SELECTION OF INITIAL SOIL MOISTURE ACCOUNTING PARAMETERS FROM SOIL PROPERTIES FOR A CONCEPTUAL RUNOFF MODEL

By

BOBBY LLOYD ARMSTRONG

Bachelor of Science

Midwestern University

Wichita Falls, Texas

1959

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1977

SELECTION OF INITIAL SOIL MOISTURE ACCOUNTING

PARAMETERS FROM SOIL PROPERTIES FOR A

CONCEPTUAL RUNOFF MODEL

Thesis Approved:

Richard N. DeVries
Thesis Adviser

Don F. Kincannon

Marcia Headstream

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

Time and financial support for this thesis was made available to me by my employer, the National Weather Service. I am grateful to Mr. Victor W. Hoffman, Hydrologist in Charge, who provided encouragement during my basic research in relating physical parameters to a rainfall-runoff system while I was assigned to the Fort Worth River Forecast Center. I also would like to thank Mr. John M. Yates, Hydrologist in Charge of the Tulsa River Forecast Center whose support made this thesis possible.

Appreciation is expressed to Dr. Richard N. DeVries, my major adviser, for his invaluable assistance in the preparation of the final manuscript.

Finally, special gratitude is expressed to my wife, Sue, for her understanding and encouragement.

TABLE OF CONTENTS

Chapter — Page

I. INTRODUCTION 1

Background 1
Objectives 5

II. REVIEW OF LITERATURE 7

III. INITIAL PARAMETER DERIVATION COMPONENTS 9

SCS Soil Survey Estimated Engineering Properties . . . 9
NWSRFS Soil Moisture Accounting Parameters 12
Description 12
Interrelation 15

IV. DERIVATION OF EQUATIONS TO COMPUTE SOIL MOISTURE PARAMETERS 19

V. BASIN APPLICATION 31

Council Creek Verification Program Output 38

VI. CONCLUSION 65

Recommendation for Future Work 66

SELECTED BIBLIOGRAPHY 67

APPENDIX 69

LIST OF TABLES

Table		Page
I.	SCS Infiltration Rates	10
II.	Specific Yields	25
III.	Coefficients of Permeability	26
IV.	Percolation Exponents	28
V.	Renfrow Estimated Engineering Soil Properties	33
VI.	Zaneis Estimated Engineering Soil Properties	34
VII.	Vernon Estimated Engineering Soil Properties	35

LIST OF FIGURES

Figure		Page
1.	Flow Diagram of NWSRFS Catchment Model	4
2.	Daily Percolation Rate Curve	17
3.	Soil Survey Interpretation	20
4.	Test Basin Map	32

NOMENCLATURE

AD	Total area of "D" Classification soils (mi^2)
ADIMC	Additional impervious contents (mm)
ADIMP	Additional impervious parameter (%)
AWC	Available water capacity (in/in)
BA	Total basin area (mi^2)
CFS	Cubic feet per second
D	Average distance from edge of basin to nearest stream (ft)
DEFR	Lower zone soil moisture deficiency (%)
I	Infiltration (in/hr)
IA	Impervious area (mi^2)
KI	Coefficient for saturated area along the stream
Kp	Coefficient of permeability (gpd/ft^2)
LTCST	Lower tension water computed soil thickness (in)
LZDEFR	Lower zone soil moisture deficiency (%)
LZFPC	Lower zone primary contents (mm)
LZFSC	Lower zone supplemental contents (mm)
LZFPM	Lower zone primary maximum (mm)
LZFSM	Lower zone supplemental maximum (mm)
LZP	Permeability of LZFSM Zone (in/hr)
LZPK	Lower zone primary drainage rate (%/day)
LZSK	Lower zone supplemental drainage rate (%)
LZT	Lower zone primary thickness (in)
LZTWC	Lower zone tension water contents (mm)

LZTWM	Lower zone tension water maximum (mm)
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
P	Permeability (in/hr)
PBASE	Maximum flow lower free water zones will produce (mm/day)
PCTIM	Percent impervious (%)
PFREE	Percolation water percentage to lower free water zones (%)
RA	Area of riparian vegetation (mi^2)
REXP	Percolation exponents
RSERV	Lower free water reserved (%)
RZV	Renfrow-Zaneis-Vernon soil association
SA	Average surface area of the stream (mi^2)
SARVA	Fraction of basin covered by water and riparian vegetation (%)
SCS	Soil Conservation Service
SCST	Supplemental computed soil thicknes (in)
SIDE	Ratio of unobserved to observed baseflow (%)
SSOUT	Flow lost from the total channel flow (m^3/sec)
TSPT	Total soil profile thickness (in)
UCST	Upper computed soil thickness (in)
USDA	United States Department of Agriculture
USFWC	Upper zone free water contents (mm)
UZFWM	Upper zone free water maximum (mm)
UZK	Upper zone drainage rate (%)
UZP	Permeability of UZFWM zone (in/hr)
UZTWC	Upper zone tension water contents (mm)
UZTWM	Upper zone tension water maximum (mm)
ZPERC	Percolation factor (%)

CHAPTER I

INTRODUCTION

Background

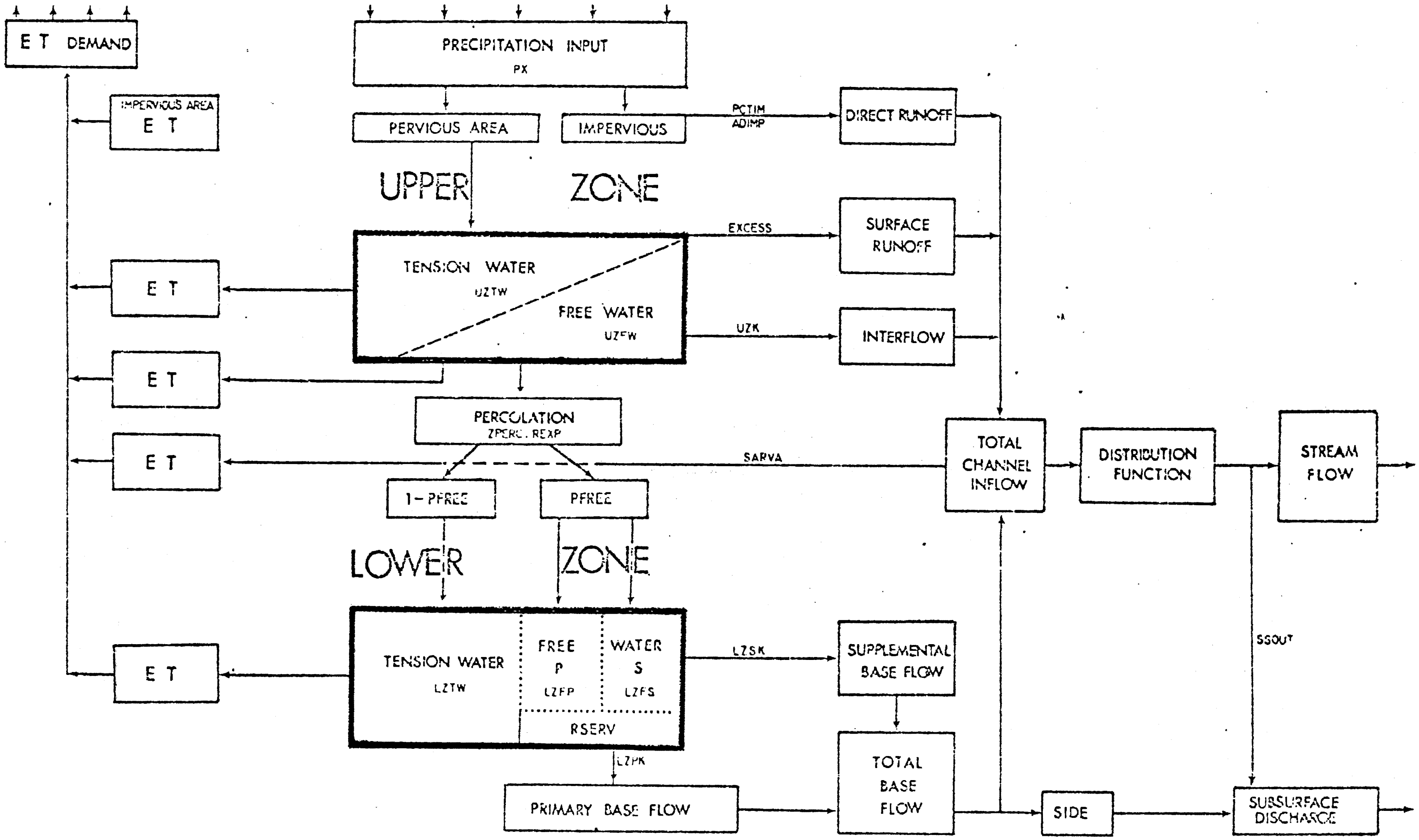
The most basic and probably the most important component of a river forecasting procedure is the rainfall-runoff relation which converts precipitation amounts to the volume of water observed in the stream channel. The maximum benefits derived from an accurate river forecast that predicts flooding is when the time between forecast issuance and flood is the greatest since this gives the maximum reaction time to take protective measures to save lives and property. A good rainfall-runoff relation will provide the maximum possible benefit since it will be possible to issue a forecast as soon as the rainfall is observed and reported. If it is necessary to adjust the forecast hydrograph by the use of observed river stages, the reaction time can be greatly reduced.

A number of methods have been developed to convert rainfall to runoff. The philosophy to use the simplest procedure that would give good results has often been followed especially before the widespread use of computers. Operational rainfall-runoff relations ranged from a procedure that would give runoff as a percentage of rainfall to coaxial relationships which would include such input as week of the year, duration of rainfall, antecedent precipitation index and amount of rainfall.

Runoff values derived from soil moisture models which are conceptual in nature relate to actual processes in nature. They are designed to reproduce all components of flow and generate continuous hydrographs. Models of this type are complex and use a considerable number of parameters. The parameters can be approximated from hydrographs or from observed basin characteristics. By the use of soil moisture models, forecasts not only for floods can be prepared, but also water quality, water supply and soil moisture levels for agriculture to name a few. Parameters to forecast a basin are usually developed by computer programs that analyze a given past period of record with a given set of soil moisture accounting parameters. The basis of the approach is that the past responses of the river is a key to future responses. It is very important that a full range of soil moisture conditions be observed over the selected period of past record which usually has a duration of several years. After a simulated hydrograph set is produced from the initially selected parameters, it is compared to the observed hydrograph set. Differences between the hydrograph sets are noted and manual changes are made in the soil moisture accounting parameters to improve the correlation and then another computer run is made with revised parameters. This procedure is complex and must be repeated many times until an optimum fit between the observed and simulated hydrographs is obtained. Obviously, the closer that the initial parameters are to the optimum, the quicker the basin can be modeled. Hence, computer time and many man-hours are saved. Also, if all the initial parameters are realistic, there is a greater probability that all of the optimum parameters will be conceptually correct. Modeling of a basin not only consists of changes in the soil moisture accounting parameters, but also may include the histogram, routing, evapotranspiration and precipitation.

The United States National Weather Service (NWS) in 1972 developed a river forecast system (NWSRFS) which will be used by their River Forecast Centers in making operational forecasts. The system includes a catchment model which uses a soil moisture accounting system. The original system (7) used a modification of the Stanford Watershed Model IV based on the work of Crawford and Linsley (1966). In 1974 the moisture accounting system used in the NWSRFS was changed to the catchment model developed in the NWS Sacramento, California River Forecast Center by Burnash and Ferral (1973). The system has the proven capability of producing top quality forecasts. The Sacramento system shown in Figure 1 defines two layers, upper and lower, with each layer consisting of free water and tension water storages. A percolation equation which moves water from the upper to lower zone is an important component of the system. A total of 17 soil moisture accounting parameters are used to simulate stream-flow. Many of the parameters are interrelated. To produce a hydrograph the model uses a histogram which can have areal zones assigned to specific histogram elements. Hence, it is possible to select a set of parameters for each areal zone that consists of different hydrologic characteristics. Since the parameters have been developed to simulate high and low flows, the model should perform equally well on streamflows of all magnitudes. The operational use of the model is dependent on the availability of high speed computers since the numerous and time consuming calculations that are performed for each basin could never be done manually on a real-time basis.

Since the modeling of a basin is an extremely time consuming



Source: Peck, Eugene L. Catchment Modeling and Initial Parameter Estimation for the National Weather Service River Forecast System, NOAA Technical Memorandum NWS Hydro-31, U. S. Department of Commerce, 1976.

Figure 1. Flow Diagram of NWSRFS Catchment Model

process and the area to be modeled is extensive, any method to decrease the time spent on each basin would be extremely valuable. One of the best approaches is to obtain a set of initial parameters as conceptually valid as possible. The method to obtain beginning parameters from an observed hydrograph set over a period of record as long as ten years has been used with some success but it has several drawbacks. The hydrograph method is dependent on the lower zones being totally saturated within the selected period of record which rarely occurs in some regions. Also, it is necessary to have streamflow records available to even get started and it is not really possible to deal with discontinuities across the basin. By the development and use of a physical characteristic method, similar basins can be modeled with similar parameters. Hence, the division of gaged basins to conform with definite discontinuities is possible as well as obtaining parameters for basins that are totally ungaged.

The most available source of measurements for a physical characteristic model is the estimated engineering soil properties derived by the United States Soil Conservation Service (SCS). Published soil surveys on a county basis are often available. Soil survey interpretations for specific soils are also available. The most apparent soil properties that are applicable to conceptual models are permeability, available water capacity, infiltration, USDA texture and shrink-swell potential.

