, the best type of calibration would be the one which simulated runoff most precisely at a second watershed.

The parameter values from the Guthrie watershed for each type of calibration were applied to three watersheds and the simulated runoff was analyzed by the same procedure used at Guthrie. A single trial was used for each type without any manipulation of parameter values.

Chickasha R-7 Watershed

The first watershed used to evaluate the calibrations was the Chickasha R-7 Watershed described in Chapter IV. It is located 79 km southeast of the Guthrie Watershed and has poor overgrazed vegetative cover and predominantly hydrologic group D soils. As shown in Table XXV, the total observed runoff from January, 1967, to December, 1974, was 1214 mm. Since the Guthrie watershed had excellent vegetative cover and group B soils, this was a transfer in distance, time, vegetative cover, and soil. The results of the Chickasha R-7 evaluations are summarized in the following paragraphs.

TABLE XXV

MONTHLY OBSERVED RUNOFF FOR CHICKASHA
R-7 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967	0	0	0	58.7	16.9	0.8	0.2	0	18.1	1.2	0	0	95.9
1968	7.4	0.4	16.0	2.8	11.5	15.7	22.9	0	12.1	10.9	18.6	0	118.3
1969	0	8.0	4.5	0	35.6	30.6	16.7	0.6	5.2	0	0	0	101.2
1970	0.3	0	0	5.4	10.7	0.2	0	1.5	45.4	10.5	0.1	0	74.1
1971	0	4.5	0	0	7.2	33.8	0	12.0	45.5	51.5	0	16.0	170.5
1972	0	0	0	32.3	16.0	0	0	0	0	79.5	11.5	0	139.3
1973	21.1	0	55.0	11.8	99.8	60.1	10.9	12.2	28.9	18.6	42.6	0	361.0
1974	0	9.3	8.7	34.5	14.1	1.6	0	27.2	6.3	39.8	10.2	2.1	153.8
TOTAL	28.8	22.2	84.2	145.5	211.8	142.8	50.7	53.5	161.5	212.0	83.0	18.1	1214.1
MEAN	3.6	2.8	10.5	18.2	26.5	17.8	6.3	6.7	20.2	26.5	10.4	2.3	151.8

Type I

The Type I parameter values resulted in a total simulated runoff of 1144 mm for a -5.77% error (Table XXVI). The regression equation (Figure 20) was

$$Q_s = -0.14 + 0.95\ Q_o \qquad (19)$$

with r = 0.93 and S.D. = 7.12 mm. Table XXVII shows the water balance.

Type II

As shown in Table XXVIII, the total simulated runoff for the Type II parameter values was 1235 mm for an error of 1.7%. The regression equation (Figure 21) was

$$Q_s = 0.13 + 1.01\ Q_o \qquad (20)$$

with r = 0.93 and S.D. = 7.76 mm. Table XXIX shows the water balance.

Type III

The Type III parameter values resulted in a simulated runoff of 1545 mm (Table XXX) for an error of 27.2%. Table XXXI shows the water balance. Figure 22 shows a regression equation of

$$Q_s = 1.96 + 1.12\ Q_o \qquad (21)$$

with r = 0.91 and S.D. = 9.77 mm.

Annual Peak Rates of Flow

The maximum observed peak rate of flow was 128.5 mm/hr or 3.6 m^3/s on May 24, 1973. This compares with simulated maximum peak rates of 159.0, 150.9, and 145.8 mm/hr for the Types I, II, and III. The smallest annual peak rate was 15.7 mm/hr or 0.4 m^3/s on September 22, 1970. This compares with 27.4, 25.1 and 21.3 mm/hr.

TABLE XXVI

MONTHLY TYPE I TEST SIMULATED RUNOFF FOR
CHICKASHA R-7 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967	0	0	0	53.2	15.5	1.6	0	0	20.7	0	0	0	91.0
1968	0.1	0	5.1	3.4	6.8	2.6	36.8	0	0	8.0	5.6	2.5	70.9
1969	0	0	0	0	27.1	48.8	38.7	0	3.5	0	0	0	118.1
1970	0	0	0	5.5	28.6	0.4	0	0	35.8	15.6	0	0	85.9
1971	0	2.1	0	0	1.2	42.6	0	18.5	51.3	58.8	0	7.2	181.7
1972	0	0	0	25.2	12.2	0	0.6	0	0	57.0	9.4	1.9	106.3
1973	6.2	0	39.5	13.7	115.8	56.5	16.8	24.9	30.3	21.7	34.8	0	360.2
1974	0	3.8	7.5	33.6	5.8	5.6	0	14.5	5.0	28.9	25.3	0	130.0
TOTAL	6.3	5.9	52.1	134.6	213.0	158.1	92.9	57.9	146.6	190.0	75.1	11.6	1144.1
MEAN	0.8	0.7	6.5	16.8	26.6	19.8	11.6	7.2	18.3	23.7	9.4	1.4	143.0

TABLE XXVII

ANNUAL SUMMARY OF TYPE I TEST WATER BALANCE
FOR CHICKASHA R-7 WATERSHED
FROM 1967 TO 1974

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpiration mm	Soil Evap mm	Ground-water Recharge mm	Chg Soil Moisture mm
1967	678	96	91	360	115	49	+63
1968	768	118	71	393	194	76	+34
1969	709	101	118	387	163	69	-28
1970	611	74	86	391	105	55	-26
1971	831	171	182	402	133	56	+58
1972	657	139	106	416	98	50	-13
1973	1154	361	360	304	375	120	-5
1974	719	154	130	320	152	83	+34
TOTAL	6127	1214	1144	2973	1335	558	+117
MEAN	766	152	143	372	167	70	+14

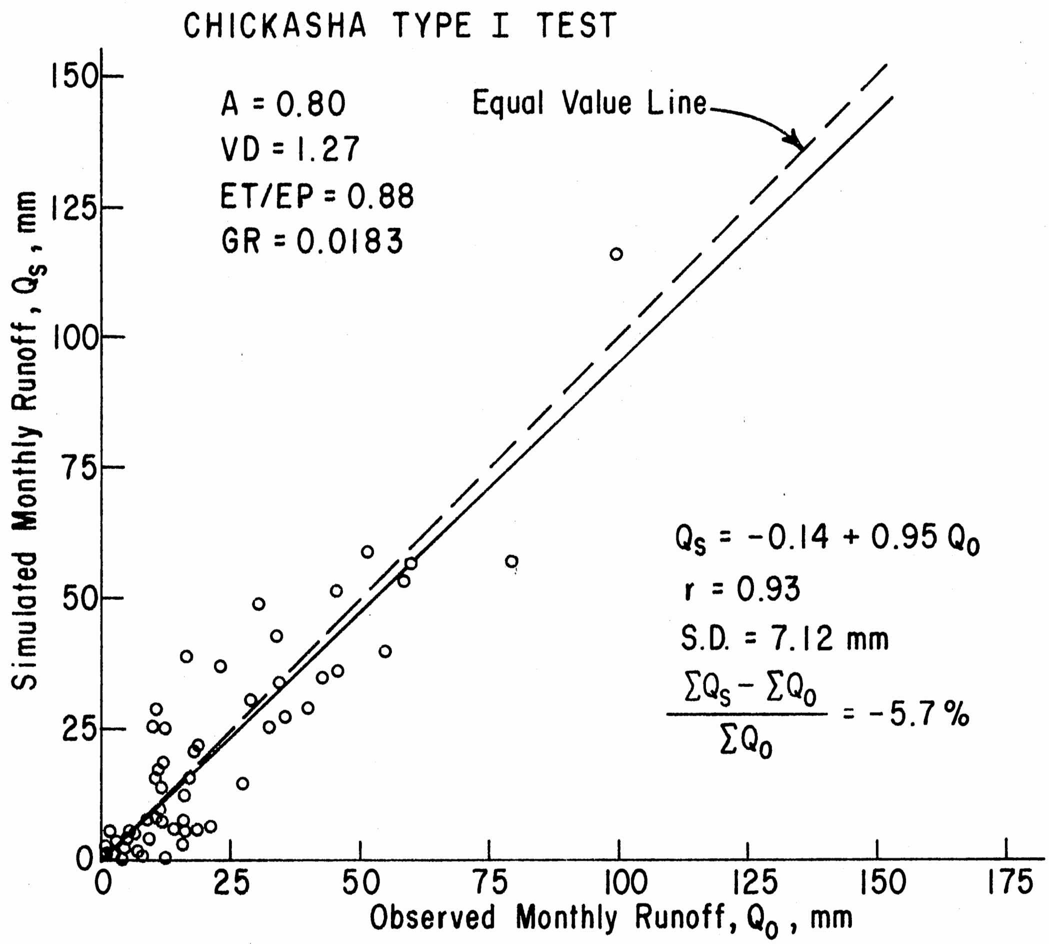

Figure 20. Monthly Runoff for Type I Test for Chickasha R-7 Watershed from 1967 to 1974

TABLE XXVIII

MONTHLY TYPE II TEST SIMULATED RUNOFF FOR CHICKASHA R-7 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967	0	0	0	57.9	17.7	2.1	0	0	23.7	0.1	0	0	101.5
1968	0.5	0	6.5	4.6	9.0	3.6	41.4	0	0	8.9	7.3	3.1	84.9
1969	0	0	0.1	0.1	30.3	51.7	39.3	0	4.3	0	0	0	125.8
1970	0	0	0	7.2	32.9	0.5	0	0	35.7	18.0	0	0	94.3
1971	0	3.4	0	0	0.4	48.5	0	18.9	55.1	60.9	0	8.9	196.1
1972	0	0	0.1	25.8	14.9	0	0.1	0	0	59.1	10.1	2.7	112.8
1973	6.8	0	38.7	15.0	123.6	60.4	19.2	27.7	32.8	22.8	37.3	0	384.3
1974	0	5.8	8.9	37.4	6.9	6.3	0	14.0	6.6	27.3	22.0	0	135.2
TOTAL	7.3	9.2	54.3	148.0	235.7	173.1	100.0	60.6	158.2	197.1	76.7	14.7	1234.9
MEAN	0.9	1.2	6.8	18.5	29.5	21.6	12.5	7.6	19.8	24.6	9.6	1.8	154.4

TABLE XXIX

ANNUAL SUMMARY OF TYPE II TEST WATER BALANCE
FOR CHICKASHA R-7 WATERSHED
FROM 1967 TO 1974

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Ground- water Recharge mm	Chg Soil Moisture mm
1967	678	96	102	363	98	56	+59
1968	768	118	85	396	168	87	+32
1969	709	101	126	390	140	78	-25
1970	611	74	94	392	88	62	-25
1971	831	171	196	407	111	62	+55
1972	657	139	113	418	83	57	-14
1973	1154	361	384	310	326	140	-6
1974	719	154	135	324	130	95	+35
TOTAL	6127	1214	1235	3000	1144	637	+111
MEAN	766	152	154	375	143	80	+14

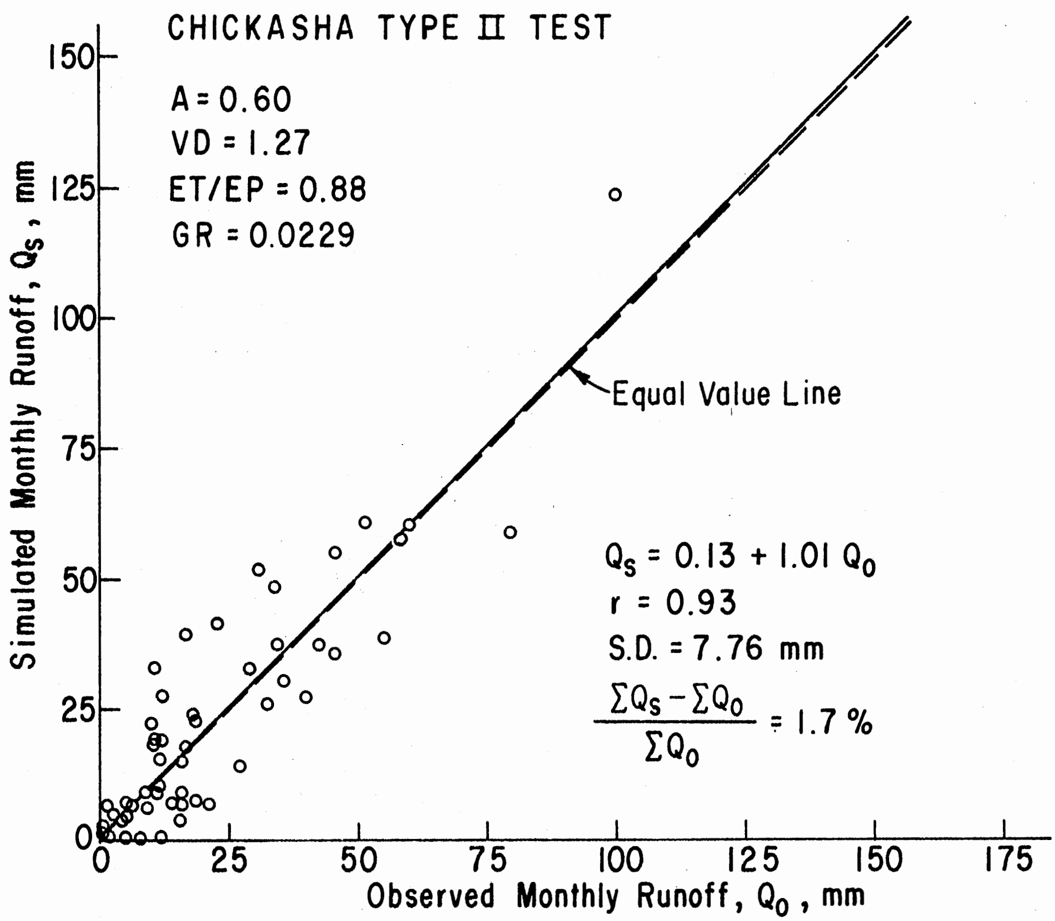

Figure 21. Monthly Runoff for Type II Test for Chickasha R-7 Watershed from 1967 to 1974

TABLE XXX

MONTHLY TYPE III TEST SIMULATED RUNOFF FOR
CHICKASHA R-7 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967	0	0	0	65.8	25.9	1.5	0.5	0	38.6	3.6	0	0.3	136.2
1968	2.0	0	9.4	8.6	13.2	6.9	52.8	0	3.6	21.7	10.5	5.0	133.7
1969	0	0.2	0.6	1.7	38.7	57.9	44.8	1.4	18.3	0	0	0	163.6
1970	0	0	0.9	12.5	41.2	1.1	0	0	44.1	25.6	0	0	125.4
1971	0	7.7	0	0	10.2	60.3	0.1	30.5	58.7	65.7	0	13.1	246.3
1972	0	0	0	36.3	21.4	0	0	0	0	58.1	8.8	4.9	129.5
1973	10.3	0	37.2	17.2	137.2	70.7	27.7	34.9	40.5	27.5	42.5	0	445.7
1974	0	12.6	11.4	46.1	9.0	8.5	0	38.2	9.9	22.4	6.4	0	164.5
TOTAL	12.3	20.5	59.5	188.2	296.8	206.9	125.9	105.0	213.7	224.6	68.2	23.3	1544.9
MEAN	1.5	2.6	7.4	23.5	37.1	25.9	15.7	13.1	26.7	28.1	8.5	2.9	193.1

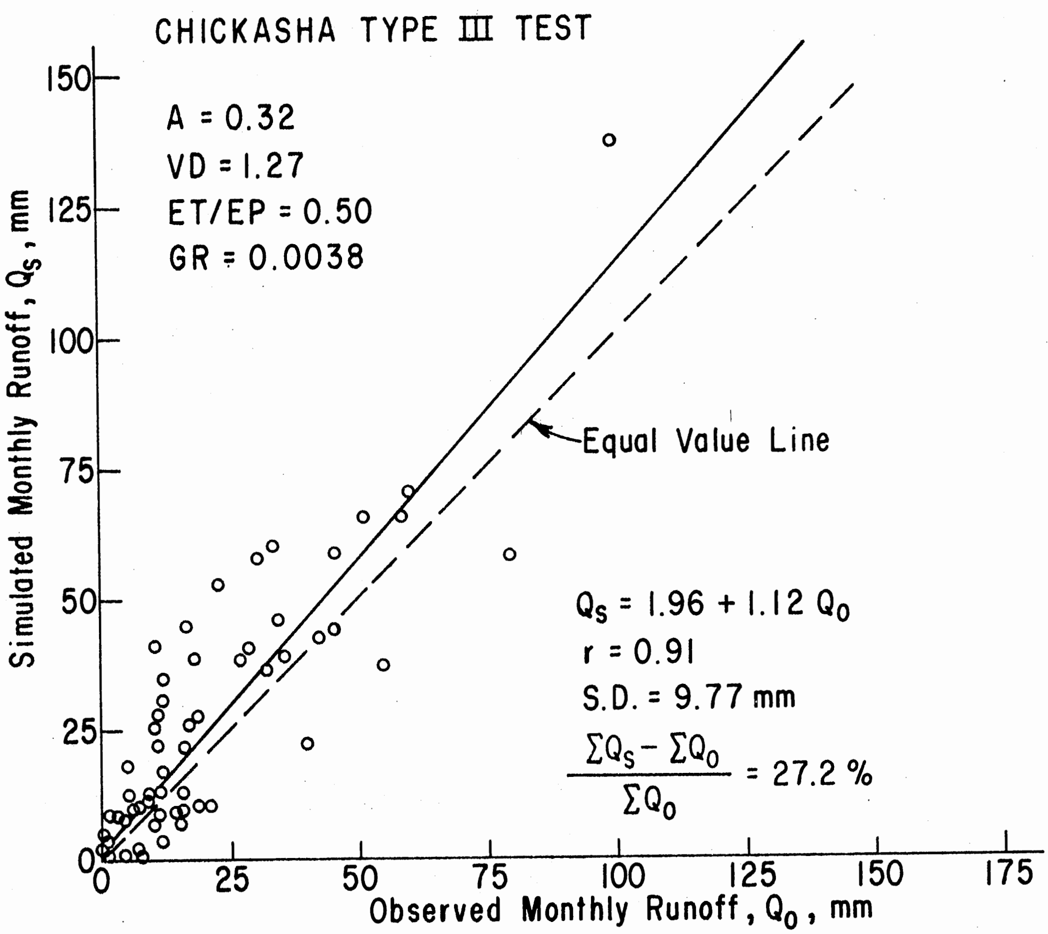

Figure 22. Monthly Runoff for Type III Test for Chickasha R-7 Watershed from 1967 to 1974

TABLE XXXI

ANNUAL SUMMARY OF TYPE III TEST WATER BALANCE
FOR CHICKASHA R-7 WATERSHED
FROM 1967 TO 1974

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Offsite Flow mm	Chg Soil Moisture mm
1967	678	96	136	227	10	268	+37
1968	768	118	134	244	12	377	+1
1969	709	101	163	242	10	293	+1
1970	611	74	125	250	9	237	-10
1971	831	171	249	252	13	309	+11
1972	657	139	130	272	11	245	-1
1973	1154	361	446	201	15	496	-4
1974	719	154	165	206	10	331	+7
TOTAL	6127	1214	1545	1894	90	2556	+42
MEAN	766	152	193	237	11	320	+5

Table XXXII shows the observed and simulated annual peak rates of flow. The observed Log Pearson Type III 100 year return period rate of flow was 173 mm/hr or 4.9 m^3/s. The simulated Log Pearson Type III 100 year rates of flow were 44.9%, 34.9%, and 16.3% larger than the observed (Table XXXIII).

Discussion of Chickasha Results

The Type II calibration was considered best because it more precisely predicted simulated runoff (1.7% error) and had the regression coefficient nearest 1.00. The annual runoff values from the double mass plot (Figure 23), closely follow the equal-value line. The statistical results are shown in Table XXXIV.

Figure 24 shows a comparison of observed and simulated mean monthly runoff. The mean simulated runoff for Type II was always greater than for Type I. The Type III runoff was greater than for Type I and II for every month except November and was larger than observed for every month except January, February, and November. Also large amounts of runoff occurred in April, May, June, September, and October. In comparison, at Guthrie the majority of the runoff occurred in April, May, and June. As at Guthrie, the model underpredicted runoff after periods of low precipitation and overpredicted shortly after periods of high precipitation.