Objectives

The objectives of this research is to relate the soil moisture accounting parameters used in the National Weather Service River

Forecast System (NWSRFS) to the engineering soil properties that are readily available in Soil Conservation Service (SCS) soil surveys, to provide a numerical procedure to derive initial soil moisture parameters for use in modeling a basin and to apply a derived parameter set to an actual basin.

In Chapter II the overall theory of the NWSRFS Catchment Model is supported by the hydrologic literature. The work previously done to obtain initial soil moisture accounting parameters is defined. Chapter III defines the SCS soil properties used in the parameter derivations and a description of the soil moisture accounting parameters. Chapter IV presents the equations that have been developed in this research to compute the parameters. Chapter V demonstrates the use of the derived equations and the application of the derived parameters on an actual basin. The computer listing of the NWSRFS Soil Moisture Accounting Subroutine in the Appendix contains the equations used in the computation of runoff increments and the contents of the model zones. Any question on a specific process can be ultimately answered after following it through the computer program. The method described in this thesis should be applicable to any headwater basin.

CHAPTER II

REVIEW OF LITERATURE

Methods of converting rainfall to runoff have changed from single event approaches described by Linsley, Kohler and Paulhus (6) to the present conceptual models that became practical with the advent of modern, high-speed computers. The present soil moisture accounting system used by the National Weather Service in the National Weather Service River Forecast System (NWSRFS) was developed at the Sacramento River Forecast Center in Sacramento, California.

Burnash and Ferral reported on a river forecast system in 1971 which would be developed to represent streamflow in a physically consistent manner. In 1973 Burnash, Ferral and McGuire (1) presented a hydrologic model that gave simplified approximations of natural processes that was consistent with soil moisture profiles determined by experimental studies (3)(4). The system was to correspond with observed characteristics of moisture movement through the soil mantle which included the formation and transmission of the wetting front.

The NWSRFS is basically a two-level model. Todd (11) described soil water zones which included the profile from the surface through the major root zone and an intermediate zone that was the profile from the lower edge of the soil water zone to the upper limit of the capillary zone of the water table. Both zones include capillary, gravitational and hygroscopic water.

Evapotranspiration is limited to the depth that roots will penetrate. George, Read, Johnson and Ferber (2) reported that it had been found in an area of 22.5 inches of annual rainfall that 97.3 percent of the roots of all plants were growing in the upper four feet of soil. Richards and Richards (9) reported that the roots of most plants would not enter wet, saturated soils and that high water tables limit root penetration and even kill roots that had penetrated below the current water table level before it experienced an upward movement. The removal of water from the tension water zones in the NWSRFS conceptual model is accomplished through evapotranspiration. Hence, the zones should be limited to the depth of root penetration.

In 1976 Peck (8) presented a procedure that expanded on the previous method to derive initial parameters from an observed hydrograph set and then applied the parameters to a basin. Four parameters were said to be readily computed, six parameters were considered more difficult to derive, one parameter could be estimated from maps, two parameters would be substituted from a nearby basin and nominal starting values were used for three.

The conceptual model used by the NWSRFS should relate to the engineering soil properties of a basin. The actual use of soil properties in deriving parameters for the model has not been described in the literature.

CHAPTER III

INITIAL PARAMETER DERIVATION COMPONENTS

The Soil Conservation Service (SCS) estimated engineering properties of soils will be used to derive the initial National Weather Service River Forecast System (NWSRFS) soil moisture accounting parameters. All components must be defined and evaluated before a procedure to relate the components will be meaningful.

SCS Soil Survey Estimated Engineering Properties

Soil profiles are divided into layers that are significantly different for purposes of soil engineering. Engineering soil properties are given for each layer.

Soil Texture is given in standard USDA terms. It relates to the relative percentage of sand, loam and clay.

Available Water Capacity (AWC) is defined as the ability of soils to hold water for use by most plants. The value of AWC is considered to be the difference between the amount of water at field capacity and the amount at the wilting point of most crop plants. Units commonly used are inches of water per inch of soil. Hence, a AWC of .17 would mean that .17 of an inch of water would wet the soil to a depth of one inch. AWC values are given in many county soil surveys and soil survey interpretations.

Shrink-Swell Potential is the extent to which the soil shrinks as it dries out and swells when it gets wet. A high shrink-swell potential would greatly reduce the downward movement of water.

Permeability is the quality of a soil that enables it to transmit water or air. Values do not take into account lateral seepage or such transient features as plowpans and surface crusts. Units commonly used are inches of soil that the water moves through per hour.

Infiltration rate is defined as the minimum rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. Infiltration rates are widely used by the SCS in estimating runoff from rainfall for watershed planning. Table I relates soil type to infiltration with the lower limit being used for clays, the average value for loam and the upper limit for sand.

TABLE I

SCS INFILTRATION RATES

Soil Type	Inches of Water per Hour
A	.45-.30
B	.30-.15
C	.15-.05
D	.05-.00

Original SCS classifications were made from rainfall-runoff data obtained from small watersheds or infiltrometer plots. The majority of the soils classified are compared to profiles already classified to determine the soil type. The theory is that similar soils will produce the same amount of runoff during heavy rainfall. Assumptions made in the classification are that the soil surfaces were bare, maximum swelling had taken place and rainfall rates exceeded surface intake rates. The SCS has given group-classification to more than 4000 soils in the United States and Puerto Rico.

Soil type A is defined as soils (low runoff potential) having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained soils or gravels. The soils have a high rate of water transmission. Soil type B is defined as soils (moderately low runoff potential) having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse texture. The soils have a moderate rate of water transmission. Soil type C is defined as soils (moderately high runoff potential) having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes the downward movement of water, soils with moderately fine to fine texture or soils with moderate water tables. The soils are somewhat poorly drained. Soil type D is defined as soils (high runoff potential) having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious materials.

NWSRFS Soil Moisture Accounting Parameters

Description

Percent impervious (PCTIM) is the permanently impervious fraction of the basin contiguous to the stream channel. Man-made impervious areas such as paved parking lots with direct drainage to the stream, areas of impervious rock formation outcrops near the stream and the actual surface area of the stream would be considered to be the basin area to be assigned to PCTIM. This component of runoff referred to as impervious runoff will be produced from a given rainfall regardless of the dryness of the soil and is computed as a percentage of the rainfall. A small rise in the stream following a prolonged dry spell would be composed of PCTIM runoff.

Additional impervious (ADIMP) is the fraction of the basin which becomes impervious as all tension water requirements are met. This parameter relates to an increase of impervious area as the saturated area of the basin increases. A small stream rise after a very wet period and after the upper zones have dried enough to intake additional rainfall would be composed of ADIMP runoff.

Upper zone tension water maximum (UZTWM) is the depth of water that must be filled in the non-impervious area before any water is available to other storages. Water retained as capillary water as well as surface detention would be included in this storage. Since this zone must be filled before there is any response by the stream, a specific amount of rainfall could be computed from rainfall amounts that occurred and did not produce a stream response any greater than the impervious contribution.

Upper zone free water maximum (UZFWM) is the depth of water which would be filled over the nonimpervious portion of the basin in excess of UZTWM. The contents of this zone is made available for interflow after percolation and evaporation requirements are fulfilled. Any overflow of this zone is surface runoff. Derivation of the parameter from a hydrograph set is not feasible. It is usually determined through trial and error.

Drainage rate (UZK) is the upper zone lateral drainage rate that is expressed as the ratio of the daily withdrawal to the available contents of the upper zone free water. The parameter value is related to the length of time after a storm of considerable runoff that interflow occurs. UZK cannot be directly determined from a hydrograph analysis. It has been suggested that a rough estimate of UZK can be determined by the formula:

$$0.10=(1-UZK)^{N} \tag{3.1}$$

N=average number of days that interflow is observed

Lower zone tension water maximum (LZTWM) is the maximum capacity of the lower zone tension water. This parameter is very difficult to extract from the hydrograph set. LZTWM would be the capillary water retained in the lower zone that does not become streamflow but is removed through evapotranspiration. Hence, it represents the water that will be removed by existing plants during dry periods.

Lower zone supplemental maximum (LZFSM) is the maximum capacity of the lower zone free water storage. The flow from the LZFSM zone is the supplemental baseflow and is the faster response component of the baseflow. This parameter may be derived from the hydrograph set if the zone is saturated during the period of record being modeled.

Lower zone supplemental drainage rate (LZSK) is the lateral drainage rate of the lower zone supplemental free water expressed as a fraction of contents per day. LZSK may be derived from the hydrograph set.

Lower zone primary maximum (LZFPM) is the maximum capacity of the lower zone primary free water storage. The flow from the LZFPM zone is the primary baseflow and is the slower response component of the baseflow. This parameter may be derived from the hydrograph set if the lower zone is saturated during the period of record being modeled.

Lower zone primary drainage rate (LZPK) is the lateral drainage rate of the lower zone primary free water expressed as a fraction of contents per day. This parameter may be derived from the hydrograph set. Variations in daily evaporation during baseflow conditions, especially during days of high temperatures, will sometimes cause problems in deriving the rate from the observed baseflow.

PBASE is the maximum flow which the subsurface zones are capable of producing as baseflow. If the lower zones are saturated, PBASE would be the maximum percolation. PBASE, an important component of the percolation equation, is not an input parameter, but is computed from the equation:

$$PBASE=(LZFPM \cdot LZPK + LZFSM \cdot LZSK) \tag{3.2}$$

DEFR is the lower zone soil moisture deficiency. The number, used in the percolation equation, is not an input parameter but is computed from the equation:

$$DEFR = 1-\left(\frac{LZTWC + LZFPC + LZFSC}{LZTWM + LZFPM + LZFSM}\right) \tag{3.3}$$

LZTWC = contents of lower zone tension water

LZFPC = contents of lower zone primary water

LZFSC = contents of lower zone supplemental water

Percolation factor (ZPERC) is a value used to define the proportional increase in percolation from a saturated to a dry condition. The initial value of ZPERC is usually estimated.

Percolation exponent (REXP) determines the rate at which the percolation demand changes from the dry condition to the saturated condition. The initial value of REXP is usually estimated.

Percolation water percentage (PFREE) is the percentage of percolation water which directly enters the lower zone free water without a prior claim by lower zone tension water. If the hydrographs of a basin return quickly to the same baseflow that was present before the rise, a small value of PFREE would be indicated.

Lower free water reserved (RSERV) is the fraction of lower zone free water not available for resupplying lower zone tension water. Initial value is estimated.

SARVA is the fraction of the basin covered by water and riparian vegetation areas.

SIDE is the ratio of unobserved to observed baseflow. Parameter represents the groundwater that does not appear at the river gage. The value is usually zero.

SSOUT is a fixed rate of discharge lost from the total channel flow. The value is usually zero.

Interrelation

The interrelation of parameters in the model greatly increases the complexity of reaching the optimum parameters. A conceptual model that truely relates to nature with the many interactions that take place must contain such an interrelationship. The heart of the conceptual model is the percolation equation and a complete understanding of the equation is important to successfully model a basin. There are eight model parameters that affect the percolation equation and by changing any one of them, the percolation curve (Figure 2) will change. The equation controls the movement of water in both the upper and lower zones and is influenced by the movement of water in all parts of the profile. The parameters directly involved in the formula are LZFPM, LZPK, LZFSM, LZSK, ZPERC, LZTWM, REXP, and UZFWM. The percolation equation is:

$$\text{Daily Percolation Rate} = \text{PBASE}(1+\text{ZPERC}\cdot\text{DEFR}^{\text{REXP}}) \qquad (3.4)$$

The shape of the percolation curve is determined by the REXP parameter which will influence the percolation between zero and 100 percent deficiencies. The maximum percolation will occur at 100 percent deficiency and is defined by the equation:

$$\text{Maximum Percolation Rate} = (1+\text{ZPERC})\cdot\text{PBASE} \qquad (3.5)$$

The minimum percolation occurs at zero deficiency and is equal to PBASE. By determining the value of DEFR (Equation (3.3)) at the beginning of a storm and plotting the point in relation to the percolation curve (Figure 2), the percolation to the lower zones may be increased or decreased to yield the desired amount of runoff necessary to produce the best fit with the observed hydrograph. If the simulated hydrograph crest is too high, the percolation should be increased or if the hydrograph crest is too low, the percolation should be decreased. By increasing or decreasing percolation, the volume of water to be

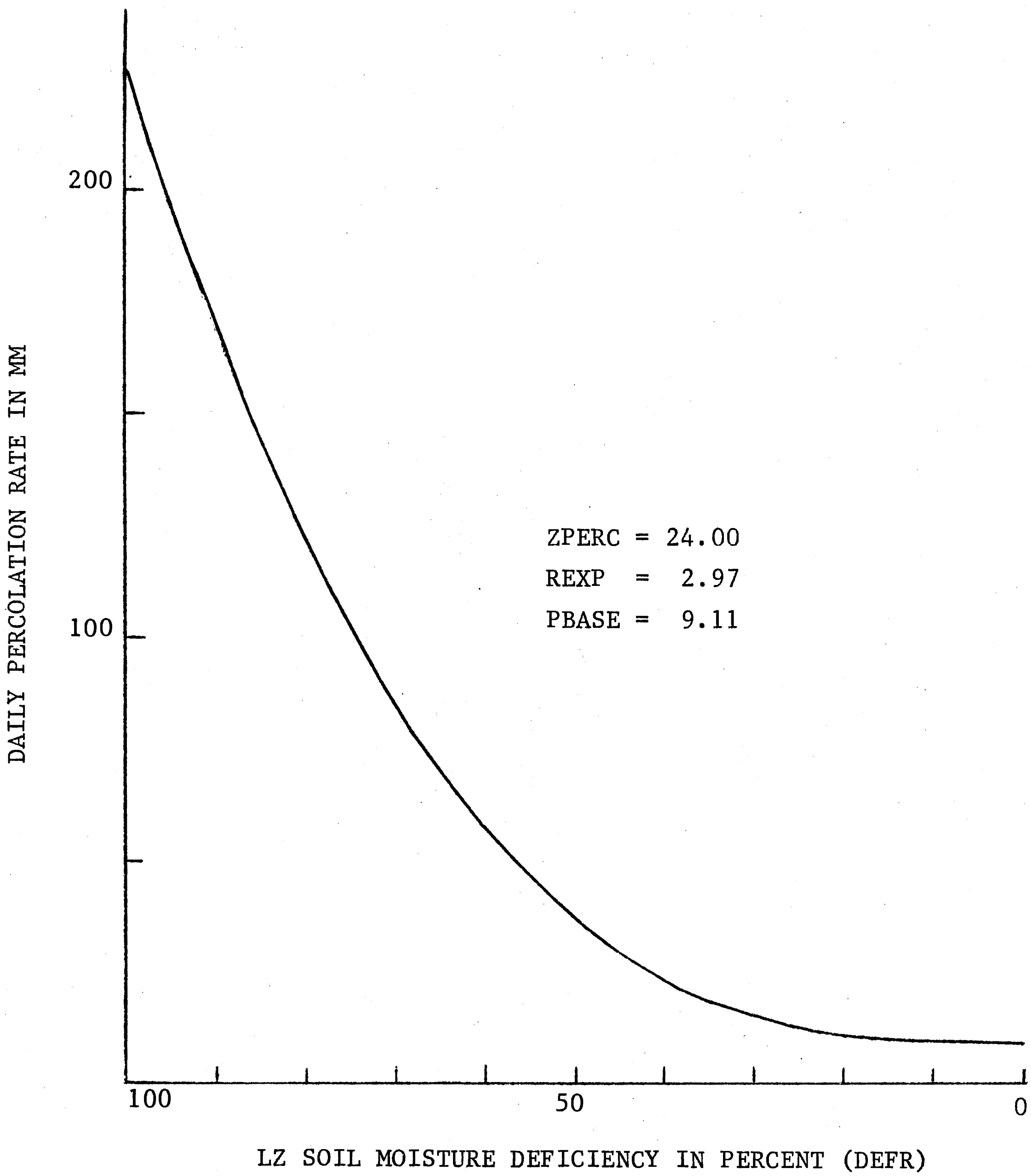


Figure 2. Daily Percolation Rate Curve

dealt with in the lower zones will also be changed. Each hydrograph rise throughout the entire simulation period should in turn be plotted in relation to the percolation curves so a decision can be made as to how the parameters should be changed to produce the best fit with the percolation curve. It is important that a full range of DEFR values be found in the given simulation period since it would be difficult to adjust the curve with values at one extreme or the other. The derivation of the optimum parameters for a basin will depend heavily on the use of the percolation curve.

CHAPTER IV

DERIVATION OF EQUATIONS TO COMPUTE SOIL MOISTURE PARAMETERS

A priority need of the highest order is a method of determining parameter values so that they will be physically consistent between basins and subareas of basins. The goal of a conceptual model is to relate to the physical processes in nature. Hence, a source of physical soil properties must be found that is available for most areas. The source used is the Soil Conservation Service (SCS) engineering soil properties found in their county soil surveys or soil survey interpretations. Figure 3 is an example of the format of a typical soil survey interpretation and shows the information usually presented.

Equations to compute twelve of the seventeen parameters required by the model were developed in this research. The equations and procedures are defined in this chapter. A thirteenth parameter is found by using Table IV. The computed parameters, which are initial values, will not be the optimum because of the obvious variations in nature, the lack of available soil properties for the computational need of each parameter and the probable inability of the model equations to exactly and realistically reproduce every possible flow component. The derivation procedure will attempt to use the measurements readily available in a realistic manner. Since past experiences in engineering are considered in making the estimates, recent SCS county soil surveys

TX0245 **S O I L   S U R V E Y   I N T E R P R E T A T I O N S**

MLRA(S): 78, 80 VERNON SERIES
WER,ERB, 12-73
TYPIC USTOCHREPTS, FINE, MIXED, THERMIC

THE VERNON SERIES CONSISTS OF MODERATELY DEEP, WELL DRAINED NEARLY LEVEL TO STRONGLY SLOPING SOILS OF UPLANDS. THE SOIL FORMED IN CLAYEY SHALE OR CLAY. IN A REPRESENTATIVE PROFILE, THE SURFACE LAYER IS REDDISH BROWN CLAY ABOUT 8 INCHES THICK. THE SUBSOIL IS RED CLAY AND EXTENDS TO A DEPTH OF 21 INCHES. THE SUBSTRATUM IS DARK RED CLAY. SLOPES RANGE FROM 1 TO 12 PERCENT.

ESTIMATED SOIL PROPERTIES (A)

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-8	C	CL, CH	A-6, A-7-6	0	95-100	90-100	90-100	80-95	35-60	20-35
0-8	CL	CL	A-6, A-7-6	0	95-100	90-100	90-100	70-95	35-55	17-30
8-21	C	CL, CH	A-6, A-7-6	0	95-100	90-100	90-100	80-95	28-60	20-35
21-60	SH-C	CL, CH	A-6, A-7-6	0-5	90-100	85-100	65-100	55-95	30-60	15-38

DEPTH (IN.)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	CORROSIVITY STEEL	CORROSIVITY CONCRETE	EROSION FACTORS K	T	WIND EROD. GROUP
0-8	<0.06	0.10-0.17	7.9-8.4	-	HIGH	HIGH	LOW	.37	2	-
0-8	0.06-0.2	0.12-0.17	7.9-8.4	-	HIGH	HIGH	LOW	.37	2	-
8-21	<0.06	0.10-0.15	7.9-8.4	-	HIGH	HIGH	LOW	.37		
21-60	<0.06	0.00-0.10	7.9-8.4	-	HIGH	HIGH	LOW			

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENTIAL FROST ACTION
NONE			>6.0			-		>40		-		D	-

SANITARY FACILITIES (B)

SEPTIC TANK ABSORPTION FIELDS	SEVERE-PERCS SLOWLY
SEWAGE LAGOON AREAS	0-2%: SLIGHT 2-7%: MODERATE-SLOPE 7+%: SEVERE-SLOPE
SANITARY LANDFILL (TRENCH)	SEVERE-TOO CLAYEY
SANITARY LANDFILL (AREA)	SLIGHT
DAILY COVER FOR LANDFILL	POOR-TOO CLAYEY

COMMUNITY DEVELOPMENT (B)

SHALLOW EXCAVATIONS	SEVERE-TOO CLAYEY
DWELLINGS WITHOUT BASEMENTS	SEVERE-LOW STRENGTH, SHRINK-SWELL
DWELLINGS WITH BASEMENTS	SEVERE-LOW STRENGTH, SHRINK-SWELL
SMALL COMMERCIAL BUILDINGS	SEVERE-LOW STRENGTH, SHRINK-SWELL
LOCAL ROADS AND STREETS	SEVERE-LOW STRENGTH, SHRINK-SWELL

REGIONAL INTERPRETATIONS

SOURCE MATERIAL (B)

ROADFILL	POOR-SHRINK-SWELL, LOW STRENGTH
SAND	UNSUITED
GRAVEL	UNSUITED
TOPSOIL	CL: FAIR-TOO CLAYEY C: POOR-TOO CLAYEY

WATER MANAGEMENT

POND RESERVOIR AREA	SLIGHT
EMBANKMENTS DIKES AND LEVEES	MODERATE-COMPRESSIBLE, LOW STRENGTH, SHRINK-SWELL
EXCAVATED PONDS AQUIFIER FED	SEVERE-NO WATER
DRAINAGE	NOT NEEDED
IRRIGATION	COMPLEX SLOPE, PERCS SLOWLY, DROUGHTY
TERRACES AND DIVERSIONS	COMPLEX SLOPE, PERCS SLOWLY
GRASSED WATERWAYS	DROUGHTY, PERCS SLOWLY, SLOPE

Figure 3. Soil Survey Interpretation

rather than the SCS soil survey interpretations should be used whenever possible. All thicknesses must be converted to millimeters (25.4 mm/in) for use in the available computer programs.

UZTWM by definition is closely related to available water capacity. UZTWM must be filled before any water is available for free water (gravity water) and the water is ultimately removed only through evapotranspiration. Available water capacity is the maximum amount of water held in the soil after gravitational water has drained away and after the rate of downward movement of water has materially decreased. An obvious problem must be resolved before a solution can be determined. The use of a standard thickness was considered but a given zone would obviously not be thick enough for soils of high permeability and not thin enough for soils of very low permeability. Also, the soil profile changes with a subsequent change in permeability so an approach to the problem is apparent. Since the drainage rates used in the model are in daily increments, the permeability (inches per hour) times 24 hours is a logical approach. Exception would be a layer of moderate to high shrink-swell potential within the computed depth. Hence, the zone thickness is the calculated thickness or the depth to a moderate to high shrink-swell potential layer whichever is less. If the computed zone thickness exceeds the depth of the entire soil profile, then the soil profile thickness will be used. If the soil profile or areal coverage consists of soils of different characteristics, the computations must contain the correct percentage of each to obtain an overall correct parameter. The computation equation is:

$$\text{UZTWM} = (25.4)(\text{AWC})(\text{UCST}) \quad (4.1)$$

UZTWM = upper zone tension water maximum (mm)

AWC = available water capacity (in/in)

UCST = upper computed soil thickness (in)

LZTWM is the capillary water retained in the lower zone that is not available to the free water of the lower zones. Water is removed only through evapotranspiration, hence the zone would be restricted to the depth of root penetration. The thickness of the zone is considered to be the soil profile below the upper zone tension water computed depth. If the zone includes a thick clay layer with a high shrink-swell potential, the computed value will tend to be much too high since the total thickness would not be saturated by percolated water. The computation equation is:

$$LZTWM = (25.4)(AWC)(LTCST) \quad (4.2)$$

LZTWM = lower zone tension water maximum (mm)

AWC = available water capacity (in/in)

LTCST = TSPT-UCST

TSPT = total soil profile thickness (in)

UCST = upper computed soil thickness (in)

UZFWM is related to the gravitational water in the soil that drains away after the available water capacity is full. The volume as used in the model must first fill the percolation requirements of the lower zones and than the remaining volume is removed to satisfy the daily interflow requirement. If the water remaining exceeds the capacity of the zone, it is the computed surface runoff. The same UCST as used in the UZTWM is used in the UZFWM equation. The equation to compute UZFWM uses a ratio of the infiltration rate of rainfall to the permeability. If the ratio approaches a value of one, a maximum free water volume for the computed soil thickness would be indicated. A ratio of one or greater would indicate a quick response of interflow and the ratio volume must be set at one in the equation. As the ratio becomes smaller and smaller, the free water in the soil would approach a minimum value. The computation equation is:

$$UZFWM = [25.4][(\frac{I}{P})(UCST)] \qquad (4.3)$$

UZFWM = upper zone free water maximum (mm)

I = infiltration (inches of water/hour)

P = permeability (movement of water through inches of soil/hour)

UCST = upper computed soil thickness (in)

A range of values are usually given for permeability. The smallest value is used for a high shrink-swell potential and the largest value for a low shrink-swell potential.