As at Guthrie, the water balances for Types I and II were more in agreement with independent research data than Type III. The water balances for Types I, II, and III calibrations show mean annual ET values of 539 mm, 518 mm, and 248 mm, respectively. The Type III value was 54% and 52% less than Types I and II and 62% less than the mean

TABLE XXXII

OBSERVED AND SIMULATED ANNUAL PEAK RATES OF FLOW FOR CHICKASHA R-7 WATERSHED, mm/hr

Year	Date	Observed	Date	SIM Type I	SIM Type II	SIM Type III
1967	4-12	38.4	4-12	41.2	36.6	38.4
1968	9-04	30.4	7-01	26.4	25.9	27.4
1969	5-06	53.5	6-14	78.5	67.8	63.8
1970	9-22	15.7	9-22	27.4	25.1	21.3
1971	10-02	49.6	10-02	69.8	64.8	64.0
1972	10-30	33.2	10-30	32.5	30.2	35.5
1973	5-24	128.5	5-24	159.0	150.9	145.8
1974	4-29	29.0	4-29	38.6	38.1	37.6

TABLE XXXIII

THE 100 YEAR RETURN PERIOD RATES OF FLOW FOR CHICKASHA R-7 WATERSHED

Type	100 Year Return Period mm/hr	100 Year Return Period m^3/s	% Error
Observed	173	4.9	——
SIM-I	252	7.1	44.9
SIM-II	232	6.6	34.7
SIM-III	201	5.7	16.3

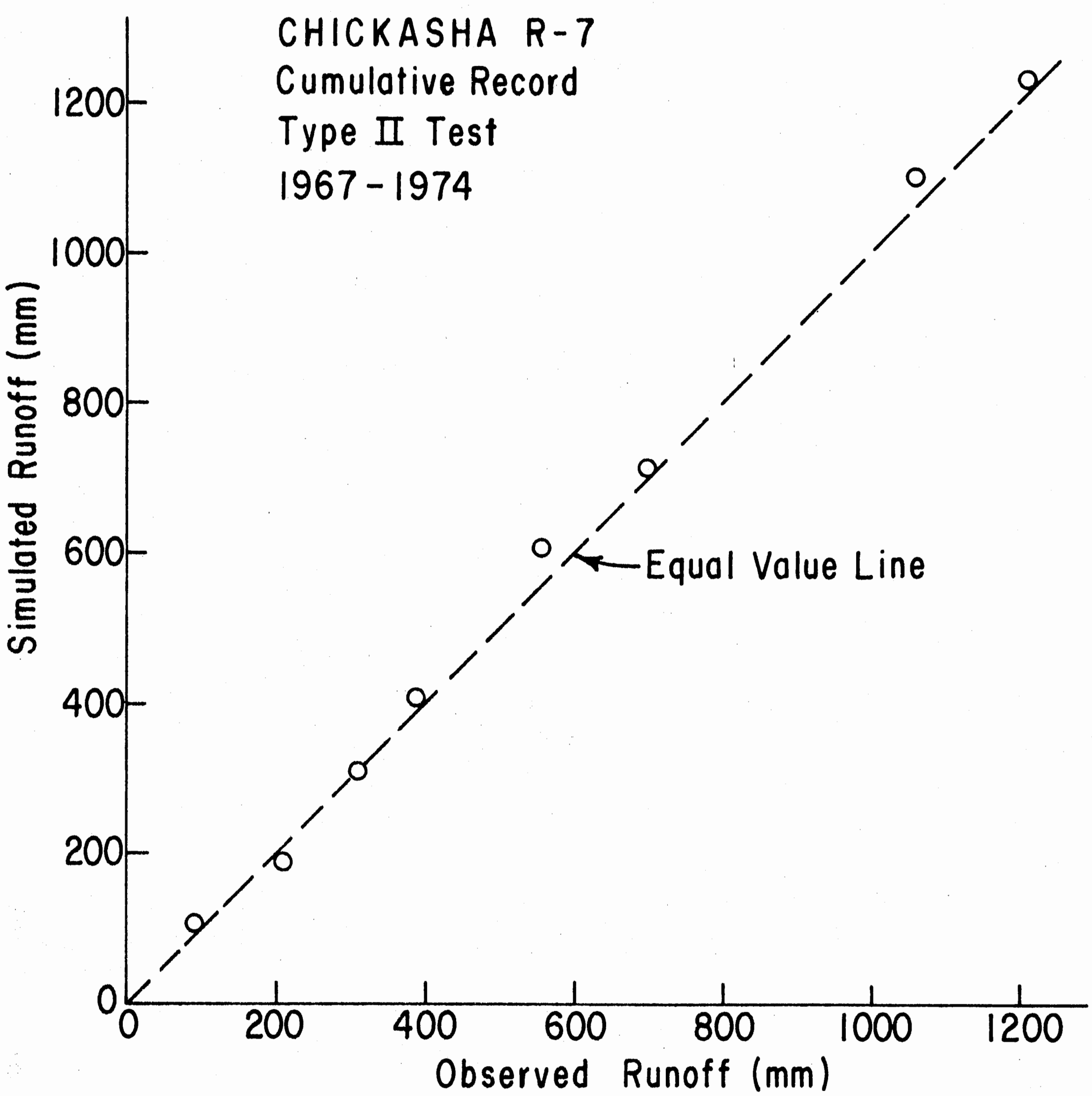

Figure 23. Type II Test Double Mass Plot for Chickasha R-7 Watershed from 1967 to 1974

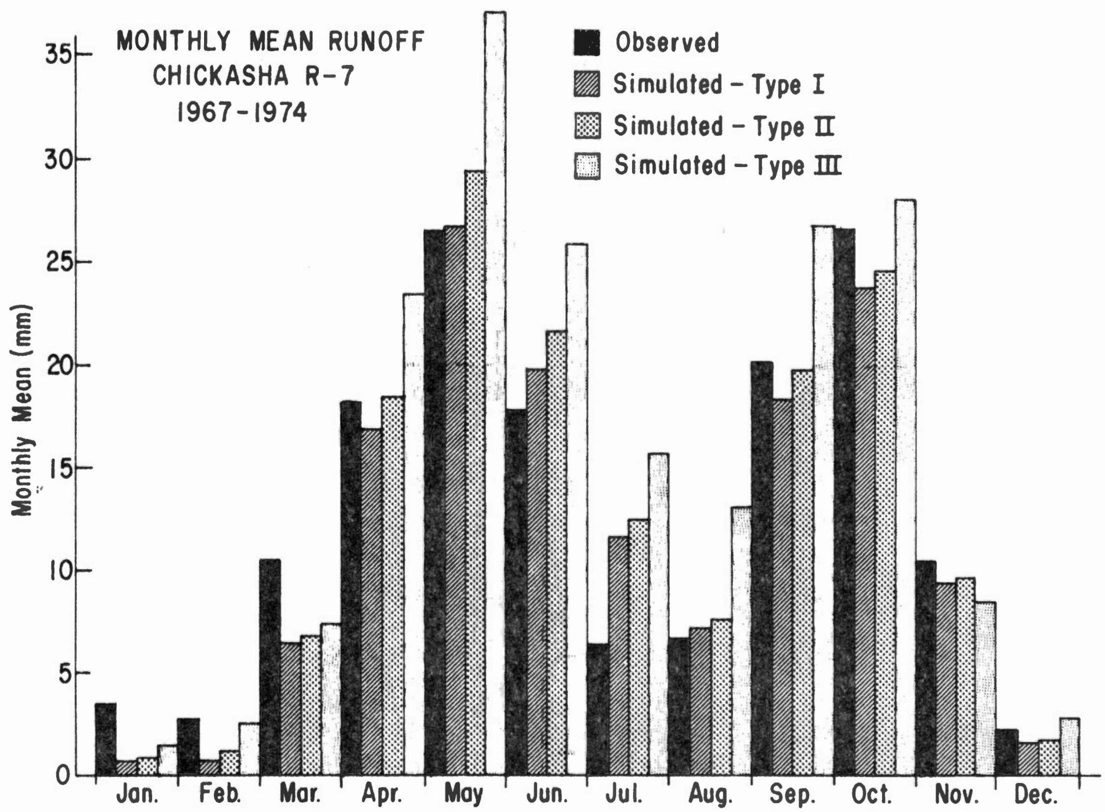

Figure 24. Comparison of Monthly Mean Runoff for Chickasha R-7 Watershed

TABLE XXXIV

STATISTICAL RESULTS OF TESTS AT CHICKASHA R-7 WATERSHED (1967-1974)

Type	Reg Coef	r	S.D., mm	Error, %
I	0.95	0.93	7.12	-5.77
II	1.01	0.93	7.76	+1.73
III	1.12	0.91	9.77	+27.26

annual ET value of 650 mm, calculated from lysimeter studies by Blad and Rosenberg (1974).

The model overpredicted annual peak rates of flow. The Type II overpredicted the 100 year return flow by 34.7%. Generally, the Type III flows were smaller than for I and II. This may indicate that the recession coefficients have a leveling effect on the simulated hydrographs.

Stillwater W-4 Watershed

The second watershed used to evaluate the calibration types was the Stillwater W-4 Watershed described in Chapter IV. It is located 70 km northeast of the Guthrie watershed and is 13 times larger. The soils are a mixture of hydrologic groups B and D. The rainfall varied from 398 mm in 1954 to 1198 mm in 1959. Table XXXV shows a total observed runoff of 2067 mm from January, 1953, to December, 1972.

TABLE XXXV

MONTHLY OBSERVED RUNOFF FOR STILLWATER W-4
WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1953	0	0	2.8	1.0	26.4	1.3	14.2	0	1.0	0	9.4	4.6	60.7
1954	0	0	0	1.5	13.7	0	0	0	0	0	0	0	15.2
1955	0	1.0	5.1	0	162.6	2.3	0	17.8	0	23.1	0	0	211.9
1956	0	0	0	0	0	0	9.6	0	0	0	0.3	0	9.9
1957	0	0.5	1.3	88.4	104.1	155.2	18.0	0	5.8	0	0	0	373.3
1958	1.5	1.3	49.5	5.6	0.5	4.1	5.8	0.3	1.8	0	0	0	70.4
1959	0	0	0.5	3.6	9.6	0.5	84.6	0.5	38.1	172.2	0	9.4	319.0
1960	6.4	16.8	16.8	1.8	41.4	2.5	9.4	0	0	1.5	0	0.5	97.1
1961	0	0	3.0	0	73.4	33.8	6.4	1.5	47.0	18.8	29.0	11.7	224.5
1962	6.4	4.1	6.9	2.0	0	51.3	0	0	0	0	0	3.0	73.7
1963	0	0	7.4	0	9.7	0	6.1	4.8	25.7	6.6	1.0	0	61.3
1964	0	4.6	0.5	11.9	16.2	0	0	6.1	0.8	0	12.2	2.0	54.3
1965	2.8	1.8	1.8	1.5	1.8	0	0.8	0	1.8	0	0	0	12.3
1966	0	0.5	0	0	0	0	16.0	3.8	0	0	0	0	20.3
1967	1.3	0	0	2.0	5.1	33.8	7.4	0	21.1	8.6	0	0	79.3
1968	0.8	0	9.1	29.2	54.6	0	0	0	0	0	3.6	0.5	97.8
1969	0	8.9	19.8	17.5	31.0	13.7	0	0.5	4.8	1.3	0	2.0	99.5
1970	0	0	10.2	31.5	0	0	0	0	1.0	0.8	0	0	43.5
1971	1.8	6.4	0	0.8	0.8	27.9	1.5	0	27.9	2.3	0	13.0	82.4
1972	0.5	0.3	0	2.0	2.5	19.8	3.0	0	0	9.1	13.5	10.2	60.9
TOTAL	21.5	46.2	134.7	200.3	553.4	346.2	182.8	35.3	176.8	244.3	69.0	56.9	2067.4
MEAN	1.1	2.3	6.7	10.0	27.7	17.3	9.1	1.8	8.8	12.2	3.4	2.8	103.4

Annual runoff varied from 10 mm in 1956 to 373 mm in 1957. This was a transfer in distance, time, size, vegetative cover, and soil.

The results of the Stillwater W-4 evaluations are summarized in the following paragraphs.

Type I

The Type I parameter values resulted in 1891 mm of simulated runoff (Table XXXVI) for a 8.5% error. Table XXXVII shows the water balance. Figure 25 shows a regression equation of

$$Q_s = 1.25 + 0.77\ Q_o \qquad (22)$$

with r = 0.91 and S.D. = 7.87 mm.

Type II

As shown in Table XXXVIII, the simulated runoff for the Type II parameter values was 2053 mm for an error of 0.7%. The regression equation (Figure 26) was

$$Q_s = 1.68 + 0.80\ Q_o \qquad (23)$$

with r = 0.90 and S.D. = 8.54 mm. Table XXXIX shows the water balance.

Type III

A simulated runoff of 2891 mm (Table XL) with an error of 39.9% was produced by the Type III parameter values. The regression equation (Figure 27) was

$$Q_s = 4.76 + 0.85\ Q_o \qquad (24)$$

with r = 0.84 and S.D. = 12.47 mm. As shown in the water balance in Table XLI, the groundwater recharge is insignificant.

TABLE XXXVI

MONTHLY TYPE I TEST SIMULATED RUNOFF FOR
STILLWATER W-4 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1953	0	0	3.6	0.4	23.9	0	32.8	0	0	0	9.4	7.0	77.1
1954	0	0	0	0	3.1	0	0	0	0	0	0	0	3.1
1955	0	0	0	0	93.6	4.1	0	31.4	0	18.4	0	0	147.5
1956	0	0	0	0	0	0	0.2	0	0	0	0	0	0.2
1957	0	0.6	1.3	69.1	74.4	105.0	15.3	0	2.5	0.2	2.8	0	271.2
1958	0	0	7.6	1.1	0	5.0	12.8	0.6	5.2	0	0	0	32.3
1959	0	0	0	0.4	9.1	3.2	93.9	4.3	71.1	145.4	0	1.0	328.4
1960	0.1	0	0	0	43.9	0.3	19.0	0	0	5.2	0	0	68.5
1961	0	0	0	0	66.2	29.0	13.5	10.2	65.8	5.8	6.2	0	196.7
1962	0	0	0	0	0	45.0	7.8	0	0.2	0	0	6.6	59.6
1963	0	0	4.9	0	29.0	0.1	14.1	26.7	34.0	14.7	0	0	123.5
1964	0	0	0	3.8	2.6	0	0	8.7	8.4	0	4.6	0	28.1
1965	0	0	0	0.1	5.3	1.4	1.3	0	0	0	0	0	8.1
1966	0	0	0	0	0	0	18.3	11.3	1.2	0	0	0	30.8
1967	0	0	0	0	0.6	38.2	16.2	0	33.0	2.0	0	0	90.0
1968	0	0	3.2	24.2	38.5	0.8	0	0	0	0	2.0	0.2	68.9
1969	0	0	0.2	16.0	31.6	25.4	0	0	16.6	4.1	0	1.0	94.9
1970	0	0	0	22.3	0	0	0	0	4.2	4.6	0	0	31.1
1971	3.8	1.2	0	1.2	1.4	51.4	23.5	0	57.5	14.6	0	4.1	158.7
1972	0	0	0	0.9	11.6	23.5	20.5	0	0.2	7.3	2.5	5.4	71.9
TOTAL	3.9	1.8	20.8	139.5	434.8	332.4	289.2	93.2	299.9	222.3	27.5	25.3	1890.6
MEAN	0.2	0.1	1.0	7.0	21.7	16.6	14.5	4.7	15.0	11.1	1.4	1.3	94.5

TABLE XXXVII

ANNUAL SUMMARY OF TYPE I TEST WATER BALANCE FOR STILLWATER W-4 WATERSHED FROM 1953 TO 1972

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi-ration mm	Soil Evap mm	Ground-water Recharge mm	Chg Soil Moisture mm
1953	788	61	77	607	30	11	+63
1954	398	15	3	475	8	3	-91
1955	913	212	148	579	116	20	+50
1956	405	10	0	421	10	1	-27
1957	1126	373	271	392	315	58	+90
1958	656	70	32	496	134	49	-55
1959	1198	319	328	546	198	48	+78
1960	737	97	69	542	105	46	-25
1961	1003	225	197	493	202	66	+45
1962	664	74	60	463	112	54	-25
1963	780	61	123	536	82	42	-3
1964	707	54	28	551	85	41	+2
1965	539	12	8	531	43	24	-67
1966	489	20	31	467	12	2	-23
1967	828	79	90	570	85	23	+60
1968	728	98	69	473	111	40	+35
1969	804	100	95	529	157	53	-30
1970	542	44	31	454	56	22	-21
1971	905	82	159	517	130	46	+53
1972	694	61	72	488	78	39	+17
TOTAL	14,904	2,067	1,891	10,130	2,069	688	+126
MEAN	745	103	94	506	103	34	+6

Offsite Flow = 0.0

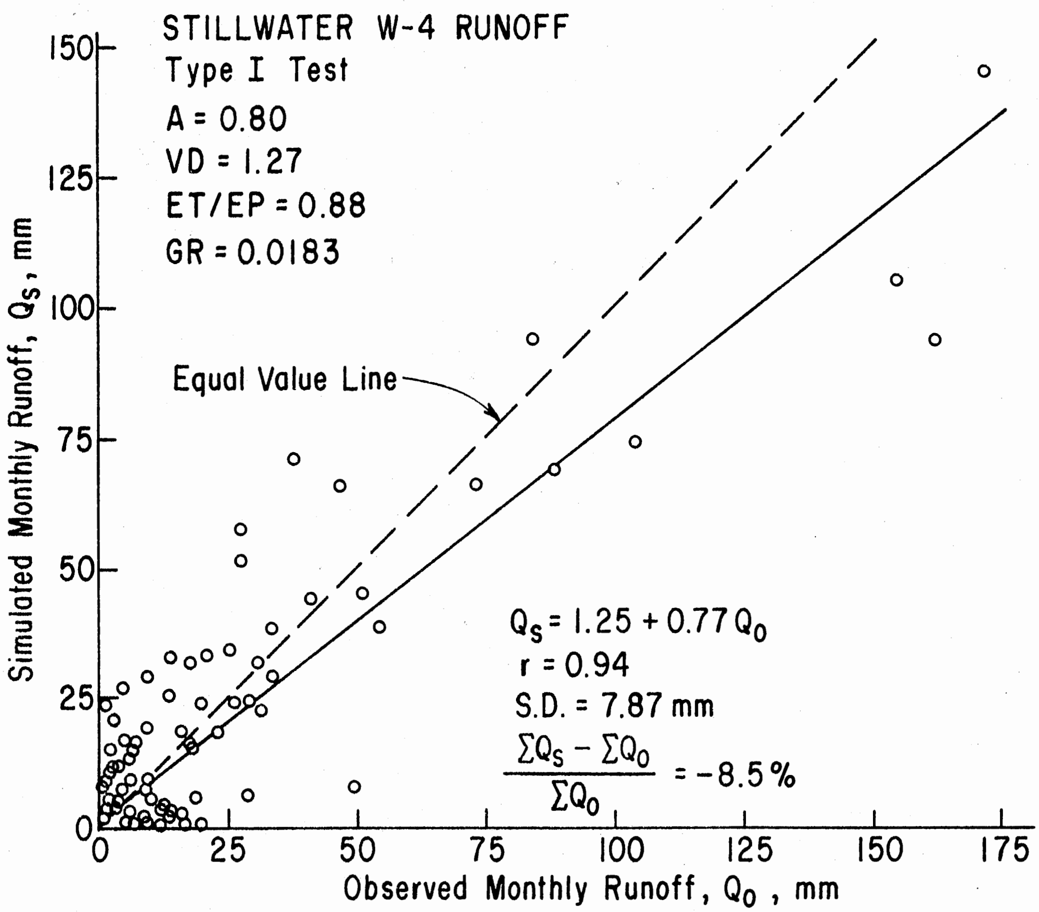

Figure 25. Monthly Runoff for Type I Test for Stillwater W-4 Watershed from 1953 to 1972

TABLE XXXVIII

MONTHLY TYPE II TEST SIMULATED RUNOFF FOR
STILLWATER W-4 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1953	0	0	4.2	0.8	25.7	0	33.2	0	0	0	10.6	8.0	82.5
1954	0	0	0	0	2.7	0	0	0	0	0	0	0	2.7
1955	0	0	0	0	97.0	5.1	0	33.9	0	18.9	0	0	154.9
1956	0	0	0	0	0	0	0.4	0	0	0	0	0	0.4
1957	0	0.7	2.1	72.2	78.1	111.3	16.7	0	2.5	0.4	3.8	0	287.8
1958	0	0.1	7.7	1.3	0	6.7	14.8	0.7	5.9	0	0	0	37.2
1959	0	0	0	0.6	10.1	4.5	102.6	4.8	74.4	139.4	0	1.5	337.9
1960	0.2	0	0	0.1	49.7	0.7	22.9	0	0	4.4	0	0	78.0
1961	0	0	0	0	70.7	32.5	15.8	11.8	68.7	7.6	9.2	0	216.3
1962	0	0	0	0	0	50.8	11.0	0	0.2	0	0	8.2	70.2
1963	0	0	4.1	0	30.9	0.1	13.7	27.7	37.5	18.3	0	0	132.3
1964	0	0	0	5.3	2.4	0	0	9.1	9.4	0	4.3	0	30.5
1965	0	0	0	0.2	6.5	1.9	1.7	0	0	0	0	0	10.3
1966	0	0	0	0	0	0	18.9	11.7	1.6	0	0	0	32.2
1967	0	0	0	0	1.1	39.8	18.8	0	38.6	2.8	0	0	101.1
1968	0	0	4.5	27.0	44.5	1.0	0	0	0	0	2.5	0.4	79.9
1969	0	0	0.3	19.2	34.8	30.2	0	0	19.6	5.5	0	1.8	111.4
1970	0	0	0	26.0	0	0.1	0	0	3.9	5.6	0	0	35.6
1971	4.6	1.7	0	1.1	1.1	57.2	27.8	0	59.8	17.5	0	5.3	176.1
1972	0	0	0	0.8	10.9	23.0	22.6	0	0.1	8.3	3.3	6.5	75.5
TOTAL	4.8	2.5	22.9	154.6	466.2	364.9	320.9	99.7	322.2	228.7	33.7	31.7	2052.8
MEAN	0.2	0.1	1.1	7.7	23.3	18.2	16.0	5.0	16.1	11.4	1.7	1.6	102.6

TABLE XXXIX

ANNUAL SUMMARY OF TYPE II TEST WATER BALANCE
FOR STILLWATER W-4 WATERSHED
FROM 1953 TO 1972

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Ground- water Recharge mm	Chg Soil Moisture mm
1953	788	61	82	604	30	11	±61
1954	398	15	3	472	9	3	−89
1955	913	212	155	578	110	22	+48
1956	405	10	1	415	13	0	−24
1957	1126	373	288	400	282	67	+89
1958	656	70	37	500	118	56	−55
1959	1198	319	338	552	177	55	+76
1960	737	97	78	544	88	51	−24
1961	1003	225	216	499	171	74	+43
1962	664	74	70	466	91	59	−22
1963	780	61	132	539	68	45	−4
1964	707	54	31	552	74	45	+5
1965	539	12	10	529	39	27	−66
1966	489	20	32	464	14	1	−22
1967	828	79	101	573	72	25	+57
1968	728	98	80	474	94	45	+35
1969	804	100	111	533	133	58	−31
1970	542	44	36	453	49	24	−20
1971	905	82	176	520	109	49	+51
1972	694	61	76	488	71	43	+16
TOTAL	14,904	2,067	2,053	10,155	1,812	760	+124
MEAN	745	103	103	508	91	38	+6