UZK must be derived from parameters that indicate vertical flow rather than lateral flow so a relationship must be attempted. The daily daily volume of interflow will be equal to water present in the upper zone free water times UZK. Hence, a value of UZK that is larger than the actual will tend to give a large component of interflow and decrease surface runoff. The ratio of infiltration to permeability was used since the larger the value, the larger the component of interflow. The value of UZK computed would tend to be the maximum to be expected, so the value should never be greater than one. The computation equation is:

$$UZK = \frac{\text{infiltration}}{\text{permeability}} \qquad (4.4)$$

UZK = upper zone drainage rate (%)

LZFSM in a number of basins has had a value similar or equal to

UZFWM and the same approach should be used. The thickness (SCST) should be computed by multiplying the permeability from the computed UCST downward by 24 hours or the thickness to a higher shrink-swell potential layer whichever is less. The computation equation is:

$$LZFSM = [25.4][(\frac{\text{infiltration}}{\text{permeability}})(SCST)] \tag{4.5}$$

LZFSM = lower zone supplemental maximum (mm)

SCST = supplemental computed soil thickness (in)

LZSK is the daily lateral drainage rate from the LZFSM zone that produces a component of baseflow in the stream. The flow has been defined as having a source of flow different from the primary flow and is observed on the hydrograph as the recession immediately following the surface runoff and the interflow. The LZFSM flow could be visualized as the flow that would emerge through the surface zone as the upper zone volume was depleted. This would give the necessary lag to the flow and would be most logical if the supplemental zone was limited by a moderate to high shrink-swell zone. By definition the upper zone is considered to be depleted when the capacity has decreased to ten percent of the maximum. Hence, a constant to relate to the upper zone depletion and the subsequent flow from the lower zone can be found. The computation equation is:

$$LZSK = \frac{UZK}{1.9 + (.9)(\frac{UZP}{LZP})} \tag{4.6}$$

LZSK = lower zone supplemental drainage rate (%)

UZP = permeability of UZFWM zone (in/hr)

LZP = permeability of LZFSM zone (in/hr)

LZFPM is the zone that supplies the volume for baseflow in the stream. Since the interrelationship of all the natural processes is very complex, a logical approach to the maximum volume in the zone is needed. If a high water table level is to remain constant there must be a balance between inflow and outflow of the aquifer. Specific yield is the ratio of water which will drain freely from the material to the total volume of the formation. The specific yield (6) of clay is 3% and sand is 25%. Table II was developed by interpolating the values. An approach will be taken that the lower zone storage is equal to the specific yield of the lower zone thickness. The layer thickness for LZFPM is the total soil profile minus the upper zone and supplemental zone thicknesses. The computation equation is:

$$LZFPM = [25.4][(LZT)(\text{specific yield})] \tag{4.7}$$

LZFPM = lower zone primary maximum (mm)

LZT = TSPT - UCST - SCST

LZT = lower zone primary thickness (in)

TSPT = total soil profile thickness (in)

UCST = upper computed soil thickness (in)

SCST = supplemental computed soil thickness (in)

TABLE II

SPECIFIC YIELDS

Soil Classification	Specific yield (%)
Clay	3
Silt loam	9
Loam	14
Sandy loam	20
Sand	25

LZPK is a parameter that through definition will be computed with difficulty from the soil properties available. In areas of a relatively shallow soil profile the lateral drainage rate is related to the coefficient of permeability (Kp) which is defined (6) as the discharge in gallons per day through an area of one square foot under a gradient of one foot per foot at 60°F. By considering LZT the aquifer thickness, the lateral rate of flow may be determined. Table III was developed by interpolating the coefficients of permeability (12) for clay and sand.

TABLE III

COEFFICIENTS OF PERMEABILITY

Soil Classification	Kp (gpd/sq.ft.)
Clay	2
Silty loam	750
Loam	1500
Sandy loam	2250
Sand	3000

LZPK is computed by determining the ratio of the coefficient of permeability to the average distance from the edge of the basin to the nearest tributary of the stream. The soil classification can be determined from the soil profile and the correct Kp value selected. It has been noted that the LZPK computed by the developed equation will tend to be the minimum limit. The computational equation is:

$$LZPK = \frac{(Kp)(.134)}{D} \tag{4.8}$$

LZPK = lower zone primary drainage rate (%)

D = average distance from the edge of the basin to the nearest tributary (ft)

Kp = coefficient of permeability (gpd/ft^2)

ZPERC may be calculated from parameters already computed. It should be noted that if any of the five parameters that are used in the equation are unrealistic, the computed ZPERC value may be in error by a rather large amount. The maximum percolation is believed to take place when the upper zones are full and the lower zones are empty. Hence, it will be assumed that the maximum daily percolation will be the maximum contents of the lower zones. By substitution into the maximum percolation rate equation and assuming 100% deficiency in the lower zones, the computation equation is:

$$ZPERC = \frac{LZTWM + LZFSM + LZFPM - PBASE}{PBASE} \tag{4.9}$$

ZPERC = percolation factor (%)

REXP is the exponent determining the rate of change of percolation from a dry condition to a saturated condition of the lower zones. The value of REXP may be related to the soil classification of the soil profile at the base of the upper zone. The minimum permissible REXP value of 1.0 would indicate an almost constant decrease of percolation as the lower zone deficiencies decrease and would relate to a sand. A large REXP would indicate a rapid decrease of percolation as the zones become saturated such as is expected in a clay. REXP values (Table IV) have been developed for each soil classification.

TABLE IV

PERCOLATION EXPONENTS

Soil Classification	REXP
Sand	1.0
Sandy loam	1.5
Loam	2.0
Silty loam	3.0
Clay, silt	4.0

PCTIM is the impervious area of the basin and would obviously consist of the surface area of the stream. Impervious areas of the basin adjacent to the stream such as paved parking lots and possibly urbanized areas should be added. A value of .001 is a good initial value for headwater basins without known impervious areas greater than the surface area of the stream. If the surface area of the stream is known, the computation equation is:

$$PCTIM = KI\left(\frac{SA}{BA}\right) \tag{4.10}$$

PCTIM = percent impervious (%)

KI = 1.10 = coefficient for estimated additional area adjacent to the stream that is saturated at all times

SA = average total surface area of the stream (mi^2)

BA = total basin area (mi^2)

ADIMP is the additional area of the basin that becomes impervious as the tension water requirements are met. It has been suggested (8) that remote sensing techniques using radiation measurements (infrared) could define the area of the basin to be assigned as ADIMP. Since measurements of this type are not readily available, another system has been devised. The soils of the basin with a hydrologic soil classification of "D" have a minimum saturation infiltration value of zero which would indicate an impervious area when saturated. An obvious approach would be to consider the area of "D" soils as the ADIMP area. Since clays have a minimal specific yield of 3%, a value of .03 is subtracted from the "D" soil percentage of the total area.

$$ADIMP = (\frac{AD}{BA}) - .03 \qquad (4.11)$$

ADIMP = additional impervious parameter (%)

AD = total area of "D" soils (mi^2)

BA = total basin area (mi^2)

SARVA provides for the removal of water from the stream by evapotranspiration. If the riparian vegetation area of the basin is not known, an estimate could be made.

$$SARVA = PCTIM + (\frac{RA}{BA-IA}) \qquad (4.12)$$

PCTIM = percent impervious (%)

RA = area of riparian vegetation (mi^2)

BA = total basin area (mi^2)

IA = impervious area (mi^2)

PFREE is the percentage of water that bypasses the lower zone tension water requirements and is placed directly in the lower zone free water. The component apparently is the water that follows paths through fissures, cracks, faults or along an impervious layer to escape the capillary demands of the soil. Since a logical manner of derivation of PFREE is not apparent, a nominal value of .30 is assumed.

RSERV is the fraction of the lower zone free water that is not available for resupplying tension water. Since a logical manner of deriving RSERV is not apparent, a nominal value of .30 is assumed.

SIDE and SSOUT are usually assumed to be zero. If obvious channel losses are evident, a value could be determined from known volume losses.

CHAPTER V

BASIN APPLICATION

A set of parameters will be derived from the developed equations for Council Creek near Stillwater. The parameters for a gaged basin are intended to be the initial soil moisture accounting parameters that will be used in a trial and error computer program to develop the optimum parameters. If a basin is not gaged, the parameters should give adequate results. Optimum parameters developed for another basin with the same engineering soil properties could be used successfully, but it is important that the original parameters be as conceptually correct as possible to avoid proliferating a number game.

Council Creek near Stillwater, Oklahoma, is located in Payne County and is a tributary of the Cimarron River. The area is in the undulating to rolling prairie area of North-Central Oklahoma. The prevailing climate is of continental origin, but relatively temperate. Pronounced seasonal variations in both temperature and precipitation is characteristic of the area. Spring is the season of the heaviest rains with a secondary maximum in early fall. The area averages about 53 thunderstorms per year. Average annual rainfall is 32.5 inches. The basin is in the great grassland area of the United States. Post and blackjack oaks are found on the ridgetops. Trees such as cottonwood, elm and hackberry grown in narrow fringes along the creek.

The Council Creek basin (Figure 4) has a drainage area of 31 square

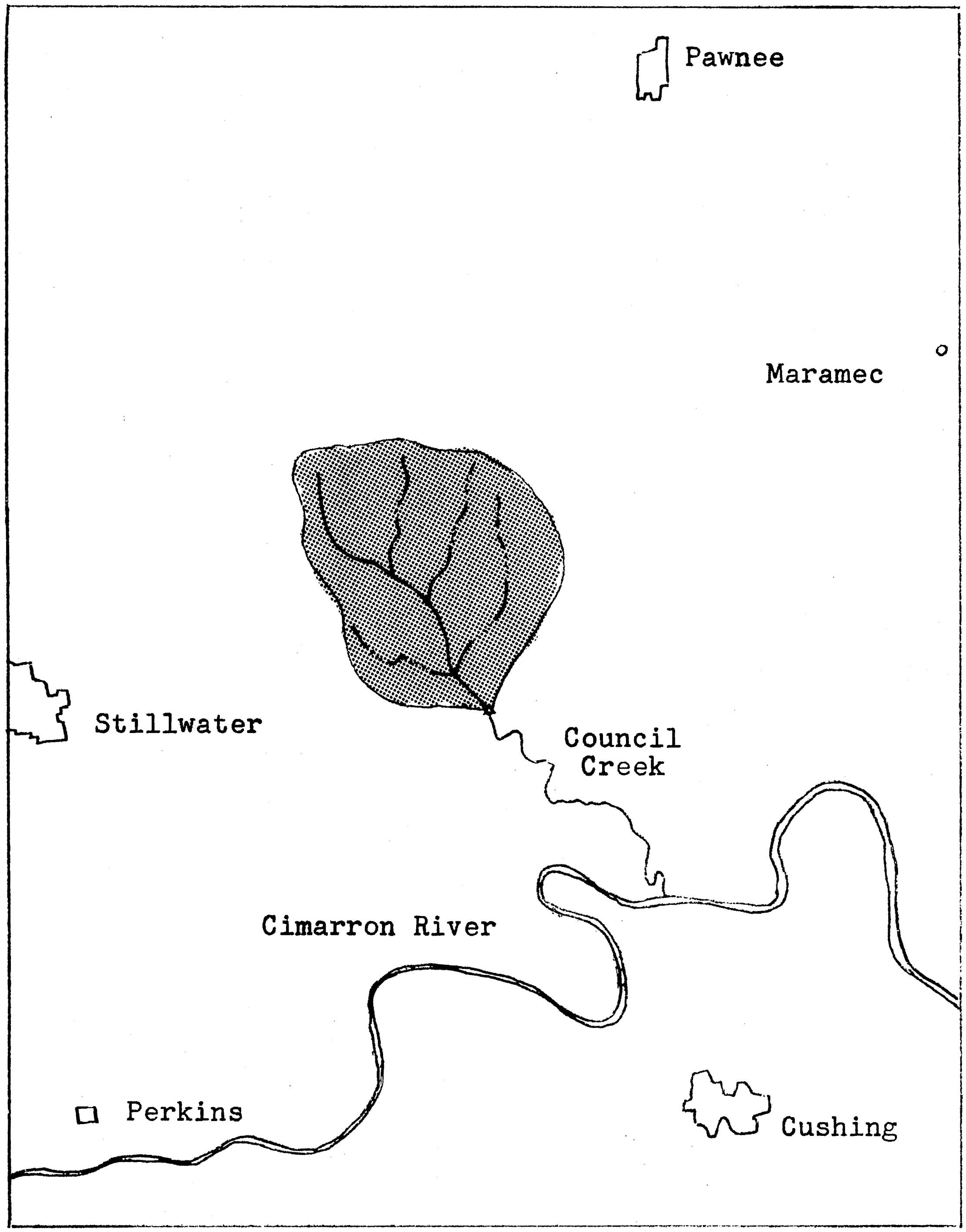


Figure 4. Test Basin Map

miles. The gage is a water-stage recorder with a concrete control. Datum of the gage is 838.28 feet. Bankfull stage is 10 feet, which is a flow of 2200 CFS. On October 2, 1959, a crest of 25000 CFS (18.9 ft.) was observed.

The area is underlain by interbedded sandstone and clay beds. The soils are susceptible to erosion damage and good range management is necessary to prevent damage. The soil association of the basin is the Renfrow-Zaneis-Vernon (RZV). The RZV soils vary from "C" to "D" type, the permeability ranges from a maximum of .50 to a minimum of less than .05 inches per hour, and available water capacity from a minimum of .14 to a maximum .17 inch of water per inch of soil. The variations of the estimated engineering soil properties in the basin should test the efficiency of the derivations. The approximate percentages of soils is 58% Renfrow, 30% Zaneis and 12% Vernon. Parameters will be derived in millimeters for the basin.

The Renfrow series is extensively distributed through central Oklahoma, south central Kansas and north central Texas. Table V is derived from SCS soil survey data.

TABLE V

RENFROW ESTIMATED ENGINEERING SOIL PROPERTIES

Soil Classification D

USDA Texture	Depth (in.)	Permeability (in./hr.)	Available Water Capacity in./in.	Shrink-Swell
Silt loam	0-12	< .05	.14	Low
Clay	12-42	< .05	.17	High

The soil parameter calculations for the Renfrow series are:

upper zone depth = (.03)(24) = .72

$$UZFWM = (25.4)(\frac{.03}{.03})(.72) = 18.29$$

$$UZTWM = (25.4)(.14)(.72) = 2.56$$

supplemental zone depth = (.03)(24) = .72

$$LZFSM = (25.4)(\frac{.03}{.03})(.72) = 18.29$$

$$LZFPM = [25.4][(.09)(10.6) + (.03)(30)] = 47.09$$

$$LZTWM = [25.4][(.14)(11.3) + (.17)(30)] = 169.72$$

$$UZK = (\frac{.03}{.03}) = 1.0$$

$$LZSK = \frac{1.0}{(1.9) + (.9)(1)} = .357$$

$$LZPK = [(\frac{10.6}{40.6})(750) + (\frac{30.0}{40.6})(1)][\frac{.134}{(.6)(5280)}] = .008$$

$$REXP = 3.0$$

The Zaneis soil is distributed extensively through south-central Kansas, central Oklahoma and north central Texas. Table VI is derived from SCS soil survey data.

TABLE VI

ZANEIS ESTIMATED ENGINEERING SOIL PROPERTIES

Soil Classification C

USDA Texture	Depth (in.)	Permeability (in./hr.)	Available Water Capacity in./in.	Shrink-Swell
Loam	0-10	.50	.14	Low
Clay loam	10-47	.50	.17	Moderate

The soil parameter calculations for the Zaneis series are:

upper zone depth = (.50)(24) = 12 since the shrink-swell changes to moderate in the depth, upper zone = 10

$$UZFWM = (25.4)(\frac{.10}{.50})(10) = 50.80$$

$$UZTWM = (25.4)(.14)(10) = 35.56$$

supplemental zone depth = (.50)(24) = 12

$$LZFSM = (25.4)(\frac{.10}{.50})(12) = 60.96$$

$$LZFPM = (25.4)(.09)(25) = 57.15$$

$$LZTWM = (25.4)(.17)(37) = 159.77$$

$$UZK = \frac{.10}{.50} = .20$$

$$LZSK = \frac{.20}{1.9 + (.9)(1)} = .071$$

$$LZPK = \frac{(750)(.134)}{(.6)(5280)} = .0317$$

$$REXP = 2.5$$

The Vernon soil is moderately distributed in west central Texas and western Oklahoma. Table VII is derived from SCS soil survey data.

TABLE VII

VERNON ESTIMATED ENGINEERING SOIL PROPERTIES

Soil Classification D

USDA Texture	Depth (in.)	Permeability (in./hr.)	Available Water Capacity (in./in.)	Shrink-Swell
Clay	0-10	< .05	.17	Moderate-High

The soil parameter calculations for the Vernon series are:

upper zone depth = (.03)(24) = .72

UZFWM = $(25.4)(\frac{.03}{.03})(.72) = 18.29$

UZTWM = (25.4)(.17)(.72) = 3.11

supplemental zone depth = (.03)(24) = .72

LZFSM = $(25.4)(\frac{.03}{.03})(.72) = 18.29$

primary zone depth = 10-.72-.72 = 8.56

LZFPM = (25.4)(.03)(8.6) = 6.55

LZTWM = (25.4)(.17)(9.3) = 40.16

UZK = $\frac{.03}{.03} = 1.00$

LZSK = $\frac{1.00}{1.9 + (.9)(1)} = .357$

LZPK = $\frac{(1)(.134)}{(.6)(5280)} = .00004$

REXP = 4.0

The basin soil moisture accounting parameters may now be calculated with the contribution of each soil type equal to its areal distribution. The basin soil parameters are:

UZFWM = (.58)(18.29) + (.30)(50.80) + (.12)(18.29) = 28.04

UZTWM = (.58)(2.56) + (.30)(35.56) + (.12)(3.11) = 12.52

LZFSM = (.58)(18.29) + (.30)(60.96) + (.12)(18.29) = 31.09

LZFPM = (.58)(47.09) + (.30)(57.15) + (.12)(6.55) = 45.24

LZTWM = (.58)(169.72)+ (.30)(159.77)+ (.12)(40.16) = 151.19

UZK = (.58)(1.00) + (.30)(.20) + (.12)(1.00) = .760

LZSK = (.58)(.357) + (.30)(.071) + (.12)(357) = .271

LZPK = (.58)(.008) + (.30)(.0317) + (.12)(.00004) = .0151

REXP = (.58)(3.0) + (.30)(2.5) + (.12)(4.0) = 2.97

ZPERC = $\frac{31.09 + 45.24 + 151.19 - 9.11}{9.11} = 24$

PBASE = (31.09)(.271) + (45.24)(.0151) = 9.11

ADIMP = .58 + .12 - .03 = .67

NOMINAL VALUES

PFREE = .30

RSERV = .30

SIDE = .00

SSOUT = .00

SARVA = .001

PCTIM = .001

The Verification Program Output for Council Creek shows a comparison between the observed hydrographs represented by a "O" and the simulated hydrographs represented by a "*". The hydrograph sets are printed on the same time base so that they may be easily compared. The simulated and observed flows in cubic feet per second as well as the rainfall in inches is printed on the right hand side of the hydrograph pages for each day. The statistics for the verification run are printed on the last page.

The simulated hydrograph set produced by the derived parameters is an excellent initial run. The parameters derived could be used successfully for the basin if it was not gaged since none of the parameter derivations were dependent on the streamflow records. The number of trial and error computer runs required to obtain an optimum solution should be minimal.

Council Creek Verification Program Output

COUNCIL CREEK NR STILLWATER OKLA

COUNCIL CREEK NEAR STILLWATER OKLA

FLOW-POINT PARAMETERS

NO.	FLOW-POINT NAME	AREA-SQ KM	K	SSOUT	OBSER	COMPAR	SIXIN	HISTOGRAMS			
1	COUNCIL CR	80.30	6.00	0.00	1	1	0	TIME-DELAY	.931	.068	.001
								GAGE AREA	1	1	1

SOIL-MOISTURE ACCOUNTING PARAMETERS   COUNCIL CREEK NR STILLWATER OKLA

COUNCIL CREEK NEAR STILLWATER OKLA

CONTENT AND CAPACITY VALUES ARE IN MM.

UPPER ZONE AND IMPERVIOUS AREA PARAMETERS

AREA NO.	AREA I.D.	AREA NAME	PX-ADJ	PE-ADJ	UZTWM	UZFWM	UZK	PCTIM	ADIMP	SARVA
1	MBP 1	COUNCIL CREEK	1.000	1.000	13.	28.	.760	.001	.670	.001

PERCOLATION AND LOWER ZONE PARAMETERS

AREA NO.	PBASE	ZPERC	REXP	LZTWM	LZFSM	LZFPM	LZSK	LZPK	PFREE	RSERV	SIDE
1	9.1	24.0	2.97	151.	31.	45.	.2710	.0151	.30	.30	0.00

PE-ADJUSTMENT OR ET-DEMAND FOR THE 16TH OF EACH MONTH

AREA NO.		1	2	3	4	5	6	7	8	9	10	11	12	I.D. OF PE DATA
1	PE-ADJUSTMENT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	STILLWATER

INITIAL STORAGE CONTENTS

AREA NO.	UZTWC	UZFWC	LZTWC	LZFSC	LZFPC	ADIMC
1	0.	0.	10.	0.	0.	11.

MEAN DAILY FLOW PLOT COUNCIL CR WATER YEAR 1959 *=SIMULATED O=OBSERVED UNITS-CFSD

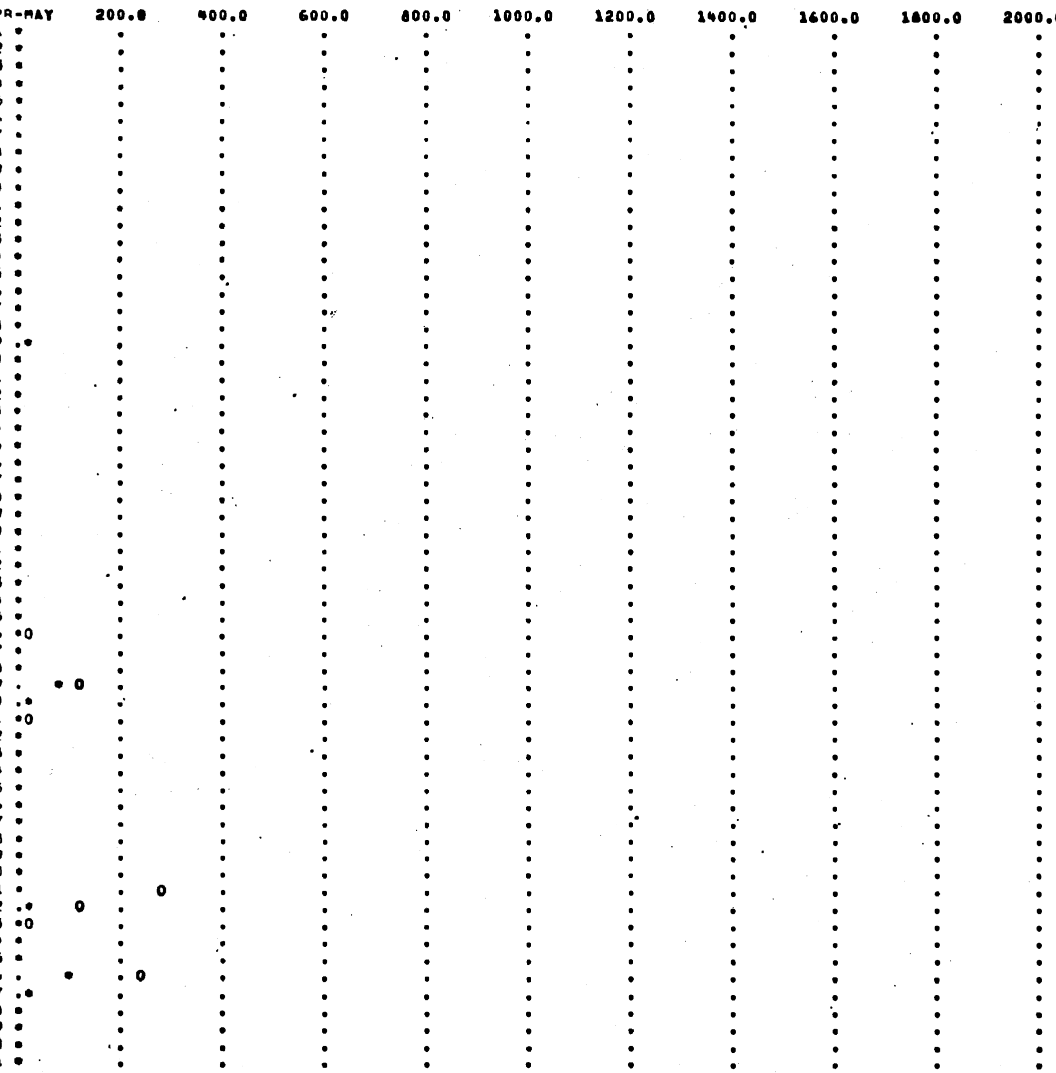
OCT-NOV 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

OCT-NOV	SIM.	OBS.	RAIN+MELT
1	0.0	0.0	.02
2	0.0	0.0	0.00
3	0.0	0.0	0.00
4	0.0	0.0	0.00
5	0.0	0.0	0.00
6	0.0	0.0	0.00
7	0.0	0.0	0.00
8	0.0	0.0	0.00
9	0.0	0.0	0.00
10	0.0	0.0	0.00
11	0.0	0.0	0.00
12	.1	0.0	.28
13	.0	0.0	0.00
14	0.0	0.0	.00
15	.2	0.0	.26
16	.0	0.0	.00
17	0.0	0.0	0.00
18	0.0	0.0	0.00
19	0.0	0.0	0.00
20	0.0	0.0	0.00
21	0.0	0.0	0.00
22	0.0	0.0	0.00
23	0.0	0.0	0.00
24	0.0	0.0	0.00
25	0.0	0.0	0.00
26	0.0	0.0	0.00
27	0.0	0.0	.01
28	0.0	0.0	0.00
29	0.0	0.0	0.00
30	0.0	0.0	0.00
31	0.0	0.0	0.00
1	0.0	0.0	0.00
2	0.0	0.0	0.00
3	0.0	0.0	0.00
4	0.0	0.0	0.00
5	0.0	0.0	0.00
6	0.0	0.0	0.00
7	0.0	0.0	0.00
8	0.0	0.0	0.00
9	0.0	0.0	0.00
10	0.0	0.0	0.00
11	0.0	0.0	0.00
12	0.0	0.0	0.00
13	.1	0.0	.13
14	.0	0.0	.00
15	0.0	0.0	.00
16	.2	.3	.35
17	.8	1.5	.35
18	1.0	.9	0.00
19	1.4	.1	0.00
20	1.1	.1	0.00
21	.8	.1	0.00
22	.6	.1	0.00
23	.4	.1	0.00
24	.3	.1	0.00
25	.3	.1	0.00
26	.2	.1	0.00
27	.2	.1	.09
28	.2	.1	.08
29	.1	.1	0.00
30	.1	.1	0.00