Offsite Flow = 0.0

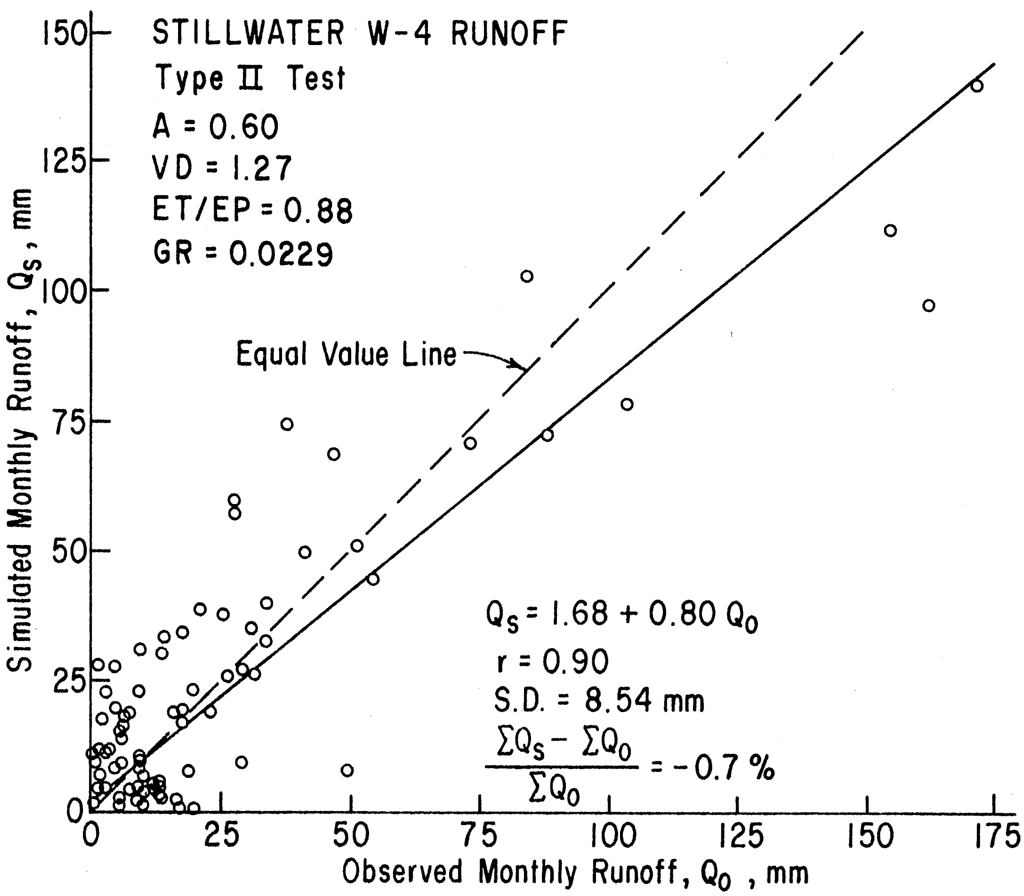

Figure 26. Monthly Runoff for Type II Test for Stillwater W-4 Watershed from 1953 to 1972

TABLE XL

MONTHLY TYPE III TEST SIMULATED RUNOFF FOR
STILLWATER W-4 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1953	0	0	2.0	2.3	44.0	0.2	51.8	0	5.9	0	28.3	10.6	145.1
1954	0	0	0	0	11.6	0.2	0	0	0	0	0	0	11.8
1955	0	0	0	0	102.3	7.7	0	52.8	0	34.9	0	0	197.7
1956	0	0	0	0	0	0	24.0	0	0	0	0	0	24.0
1957	0	0.2	5.0	83.1	87.5	123.8	19.4	0	4.2	0.7	4.7	0	328.6
1958	0	1.0	8.2	2.4	0.2	16.3	23.3	2.4	8.1	0	0	0	61.9
1959	0	0	0	7.5	16.1	7.4	120.0	10.5	72.3	113.1	0	2.8	349.7
1960	0.4	0	0	1.6	68.6	2.3	40.6	0	0	9.7	0	0	123.2
1961	0	1.0	0.4	0	82.0	43.5	28.8	15.5	74.0	11.6	15.3	0	272.1
1962	0	0.2	0	0	0	65.7	19.4	0	2.2	1.2	0	10.7	99.4
1963	0	0	14.1	0	44.8	2.2	39.0	40.0	45.8	25.9	0	0	211.8
1964	0	0	0	7.1	10.8	0	0	6.6	16.4	0.5	14.3	0	55.7
1965	0.2	0	0	1.2	22.6	3.7	16.9	0	10.9	0	0	0	55.5
1966	0	0	0	0	0	0	47.9	27.4	4.7	0	0	0	80.0
1967	0	0	0	0	15.5	53.0	24.6	0	53.2	6.3	0	0	152.6
1968	0.2	0	8.0	34.6	55.5	3.3	0	0	0	0	15.5	1.5	118.6
1969	0.7	0.3	1.2	24.6	43.7	44.9	0	0.3	51.1	10.2	0	4.6	181.6
1970	0	0	0.9	32.8	0	2.5	0	0	7.5	10.8	0	0	54.5
1971	6.7	3.9	0	4.7	10.0	68.0	33.6	0	76.0	24.5	0	6.7	234.1
1972	0	0	0	10.2	20.8	42.0	30.6	0	5.5	10.2	4.5	9.1	132.9
TOTAL	8.2	6.6	39.8	212.1	636.0	486.7	519.9	155.5	437.8	259.6	82.6	46.0	2,890.8
MEAN	0.4	0.3	2.0	10.6	31.8	24.3	26.0	7.8	21.9	13.0	4.1	2.3	144.5

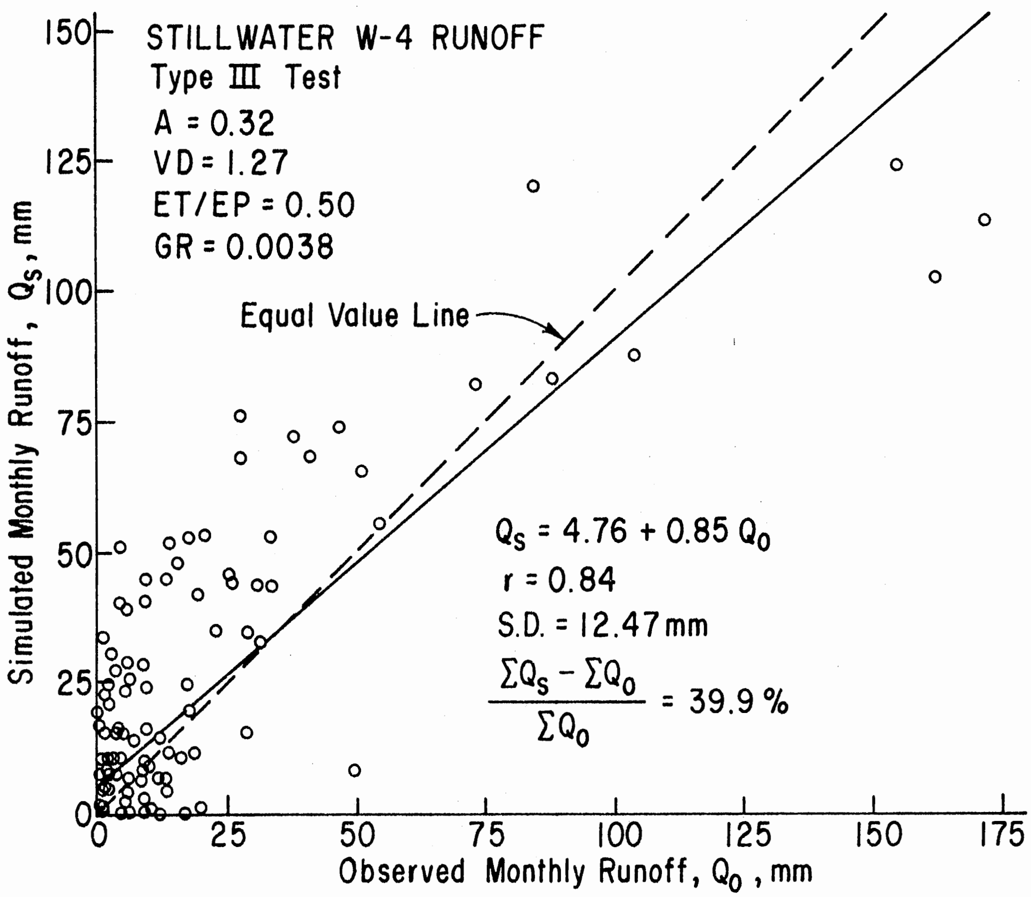

Figure 27. Monthly Runoff for Type III Test for Stillwater W-4 Watershed from 1953 to 1972

TABLE XLI

ANNUAL SUMMARY OF TYPE III TEST WATER BALANCE FOR STILLWATER W-4 WATERSHED FROM 1953 TO 1972

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Offsite Flow mm	Chg Soil Moisture mm
1953	788	61	145	402	23	176	+42
1954	398	15	12	356	14	81	-65
1955	913	212	198	366	33	288	+28
1956	405	10	24	317	16	46	+2
1957	1126	373	328	260	25	474	+39
1958	656	70	62	308	19	289	-22
1959	1198	319	350	342	30	452	+24
1960	737	97	123	335	18	260	+1
1961	1003	225	272	308	23	402	-2
1962	664	74	99	287	14	262	+2
1963	780	61	212	328	15	225	0
1964	707	54	56	354	25	275	-3
1965	539	12	56	336	17	135	-5
1966	489	20	80	317	12	91	-11
1967	828	79	153	355	15	285	+20
1968	728	98	118	300	15	294	+1
1969	804	100	182	334	21	269	-2
1970	542	44	54	296	16	175	+1
1971	905	82	234	314	30	323	+4
1972	694	61	133	299	25	237	0
TOTAL	14,904	2,067	2,891	6,514	406	5,039	+54
MEAN	745	103	144	326	20	252	+3

Groundwater Flow = 6 mm

Annual Peak Rates of Flow

The maximum observed peak rate of flow was 60.7 mm/hr or 14 m^3/s on April 18, 1957. It had a return period of greater than 200 years. The smallest observed annual peak rate of flow was 0.7 mm/hr or 0.16 m^3/s on September 20, 1965. Table XLII shows the observed and simulated yearly peak rates of flow. The Log Pearson Type III observed 100 year return period rate of flow was 46.9 mm/hr or 10.86 m^3/s. The Log Pearson Type III simulated 100 year rates of flow were 46.0, 56.7, and 72.6 mm/hr for the Type I, II, and III tests, respectively.

Discussion of W-4 Results

The statistical results from the evaluations are shown in Table XLIV. The Type II test produced the smallest error, the Type I had the smallest standard deviation, and the Type III had the regression coefficient nearest unity. All of the types overpredicted small monthly runoff and underpredicted large monthly runoff. Three extremely large monthly runoff values averaging 166 mm were underpredicted by approximately 30% causing the low regression coefficients.

The Types I and II water balances were more in agreement with independent research. The water balances showed annual mean ET values of 609 mm, 599 mm, and 346 mm for the Types I, II, and III. The Types I and II closely approximate the lysimeter ET of 650 mm from Blad and Rosenberg (1974) while the Type III ET was 47% less.

The Type II proved to be the best calibration by predicting simulated runoff with an error of only 0.7%. The double mass plot (Figure 28) shows a reasonable prediction of yearly runoff except for

TABLE XLII

OBSERVED AND SIMULATED ANNUAL PEAK RATES OF FLOW FOR STILLWATER W-4 WATERSHED (mm/hr)

Year	Date	Observed	Date	SIM Type I	SIM Type II	SIM Type III
1953	5-12	15.8	5-12	13.3	14.0	20.3
1954	5-01	8.1	5-06	5.6	4.0	8.5
1955	5-26	35.4	5-26	43.2	44.1	45.7
1956	7-06	11.5	7-06	0.3	0.7	27.9
1957	4-18	60.7	4-18	56.1	57.5	59.6
1958	3-23	10.0	7-12	21.7	23.7	32.7
1959	10-02	41.5	10-02	33.6	34.1	32.7
1960	5-29	25.3	5-29	29.9	32.1	35.2
1961	5-21	31.9	5-21	58.9	61.4	69.5
1962	6-07	29.3	6-07	29.2	31.1	33.9
1963	9-04	11.8	9-04	23.3	24.9	28.3
1964	5-10	4.2	9-26	17.2	17.6	27.2
1965	9-20	0.7	5-31	3.9	3.9	9.7
1966	7-23	14.2	7-23	17.9	19.0	51.7
1967	6-24	21.6	6-25	41.4	44.1	48.1
1968	4-03	14.2	4-03	20.2	21.0	23.3
1969	5-07	13.0	4-16	13.7	14.8	17.0
1970	4-30	7.4	4-30	21.7	23.5	27.6
1971	6-02	9.6	6-02	26.9	28.8	32.2
1972	6-19	13.7	7-02	25.5	26.7	31.9

TABLE XLIII

THE 100 YEAR RETURN PERIOD RATES OF FLOW
FOR STILLWATER W-4 WATERSHED
(mm/hr)

Type	100 Year Return Period		% Error
	mm/hr	m^3/s	
Observed	46.9	10.86	——
SIM - I	46.0	10.66	-1.8
SIM - II	56.7	13.12	+20.8
SIM - III	72.6	16.82	+54.9

TABLE XLIV

STATISTICAL RESULTS OF TESTS AT STILLWATER
W-4 WATERSHED (1953-1972)

Type	Reg Coef.	r	S.D. mm	% Error
I	0.77	0.91	7.87	-8.5
II	0.80	0.90	8.54	-0.7
III	0.85	0.84	12.47	+39.9

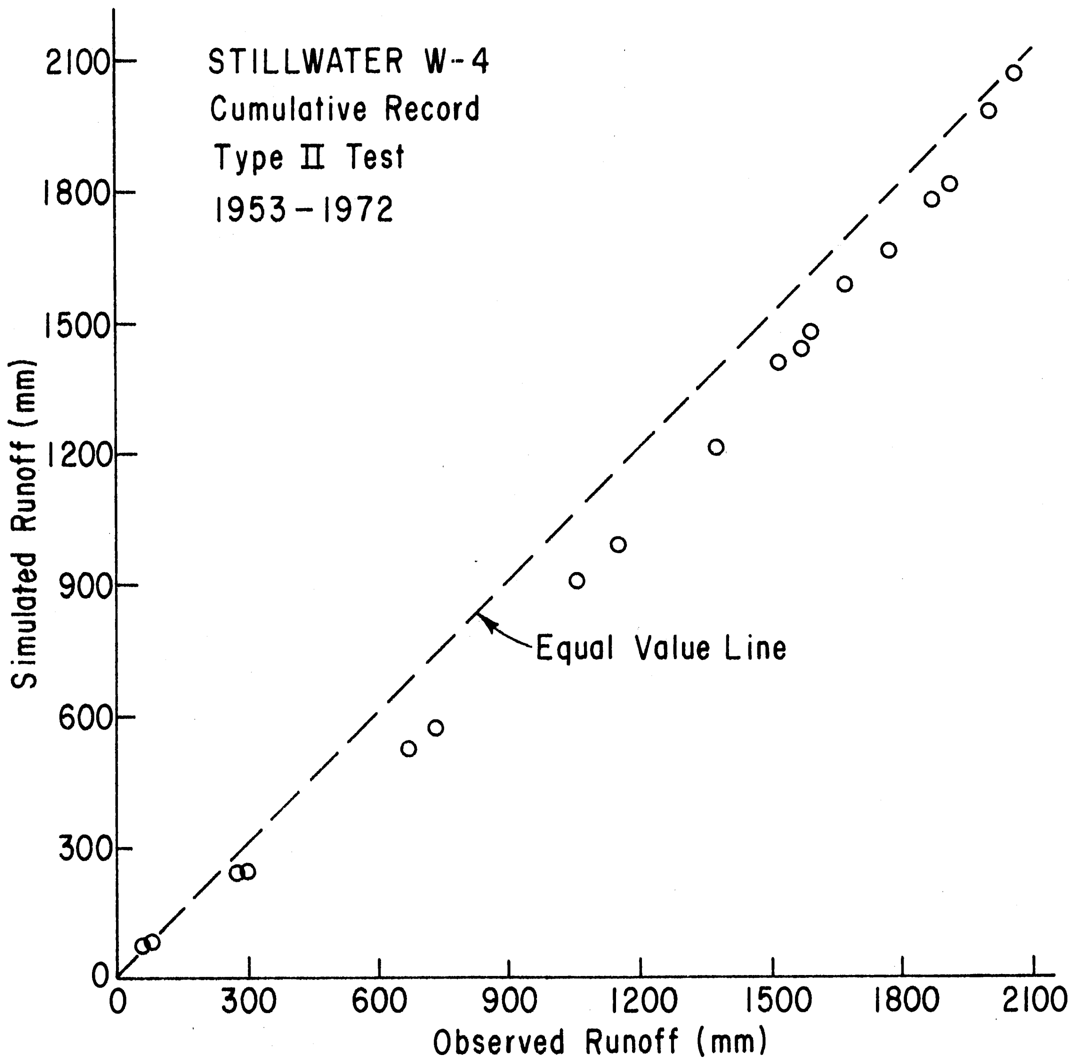

Figure 28. Type II Test Double Mass Plot for Stillwater W-4 Watershed from 1953 to 1972

1957 and 1971. However, the individual monthly runoff values were not precisely predicted.

The observed and simulated mean monthly runoff are compared in Figure 29. The Types I and II underpredicted in March, April, May, November, and December and overpredicted in July, August, and September. The Type III values were always larger than Types I and II. The central Oklahoma rainfall pattern is such that normally the first large rains occur in March after a dry winter. Also normally, the rainfall amounts in July and August are small compared to the amounts during April, May, and June. The evidence reveals that the model underpredicted simulated runoff after dry weather and overpredicted after periods of large rainfall.

The model responded to parameter value changes which increased runoff yield by increasing the annual peak rates of flow. The Type I test predicted a Log Pearson Type III 100 year return period rate of flow of 46.0 mm/hr which was very near the observed of 46.9 mm/hr. As the simulated runoff yield for the Types II and III increased by 8.5% and 53% over the Type I, the Log Pearson Type III 100 year return period rates of flow were increased by 23% and 58%, respectively.

Stillwater Environmental Watershed

The third watershed used to evaluate the calibration was the Stillwater Environmental Watershed described in Chapter IV. This was a transfer in distance, time, size, and vegetative cover. The watershed is located 40 km northeast of the Guthrie watershed and is nine times larger. A total observed runoff of 178 mm occurred between January, 1977, and October, 1979 (Table XLV). Hydrologic group B

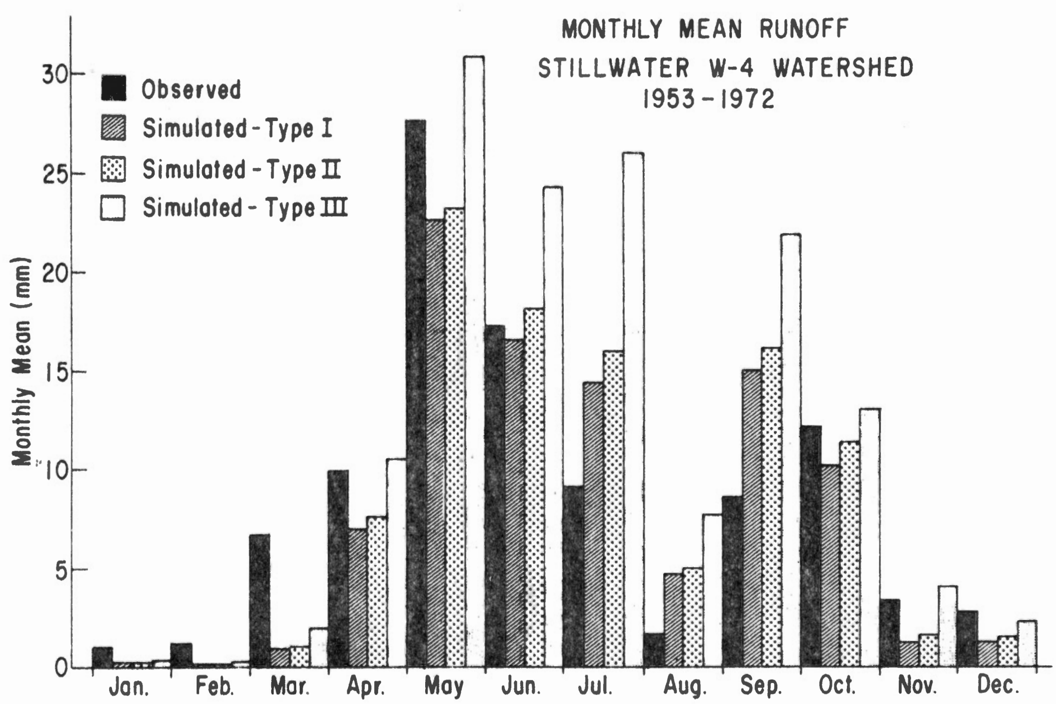

Figure 29. Comparison of Monthly Mean Runoff for Stillwater W-4 Watershed

TABLE XLV

MONTHLY OBSERVED RUNOFF FOR STILLWATER ENVIRONMENTAL WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	0	0	0	0	59.8	0	2.6	0	0	0	0	0	62.4
1978	0	3.6	0.4	0	2.7	6.3	0	0	0	0	1.7	0	14.7
1979*	8.5	0	19.3	2.2	33.3	10.4	27.7	0	0	0	--	--	101.4
TOTAL	8.5	3.6	19.7	2.2	95.8	16.7	30.3	0	0	0	1.7	0	178.5
MEAN	2.8	1.2	6.6	0.7	31.9	5.6	10.1	0	0	0	0.6	0	59.5

*January - October, 1979

soils are predominant. The vegetative cover consists of 89% grass pasture, 6% wheat, and 5% woods.

For the model tests, the Guthrie parameter values were used for the grass pasture and wheat. The parameter values from England (1977) were used for the vegetative cover, woods. These were A = 1.00, VD = 16.26 mm, ET/EP = 1.20, TU = 28.3^{o} C, and TL = 0.0^{o} C.

The results of the Stillwater Environmental Watershed evaluations are summarized in the following paragraphs.

Type I

The simulated runoff for the Type I parameter values (Table XLVI) was 279 mm for a 55.9% error. Figure 30 shows a regression equation of

$$Q_s = 1.16 + 1.34\ Q_o \qquad (25)$$

with r = 0.90 and S.D. = 8.08 mm. The water balance is shown in Table XLVII.

Type II

The Type II Parameter values resulted in a simulated runoff of 301 mm (Table XLVIII) for an error of 68.2%. The regression equation (Figure 31) was

$$Q_s = 1.45 + 1.41\ Q_o \qquad (26)$$

with r = 0.90 and S.D. = 8.53 mm. Table XLIX shows the water balance.

Type III

As shown in Table L, the simulated runoff for the Type III parameter values was 341 mm for a 90.5% error. Figure 32 shows a regression equation of

TABLE XLVI

MONTHLY TYPE I TEST SIMULATED RUNOFF FOR STILLWATER ENVIRONMENTAL WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	0	0	0	0	81.3	0	12.6	0	0	0	0	0	93.9
1978	0	8.2	0.2	0	0.8	24.6	0	0	0	0	0.3	0	34.1
1979*	0.2	0	32.3	4.4	19.2	35.3	59.4	0	0	0	--	--	150.8
TOTAL	0.2	8.2	32.5	4.4	101.3	59.9	72.0	0	0	0	0.3	0	278.8
MEAN	0.1	2.7	10.8	1.5	33.8	20.0	24.0	0	0	0	0.1	0	92.9

*January - October, 1979

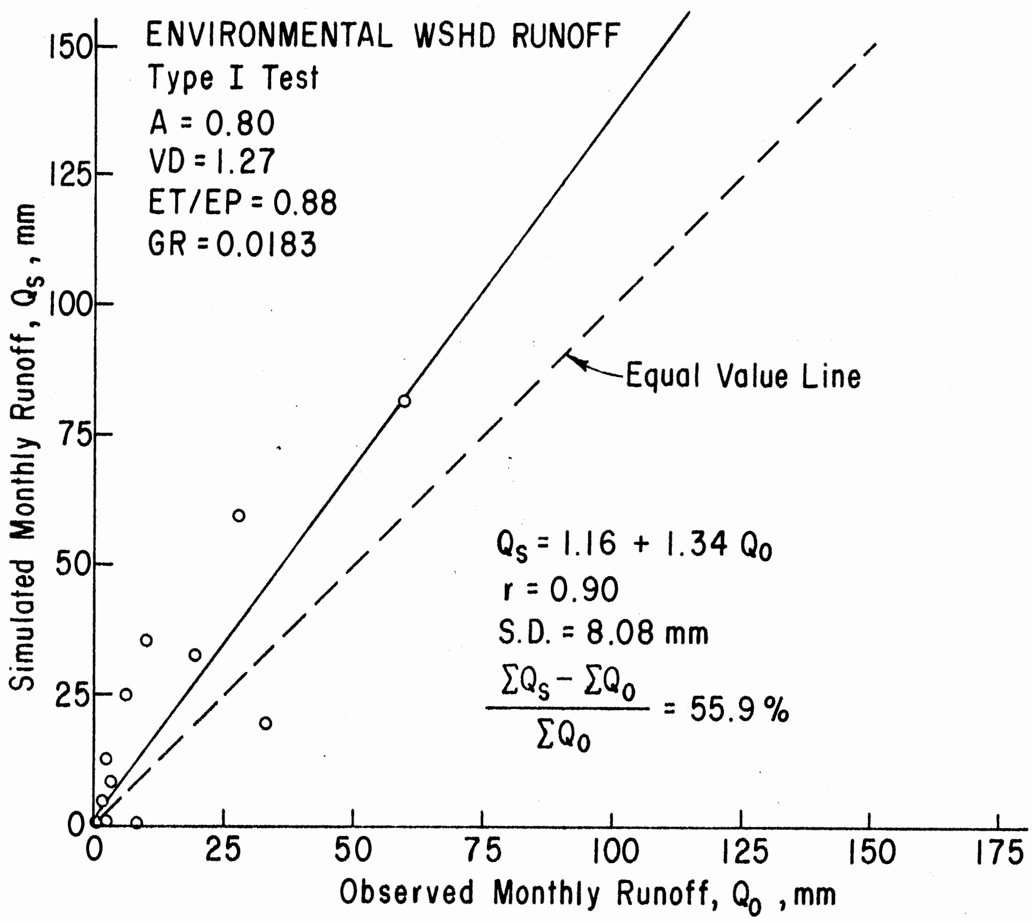

Figure 30. Monthly Runoff for Type I Test for Stillwater Environmental Watershed from 1977 to 1979

TABLE XLVII

ANNUAL SUMMARY OF TYPE I TEST WATER BALANCE FOR STILLWATER ENVIRONMENTAL WATERSHED FROM 1977 TO 1979

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi-ration mm	Soil Evap mm	Ground-water Recharge mm	Chg Soil Moisture mm
1977	725	62	94	545	62	9	+15
1978	678	15	34	487	98	28	+31
1979*	748	101	151	493	128	34	-58
TOTAL	2151	178	279	1525	288	71	-12
MEAN	717	59	93	508	96	24	-4

*January - October, 1979

Offsite Flow = 0.0

TABLE XLVIII

MONTHLY TYPE II TEST SIMULATED RUNOFF FOR STILLWATER ENVIRONMENTAL WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	0	0	0	0	85.1	0	13.9	0	0	0	0	0	99.0
1978	0	9.4	0.4	0	2.0	27.3	0	0	0	0	0.5	0	39.6
1979*	0.4	0	34.9	5.8	21.3	38.4	61.7	0	0	0	--	--	162.5
TOTAL	0.4	9.4	35.3	5.8	108.4	65.7	75.6	0	0	0	0.5	0	301.1
MEAN	0.1	3.1	11.8	1.9	36.1	21.9	25.2	0	0	0	0.2	0	100.4

*January - October, 1979

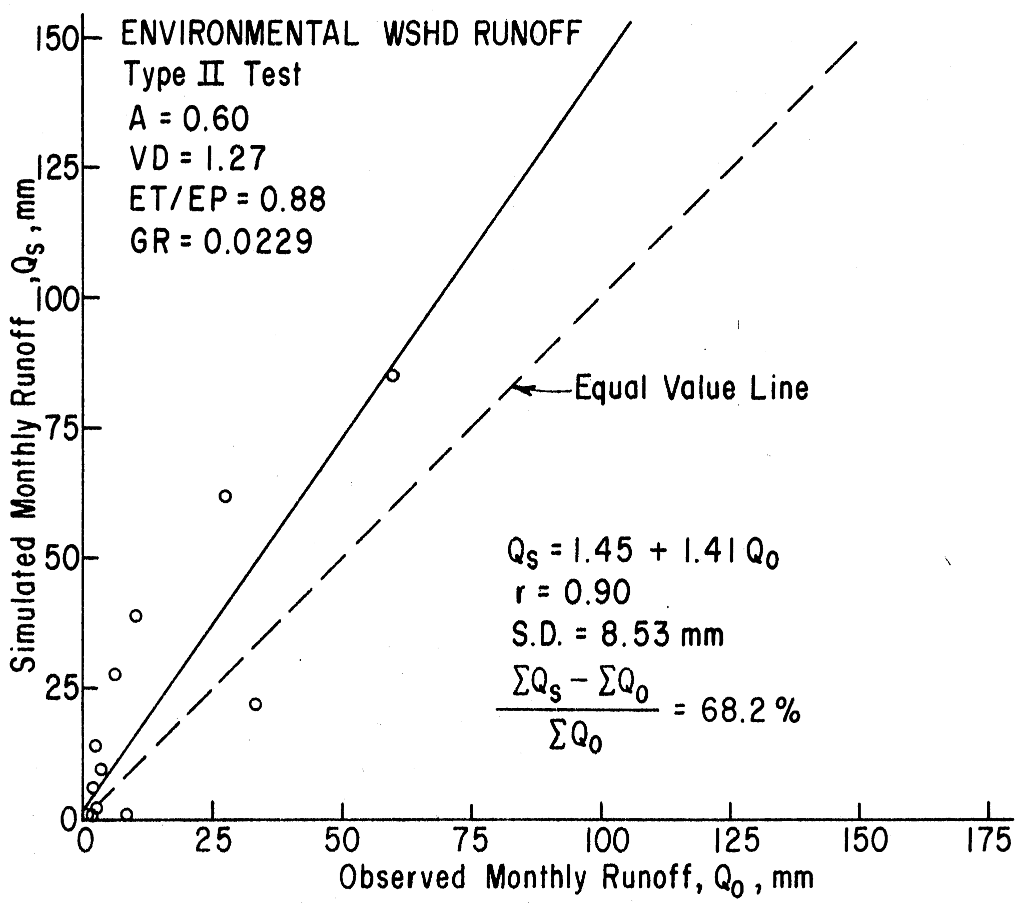

Figure 31. Monthly Runoff for Type II Test for Stillwater Environmental Watershed from 1977 to 1979

TABLE XLIX

ANNUAL SUMMARY OF TYPE II TEST WATER BALANCE
FOR STILLWATER ENVIRONMENTAL WATERSHED
FROM 1977 TO 1979

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Ground- water Recharge mm	Chg Soil Moisture mm
1977	725	62	99	544	57	11	+14
1978	678	15	40	487	88	32	+31
1979*	748	101	162	494	111	38	-57
TOTAL	2151	178	301	1525	256	81	-12
MEAN	717	59	100	508	85	27	-4

*January - October, 1979

Offsite Flow = 0.0

TABLE L

MONTHLY TYPE III TEST SIMULATED RUNOFF FOR
STILLWATER ENVIRONMENTAL WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	0	0	5.2	1.2	90.6	0	12.7	0	0	0	0	0	109.7
1978	0	11.0	0.9	0	3.2	30.2	0	0	0	0.1	9.2	0	54.6
1979*	2.0	0	37.6	9.0	23.7	35.7	68.3	0	0	0	--	--	176.3
TOTAL	2.0	11.0	43.7	10.2	117.5	65.9	81.0	0	0	0.1	9.2	0	340.6
MEAN	0.7	3.7	14.6	3.4	39.2	22.0	27.0	0	0	0	3.1	0	113.5

*January - October, 1979

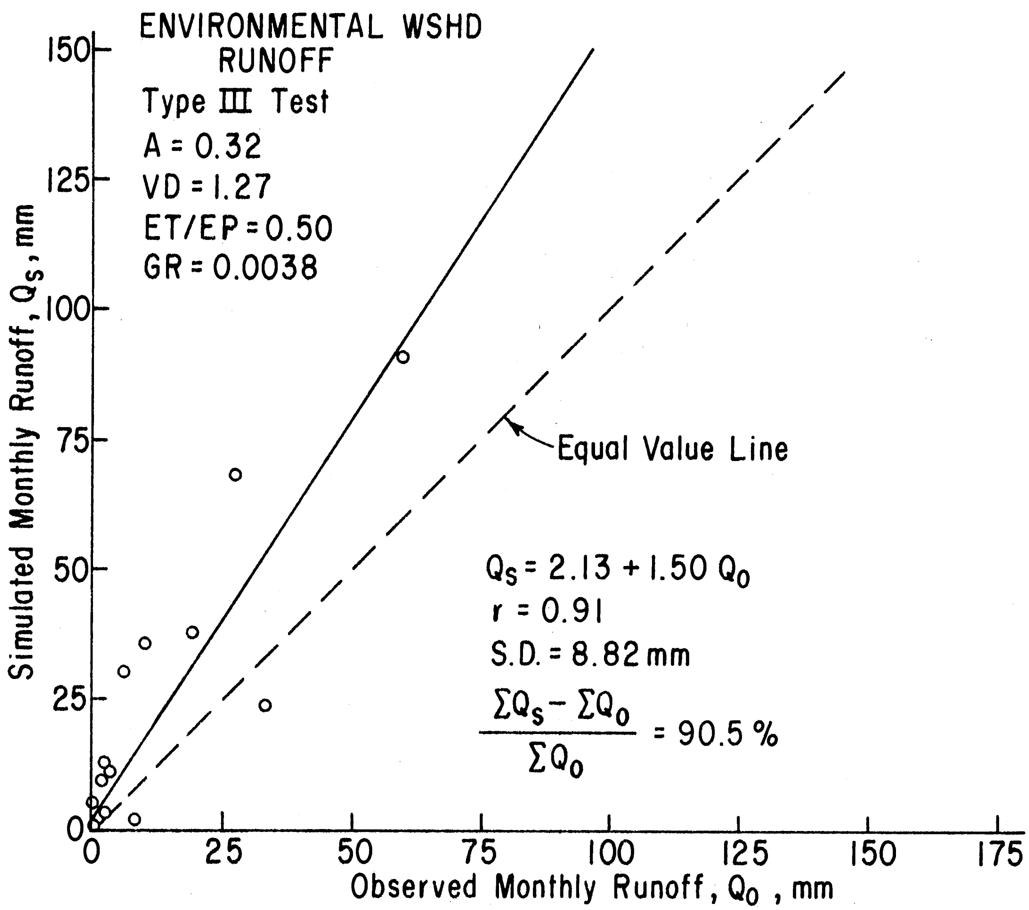

Figure 32. Monthly Runoff for Type III Test for Stillwater Environmental Watershed from 1977 to 1979

$$Q_s = 2.13 + 1.50\ Q_o \tag{27}$$

with r = 0.91 and S.D. = 8.82 mm. The water balance is shown in Table LI.

Annual Peak Rates of Flow

The maximum observed peak rate of flow was 41.1 mm/hr or 6.6 m^3/s on May 21, 1977. The smallest observed annual peak rate of flow was 5 mm/hr or 0.8 m^3/s on June 5, 1978. Table LII shows the observed and simulated annual peak rates of flow. The Log Pearson Type III observed 100 year return period rate of flow was 55 mm/hr or 8.8 m^3/s. The simulated Log Pearson Type III 100 year rates of flow for the Type I, II, and III calibrations were 60.2%, 63.6%, and 69.3% larger than the observed.

Discussion of the Environmental Watershed Results

The statistical results in Table LIV show that the model overpredicted simulated runoff from 56 to 90%. The Type I prediction was closest to the observed runoff and the Type III predicted more runoff than the Type II.

The model overpredicted for February through July (Figure 33). The average errors for June and July were 284% and 151%, respectively. May is a high rainfall month. From 1977 to 1979, 24% of the rain and 34% of the observed runoff occurred during May and the model only overpredicted the May runoff by 13%.

The ET values from the water balances were 604 mm, 593 mm, and 366 mm for the Types I, II, and III. The Type III ET was 44% less

TABLE LI

ANNUAL SUMMARY OF TYPE III TEST WATER BALANCE
FOR STILLWATER ENVIRONMENTAL WATERSHED
FROM 1977 TO 1979

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Offsite Flow mm	Chg Soil Moisture mm
1977	725	62	110	368	9	228	+10
1978	678	15	55	345	9	257	+12
1979*	748	101	176	358	10	241	-37
TOTAL	2151	178	341	1071	28	726	-15
MEAN	717	59	114	357	9	242	-5

*January - October, 1979

Groundwater Flow = 0.0

TABLE LII

OBSERVED AND SIMULATED ANNUAL PEAK RATES OF
FLOW FOR STILLWATER ENVIRONMENTAL
WATERSHED (mm/hr)

Year	Date	Observed	Date	SIM Type I	SIM Type II	SIM Type III	SIM ENVW
1977	5-20	41.6	5-20	52.2	54.1	56.4	48.0
1978	6-05	5.0	6-05	33.0	36.1	39.2	14.8
1979	7-17	31.1	7-17	66.3	68.1	70.8	59.7

TABLE LIII

THE 100 YEAR RETURN PERIOD RATES OF FLOW FOR STILLWATER ENVIRONMENTAL WATERSHED

Type	100 Year Return Period		%
	mm/hr	m^3/s	Error
Observed	74	11.8	——
SIM - I	88	14.1	18.9
SIM - II	90	14.4	21.6
SIM - III	93	14.9	25.7
ENVW	87	13.9	17.5

TABLE LIV

STATISTICAL RESULTS OF TESTS AT STILLWATER ENVIRONMENTAL WATERSHED

Type	Reg. Coef.	r mm	S.D. mm	% Error
I	1.34	0.90	8.08	55.9
II	1.41	0.90	8.53	68.2
III	1.50	0.91	8.82	90.5
ENVW	1.03	0.89	6.59	-3.3

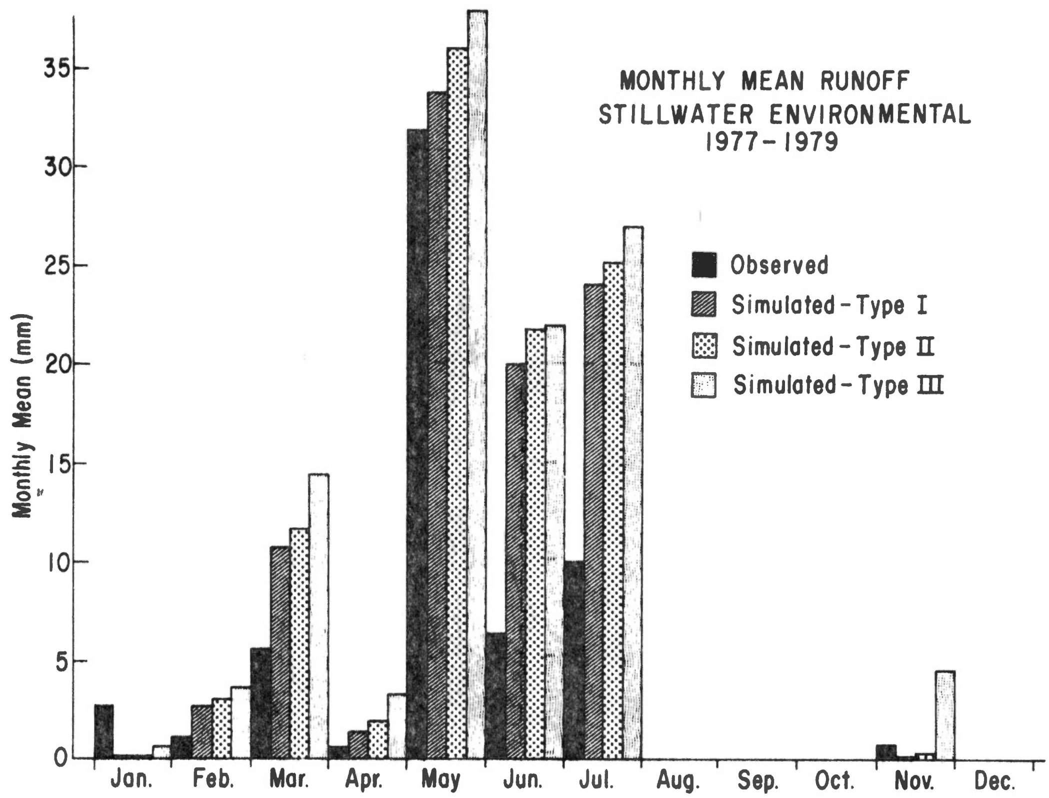

Figure 33. Comparison of Monthly Mean Runoff for Stillwater Environmental Watershed

than the 650 mm from Blad and Rosenberg (1974).

The model overpredicted the Log Pearson Type III 100 year rates of flow by errors of 18.9%, 21.6%, and 25.7% for the Types I, II, and III, respectively. However, this was less than might have been expected considering that the total runoff had been overpredicted by a greater percentage.

Environmental Watershed (ENVW) Calibration

Because of the large errors caused by using parameter values determined by calibration at the Guthrie watershed, it was decided that a new calibration should be made for the Environmental Watershed in an attempt to improve agreement between observed and simulated runoff. The parameters, VD and GR, were adjusted until a simulated runoff of 173 mm (Table LV) was achieved. An error of -3.3% was accepted because the model would not simulate an observed runoff of 8.5 mm that resulted from a rainfall of 20.7 mm that fell on frozen ground on January 18, 1979.

The regression equation (Figure 34) was

$$Q_s = -0.29 + 1.03\ Q_o \qquad (28)$$

with r = 0.89 and S.D. = 6.59 mm. The simulated runoff decreased 42.5% from the Type II. There was a comparable 29% decrease in the standard deviation.

The water balance shown in Table LVI reveals an ET of 604 mm which is a 1.8% increase from the Type II and is near the 650 mm from Blad and Rosenberg (1974). The double mass plot shown in Figure 36 illustrates a reasonable prediction of annual runoff. The final parameter values were A = 0.6, VD = 9.7 mm, ET/EP = 0.88, and GR = 0.05 mm/hr.