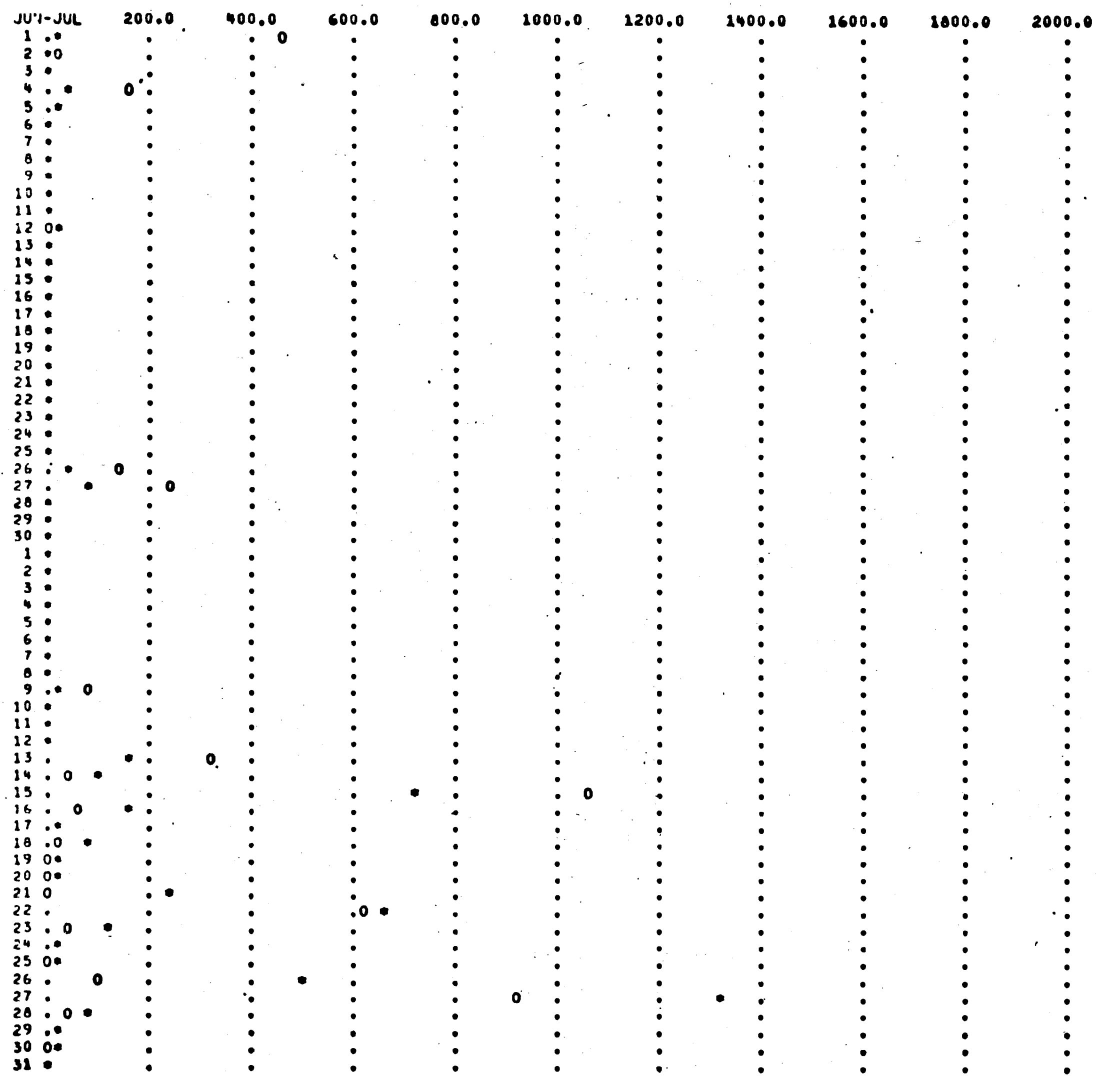
DEC-JAN	200.0	400.0	600.0	800.0	1000.0	1200.0	1400.0	1600.0	1800.0	2000.0	SIM.	OBS.	RAIN+MELT
1 •	.	.	.	.	.	.	.	.	.	.	.1	.1	.03
2 •	.	.	.	.	.	.	.	.	.	.	.1	.1	0.00
3 •	.	.	.	.	.	.	.	.	.	.	.1	.1	0.00
4 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
5 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
6 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
7 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
8 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
9 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
10 •	.	.	.	.	.	.	.	.	.	.	.1	.1	0.00
11 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
12 •	.	.	.	.	.	.	.	.	.	.	.2	.2	.29
13 •	.	.	.	.	.	.	.	.	.	.	.1	.1	.00
14 •	.	.	.	.	.	.	.	.	.	.	.1	.1	0.00
15 •	.	.	.	.	.	.	.	.	.	.	.1	.1	0.00
16 •	.	.	.	.	.	.	.	.	.	.	.0	.1	0.00
17 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
18 •	.	.	.	.	.	.	.	.	.	.	.0	.3	0.00
19 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
20 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
21 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
22 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
23 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
24 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
25 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
26 •	.	.	.	.	.	.	.	.	.	.	.1	.2	.06
27 •	.	.	.	.	.	.	.	.	.	.	.1	.2	0.00
28 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
29 •	.	.	.	.	.	.	.	.	.	.	.1	.2	.06
30 •	.	.	.	.	.	.	.	.	.	.	.2	.3	.25
31 •	.	.	.	.	.	.	.	.	.	.	.2	.6	.09
1 •	.	.	.	.	.	.	.	.	.	.	.0	.5	0.00
2 •	.	.	.	.	.	.	.	.	.	.	.0	.5	0.00
3 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
4 •	.	.	.	.	.	.	.	.	.	.	.1	.1	.03
5 •	.	.	.	.	.	.	.	.	.	.	.0	0.0	0.00
6 •	.	.	.	.	.	.	.	.	.	.	.0	.1	0.00
7 •	.	.	.	.	.	.	.	.	.	.	.0	.5	0.00
8 •	.	.	.	.	.	.	.	.	.	.	.0	.6	0.00
9 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
10 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
11 •	.	.	.	.	.	.	.	.	.	.	.0	.3	0.00
12 •	.	.	.	.	.	.	.	.	.	.	.0	.3	0.00
13 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
14 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
15 •	.	.	.	.	.	.	.	.	.	.	.1	.3	.05
16 •	.	.	.	.	.	.	.	.	.	.	.0	.3	0.00
17 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
18 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
19 •	.	.	.	.	.	.	.	.	.	.	.0	.3	0.00
20 •	.	.	.	.	.	.	.	.	.	.	.1	.4	.05
21 •	.	.	.	.	.	.	.	.	.	.	.1	.4	.03
22 •	.	.	.	.	.	.	.	.	.	.	.0	.2	.00
23 •	.	.	.	.	.	.	.	.	.	.	.0	.2	0.00
24 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
25 •	.	.	.	.	.	.	.	.	.	.	.0	.5	0.00
26 •	.	.	.	.	.	.	.	.	.	.	.0	.5	0.00
27 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
28 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
29 •	.	.	.	.	.	.	.	.	.	.	.0	.3	0.00
30 •	.	.	.	.	.	.	.	.	.	.	.0	.4	0.00
31 •	.	.	.	.	.	.	.	.	.	.	.0	.5	.04

FEB-MAR 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

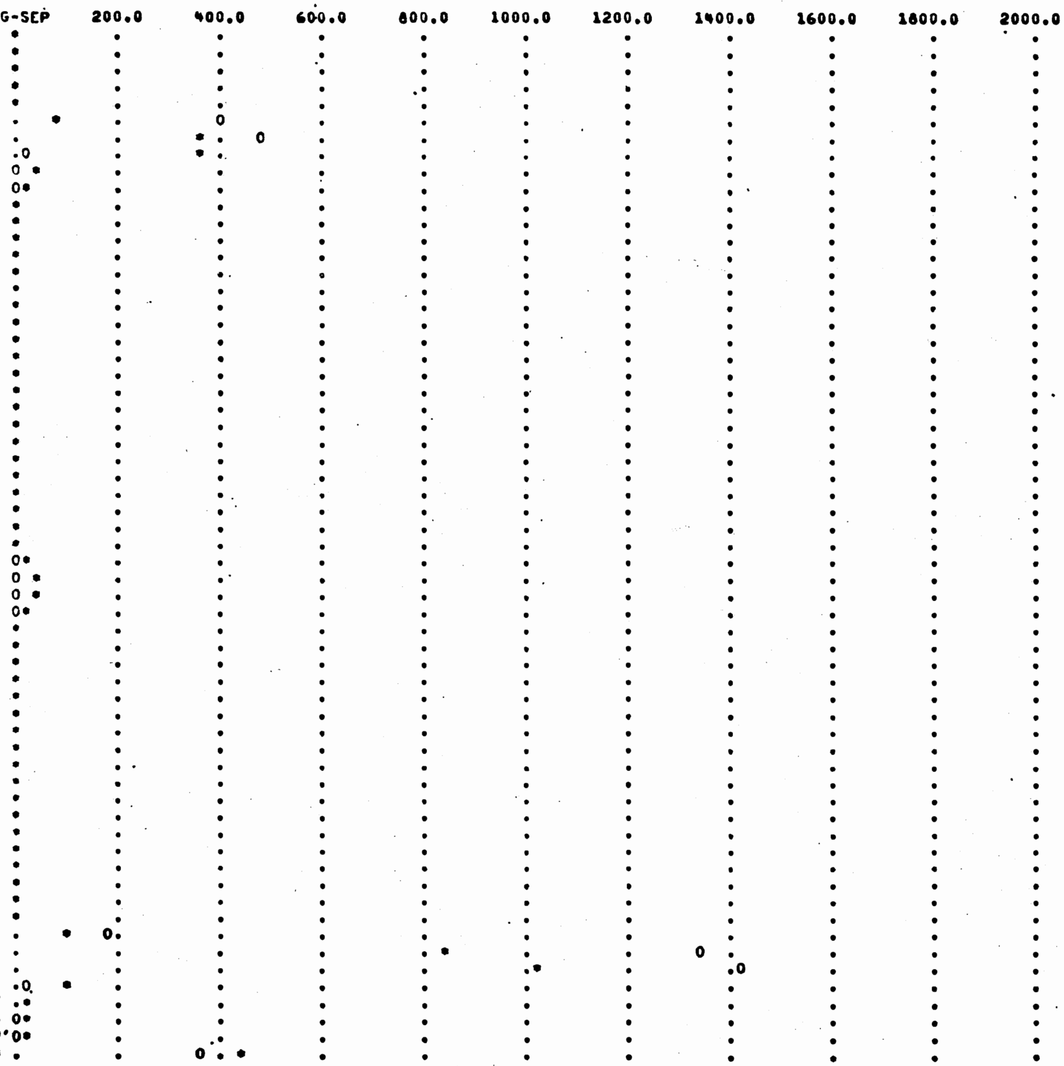
FEB-MAR	Plot	SIM.	OBS.	RAIN+MELT
1	•	.0	.4	0.00
2	•	.0	.4	.00
3	•	.1	.6	.06
4	•	.0	.6	0.00
5	•	.1	.5	.07
6	•	.0	.4	.01
7	•	.0	.4	0.00
8	•	.0	.6	0.00
9	•	.4	1.0	.62
10	•	1.8	1.7	0.00
11	•	1.8	.7	0.00
12	•	1.4	.5	.03
13	•	1.0	.5	0.00
14	•	.8	.5	.00
15	•	.6	.5	0.00
16	•	.5	.5	0.00
17	•	.4	.5	0.00
18	•	.3	.4	0.00
19	•	.3	.4	0.00
20	•	.2	.4	0.00
21	•	.2	.4	0.00
22	•	.2	.5	0.00
23	•	.1	.5	0.00
24	•	.1	.5	0.00
25	•	.1	.5	0.00
26	•	.1	.6	0.00
27	•	.3	.7	.58
28	•	1.2	1.4	.01
1	•	1.1	.7	.00
2	•	.8	.5	0.00
3	•	.6	.3	0.00
4	•	.5	.3	.11
5	•	.7	.9	.20
6	•	.3	1.0	0.00
7	•	.2	.9	0.00
8	•	.2	.6	0.00
9	•	.2	.5	0.00
10	•	.2	.4	0.00
11	•	.1	.4	0.00
12	•	.1	.4	0.00
13	•	.1	.4	0.00
14	•	.1	.4	0.00
15	•	.1	.2	0.00
16	•	.1	.3	0.00
17	•	.1	.5	0.00
18	•	.1	.5	0.00
19	•	.1	.5	0.00
20	•	2.3	3.8	1.07
21	•	6.1	6.2	.02
22	•	4.3	1.4	0.00
23	•	3.2	.9	0.00
24	•	2.5	.8	0.00
25	•O	3.0	22.0	.56
26	•O	2.8	11.0	0.00
27	•	2.1	1.5	0.00
28	•	1.7	1.0	.03
29	•	1.3	.9	.03
30	•	1.1	1.0	.04
31	•O	.9	12.0	.06



APR-MAY	SIM.	OBS.	RAIN+MELT
1	.9	4.8	.19
2	.6	2.1	0.00
3	.6	1.1	0.00
4	.5	.8	0.00
5	.5	.7	0.00
6	.4	.8	0.00
7	.4	.9	0.00
8	5.8	7.7	.68
9	3.6	4.3	0.00
10	2.7	1.5	.02
11	2.1	1.1	0.00
12	1.6	.9	0.00
13	1.3	.7	0.00
14	1.1	.6	0.00
15	.9	.5	0.00
16	.8	.6	0.00
17	.9	1.0	.28
18	6.3	4.2	.95
19	17.4	30.0	.01
20	5.2	2.7	0.00
21	3.9	1.4	0.00
22	3.0	1.0	0.00
23	2.4	.9	0.00
24	1.9	.8	0.00
25	1.6	.7	0.00
26	1.3	.7	0.00
27	1.2	.6	0.00
28	1.0	.5	0.00
29	.9	.4	0.00
30	.8	.4	0.00
1	.8	.4	0.00
2	.8	.3	.05
3	.7	.2	0.00
4	.7	.2	0.00
5	3.7	1.3	.80
6	7.4	12.0	0.00
7	3.7	1.1	0.00
8	9.7	.7	1.03
9	85.7	120.0	.73
10	15.9	23.0	.52
11	9.4	28.0	0.00
12	7.0	3.5	0.00
13	5.4	2.0	0.00
14	4.3	1.1	0.00
15	3.5	1.0	.00
16	3.0	1.1	.11
17	2.5	1.3	.19
18	2.2	1.0	.01
19	1.9	.7	0.00
20	1.7	.4	0.00
21	1.7	289.0	.30
22	28.0	115.0	.65
23	6.7	12.0	0.00
24	4.3	4.2	.02
25	3.5	3.2	0.00
26	102.8	245.0	1.42
27	22.5	26.0	0.00
28	8.4	6.0	0.00
29	6.5	3.2	0.00
30	5.2	2.1	0.00
31	4.2	1.8	.01