TABLE LV

MONTHLY ENVW CALIBRATION SIMULATED RUNOFF FOR
STILLWATER ENVIRONMENTAL WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	0	0	0	0	66.6	0	2.6	0	0	0	0	0	69.2
1978	0	1.3	0	0	0	12.1	0	0	0	0	0.1	0	13.5
1979*	0	0	20.5	0.2	6.3	14.1	49.6	0	0	0	--	--	90.7
TOTAL	0	1.3	20.5	0.2	72.9	26.2	52.2	0	0	0	0.1	0	173.4
MEAN	0	0.4	6.8	0.1	24.3	8.7	17.4	0	0	0	0	0	57.8

*January - October, 1979

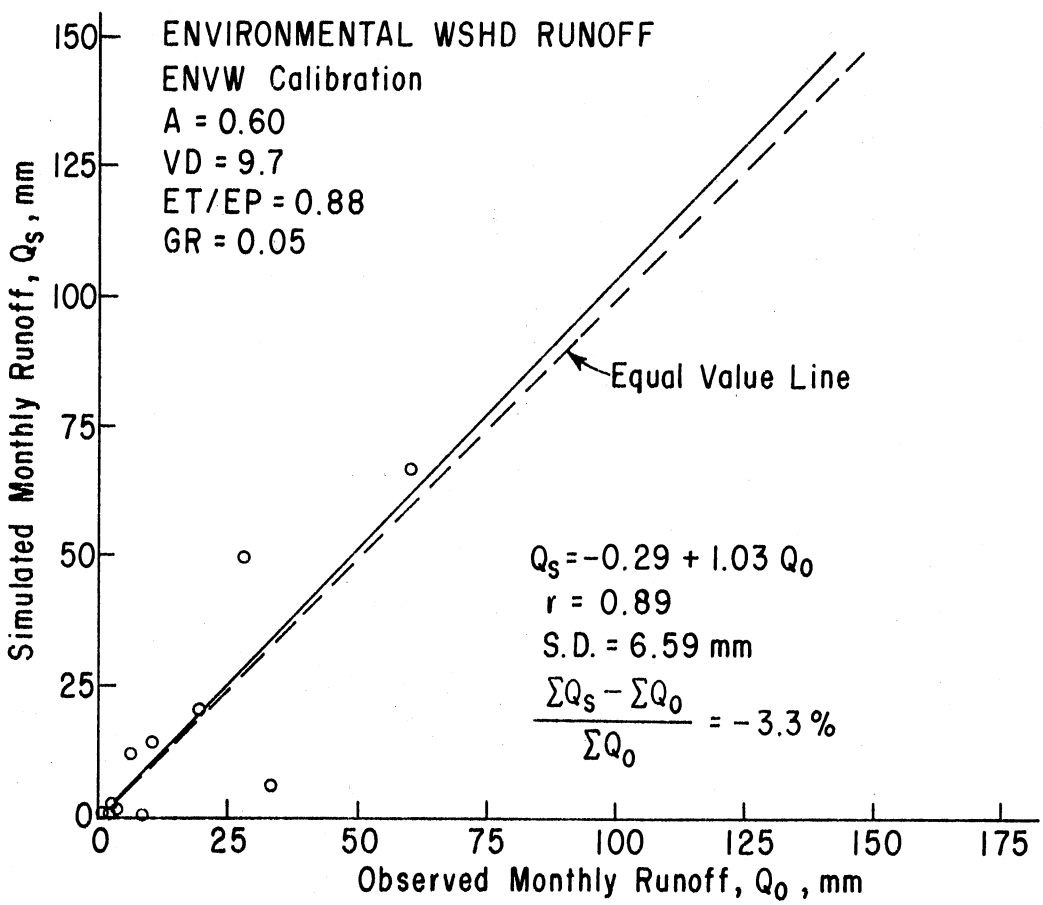

Figure 34. Monthly Runoff for ENVW Calibration for Stillwater Environmental Watershed from 1977 to 1979

TABLE LVI

ANNUAL SUMMARY OF ENVW CALIBRATION WATER BALANCE FOR STILLWATER ENVIRONMENTAL WATERSHED FROM 1977 TO 1979

Year	Rain mm	Observed Runoff mm	Simulated Runoff mm	Transpi- ration mm	Soil Evap mm	Ground- water Recharge mm	Chg Soil Moisture mm
1977	725	62	69	547	68	24	+17
1978	678	15	14	490	80	67	+27
1979*	748	101	91	495	131	85	-54
TOTAL	2151	178	174	1532	279	176	-10
MEAN	717	59	58	511	93	59	-3

*January - October, 1979

Offsite Flow = 0.0

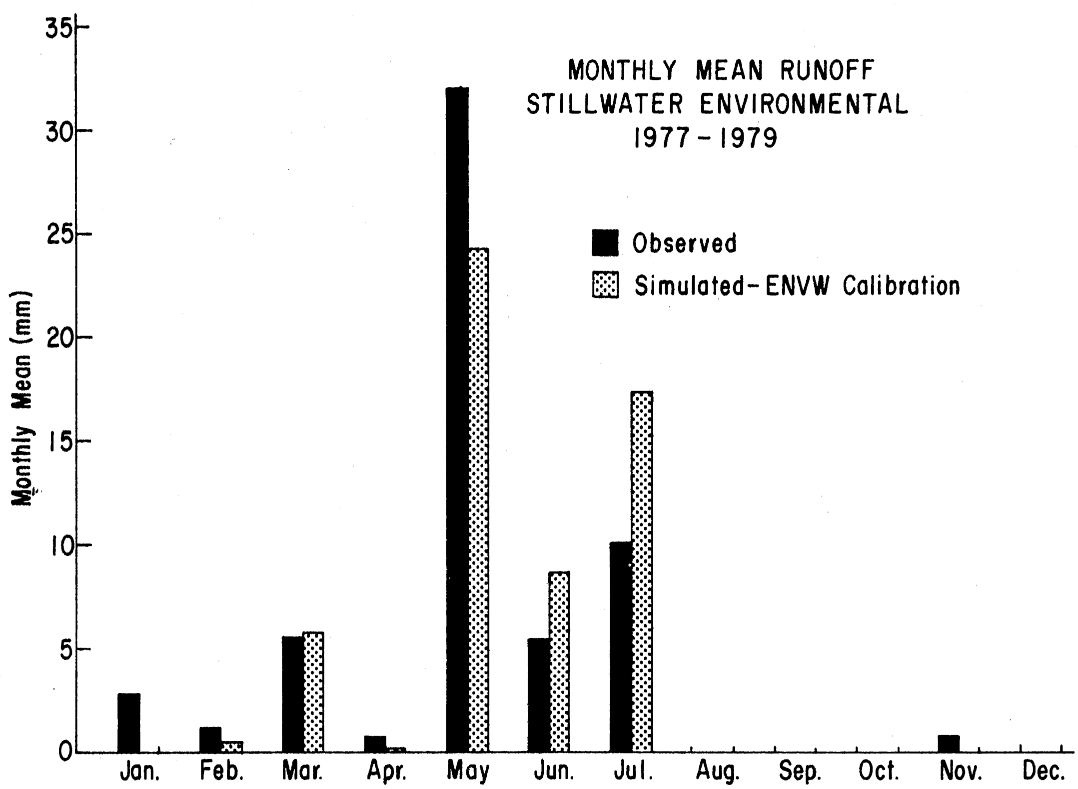

Figure 35. Comparison of Mean Monthly Observed and ENVW Calibration Simulated Runoff for Stillwater Environmental Watershed

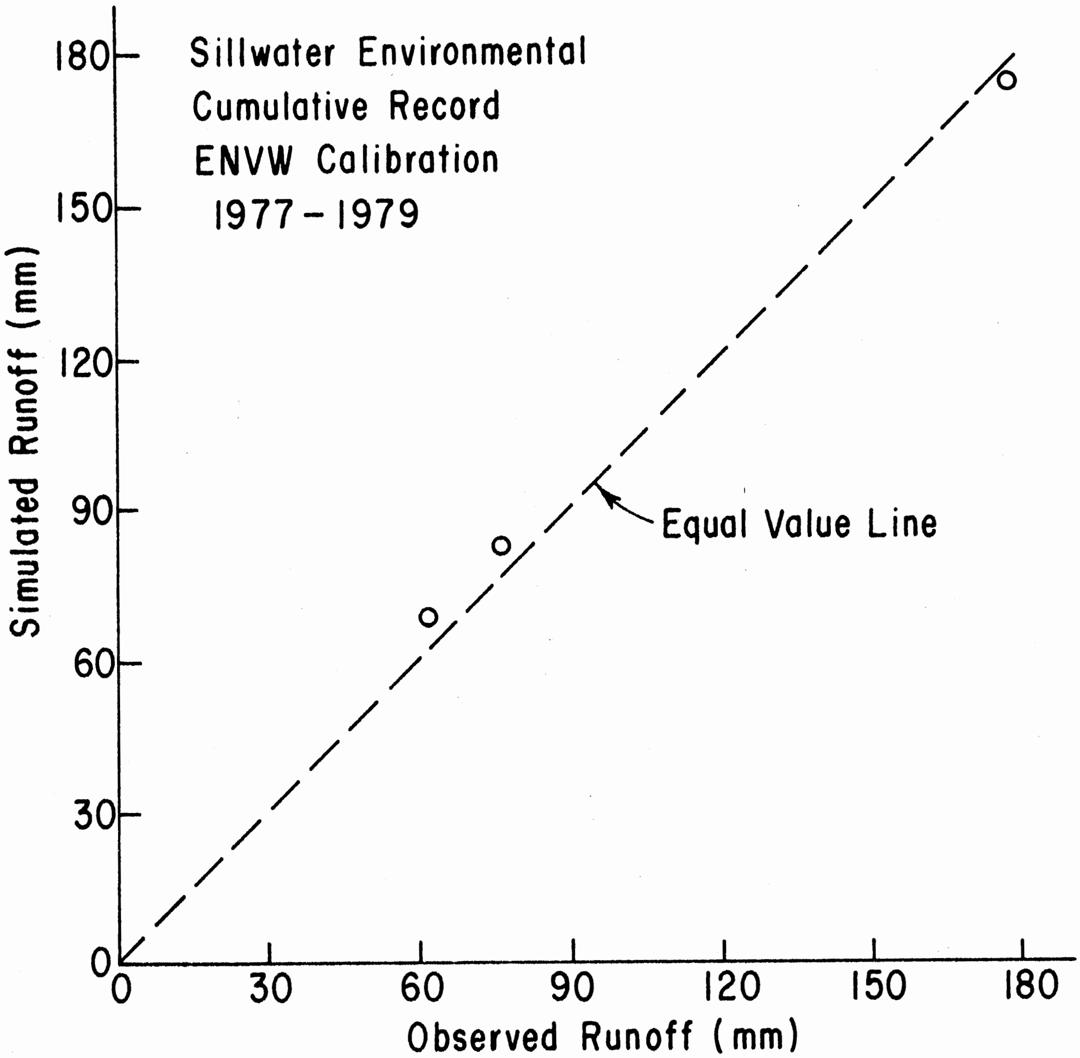

Figure 36. ENVW Calibration Double Mass Plot for Stillwater Environmental Watershed from 1977 to 1979

The GR was increased by 118% and VD increased by 660%. The GR and VD increases may have been required by the sandier subsoils and rougher ground surface. However, the ground surface did not look any different than the surfaces of the preceding watersheds. As shown in Figure 35, this calibration underpredicts May by 24% and overpredicts June and July by 57% and 72%.

The results from the ENVW calibration demonstrated some conceptual weaknesses in the USDAHL model. The model had difficulty simulating runoff from frozen ground and from very high or very low intensity rain storms. For the first example, on January 18, 1979, 20.7 mm of rain fell on frozen ground resulting in 8.5 mm of observed runoff but the model predicted zero runoff. For the second example, on July 17, 1979, 82 mm of rain fell with a maximum intensity of 112 mm/hr resulting in 23.7 mm of runoff but the model overpredicted the runoff by simulating 44.4 mm for an error of 87%. For the third example, starting on May 2, 1979, 99.4 mm of rain fell intermittently over three days with a maximum intensity of 38 mm/hr resulting in 33.3 mm of observed runoff. A simulated runoff of 6.3 mm with an error of -81% was predicted by the model.

A possible explanation for the last two deficiencies lies with the infiltration equation (Equation 2) used by the model. It is a decaying differential equation based on the unsaturated volume remaining in the soil. As shown in Figure 37, during a high intensity rain, the infiltration rate will decay at the maximum rate leaving a large amount of the rainfall to be allocated as runoff. The infiltration rate for the low intensity storm will decay at a less than a maximum rate as shown by the flatter curve in Figure 38 and the model will allocate more

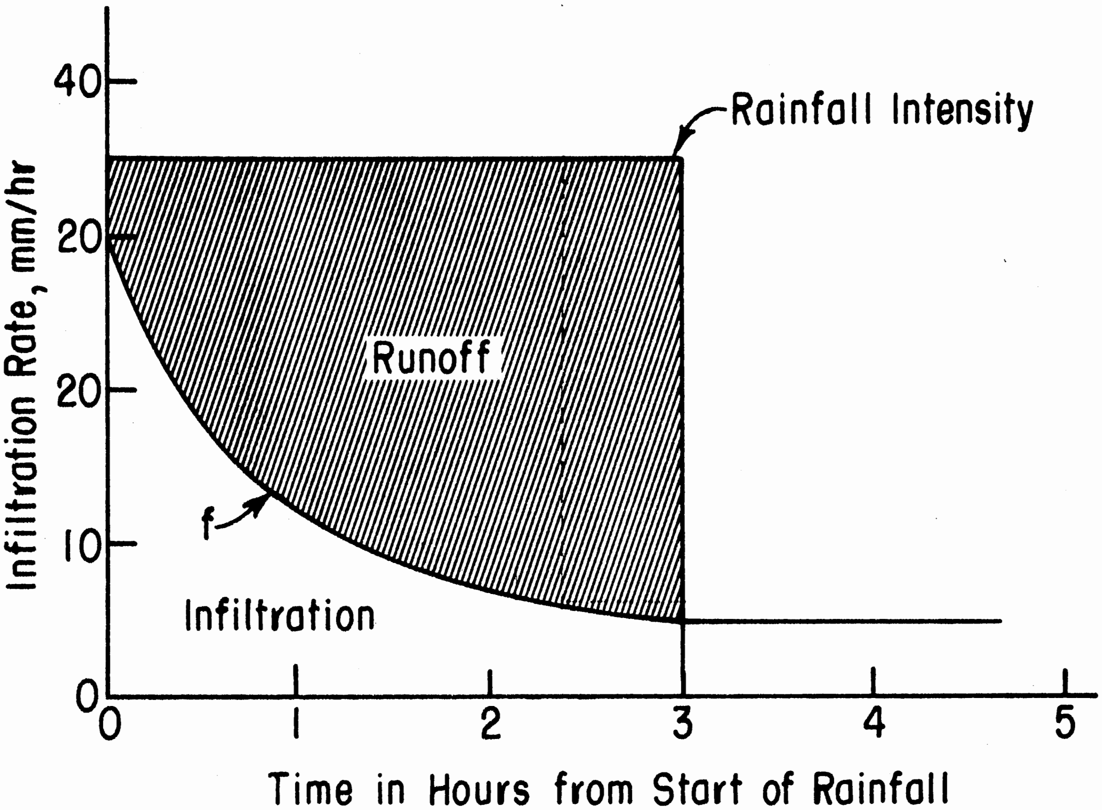

Figure 37. Infiltration Rate for High Intensity Rainfall

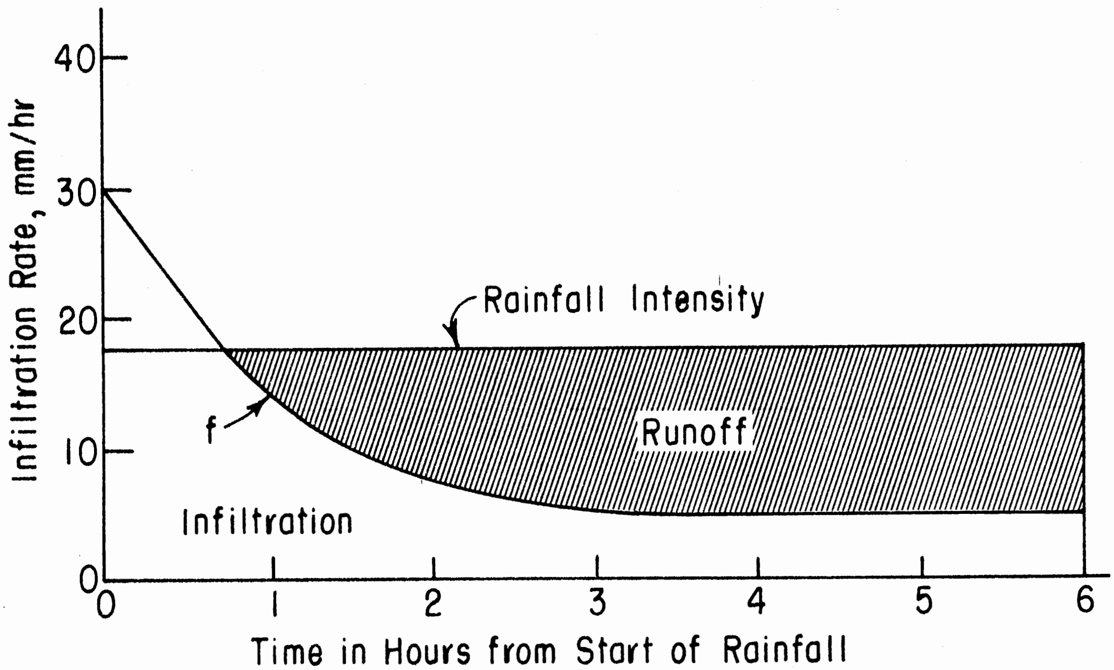

Figure 38. Infiltration Rate for Low Intensity Rainfall

water to the soil as infiltration. However, these deficiencies are minimized over the long term by the normal distribution of rainfall data. The errors from the high intensity storms cancel those from the low intensity storms. Nevertheless, these deficiencies may result in large errors for individual events or months.

Discussion of Overall Results

The transfer of the Guthrie Type II calibration parameter values to the Chickasha watershed provided the best fit of monthly runoff data with a regression coefficient near unity and an error of 1.7%. This was a transfer between comparable sized grassland watersheds. The Type II transfer to the W-4 watershed resulted in a small error (0.7%), nevertheless, the individual months were not predicted very precisely (S.D. = 8.84 mm).

The model overpredicted simulated runoff from the Environmental Watershed, however, when the model was re-calibrated by increasing VD to 9.7 mm and GR to 0.05 mm/hr, the simulated error was -3.3%. These results plus the independent research by Li et al. (1977), and Doorenbos and Pruitt (1977) confirm that the values of 0.6 for A and 0.88 for the ET/EP ratio are satisfactory approximations for central Oklahoma grasslands.

Generally, the Type II calibration caused greater simulated runoff than Type I and less than Type III. The Type III overpredicted runoff by an average of 52%. The failure of the Type III reveals that routing coefficients cannot be established by analyzing hydrographs from different watersheds and transferring them to the watershed to be modeled. Routing coefficients are unique to individual watersheds.

However, the success of the Type II calibration shows that routing coefficients are not required for small watersheds of the type studied with ephemeral flow, thereby increasing the user's confidence of applying the model to field size agricultural watersheds. Nevertheless, routing coefficients would be required for larger watersheds with runoff for extended periods of time after precipitation. This casts doubt on the ability of the model to simulate runoff for large ungaged watersheds with sufficient accuracy to merit much confidence.

The comparison of the Log Pearson Type III 100 year return observed and simulated rates of flow showed that when the model was calibrated for runoff yield, it overpredicted rates of flow by an average of 24%. This demonstrated that the model is a runoff yield model and not a rate of flow model. Nevertheless, it does approximate evapotranspiration, soil moisture, and total runoff yield in a reasonable manner. It keeps an accounting of the daily water transactions in a watershed and could fulfill the requirements for an irrigation scheduling model. Also because it is sensitive to land use, it is useful as a model to investigate hydrologic changes for environmental impact statements.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

A study of the capabilities of the USDAHL model was conducted on four grassland watersheds located in central Oklahoma. The objectives of this study were: (1) to calibrate the USDAHL model to find those hydrologic parameters which best simulate the observed runoff, (2) to test the transferability of the model by applying it to three watersheds using the preceding hydrologic parameters and comparing the observed runoff against the simulated runoff, and (3) to identify any components of the USDAHL model that require improvements.

The model was calibrated on a 6.3 ha watershed located 7 km southeast of Guthrie, Oklahoma, using three different criteria. The Type I calibration was based on the coincidence of the regression line between observed and simulated monthly runoff with the plotted equal-value line. The Type II was based on the equality of the total simulated and observed runoff for the calibration period. The Type III is the same as the Type II but considers lateral subflow. The vegetative parameter (A), depression storage parameter (VD), evapotranspiration parameter (ET/EP), and groundwater recharge parameter (GR) were adjusted until each type of calibration was accomplished.

To evaluate the three types of calibration, the hydrologic parameter values were transferred to 7.8 ha, 83.4 ha, and 57.5 ha watersheds, located 79 km southeast, 70 km and 40 km northeast of the Guthrie watershed, respectively. Only one trial was used without further manipulation of parameters.

The Type II calibration proved best for the 7.8 ha watershed. A regression analysis of simulated versus observed runoff produced the best fit of all of the watershed evaluations. The regression equation was

$$Q_s = 0.13 + 1.01\ Q_o \tag{20}$$

with r = 0.93 and S.D. = 7.76 mm. The Type II parameter values were A = 0.6, VD = 1.27 mm, ET/EP = 0.88, and GR = 0.0229 mm/hr.

The Type II calibration again produced the best results on the 83.4 ha watershed. It simulated runoff over a 20 year period within 0.7% of the observed amount. However, the fit from the regression analysis proved less desirable with an equation of

$$Q_s = 1.68 + 0.80\ Q_o \tag{23}$$

with r = 0.90 and S.D. = 8.54 mm. The small runoff events were overpredicted and the large events were underpredicted.

All calibrations overpredicted simulated runoff for the 57.5 ha watershed with errors ranging from 56% to 90%. To improve on these results, the parameters, VD and GR, were adjusted until simulated runoff was within -3.3% of observed runoff. The parameters, VD and GR, were increased to 9.7 mm and 0.05 mm/hr, respectively. The regression equation was

$$Q_s = 0.29 + 1.03\ Q_o \tag{28}$$

with r = 0.89 and S.D. = 6.59 mm.

The mean annual simulated evapotranspiration values for the Types I and II calibrations for all watersheds agreed with findings from independent lysimeter research conducted by Blad and Rosenberg (1974). The Type III calibration produced evapotranspiration values generally 50% less than Blad and Rosenberg's findings. The model allocated the difference to offsite subsurface flow and surface runoff and generally overpredicted surface runoff by 50%. This demonstrated that hydrograph recession coefficients are watershed unique and not transferable.

The Log Pearson Type III 100 year return period observed and simulated rates of flow were compared. The model overpredicted these rates of flow by an average of 24%.

Conclusions

Based on the analysis and interpretation of the results of this study, the following conclusions were made:

1. The hydrologic parameters to be varied during calibration are the vegetative parameter (A), depression storage (VD), evapotranspiration (ET/EP), and deep groundwater recharge (GR).
2. The Type II calibration procedure proved to be the best procedure for calibrating the USDAHL model.
3. Subsurface flow can be ignored for small watersheds of the type studied with ephemeral runoff.
4. The model overpredicted annual peak rates of flow when calibrated for runoff yield.

Recommendations for Future Research

Based on the results of this study, the following research is recommended:

1. Study the infiltration rate equation

   $$f = (GI)\ (a)\ (Sa)^{1.4} + fc \qquad (2)$$

   to recommend changes to enable the model to better simulate the rate of soil moisture accretion or depletion.

2. A study should be conducted to see if the model can be calibrated to precisely predict peak rates of flow.

REFERENCES CITED

1. Baker, R. 1976. Frequency distribution of species on an Oklahoma rangeland watershed as affected by slope and aspect. Unpublished report. Oklahoma State University.

2. Barnes, B. S. 1939. The structure of discharge-recession curves. Amer. Geophys. Union Trans. pt IV, 721-725.

3. Blad, B. L. and N. J. Rosenberg. 1974. Evapotranspiration by subirrigated alfalfa and pasture in the east central great plains. Agron. Journ., 66 (March-April):248-252.

4. Comer, G. H. and W. H. Henson. 1976. An optimization technique adapted to USDAHL-74 revised model of watershed hydrology. Water Resources Bulletin, 12(1):139-146.

5. Crow, F. R., M. D. Paine, and T. Ghermazien. 1976. Sensitivity of a hydrology runoff simulation model to changes in soil and land use parameters for grassland watersheds. Paper No. J-3348 presented at the 1976 Fall Annual Meeting, American Geophysical Union, San Francisco, CA (December 10).

6. Crow, F. R., W. O. Ree, S. B. Loesch, and M. D. Paine. 1977. Evaluating components of the USDAHL hydrology model applied to grassland watersheds. Transactions of the ASAE, 20(4): 692-696.

7. Crow, F. R., T. Ghermazien, and R. L. Bengtson. 1978. Transferability of the USDAHL hydrology model to ungaged watersheds. Paper No. 78-2066 presented at the 1978 Annual Meeting of ASAE, Logan, UT (June).

8. Doorenbos, J. and W. O. Pruitt. 1977. Guidelines for the prediction of crop water requirements. Food and Agric. Org., Rome, Irrig. and Drainage Paper No. 24, 144 pp.

9. England, C. B. and H. N. Holtan. 1969. Geomorphic grouping of soils in watershed engineering. Journ. of Hydrology, 7:217-225.

10. England, C. B. 1970. Land capability: a hydrologic response unit in agricultural watersheds. USDA-ARS, 41-172 (September).

11. England, C. B. and M. J. Coates. 1971. Component testing within a comprehensive watershed model. Water Resources Bulletin, 7(3):421-427.

12. England, C. B. 1975a. Soil moisture accounting component of the USDAHL-74 model of watershed hydrology. Water Resources Bulletin, 11(3):559-567.

13. England, C. B. 1975b. Root depth as a sensitive parameter in a deterministic hydrologic model. Water Resources Bulletin, 11(5):1046-1051.

14. England, C. B. 1977. Modeling soil water hydrology under a post oak (Quercus stellata Wangenh.)-shortleaf pine (Pinus echinata Mill.) stand in east Texas. Water Resources Research, 13(3):683-686.

15. Engman, E. T. 1978. Evaluation of USDAHL-74. Unpublished report. USDA-SEA Beltsville Agricultural Research Center, Beltsville, MD.

16. Fisher, G. T., J. E. Ayars, H. N. Holtan, and D. L. Nelson. 1977. USDAHL-74 model as a planning tool. Paper No. 77-4045 presented at the 1977 Annual Meeting of ASAE, Raleigh, NC (June).

17. Ghermazien, T. 1978. Transferability and capability of the USDAHL-74 model to simulate runoff from grassland watersheds. Unpublished PhD dissertation, Oklahoma State University.

18. Gray, F. and E. Nance. 1978. Environmental research watershed, Noble County, Oklahoma State University, Agr. Exp. Sta. Research Report P-764 (February).

19. Grossman, B. R., B. R. Brasher, D. P. Franzmeier, and J. L. Walker. 1968. Linear extensibility as calculated from natural-clod bulk density measurements. Soil Sci. Soc. Amer. Proc., 32(4): 570-573.

20. Haan, C. T. 1977. Statistical methods in hydrology. Iowa State University Press, Ames, IA, 378 pp.

21. Hanson, C. L. 1977. Evaluation of the components of the USDAHL-74 model of watershed hydrology. Paper No. 77-2533 presented at the 1977 Winter Meeting of ASAE, Chicago, IL (December).

22. Hjelmfelt, A. T. and J. J. Cassidy. 1975. Hydrology for engineers and planners. Iowa State University Press, Ames, IA, 15-38.

23. Holtan, H. N. 1961. A concept for infiltration estimates in watershed engineering. USDA-ARS-41-51, 25 pp.

24. Holtan, H. N. 1965. A model for computing watershed retention from soil parameters. Journ. Soil and Water Conser., 20(3): 91-94.

25. Holtan, H. N. and N. C. Lopez. 1971. USDAHL-70 model of watershed hydrology. USDA-ARS Technical Bulletin No. 1435.

26. Holtan, H. N., G. J. Stiltner, W. H. Henson, and N. C. Lopez. 1975. USDAHL-74 revised model of watershed hydrology. USDA-ARS Technical Bulletin No. 1518, 99 pp.

27. Holtan, H. N. and M. Yaramanoglu. 1977. A user's manual for the University of Maryland version of the USDAHL model of watershed hydrology. University of Maryland, MP 918.

28. James, L. G., M. F. Walter, and R. E. Muck. 1977. Evaluation of several levels of hydrologic models on small watersheds. Paper No. 77-2050 presented at the 1977 Summer Meeting of ASAE, Raleigh, NC (June).

29. Kohler, M. A., T. J. Nordenson, and W. E. Fox. 1955. Evaporation from pans and lakes. US Weather Bureau Research Paper 38, 21 pp.

30. Kohler, M. A., T. J. Nordenson, and D. R. Baker. 1959. Evaporation maps for the United States. US Weather Bureau Technical Paper 37, 13 pp.

31. Langford, K. J. and J. L. McGuinness. 1976. A comparison of modeling and statistical evaluation of hydrologic change. Water Resources Research, 12(6):1322-1324.

32. Li, E. A., V. O. Shanholtz, D. N. Contractor, and N. C. Carr. 1977. Generating rainfall excess based on readily determinable soil and land use characteristics. Transactions of ASAE, 20(6):1070-1078.

33. Lind, O. T. 1979. Handbook of common methods in limnology. The C. V. Mosby Co., St. Louis, 13-15.

34. Molnau, M. and K. H. Yoo. 1977. Application of runoff models to a palouse watershed. Paper 77-2048 presented at the 1977 Annual Meeting of ASAE, Raleigh, NC (June).

35. Musgrave, G. W. 1955. How much of the rain enters the soil? Water, USDA Yearbook, 151-159.

36. Myers, H. R. 1976. Climatological data of Stillwater, Oklahoma, 1893-1975. Oklahoma State University, Agr. Exp. Sta. Research Report P-739 (August), 29 pp.

37. Nance, E. 1977. Personal communication.

38. Nicks, A. D., G. A. Gander, and M. H. Frere. 1977. Evaluation of the USDAHL hydrologic model on watersheds in the southeastern great plains. Paper No. 77-2049 presented at the 1977 Annual Meeting of ASAE, Raleigh, NC (June).

39. Nicks, A. D. 1978. Personal communication.

40. Ree, W. O., F. L. Wimberly, and F. R. Crow. 1977. Manning n and the overland flow equation. Transactions of the ASAE, 20(1): 89-95.

41. US Department of Agriculture, Agricultural Research Service. 1956. Monthly precipitation and runoff for small agricultural watersheds in the United States. pp. 35.10-1, 35.10-2, 37.3-1, and 37.3-2.

42. US Department of Agriculture, Agricultural Research Service. 1972. Hydrologic data for experimental agricultural watersheds in the United States, 1966. Misc. Pub. No. 1226, pp. 69.44-1 to 69.44-3.

43. US Department of Agriculture, Soil Conservation Service. 1956. Soil survey of Noble County, Oklahoma. Series 1941, No. 16.

44. US Department of Agriculture, Soil Conservation Service. 1960. Soil survey of Logan County, Oklahoma. Series 1948, No. 7.

45. US Department of Agriculture, Soil Conservation Service. 1978. Soil survey of Grady County, Oklahoma.

APPENDIXES

APPENDIX A

RAINFALL, PAN EVAPORATION, AND TEMPERATURE

DATA FOR THE GUTHRIE W-V WATERSHED

TABLE LVII

OBSERVED MONTHLY RAINFALL FOR GUTHRIE
W-V WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1942	4.1	36.6	15.5	204.5	32.8	142.0	2.8	106.7	135.6	56.4	10.9	41.9	789.8
1943	0.0	15.7	23.6	34.8	235.7	59.4	4.8	5.8	24.4	94.5	4.6	63.5	566.8
1944	23.4	28.4	72.9	109.7	101.3	52.3	71.6	42.9	78.2	106.7	43.4	53.1	783.9
1945	23.1	45.5	57.6	89.7	18.0	263.4	76.2	18.0	205.5	13.0	0.0	0.8	810.8
1946	64.8	40.6	62.0	52.6	112.5	71.4	0.0	70.1	12.7	62.2	106.2	23.4	678.5
1947	8.4	0.2	6.8	256.8	154.9	41.6	58.2	1.3	30.5	15.5	30.5	45.5	650.2
1948	1.8	35.8	83.6	75.4	61.5	172.0	34.0	45.0	0.0	14.7	54.9	2.5	581.2
1949	106.7	22.9	36.1	30.5	314.7	208.3	99.8	31.5	98.3	77.2	0.0	26.4	1052.6
1950	22.6	34.8	7.9	23.9	121.7	126.7	226.0	61.0	30.0	6.8	15.0	0.5	676.9
1951	20.8	44.7	24.9	66.5	147.8	147.1	90.7	64.3	102.1	66.0	44.4	0.2	819.5
1952	9.6	30.0	77.2	50.0	95.5	17.0	77.0	56.6	7.4	0.0	40.1	22.9	483.3
1953	13.5	32.8	102.1	66.5	45.0	35.3	130.0	133.6	58.7	142.2	21.1	28.4	809.2
TOTAL	298.8	368.0	570.2	1060.9	1441.4	1336.5	871.1	636.8	783.4	655.2	371.1	309.1	8702.7
MEAN	24.9	30.7	47.5	88.4	120.1	111.4	72.6	53.1	65.3	54.6	30.9	25.7	725.2

TABLE LVIII

PAN EVAPORATION DATA IN WEEKLY AVERAGES IN MILLIMETERS FOR THE PERIOD OF 1942 TO 1953 FOR THE GUTHRIE W-V WATERSHED

1942	0.5	0.5	0.5	1.0	1948	0.6	2.0	2.5	3.9
	1.5	2.3	2.3	2.3		1.3	0.3	0.6	2.5
	2.5	3.9	3.4	6.7		2.5	2.0	4.0	5.3
	3.9	6.0	3.3	3.4		6.8	6.6	7.7	8.2
	4.3	7.2	6.0	4.2		6.0	6.1	5.8	5.8
	7.0	8.4	4.5	5.3		4.5	4.5	6.6	6.5
	10.0	6.8	7.0	8.5		9.4	5.1	5.3	4.9
	7.6	8.0	9.3	7.1		6.8	6.4	6.8	4.8
	4.0	5.3	5.5	4.0		5.2	8.3	5.8	7.3
	6.0	4.7	4.9	2.9		6.6	6.7	5.3	5.5
	3.8	1.9	2.0	2.7		4.6	4.2	3.5	3.9
	1.4	3.2	2.6	1.7		4.2	3.0	2.7	2.1
	1.0	1.0	1.3	0.7		3.7	2.9	1.9	1.1
1943	1.5	0.6	2.1	2.1	1949	2.1	0.9	1.7	2.7
	1.9	3.7	2.5	3.9		1.0	2.0	2.3	1.8
	2.3	2.4	3.8	2.8		2.2	2.4	2.1	3.7
	5.0	6.2	5.3	4.6		5.6	3.7	4.1	4.6
	6.3	8.5	2.7	2.5		3.7	5.7	4.8	5.7
	3.7	6.4	4.2	10.7		5.4	7.2	5.0	6.1
	8.0	7.6	7.7	8.1		5.8	7.4	7.1	4.9
	9.7	8.3	10.5	11.0		8.0	7.6	6.2	5.3
	11.0	11.0	8.4	9.0		4.9	6.5	5.3	4.8
	8.8	6.9	4.8	3.9		4.9	3.9	4.3	2.8
	4.7	5.4	2.8	3.4		3.9	2.7	1.6	3.3
	2.0	2.8	2.5	0.9		4.6	4.5	3.6	4.0
	1.2	1.8	3.9	0.4		3.2	1.4	1.9	1.8
1944	1.1	1.1	1.3	2.5	1950	1.3	1.5	2.0	2.0
	2.0	2.4	2.0	2.4		1.8	1.5	1.5	3.7
	2.3	3.4	2.0	2.0		3.3	2.9	4.1	2.6
	2.9	4.7	6.2	4.8		8.2	5.6	5.9	4.5
	4.8	4.3	4.3	8.0		6.2	5.8	2.6	5.8
	3.9	5.1	5.7	9.0		5.5	6.1	4.9	7.1
	9.0	7.8	9.6	7.0		7.1	7.7	4.9	4.7
	7.1	6.3	9.7	9.2		4.3	3.8	6.0	5.5
	10.1	7.7	5.3	5.7		5.6	4.4	4.9	3.3
	6.2	7.8	3.3	2.7		2.2	4.6	3.8	3.5
	4.3	3.2	2.7	3.7		4.3	3.8	4.0	3.7
	3.1	2.9	0.8	1.1		2.0	3.0	2.6	2.8
	0.9	1.7	2.3	1.2		2.5	1.3	1.3	4.0
1945	1.1	2.0	1.4	1.4	1951	2.1	1.6	4.3	2.8
	2.2	2.9	2.4	2.1		2.5	2.3	1.2	2.4
	1.4	2.2	3.1	4.9		3.2	3.2	2.6	6.1
	4.2	5.0	3.3	3.2		3.7	4.2	5.1	5.5
	2.2	5.0	3.8	5.7		6.5	6.2	5.9	4.5
	7.6	6.4	6.1	5.1		4.6	6.2	5.7	6.2
	5.9	7.6	5.8	5.2		5.9	6.2	7.5	7.0
	6.1	5.9	8.0	5.0		7.8	5.8	7.1	6.6
	5.2	5.6	6.5	6.9		7.0	5.4	9.6	6.0
	5.3	5.1	1.4	1.6		4.5	5.2	5.0	4.8
	3.4	3.1	3.0	3.5		4.2	3.8	2.4	1.9
	3.7	2.9	2.4	2.1		2.6	2.1	2.6	1.0
	1.8	1.7	2.3	1.9		2.9	1.5	1.5	3.5
1946	2.1	1.1	0.6	1.7	1952	1.4	2.0	3.3	1.5
	2.2	3.1	2.4	3.6		1.4	3.5	1.4	2.9
	4.6	4.2	3.0	4.0		1.9	2.7	3.7	3.8
	5.4	5.6	3.8	5.3		2.5	5.4	4.3	3.1
	4.7	5.5	4.5	5.0		4.6	5.0	6.7	5.8
	5.9	4.6	7.5	8.5		6.6	5.0	6.6	9.8
	6.6	7.6	6.7	7.6		10.5	10.9	7.9	5.1
	8.5	8.6	7.9	9.5		5.9	10.6	7.3	7.4
	10.1	4.9	4.0	5.5		7.8	6.2	9.5	8.9
	4.0	3.8	4.2	4.5		7.3	5.3	5.5	5.5
	3.5	2.9	4.2	4.5		5.5	5.1	5.2	5.1
	2.5	1.7	2.1	1.7		4.3	3.0	2.9	1.4
	2.1	2.6	2.4	1.9		2.5	2.4	1.1	1.1
1947	1.2	2.0	1.2	2.0	1953	2.5	3.3	2.4	3.2
	3.3	3.1	2.6	3.2		4.7	4.6	3.8	3.5
	2.8	1.7	2.1	3.5		3.9	2.6	4.2	8.8
	4.2	4.5	3.4	4.7		7.4	4.0	5.0	6.5
	2.6	6.7	5.0	4.3		5.7	5.4	5.2	4.1
	5.5	6.0	8.7	7.0		8.2	9.9	8.7	10.8
	5.0	8.4	6.3	7.7		11.9	8.7	10.4	4.4
	6.2	6.0	9.1	7.8		3.7	7.0	7.5	6.2
	8.4	6.0	7.0	9.3		4.5	5.7	6.4	6.9
	6.5	6.5	5.4	6.9		7.1	7.0	6.8	4.1
	4.8	5.5	3.2	3.0		4.2	4.0	2.3	2.5
	3.6	0.8	0.6	1.7		1.7	3.5	1.8	2.4
	2.1	0.6	1.6	1.9		3.2	2.5	1.3	1.3

TABLE LIX

TEMPERATURE DATA IN WEEKLY AVERAGES OF DAILY MEANS IN DEGREES CELSIUS FOR THE PERIOD OF 1942 TO 1953 FOR THE GUTHRIE W-V WATERSHED

1942	-6.1	-3.1	6.2	8.8
	6.0	9.6	6.5	1.4
	-1.1	5.9	13.7	10.6
	9.5	17.8	11.0	18.1
	16.9	18.5	17.9	17.3
	17.1	25.9	25.0	20.9
	24.9	26.1	24.7	27.3
	29.1	25.5	30.8	28.1
	24.1	25.1	25.9	24.1
	25.2	20.4	14.7	15.3
	19.6	17.3	9.1	13.0
	11.2	9.3	12.8	6.1
	-0.3	3.7	5.3	5.3
1943	3.1	1.2	0.2	1.0
	0.2	8.7	3.6	9.7
	3.9	-3.4	9.2	5.1
	12.8	19.3	18.9	12.6
	19.7	21.0	17.6	15.1
	14.8	22.1	25.4	25.4
	26.7	28.0	25.5	26.3
	29.3	32.0	31.2	32.5
	32.7	27.4	30.4	27.1
	22.7	22.2	22.6	18.7
	16.0	15.4	15.4	11.8
	8.8	9.1	11.1	5.4
	6.9	1.4	-1.3	-2.0
1944	0.7	-5.1	4.4	10.5
	7.4	4.5	0.1	10.1
	6.0	5.3	10.7	6.9
	5.8	11.3	15.1	12.0
	15.4	15.2	17.8	24.1
	21.9	22.4	21.6	24.8
	27.4	27.6	26.1	26.6
	26.4	26.0	29.9	29.3
	29.2	28.9	21.0	23.2
	21.0	26.8	18.9	19.8
	13.7	17.8	17.1	20.2
	15.2	12.3	6.1	1.7
	3.5	0.1	3.0	0.6
1945	0.7	6.8	3.1	3.1
	0.9	6.6	5.4	3.4
	1.6	7.7	14.9	14.3
	15.6	10.1	18.2	15.4
	12.1	15.6	17.1	15.7
	22.0	21.9	24.3	19.7
	15.8	25.2	23.3	24.4
	26.6	28.0	28.3	26.2
	27.3	24.2	27.6	27.5
	20.7	22.5	18.9	15.1
	17.1	15.9	12.2	17.0
	14.8	12.2	7.6	10.2
	2.1	-0.9	-3.7	1.1
1946	5.9	-0.2	1.7	1.9
	10.0	7.5	5.7	11.3
	12.1	9.1	11.4	14.2
	18.6	20.8	14.1	16.9
	17.8	17.0	13.9	18.4
	18.6	18.0	22.5	27.2
	24.6	25.9	25.8	27.3
	28.9	30.8	30.4	32.3
	33.2	27.5	24.1	26.6
	21.4	19.1	18.9	19.3
	14.5	15.1	17.3	15.2
	8.0	7.4	9.4	6.4
	13.7	8.3	2.8	1.1
1947	-10.2	5.4	1.4	8.0
	2.4	-1.2	7.3	-1.4
	-0.3	3.0	3.0	10.5
	11.6	15.6	10.8	13.1
	13.8	19.7	17.2	19.5
	17.7	17.8	26.2	20.7
	24.7	27.8	24.7	26.4
	26.4	24.5	29.1	30.2
	29.7	28.3	30.4	30.2
	22.6	22.4	20.7	22.8
	22.7	21.1	15.7	14.2
	6.3	4.4	3.2	6.9
	4.7	-1.2	4.3	2.8
1948	1.6	3.8	-1.4	-8.2
	-2.2	-3.9	2.5	1.3
	5.2	-2.3	1.3	12.3
	10.1	15.8	15.1	21.4
	19.0	18.7	15.3	20.9
	20.4	20.2	24.9	25.2
	24.5	23.0	24.5	25.6
	27.4	27.3	24.5	23.6
	20.4	26.1	17.0	17.3
	14.7	12.8	13.9	16.9
	7.8	10.2	2.4	3.4
	24.9	29.2	26.8	25.1
	5.0	7.7	2.8	-0.9
1949	1.3	0.7	-6.1	-6.8
	-7.7	2.1	2.8	6.6
	5.0	5.6	8.1	9.5
	11.3	11.0	11.9	15.2
	19.9	22.3	18.4	15.3
	20.4	24.8	23.4	24.5
	25.4	25.1	26.4	25.2
	27.4	25.7	23.3	25.0
	26.2	22.7	22.1	23.2
	17.1	20.1	15.8	19.7
	15.3	16.5	8.6	7.7
	14.2	7.6	7.4	9.7
	4.7	1.0	3.2	4.8
1950	0.4	0.1	6.5	1.7
	-2.4	7.2	2.9	5.4
	5.3	7.1	4.9	7.8
	10.4	11.8	12.0	13.6
	15.8	17.7	16.3	20.4
	18.2	18.9	20.6	25.7
	25.2	24.5	24.2	22.7
	22.7	22.7	23.1	25.8
	24.0	22.2	21.1	18.8
	18.8	22.0	20.2	15.4
	18.9	19.8	17.8	12.8
	5.9	9.8	5.1	5.4
	13.2	6.2	3.4	3.2
1951	2.7	3.6	7.8	2.7
	-8.0	0.3	6.3	10.2
	9.8	5.9	1.8	8.6
	9.3	10.4	8.0	13.1
	21.3	15.9	16.3	20.1
	17.4	22.6	20.0	22.3
	25.2	24.8	25.9	25.9
	28.4	26.9	28.8	27.7
	25.9	24.7	30.8	23.7
	17.4	17.4	19.8	19.5
	16.3	14.4	9.3	3.5
	4.3	4.1	5.2	9.1
	4.8	-0.4	-1.6	4.9
1952	-3.3	6.8	11.2	3.7
	5.2	6.4	6.4	3.1
	4.2	5.3	6.2	14.5
	11.0	11.1	8.9	14.4
	13.7	20.8	18.8	18.5
	18.7	20.5	24.7	27.9
	27.7	29.1	26.7	23.8
	25.6	29.3	28.8	27.7
	28.8	28.1	27.3	23.1
	25.2	21.3	20.8	17.0
	13.7	11.6	13.7	11.8
	8.6	13.1	4.4	-3.6
	4.8	1.9	1.6	-1.5
1953	1.7	6.3	-0.9	4.9
	8.7	6.3	3.1	-0.3
	6.7	7.7	11.1	11.2
	13.3	10.6	8.2	9.5
	15.2	12.2	13.9	15.5
	26.3	26.7	25.8	30.1
	29.5	28.0	29.9	19.7
	24.2	25.5	26.7	23.9
	22.8	21.1	23.9	20.2
	23.1	20.6	24.7	15.8
	18.2	19.1	9.1	12.0
	4.2	12.1	3.4	6.9
	4.2	0.8	-1.3	0.5