JUN-JUL	SIM.	OBS.	RAIN+MELT
1	29.7	451.0	.72
2	6.1	16.0	0.00
3	4.4	6.0	0.00
4	42.9	161.0	.85
5	12.8	25.0	0.00
6	5.4	8.1	0.00
7	4.3	4.2	0.00
8	3.6	2.9	0.00
9	3.1	2.9	0.00
10	2.7	3.2	0.00
11	9.2	2.9	.68
12	21.8	10.0	.03
13	4.6	2.9	0.00
14	3.6	2.5	0.00
15	3.1	2.1	0.00
16	2.7	1.8	0.00
17	2.4	1.7	0.00
18	2.2	1.5	.01
19	2.1	1.4	.03
20	1.9	1.3	0.00
21	1.8	1.1	.05
22	4.4	1.1	.51
23	2.3	1.4	.03
24	2.0	1.3	.14
25	1.8	1.1	0.00
26	35.8	132.0	1.22
27	86.3	249.0	0.00
28	9.5	7.0	0.00
29	6.5	3.5	0.00
30	5.2	2.3	.26
1	8.0	2.7	.24
2	4.0	2.1	0.00
3	3.3	1.7	0.00
4	2.8	1.7	0.00
5	2.5	1.5	0.00
6	2.3	1.4	0.00
7	2.1	1.3	0.00
8	5.9	1.0	.65
9	29.5	81.0	.13
10	5.0	3.5	0.00
11	3.7	1.8	0.00
12	3.1	1.3	.00
13	162.8	324.0	1.79
14	90.9	40.0	.23
15	711.8	1070.0	2.42
16	159.4	53.0	.01
17	24.0	17.0	.28
18	70.7	13.0	.21
19	17.1	8.1	.11
20	10.3	6.0	0.00
21	245.2	8.9	1.28
22	663.6	619.0	1.42
23	125.8	47.0	.00
24	20.2	14.0	0.00
25	11.8	9.3	0.00
26	490.5	97.0	3.07
27	1320.9	927.0	.26
28	70.0	35.0	0.00
29	16.4	15.0	0.00
30	10.6	10.0	0.00
31	8.5	8.1	0.00

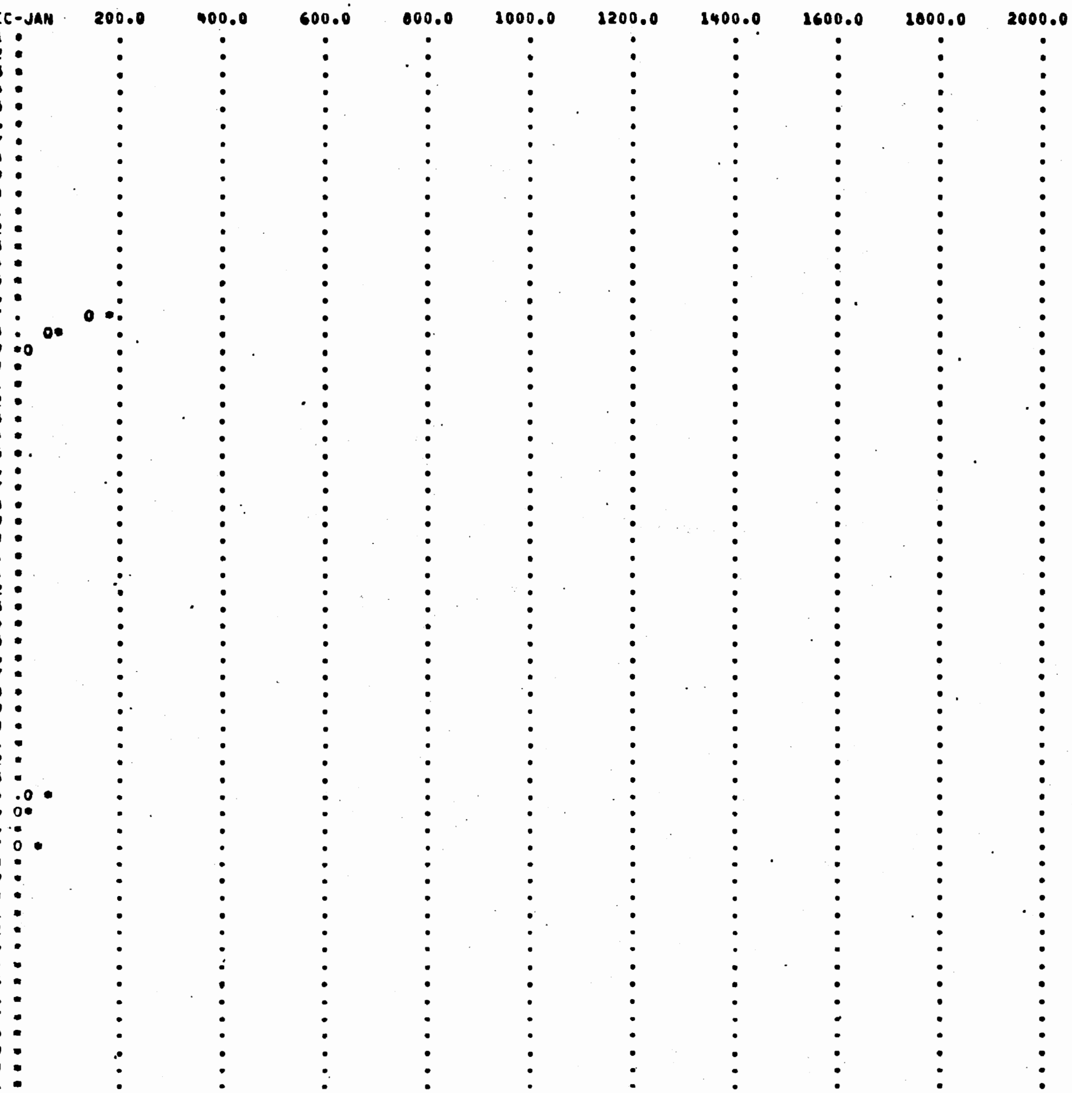


AUG-SEP	SIM.	OBS.	RAIN+MELT
1	7.0	7.0	0.00
2	6.0	6.0	0.00
3	5.2	5.1	0.00
4	4.6	4.7	0.00
5	4.2	3.8	0.00
6	84.9	400.0	1.36
7	363.0	478.0	1.21
8	361.3	11.0	0.00
9	32.8	8.1	0.00
10	11.9	6.5	0.00
11	8.8	5.1	0.00
12	7.3	4.2	0.00
13	6.1	3.8	0.00
14	5.3	3.8	0.00
15	4.7	3.5	0.00
16	4.2	3.5	0.00
17	3.9	3.2	0.00
18	3.8	2.9	.33
19	3.5	2.9	0.00
20	3.2	2.5	0.00
21	3.1	2.3	0.00
22	3.0	2.1	0.00
23	2.9	1.8	0.00
24	2.8	1.8	0.00
25	2.8	1.7	0.00
26	2.7	1.7	0.00
27	2.7	1.5	.08
28	2.7	1.5	.13
29	2.6	1.5	0.00
30	2.5	1.4	0.00
31	2.5	1.4	0.00
1	14.0	2.1	.81
2	39.9	4.5	0.00
3	49.6	2.5	.54
4	13.9	1.8	0.00
5	6.2	1.4	0.00
6	5.1	1.3	0.00
7	4.3	1.0	0.00
8	3.8	.9	0.00
9	4.4	3.4	.52
10	5.9	3.9	0.00
11	3.2	1.0	0.00
12	2.9	.8	0.00
13	2.7	.8	0.00
14	2.5	.8	0.00
15	2.4	1.0	0.00
16	2.3	1.0	0.00
17	2.2	.8	.00
18	2.2	.8	0.00
19	2.1	1.0	0.00
20	2.1	1.3	0.00
21	2.0	1.3	0.00
22	2.0	1.3	0.00
23	99.5	174.0	2.53
24	848.0	1340.0	3.01
25	1027.8	1430.0	.94
26	108.0	30.0	0.00
27	29.2	12.0	0.00
28	19.4	8.1	0.00
29	15.0	6.5	.10
30	435.6	365.0	1.33

MEAN DAILY FLOW PLOT   COUNCIL CR   WATER YEAR 1960   *=SIMULATED   O=OBSERVED   UNITS=CFSD

OCT-NOV 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

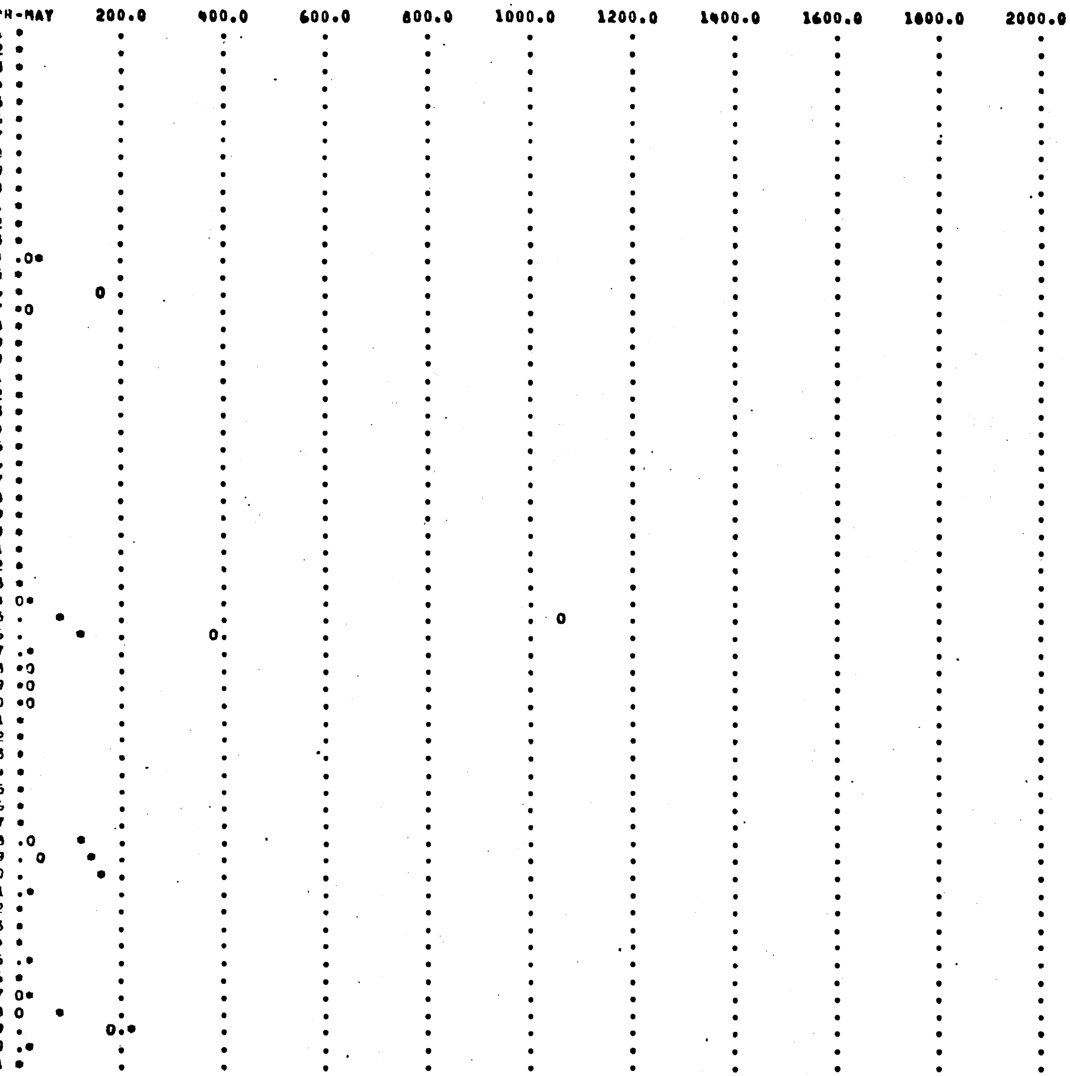
OCT-NOV	SIM.	OBS.	RAIN+MELT
1	399.0	143.0	1.26
2	5788.0	11000.0	7.83
3	1008.9	370.0	1.09
4	1031.2	1200.0	1.50
5	188.5	140.0	.00
6	37.0	30.0	.00
7	10.0	24.0	.21
8	13.0	17.0	.06
9	10.3	15.0	0.00
10	8.6	13.0	0.00
11	7.4	11.0	.02
12	6.5	11.0	0.00
13	133.2	176.0	.64
14	27.4	24.0	0.00
15	8.1	11.0	0.00
16	5.6	9.3	0.00
17	4.9	8.1	0.00
18	4.6	7.6	0.00
19	4.3	7.0	0.00
20	4.1	6.5	0.00
21	3.9	6.0	0.00
22	3.8	6.0	0.00
23	3.7	5.6	0.00
24	3.6	5.1	0.00
25	3.5	5.1	0.00
26	3.4	6.0	0.00
27	3.4	5.6	0.00
28	3.3	5.1	0.00
29	3.2	5.1	0.00
30	25.6	9.3	.58
31	9.0	8.1	0.00
1	3.3	6.5	0.00
2	3.3	6.0	0.00
3	27.3	8.7	.43
4	20.0	9.3	0.00
5	4.7	5.6	0.00
6	3.5	5.1	0.00
7	3.2	4.7	0.00
8	3.1	5.1	0.00
9	3.0	5.1	0.00
10	2.9	5.1	0.00
11	2.8	5.1	0.00
12	2.7	5.1	0.00
13	2.7	5.1	0.00
14	2.6	4.7	0.00
15	2.6	4.7	0.00
16	2.5	5.1	0.00
17	2.5	4.7	0.00
18	2.4	4.7	0.00
19	2.4	4.2	0.00
20	2.3	3.8	0.00
21	2.3	3.5	0.00
22	2.3	3.2	0.00
23	2.2	3.2	0.00
24	2.2	2.9	0.00
25	2.2	2.9	0.00
26	2.1	2.9	.01
27	2.1	2.7	0.00
28	2.1	2.7	0.00
29	2.0	2.7	0.00
30	2.0	3.2	0.00