APPENDIX B

RAINFALL, PAN EVAPORATION, AND TEMPERATURE

DATA FOR THE CHICKASHA R-7 WATERSHED

TABLE LX

OBSERVED MONTHLY RAINFALL FOR CHICKASHA
R-7 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967	2.5	2.5	59.4	163.3	109.7	49.5	39.1	28.4	137.7	54.1	5.8	25.9	677.9
1968	63.5	27.7	43.2	58.9	103.9	58.2	108.2	26.4	75.4	60.7	109.0	32.8	767.9
1969	18.0	59.9	49.5	26.7	120.9	100.3	97.0	61.5	86.6	41.1	9.4	37.8	709.1
1970	4.3	17.0	57.2	66.0	81.5	30.5	26.2	47.5	172.5	75.2	25.1	8.1	611.1
1971	14.5	42.4	4.1	14.0	105.2	126.7	43.9	97.0	156.2	140.7	12.4	73.9	831.0
1972	2.0	15.2	24.1	119.1	74.7	18.3	25.9	42.2	37.3	226.1	54.9	17.5	657.3
1973	79.2	11.2	154.2	65.0	201.9	150.6	93.7	54.6	163.3	86.6	90.2	3.0	1153.2
1974	4.1	45.5	41.1	101.8	66.3	26.4	18.0	128.0	88.6	121.4	41.4	36.3	718.9
TOTAL	188.1	221.4	432.8	614.8	864.1	560.5	452.0	485.6	917.6	806.2	348.2	235.3	6126.4
MEAN	23.5	27.7	54.1	76.8	108.0	70.1	56.5	60.7	114.7	100.8	43.5	29.4	765.8

TABLE LXI

PAN EVAPORATION DATA IN WEEKLY AVERAGES IN MILLIMETERS FOR THE PERIOD OF 1967 TO 1974 FOR THE CHICKASHA R-7 WATERSHED

1967	2.2	1.5	2.5	3.1	1971	1.3	1.8	2.0	2.1
	1.7	2.2	3.5	2.8		1.9	2.1	3.2	2.5
	4.8	4.2	4.0	4.4		2.8	5.2	5.2	4.4
	4.3	5.6	4.4	4.6		6.9	5.9	7.3	5.1
	4.1	4.4	5.6	6.6		4.7	6.4	5.5	7.4
	7.2	3.9	7.0	7.4		6.8	4.9	7.0	6.4
	7.3	4.4	4.3	6.9		7.2	9.1	9.0	11.3
	3.9	7.5	5.5	8.0		8.1	4.7	6.4	4.3
	5.9	5.2	5.4	3.2		4.1	6.3	5.8	6.9
	3.6	4.5	4.3	4.3		6.2	2.1	4.4	3.9
	3.8	3.7	4.0	1.7		3.5	2.9	2.2	2.8
	2.0	2.5	1.9	1.5		3.1	2.8	1.4	1.3
	2.4	0.8	1.7	1.1		0.1	1.5	2.0	1.8
1968	0.6	0.9	0.9	1.4	1972	1.4	2.3	2.2	1.7
	1.9	2.0	1.0	1.6		1.4	2.0	3.1	2.8
	4.3	2.1	3.4	2.5		5.2	5.4	5.0	4.4
	4.2	4.9	5.9	5.2		4.3	6.2	7.8	4.8
	5.7	7.3	2.9	5.5		4.8	5.3	4.0	6.6
	3.6	5.0	5.8	7.3		6.3	6.0	7.5	5.5
	7.2	8.2	5.5	6.2		7.3	8.5	6.1	8.0
	7.4	8.0	8.5	3.3		9.8	9.4	8.8	7.3
	6.6	10.2	4.7	4.9		6.9	6.7	5.7	5.0
	4.6	6.6	4.5	4.8		6.4	6.3	5.1	6.1
	3.5	4.2	3.7	3.5		5.8	7.2	1.7	1.5
	1.6	1.9	1.9	1.8		3.4	1.2	0.7	2.3
	2.1	2.2	2.3	1.6		0.9	0.7	2.1	2.1
1969	1.7	1.9	0.9	2.1	1973	0.6	0.6	1.4	1.3
	1.5	3.2	1.2	1.0		2.3	1.4	1.3	1.7
	3.3	1.7	2.5	4.2		1.2	2.6	4.1	1.9
	3.3	4.9	5.5	5.2		2.5	2.7	3.2	4.5
	4.0	5.2	5.2	3.9		4.0	5.7	6.0	6.2
	5.5	7.4	7.0	4.7		5.8	4.9	7.0	5.6
	7.8	9.5	11.4	10.6		7.0	7.2	8.0	5.5
	7.2	6.4	5.7	9.5		7.1	5.3	5.0	6.1
	7.2	5.1	5.2	6.0		5.8	6.7	4.5	3.3
	4.1	3.8	5.2	4.6		2.8	2.8	2.0	3.1
	3.7	2.7	1.5	1.5		2.8	2.8	3.0	2.3
	3.0	3.0	2.4	1.9		0.6	2.5	1.3	2.1
	1.2	1.7	1.7	1.2		1.3	1.5	1.7	1.3
1970	0.9	0.5	0.3	2.1	1974	0.8	0.5	1.3	1.7
	2.4	2.2	2.3	2.0		2.4	1.9	2.5	2.9
	3.2	1.8	1.7	2.8		3.8	3.0	2.6	1.5
	1.6	5.0	6.1	4.8		5.6	5.1	5.4	4.4
	4.4	6.4	7.9	7.1		4.1	3.6	5.8	7.6
	5.2	4.1	6.4	3.2		4.9	6.5	5.9	6.1
	7.8	8.8	9.1	6.9		8.8	7.5	8.2	8.4
	7.7	8.1	8.9	9.6		7.4	6.5	5.3	4.5
	8.4	5.9	5.8	10.1		6.2	5.3	2.6	4.1
	5.4	3.4	3.4	4.1		2.9	1.2	3.0	2.8
	2.5	2.1	3.3	2.5		2.1	2.9	0.8	1.3
	2.9	2.1	4.0	2.9		0.9	1.1	2.3	1.3
	2.7	2.1	2.3	1.9		0.9	0.7	1.3	0.6

TABLE LXII

TEMPERATURE DATA IN WEEKLY AVERAGES OF DAILY MEANS IN DEGREES CELSIUS FOR THE PERIOD OF 1967 TO 1974 FOR THE CHICKASHA R-7 WATERSHED

1967	3.8	2.7	3.7	9.9	1971	-0.4	2.4	3.3	5.5
	8.7	4.1	6.3	2.6		4.1	0.6	7.5	5.0
	13.1	9.3	12.7	15.6		3.8	8.7	12.2	7.0
	19.2	22.3	18.9	18.1		13.8	9.2	17.2	18.6
	15.6	15.5	19.8	18.3		16.0	18.5	16.3	19.4
	21.3	21.8	26.3	26.5		21.3	21.6	24.0	25.1
	27.7	24.8	25.2	27.4		25.8	26.6	29.0	30.6
	23.8	29.8	28.2	25.7		27.9	24.4	21.9	24.8
	24.8	25.3	23.0	21.2		24.2	26.3	25.3	27.9
	23.3	24.5	19.3	23.3		24.2	13.3	22.9	19.5
	17.9	15.5	15.5	9.1		16.6	18.4	15.7	13.2
	10.4	13.5	10.2	7.7		9.3	15.3	6.0	4.0
	9.0	3.0	7.5	2.2		3.2	6.2	6.0	9.2
1968	-4.0	-2.3	5.4	8.7	1972	0.2	4.2	4.0	1.2
	7.9	3.7	-1.0	0.9		-1.1	1.8	5.5	9.8
	3.9	10.6	8.8	5.5		10.2	9.9	15.5	14.3
	16.7	10.7	15.1	17.6		9.6	14.2	21.9	18.2
	13.9	19.0	16.5	18.1		15.2	17.5	16.2	20.7
	17.8	21.1	23.4	25.0		23.2	20.9	24.9	25.2
	24.2	24.3	23.0	25.1		24.9	29.2	22.7	26.6
	26.2	28.1	27.8	28.1		28.2	29.2	27.3	27.5
	26.3	29.0	22.9	22.0		27.3	26.7	25.5	24.0
	19.5	22.9	20.6	17.7		27.1	24.7	21.4	18.7
	18.6	17.1	14.3	15.2		21.7	16.4	9.9	10.0
	6.8	8.3	7.6	5.6		12.2	4.9	1.7	5.0
	3.8	4.0	5.5	3.4		-1.2	-4.1	4.5	7.6
1969	1.2	3.0	8.9	3.8	1973	-2.2	-7.6	8.5	3.1
	3.1	7.9	1.9	5.8		6.3	1.9	3.2	5.2
	5.8	0.4	5.5	9.5		9.0	11.9	12.0	10.1
	9.3	16.6	15.4	16.3		10.7	8.4	11.4	15.9
	13.4	19.0	16.9	19.0		15.4	16.5	19.7	19.7
	21.8	21.9	22.1	21.1		22.1	20.6	22.7	24.8
	26.9	28.7	30.2	31.5		23.4	26.3	27.9	25.4
	29.5	25.6	26.3	28.9		26.8	25.7	23.2	26.4
	27.7	26.6	24.7	25.8		26.4	27.6	25.8	23.7
	22.3	21.0	23.1	19.9		20.8	20.8	19.6	19.6
	13.5	14.3	11.0	7.7		19.9	16.3	16.0	11.3
	15.5	8.3	8.2	5.4		8.3	14.9	12.1	10.4
	4.5	5.5	7.5	1.9		4.5	4.5	3.5	2.6
1970	-3.6	-2.5	-3.3	9.0	1974	-5.4	-3.5	6.9	4.9
	3.2	7.4	3.1	5.5		6.7	2.0	9.9	5.0
	12.9	7.7	3.3	7.5		13.6	15.2	11.3	2.5
	6.5	11.8	15.6	17.1		16.9	11.7	13.3	16.5
	19.5	16.3	23.2	19.8		18.9	17.3	21.1	24.6
	22.1	19.3	21.3	27.3		22.3	23.8	23.4	23.5
	26.5	28.5	28.9	28.4		26.3	22.9	26.5	27.7
	27.0	27.2	31.8	30.4		28.7	28.0	23.9	24.0
	29.7	25.7	26.8	33.5		27.3	25.1	22.7	17.8
	24.3	22.8	17.8	21.2		19.5	17.9	15.5	17.2
	11.6	12.7	15.1	8.0		17.8	14.8	16.5	15.9
	10.8	6.1	6.7	12.2		9.7	7.2	10.3	2.4
	2.9	5.3	5.9	4.1		4.4	3.3	6.0	1.3

APPENDIX C

RAINFALL, PAN EVAPORATION, AND TEMPERATURE

DATA FOR THE STILLWATER W-4 WATERSHED

TABLE LXIII

OBSERVED MONTHLY RAINFALL FOR STILLWATER
W-4 WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1953	4.3	23.1	85.3	58.2	109.7	78.2	173.2	23.4	61.7	55.9	85.1	30.2	788.2
1954	0.0	17.5	3.8	74.7	101.1	31.8	3.3	54.1	20.6	48.8	5.8	37.1	398.6
1955	22.6	42.4	52.3	21.3	343.2	66.0	7.1	187.2	40.9	129.5	0.0	0.0	912.5
1956	11.4	17.5	13.7	26.4	65.0	46.5	98.3	19.8	12.4	22.4	35.8	35.6	404.9
1957	13.7	57.6	72.9	184.4	238.2	267.0	39.6	20.8	117.1	41.4	55.6	17.8	1126.1
1958	20.8	21.6	102.9	34.3	32.5	109.7	130.3	82.3	91.2	6.4	8.4	15.5	655.9
1959	4.3	16.8	43.2	81.3	128.3	96.8	255.3	62.7	204.0	257.0	4.6	43.9	1198.2
1960	16.2	51.0	20.8	33.8	169.2	48.0	162.6	68.8	15.2	106.7	2.5	42.4	737.2
1961	0.0	26.7	62.7	7.6	199.6	111.2	127.0	78.2	213.4	59.9	88.9	27.7	1002.9
1962	9.4	12.4	34.5	30.2	36.1	193.8	88.6	22.6	84.6	76.4	32.5	43.2	664.3
1963	11.4	0.0	80.5	34.5	85.1	39.1	157.5	115.3	127.0	77.5	39.9	11.9	779.7
1964	13.7	33.0	21.6	56.9	125.7	24.6	27.2	180.3	63.2	25.4	117.3	18.3	707.2
1965	19.8	16.2	22.1	34.0	106.7	61.5	75.7	46.2	98.6	6.4	0.0	52.1	539.3
1966	3.5	36.3	5.1	42.9	31.2	47.7	146.8	94.7	40.9	13.2	1.0	25.6	488.9
1967	26.4	10.1	26.9	64.3	88.4	197.1	104.6	38.9	177.3	59.4	15.7	18.3	827.4
1968	28.4	11.4	50.8	91.9	167.1	68.3	27.2	47.0	36.6	53.6	118.4	26.9	727.6
1969	14.0	45.7	61.5	65.0	99.3	163.3	25.1	81.3	132.6	70.4	6.8	38.6	803.6
1970	5.3	5.1	74.7	114.3	28.4	68.8	25.4	4.3	139.4	46.5	7.1	22.9	542.2
1971	37.1	45.7	1.3	68.6	71.9	132.6	135.4	27.2	230.9	82.3	14.7	57.2	904.9
1972	4.1	9.9	17.8	70.6	55.9	115.3	88.6	46.7	62.0	138.7	53.8	30.7	694.1
TOTAL	266.4	500.0	854.4	1195.2	2282.6	1967.3	1898.8	1301.8	1969.6	1377.8	693.9	595.9	14903.7
MEAN	13.3	25.0	42.7	59.8	114.1	98.4	94.9	65.1	98.5	68.9	34.7	29.8	745.2

TABLE LXIV

PAN EVAPORATION DATA IN WEEKLY AVERAGES IN MILLIMETERS FOR THE PERIOD OF 1953 TO 1972 FOR THE STILLWATER W-4 WATERSHED

1953	1.5	1.5	1.8	2.0	1959	1.5	1.5	1.8	2.0
	2.3	2.5	2.8	3.0		2.0	2.3	2.5	2.8
	3.3	3.6	4.1	4.3		3.0	3.6	4.3	5.8
	5.1	6.1	6.3	5.9		6.6	6.9	7.1	7.4
	7.1	7.1	7.4	7.9		7.6	7.6	7.9	8.1
	8.6	10.2	12.2	12.7		7.9	7.4	6.5	5.8
	12.4	10.9	9.1	7.9		6.1	6.9	8.1	9.9
	7.1	6.6	6.3	6.6		10.2	9.1	8.1	7.4
	7.1	7.4	7.9	8.4		6.9	7.1	7.9	7.5
	8.6	8.6	8.1	5.9		7.4	6.6	5.8	5.1
	5.1	4.3	3.8	3.3		4.3	3.8	3.0	2.8
	2.8	2.5	2.3	2.0		2.3	2.0	2.3	2.5
	1.8	1.5	1.5	1.3		2.5	2.3	2.0	1.5
1954	1.5	2.0	2.3	3.0	1960	0.5	0.8	1.0	1.3
	3.8	5.3	5.5	5.1		1.5	2.0	2.3	2.8
	3.6	3.3	3.8	4.8		3.0	3.6	4.3	4.8
	5.8	7.6	8.5	8.6		5.6	6.6	7.4	7.4
	7.9	6.6	5.1	5.1		7.1	6.6	6.3	6.1
	5.3	7.1	10.4	11.4		6.3	7.4	8.5	9.1
	11.9	12.4	13.0	13.5		8.9	8.1	8.9	7.4
	14.2	14.5	14.7	14.5		7.1	7.1	6.9	7.1
	14.2	12.7	11.9	11.4		7.4	7.6	7.9	7.5
	10.9	10.7	10.2	9.7		7.1	6.3	5.8	5.3
	8.1	5.8	5.1	4.6		4.8	4.6	4.1	3.8
	4.1	3.8	3.3	3.0		3.6	3.3	3.0	2.5
	2.8	2.3	2.0	1.3		2.3	1.8	1.3	0.8
1955	1.5	1.5	1.8	2.0	1961	1.5	1.8	1.8	2.0
	2.3	2.5	2.8	3.3		2.3	2.3	2.5	2.8
	3.6	4.1	4.8	5.8		3.0	3.6	3.8	4.3
	6.9	8.4	9.1	9.1		4.8	5.3	6.1	6.9
	8.6	7.9	7.6	7.6		7.4	7.6	7.9	7.9
	7.4	7.6	8.1	8.4		7.6	7.4	7.1	5.9
	8.9	9.4	10.2	10.9		7.1	7.4	7.9	8.1
	10.9	10.7	10.2	9.9		8.1	7.9	7.1	6.6
	9.7	8.9	8.4	7.6		6.1	5.8	5.6	5.8
	7.1	6.6	6.1	5.6		6.3	6.3	6.1	5.3
	5.1	4.6	4.3	4.1		4.6	4.1	3.5	3.0
	3.6	3.3	3.0	2.8		2.5	2.3	2.0	1.8
	2.5	2.5	2.3	2.0		1.5	1.3	1.3	1.0
1956	2.3	2.5	2.5	2.3	1962	1.5	1.5	1.8	2.0
	2.0	1.8	1.5	1.8		2.3	2.5	2.8	3.0
	2.5	4.1	5.1	5.5		3.3	3.8	4.1	4.5
	5.8	6.3	6.6	6.9		5.1	5.3	5.8	6.3
	7.4	7.6	7.9	8.4		7.1	8.4	11.2	11.2
	8.6	9.1	9.7	10.2		10.4	7.9	6.9	5.5
	10.7	11.2	11.9	12.7		6.9	7.1	7.4	7.6
	12.7	11.7	10.9	10.4		7.6	7.9	8.1	8.1
	9.7	9.1	9.1	8.1		8.4	8.1	7.1	5.5
	10.7	10.4	9.9	9.1		4.6	4.3	5.6	5.8
	7.9	6.3	5.5	4.8		5.1	4.3	3.5	3.0
	4.3	3.8	3.3	2.8		2.8	2.5	2.3	2.0
	2.5	2.0	1.5	1.3		2.0	1.8	1.8	1.5
1957	1.3	1.5	1.5	1.5	1963	2.0	2.5	2.5	2.0
	1.8	1.8	2.0	2.3		1.3	1.5	2.3	3.0
	2.5	2.8	3.0	3.3		3.6	4.1	5.1	6.6
	3.3	3.6	3.8	3.8		7.1	6.9	6.3	5.5
	4.1	4.6	4.8	5.3		5.1	5.1	5.6	6.1
	5.6	5.8	5.8	6.1		6.6	6.9	7.1	7.4
	6.5	7.1	8.1	9.4		7.6	7.9	8.1	8.6
	11.2	11.7	11.9	11.2		8.6	8.1	7.9	7.6
	9.7	8.1	6.9	5.8		7.1	6.9	6.1	5.5
	5.1	4.3	3.8	3.8		4.6	4.6	6.1	6.1
	5.1	5.1	4.5	3.5		5.6	4.8	4.1	3.6
	2.8	1.8	1.0	1.0		2.8	2.3	2.0	1.5
	1.5	2.3	2.5	2.3		1.3	1.0	1.0	0.8
1958	1.5	1.5	1.8	2.0	1964	1.5	1.6	1.8	2.0
	2.3	2.5	2.5	2.5		2.0	2.3	2.3	2.5
	2.0	1.3	1.0	1.0		3.0	3.8	4.5	5.3
	1.5	2.5	3.6	4.8		6.1	6.9	7.5	9.1
	5.8	6.1	6.5	6.6		9.9	9.7	9.1	8.1
	6.6	6.9	6.9	5.9		7.6	7.4	7.4	7.9
	7.1	7.9	9.1	10.2		10.2	11.9	13.5	15.0
	10.2	9.1	8.4	7.6		15.0	14.0	12.4	11.4
	7.4	6.9	6.6	5.1		10.4	9.4	8.4	7.6
	6.1	5.8	5.6	5.3		6.9	6.1	5.8	5.6
	5.1	5.1	4.8	4.8		5.1	4.6	4.3	3.8
	4.6	4.3	3.8	3.0		3.3	2.8	2.5	2.0
	2.0	1.0	0.5	0.5		1.8	1.5	1.3	1.0

TABLE LXIV (Continued)

1965	1.0	1.3	1.5	1.8	1969	0.8	1.0	1.3	1.5
	1.8	2.0	2.3	2.3		1.8	2.3	2.5	3.0
	2.5	2.8	2.9	3.0		3.6	3.8	4.3	4.3
	4.1	5.8	6.9	7.1		5.1	5.6	5.6	5.8
	7.4	7.4	7.4	7.6		6.1	6.3	6.3	6.6
	7.6	8.1	9.1	10.2		6.9	7.1	7.1	7.5
	9.7	8.4	8.4	8.9		7.9	8.4	8.9	9.7
	9.4	9.9	10.4	10.9		9.7	9.1	8.9	8.6
	11.4	10.7	9.7	8.6		8.4	7.9	7.6	7.1
	7.6	6.9	6.1	5.3		6.6	6.1	5.6	5.3
	4.8	4.6	4.1	3.8		5.1	4.6	4.3	4.1
	3.6	3.3	3.3	2.5		3.6	3.3	3.0	2.8
	2.5	2.0	1.8	1.5		2.5	2.3	2.3	2.0
1966	1.8	2.3	2.3	2.0	1970	1.3	1.5	1.8	2.0
	1.5	1.8	2.3	3.6		2.5	2.8	3.0	3.3
	4.6	5.6	6.1	6.1		3.6	4.1	4.3	4.5
	6.1	6.3	6.3	6.6		5.1	5.3	5.8	6.6
	7.1	7.4	7.6	7.9		7.1	8.1	9.4	9.7
	8.4	8.9	9.7	10.9		9.1	7.9	8.1	8.5
	12.2	12.4	12.4	11.7		8.9	9.1	9.4	9.7
	10.7	9.7	8.6	8.1		9.9	10.7	10.9	10.4
	7.6	7.1	6.5	5.1		9.7	9.1	8.4	7.6
	5.8	5.3	5.1	5.1		6.9	6.1	5.1	4.1
	5.6	6.1	5.8	5.1		2.8	2.5	3.3	4.3
	4.6	4.1	3.8	3.5		4.1	3.3	2.5	2.0
	3.0	2.8	2.5	2.3		2.0	1.8	1.5	1.5
1967	1.5	2.0	2.0	1.3	1971	1.5	1.5	1.8	2.0
	1.3	1.3	2.0	3.6		2.0	2.3	2.5	2.8
	4.5	5.6	5.8	6.1		3.0	3.6	4.3	5.1
	6.1	6.1	6.1	5.3		5.8	6.3	6.9	7.1
	6.6	6.9	7.1	7.6		7.4	7.4	7.4	7.6
	7.9	8.1	7.9	7.4		7.9	8.1	8.1	8.4
	6.9	6.3	6.3	7.1		8.6	8.9	9.4	9.9
	7.9	8.1	7.9	7.1		9.9	9.4	8.4	5.9
	6.6	6.1	5.8	5.6		6.6	7.1	9.1	9.7
	5.3	5.3	5.8	7.6		9.4	8.6	7.1	5.1
	7.6	6.9	5.3	4.1		4.1	3.6	3.3	3.0
	3.3	2.5	2.0	2.0		3.3	2.8	2.5	2.3
	2.0	1.8	1.8	1.5		3.0	2.8	2.5	2.3
1968	2.3	1.8	1.5	1.5	1972	1.5	1.5	1.8	2.0
	1.3	1.3	2.0	2.5		2.0	2.3	2.3	3.0
	3.3	3.8	4.6	5.1		4.1	5.6	6.3	5.5
	5.8	6.3	6.9	5.9		6.9	7.1	7.4	7.6
	6.6	6.1	5.8	5.6		7.9	7.6	6.5	6.6
	5.5	6.3	7.5	8.1		6.9	7.9	9.1	9.7
	8.1	7.9	7.4	7.1		9.7	8.1	7.9	8.1
	7.1	7.4	8.1	10.4		9.1	9.4	9.4	9.1
	10.7	10.4	8.4	7.4		8.4	7.6	6.6	6.1
	6.6	6.1	5.5	5.1		5.6	5.3	5.1	4.8
	4.8	4.3	3.6	3.0		4.6	4.3	3.8	3.6
	2.5	2.3	2.0	2.0		3.0	2.8	2.5	2.3
	1.8	1.8	1.8	1.5		2.0	2.0	1.8	1.5

TABLE LXV

TEMPERATURE DATA IN WEEKLY AVERAGES OF DAILY MEANS IN DEGREES CELSIUS FOR THE PERIOD OF 1953 TO 1972 FOR THE STILLWATER W-4 WATERSHED

1953	3.8	7.9	0.9	7.2	1959	-5.2	6.2	1.1	4.1
	10.9	10.5	6.2	4.2		-0.3	4.5	8.5	3.8
	8.5	8.8	12.9	14.1		8.4	7.4	11.3	14.2
	14.9	12.6	11.9	11.1		11.6	18.1	8.8	14.9
	17.8	15.1	16.5	17.1		20.9	22.8	18.8	20.9
	27.7	28.0	26.2	31.4		21.3	23.3	22.1	24.7
	29.4	29.2	30.8	21.7		25.3	26.4	26.1	24.1
	25.3	26.8	28.2	26.0		24.2	25.3	28.7	25.0
	24.8	23.2	25.9	22.2		27.1	27.4	27.2	25.8
	24.7	21.7	25.7	19.2		18.9	25.3	20.2	15.8
	19.5	20.9	12.4	14.3		15.9	14.4	14.5	15.5
	7.8	14.2	8.1	9.2		7.4	1.3	8.7	3.2
	8.9	4.5	3.0	3.5		7.3	8.3	5.9	6.4
1954	7.9	0.0	0.5	1.4	1960	0.0	10.5	-2.2	2.3
	8.3	9.1	12.9	11.5		5.8	6.6	-0.2	-0.1
	3.9	11.3	8.0	11.9		-6.9	0.3	2.7	7.3
	9.2	19.5	17.7	19.4		15.4	13.7	18.4	18.3
	22.2	12.9	14.8	19.5		19.8	15.3	14.7	21.1
	21.8	21.3	23.3	26.0		21.9	22.4	24.4	24.1
	29.0	29.1	31.1	33.9		27.0	27.3	24.8	27.2
	34.2	31.4	29.9	29.5		25.2	27.1	26.9	25.8
	32.8	30.2	30.4	28.3		25.4	26.9	26.8	26.2
	24.8	25.2	24.8	22.4		22.2	25.3	20.1	22.5
	24.4	17.4	14.4	5.9		20.7	14.3	18.4	13.4
	14.7	14.9	10.5	8.3		9.2	15.1	10.0	8.0
	7.3	5.1	6.5	4.2		7.1	1.7	0.4	5.2
1955	9.1	2.8	2.6	2.6	1961	3.1	5.1	2.5	-2.2
	3.9	4.2	7.2	2.7		2.6	3.6	12.4	5.3
	15.6	12.5	13.4	7.3		12.3	12.1	12.4	8.4
	7.2	14.3	17.8	23.6		11.4	12.7	11.1	18.9
	21.1	24.2	21.0	19.8		18.4	17.7	20.3	19.9
	18.6	22.8	20.2	21.3		18.6	24.7	23.0	23.6
	24.4	27.8	29.0	30.0		21.6	25.4	26.1	22.9
	27.6	30.1	29.8	27.7		26.8	27.2	28.5	27.7
	25.7	29.9	25.4	25.8		24.2	22.4	27.2	23.4
	25.4	27.2	22.7	20.6		19.4	21.4	19.0	15.3
	17.8	15.6	16.9	14.3		21.0	15.4	16.2	15.3
	10.2	8.3	11.1	2.2		8.8	8.8	8.7	7.4
	3.0	1.3	2.1	8.2		7.1	-2.8	3.4	2.2
1956	8.7	2.2	-2.0	3.2	1962	4.3	-3.8	-4.7	1.3
	-2.3	3.4	5.7	11.6		10.7	7.2	13.6	5.4
	11.7	14.3	5.3	10.2		-0.3	7.4	5.7	14.7
	18.2	14.5	15.6	12.4		12.4	10.4	11.9	18.3
	17.7	18.8	26.4	23.2		18.8	20.6	24.5	25.1
	22.3	22.9	25.1	26.1		25.4	22.6	23.4	24.2
	29.6	29.2	29.5	29.7		25.8	25.2	29.3	28.3
	28.8	30.1	31.9	31.8		27.0	25.1	26.7	30.9
	33.3	26.3	28.1	24.9		26.5	27.0	26.1	21.1
	30.1	27.4	22.8	23.5		25.1	23.0	19.2	19.5
	22.8	18.4	16.9	14.4		20.5	18.4	14.6	10.2
	9.1	11.9	8.0	5.5		9.8	10.9	9.5	12.8
	6.2	3.1	5.1	7.9		5.8	2.9	5.1	-0.3
1957	4.5	-0.1	2.8	-2.4	1963	5.4	-1.3	-1.9	-6.1
	2.1	9.7	9.1	5.5		3.3	5.2	2.5	5.9
	7.2	8.6	11.1	7.4		8.4	7.6	11.6	14.3
	11.3	11.8	8.1	18.1		19.2	15.7	18.0	23.5
	17.7	19.0	18.8	21.3		16.9	18.7	25.2	22.3
	19.8	19.7	24.7	26.4		19.0	22.4	26.6	26.4
	22.6	25.5	28.3	29.8		24.6	27.7	29.7	25.7
	29.3	29.8	28.8	25.5		30.2	28.4	28.6	29.3
	27.0	27.0	28.8	23.3		25.0	27.4	27.7	26.6
	20.9	20.8	18.7	20.6		23.9	24.1	19.9	21.0
	15.3	14.0	8.5	13.1		22.4	21.9	20.8	13.3
	8.1	9.9	4.7	5.2		14.8	10.7	8.9	6.1
	8.9	4.9	10.6	5.2		7.0	-3.4	-6.2	1.9
1958	2.4	6.4	4.3	2.8	1964	5.7	-0.8	5.7	9.3
	3.1	-2.4	-3.7	9.4		8.8	4.4	5.3	3.3
	5.1	5.9	2.1	6.9		7.6	6.6	11.2	8.1
	9.3	13.9	10.6	17.4		8.3	15.8	15.8	20.8
	16.4	16.5	18.9	20.3		19.8	21.8	19.8	21.7
	24.3	27.0	29.2	28.3		25.6	17.0	24.6	26.2
	23.9	22.8	25.4	27.6		28.4	25.5	30.5	27.7
	28.2	27.8	28.3	28.0		29.7	30.8	31.7	29.5
	26.7	24.4	27.7	26.6		23.4	25.9	26.7	28.0
	21.2	21.9	21.2	17.4		21.5	21.9	17.8	15.3
	19.8	20.7	14.0	12.4		13.9	16.0	16.6	18.9
	13.4	15.4	9.1	4.5		17.0	14.2	3.8	4.8
	3.6	-3.7	8.1	4.1		-0.3	5.6	0.3	9.0

TABLE LXV (Continued)

1965	9.1	2.6	3.2	5.1	1969	0.8	1.9	7.7	3.9
	-0.8	7.4	3.3	2.8		1.8	7.4	1.6	4.1
	6.4	4.3	7.3	1.3		5.3	0.0	2.8	10.7
	10.2	19.8	19.1	20.4		5.8	16.3	16.1	15.2
	16.4	21.6	19.8	21.4		14.3	19.4	17.2	18.7
	22.2	22.7	24.1	23.7		21.1	23.1	21.7	20.5
	24.7	26.7	27.2	28.8		29.4	27.2	24.8	27.3
	28.9	23.7	25.7	26.5		25.3	28.7	29.8	31.3
	27.4	28.0	24.8	27.0		25.4	25.8	25.5	25.5
	27.6	20.6	18.2	15.9		23.1	20.6	21.8	21.2
	17.9	18.6	12.3	15.0		14.3	12.3	10.8	7.0
	14.8	13.6	12.8	7.5		13.3	9.3	6.7	4.8
	10.9	8.4	6.3	7.4		4.5	4.7	5.1	0.5
1966	6.0	5.9	-0.5	-4.5	1970	-3.8	-4.7	-4.2	4.4
	-5.4	9.2	2.4	1.3		1.6	7.5	3.2	5.5
	7.7	7.4	13.7	12.3		11.4	8.4	1.1	6.7
	12.7	12.1	13.2	13.8		4.9	9.7	14.8	15.5
	15.2	14.5	17.0	21.1		19.6	16.9	23.2	20.3
	20.2	22.8	23.7	25.4		22.9	20.8	21.1	27.4
	24.6	28.0	29.2	31.2		25.5	27.4	28.2	28.2
	20.2	28.0	26.5	26.1		25.2	25.1	30.2	29.3
	29.4	22.0	24.1	23.4		28.8	25.1	27.1	28.8
	20.8	18.5	21.2	19.4		23.5	22.8	16.4	20.3
	20.6	11.1	14.4	8.7		11.4	9.9	15.1	7.4
	14.3	13.9	17.7	5.2		9.5	4.5	4.7	10.4
	9.6	1.7	5.5	-3.9		8.1	4.6	4.8	0.7
1967	3.0	2.4	3.6	9.7	1971	-1.4	0.1	-0.1	3.7
	7.8	3.9	5.8	1.3		3.0	-2.8	4.5	1.8
	12.9	8.8	11.2	15.5		2.8	6.1	12.8	5.9
	10.5	21.8	19.1	18.4		12.4	9.2	17.2	18.8
	14.9	16.1	18.9	19.5		16.3	16.7	16.2	19.1
	20.8	20.6	24.7	25.1		20.4	20.9	24.4	24.5
	25.8	25.1	23.5	25.6		26.3	27.3	27.2	29.9
	23.2	28.2	27.4	25.1		27.4	25.1	21.3	24.9
	24.2	23.9	22.9	20.4		25.5	27.6	25.2	27.6
	22.8	23.9	18.4	23.7		24.0	13.1	22.0	19.4
	16.6	14.8	15.4	7.6		16.1	18.6	15.4	11.5
	9.8	12.3	9.2	6.2		7.8	15.6	5.6	5.6
	8.1	2.6	6.9	0.1		3.7	5.8	4.2	9.2
1968	-4.5	-1.9	6.2	10.3	1972	-0.6	4.8	0.5	-0.3
	9.1	4.4	0.0	2.9		-3.1	1.8	3.9	8.0
	5.1	11.6	11.1	7.2		8.6	10.6	14.6	13.0
	17.8	12.7	16.4	18.6		8.2	13.8	22.3	17.7
	14.8	19.8	17.0	13.5		14.1	15.8	16.0	21.5
	18.3	20.7	24.9	25.3		22.9	21.8	26.3	25.2
	25.3	25.1	22.7	26.5		23.9	28.4	22.0	27.2
	27.8	29.1	29.5	29.4		27.8	29.6	27.7	25.2
	27.3	28.4	22.4	22.1		28.0	26.2	22.7	22.7
	20.3	24.1	20.5	18.3		26.2	24.6	21.1	18.5
	10.4	17.5	12.9	15.1		20.8	13.6	9.9	8.4
	7.3	8.6	8.3	5.8		10.6	5.0	1.9	4.4
	3.4	3.9	4.4	0.3		-3.4	-6.7	4.1	5.0

APPENDIX D

RAINFALL, PAN EVAPORATION, AND TEMPERATURE DATA FOR THE STILLWATER ENVIRONMENTAL WATERSHED

TABLE LXVI

OBSERVED MONTHLY RAINFALL FOR STILLWATER
ENVIRONMENTAL WATERSHED, mm

Year / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	15.2	29.7	52.6	52.8	257.0	29.5	98.6	53.6	57.2	37.3	34.3	7.1	724.9
1978	24.9	63.2	34.0	25.4	134.4	105.4	37.3	58.4	32.5	58.4	92.7	11.4	678.0
1979*	37.8	8.9	96.5	52.8	124.0	131.6	148.1	73.7	38.1	36.8	--	--	748.3
TOTAL	77.9	101.8	183.1	131.0	515.4	266.5	284.0	185.7	127.8	132.5	127.0	18.5	2151.2
MEAN	26.0	33.9	61.0	43.7	171.8	88.8	94.7	61.9	42.6	44.2	63.5	9.2	717.1

*January - October, 1979

TABLE LXVII

PAN EVAPORATION DATA IN WEEKLY AVERAGES IN MILLIMETERS FOR THE PERIOD OF 1977 TO 1979 FOR THE STILLWATER ENVIRONMENTAL WATERSHED

1977	1.0	1.8	1.3	1.3
	1.8	1.5	1.5	1.8
	3.0	6.3	5.1	6.3
	4.3	6.6	7.9	3.3
	6.6	5.8	6.3	5.8
	7.1	6.3	7.5	7.9
	6.6	8.4	8.9	12.4
	10.2	7.4	7.4	7.9
	4.8	6.6	5.8	5.5
	3.3	6.1	5.1	3.0
	4.5	4.1	3.0	2.3
	3.8	1.5	4.1	3.3
	3.8	1.5	1.8	2.3
1978	0.8	0.3	0.2	0.3
	0.2	0.5	0.3	1.3
	0.5	1.7	2.6	2.5
	5.2	4.6	5.7	5.1
	6.6	3.0	6.6	6.1
	6.7	6.5	5.6	8.0
	6.5	10.2	9.9	11.5
	10.6	8.2	7.2	7.6
	14.0	9.8	8.5	7.6
	6.8	8.7	4.2	7.5
	6.3	5.7	4.3	4.0
	3.2	1.1	1.4	2.2
	3.7	2.4	2.3	2.4
1979	0.0	0.4	0.7	0.4
	0.2	0.6	0.7	1.7
	2.4	3.4	3.4	3.3
	3.8	4.3	5.4	5.3
	4.8	5.5	6.6	7.0
	5.3	5.2	3.6	7.9
	6.7	5.4	7.3	7.3
	5.3	6.1	7.5	9.8
	7.4	6.3	6.7	9.0
	5.4	4.7	5.5	3.3
	7.4	3.8	3.6	3.0

TABLE LXVIII

TEMPERATURE DATA IN WEEKLY AVERAGES OF DAILY MEANS IN DEGREES CELSIUS FOR THE PERIOD OF 1977 TO 1979 FOR THE STILLWATER ENVIRONMENTAL WATERSHED

1977	-3.1	-5.7	-1.9	1.1
	2.3	5.9	6.1	10.1
	5.2	11.7	12.4	11.9
	12.4	15.0	19.3	15.9
	18.0	21.7	20.0	21.0
	22.7	24.3	25.9	26.7
	25.9	26.6	27.5	29.8
	28.8	28.4	27.6	27.7
	24.9	27.8	25.6	23.9
	22.2	23.9	24.6	16.1
	13.5	18.0	18.0	15.5
	9.8	13.8	6.0	3.5
	-1.2	9.5	4.9	1.2
1978	1.3	-5.2	-7.2	-4.1
	-3.5	-3.4	-5.0	-1.1
	-0.7	5.8	9.4	12.0
	16.5	20.7	16.5	14.9
	15.6	13.3	18.3	20.8
	22.9	21.7	21.4	25.0
	24.2	28.8	30.1	30.8
	30.3	27.9	28.3	27.8
	28.9	29.3	24.9	27.1
	23.3	22.2	25.6	16.9
	17.6	15.9	14.0	15.5
	11.6	4.6	7.9	5.1
	-1.1	4.4	6.7	-0.9
1979	-10.1	-6.1	1.4	-3.9
	-7.4	-5.7	-2.6	4.0
	7.3	8.1	10.0	9.7
	12.2	10.7	16.2	17.2
	13.8	15.3	17.8	22.4
	18.4	20.1	22.2	25.1
	7.9	26.3	26.4	27.4
	23.8	27.7	26.7	27.2
	29.3	24.0	25.4	24.4
	19.9	10.9	23.4	18.7
	16.7	21.4	14.8	9.7

VITA

Richard Lee Bengtson

Candidate for the Degree of

Doctor of Philosophy

Dissertation: PREDICTING STORM RUNOFF FROM SMALL GRASSLAND WATERSHEDS WITH THE USDAHL HYDROLOGIC MODEL

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Clinton, Iowa, son of Mr. and Mrs. Robert E. Bengtson.

Education: Graduated from Fremont County Vocational High School, Lander, Wyoming, in 1961; received Bachelor of Science degree in Agricultural Engineering from the University of Wyoming, Laramie, Wyoming, in 1966; received the Master of Science degree in Agricultural Engineering from the University of Illinois, Urbana, Illinois, in 1967; completed the requirements for the Doctor of Philosophy degree from Oklahoma State University in May, 1980.

Professional Experience: Served as a graduate research assistant at the University of Illinois from February, 1966, to June, 1967; served as field artillery officer for the U.S. Army from July, 1967, to December, 1976; conducted research for U.S. Army Combat Developments Command from August, 1970, to August, 1972; served as a graduate research associate at Oklahoma State University from January, 1977, to December, 1979.

Professional Organizations: Member of the American Society of Agricultural Engineers.