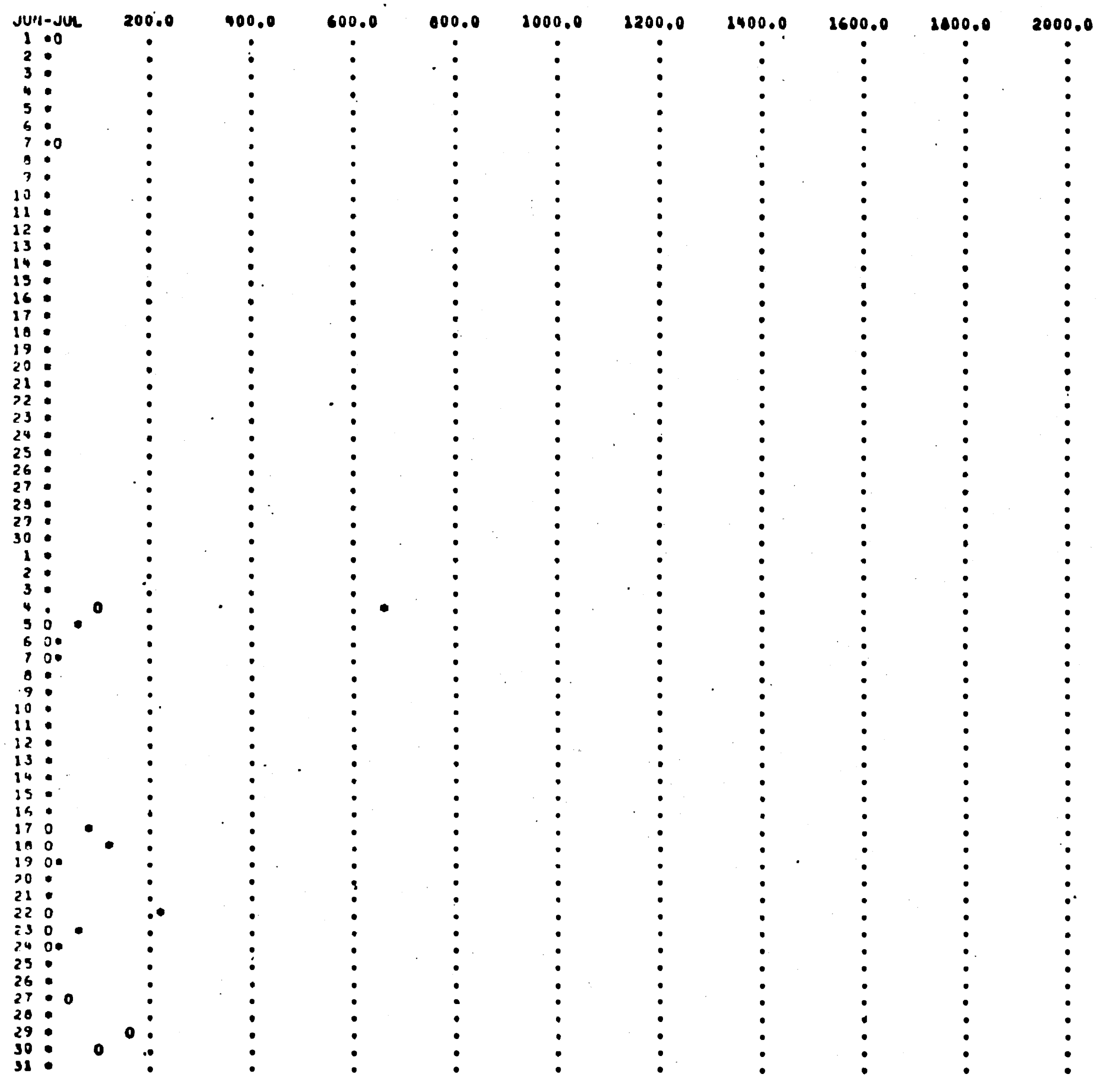
DEC-JAN	SIM.	OBS.	RAIN+MELT
1	2.0	3.5	0.00
2	1.9	3.2	0.00
3	1.9	3.2	0.00
4	1.9	3.8	0.00
5	1.8	3.5	0.04
6	1.8	3.5	0.00
7	1.8	3.5	0.00
8	1.8	3.5	0.00
9	1.7	3.2	0.00
10	1.8	3.5	.13
11	1.7	4.2	0.00
12	1.7	3.8	0.00
13	1.6	3.2	0.00
14	1.6	3.2	0.00
15	1.6	3.2	.01
16	1.9	3.8	.41
17	178.0	137.0	1.20
18	77.3	52.0	0.00
19	9.6	11.0	0.00
20	6.5	8.1	0.00
21	5.2	6.5	0.00
22	4.3	6.5	.11
23	3.7	7.6	.03
24	3.1	6.5	0.00
25	2.7	6.0	0.00
26	2.5	6.5	.24
27	2.4	9.3	.00
28	2.1	6.0	0.00
29	2.0	4.7	0.00
30	1.9	4.2	0.00
31	1.8	4.2	.00
1	1.7	4.2	0.00
2	1.7	4.2	0.00
3	1.6	3.8	0.00
4	1.6	3.5	0.00
5	1.7	4.2	.13
6	1.6	4.7	0.00
7	1.5	5.6	0.00
8	1.5	5.6	0.00
9	1.5	5.1	0.00
10	1.4	5.6	0.00
11	1.4	5.1	0.00
12	1.6	6.5	.25
13	1.4	6.0	0.00
14	63.3	11.0	.34
15	10.7	7.0	0.00
16	5.7	4.2	.06
17	40.8	5.6	.13
18	5.8	6.5	0.00
19	3.2	3.2	0.00
20	2.7	2.9	0.00
21	2.3	3.2	0.00
22	2.1	3.2	0.00
23	1.9	3.2	0.00
24	1.7	3.5	0.00
25	1.6	4.2	0.00
26	1.5	5.6	0.00
27	1.4	6.0	0.00
28	1.4	4.7	0.00
29	1.3	4.2	0.00
30	1.3	4.2	0.00
31	1.3	4.7	.00

FEB-MAR	200.0 … 2000.0	SIM.	OBS.	RAIN+MELT
1	*	1.2	4.7	.01
2	*	1.2	4.7	0.00
3	0 *	37.0	7.5	.73
4	. *0	243.0	254.0	.43
5	.*	21.8	29.0	0.00
6	*0	5.9	12.0	0.00
7	*	4.4	7.3	0.00
8	*	3.6	6.7	0.00
9	*	3.0	7.3	0.00
10	*	2.6	7.6	0.00
11	*	2.2	5.6	0.00
12	*	2.0	5.1	0.00
13	*	1.6	5.6	0.00
14	*	1.7	5.6	0.00
15	*	7.7	6.5	.28
16	*	2.7	6.1	0.00
17	*	1.6	7.5	0.00
18	*	1.4	6.5	0.00
19	*	1.4	6.2	0.00
20	*	1.4	6.0	[illegible]
21	*	1.3	7.0	0.00
22	*	1.2	6.0	0.00
23	*	1.3	[illegible]	.12
24	*	1.2	4.7	0.00
25		1.1	4.2	[illegible]
26		1.1	4.7	0.00
27	0 *	[illegible]	[illegible]	[illegible]
28	0 *	30.2	5.6	.01
29	*	3.4	5.6	.00
1	*	2.2	5.6	.10
2	0 *	50.2	6.0	.19
3	0*	11.0	6.5	0.00
4	*	2.8	6.0	0.00
5	*	2.2	5.6	0.00
6	*	1.9	5.6	0.00
7	*	1.6	6.5	0.00
8	*0	1.5	14.0	.04
9	* 0	1.4	121.0	0.00
10	* 0	1.3	54.0	.01
11	*0	1.2	20.0	0.00
12	*0	1.1	12.0	0.00
13	*	1.1	10.0	0.00
14	*	1.1	10.0	.11
15	*0	1.1	27.0	.14
16	*0	1.0	29.0	0.00
17	*0	1.0	11.0	0.00
18	*	.9	10.0	0.00
19	*	.9	8.7	0.00
20	*	.9	7.6	0.00
21	*	.9	7.0	0.00
22	*	.9	7.0	0.00
23	*	.8	6.0	0.00
24	*	.8	6.0	.00
25	*	.8	6.0	0.00
26	*	.8	6.0	0.00
27	*	.8	6.0	0.00
28	*	.8	6.0	0.00
29	*	.8	5.6	.15
30	*	.8	5.6	0.00
31	*	.8	5.1	.25

Scale: 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0



APR-MAY	SIM.	OBS.	RAIN+MELT
1	.8	5.1	0.00
2	.6	4.2	0.00
3	.6	3.8	0.00
4	.6	3.8	0.00
5	.6	3.8	0.00
6	.6	4.2	0.00
7	.6	4.2	0.00
8	.6	4.7	.12
9	.5	5.1	0.00
10	.5	4.7	0.00
11	.5	4.7	0.00
12	.5	5.1	0.00
13	.8	6.7	.46
14	32.2	16.0	.42
15	6.3	7.0	.30
16	3.3	162.0	.15
17	1.9	10.0	0.00
18	1.5	8.7	0.00
19	1.2	7.6	0.00
20	1.0	7.0	0.00
21	.9	7.0	0.00
22	.8	6.5	0.00
23	.7	6.0	0.00
24	.6	5.6	0.00
25	.6	5.1	0.00
26	.6	5.1	0.00
27	.7	4.7	.25
28	.7	5.6	.23
29	5.5	6.5	.30
30	2.8	6.5	0.00
1	1.3	5.6	0.00
2	1.1	5.1	0.00
3	2.1	5.1	.47
4	13.3	6.1	.47
5	80.5	1060.0	1.13
6	111.1	376.0	.06
7	11.9	27.0	0.00
8	7.5	18.0	0.00
9	5.8	14.0	0.00
10	4.5	11.0	0.00
11	3.6	9.3	0.00
12	2.9	8.1	0.00
13	2.4	7.6	0.00
14	2.1	7.6	0.00
15	1.8	7.6	0.00
16	1.6	7.0	.05
17	6.4	6.0	.64
18	111.5	29.0	1.24
19	139.6	37.0	.40
20	154.4	152.0	.38
21	18.3	15.0	0.00
22	9.3	8.7	0.00
23	7.2	7.0	0.00
24	5.7	6.0	.17
25	10.3	18.0	.31
26	4.3	6.5	0.00
27	10.1	5.6	.50
28	89.6	9.3	1.04
29	212.2	179.0	.07
30	16.3	12.0	0.00
31	7.6	8.1	.02



JUN-JUL	SIM.	OBS.	RAIN+MELT
1	6.2	11.0	.23
2	4.9	7.6	.03
3	4.1	6.5	0.00
4	3.5	5.6	0.00
5	3.0	4.7	.05
6	3.0	5.1	.44
7	2.6	20.0	.14
8	2.3	8.1	.01
9	2.1	5.1	.01
10	2.0	3.8	0.00
11	1.9	3.2	.04
12	1.8	2.7	.08
13	1.9	2.9	.19
14	1.7	2.7	0.00
15	1.6	2.7	0.00
16	1.6	2.3	.07
17	1.6	2.0	0.00
18	1.5	1.8	0.00
19	1.5	1.7	0.00
20	1.7	1.7	.37
21	1.5	2.1	0.00
22	1.4	1.8	0.00
23	1.4	1.7	0.00
24	1.5	1.4	.19
25	1.4	1.4	.01
26	1.3	1.4	.00
27	1.3	1.4	.00
28	1.3	1.4	0.00
29	1.3	1.0	0.00
30	1.2	.9	0.00
1	1.2	.8	0.00
2	1.2	.7	0.00
3	2.1	.6	.59
4	654.9	102.0	2.79
5	53.1	3.8	0.00
6	15.9	2.1	.09
7	11.8	1.8	0.00
8	9.2	1.7	.00
9	7.3	1.5	0.00
10	5.9	1.3	.07
11	4.9	1.0	0.00
12	4.1	.8	.01
13	3.5	.8	.01
14	3.1	.8	.00
15	2.8	.8	0.00
16	2.6	.7	0.00
17	85.1	.5	1.56
18	121.4	.7	0.00
19	12.3	.6	0.00
20	8.1	.4	0.00
21	6.5	.2	.08
22	219.6	1.1	1.54
23	64.3	2.0	.08
24	12.8	1.4	.00
25	8.7	1.0	0.00
26	7.0	.6	0.00
27	6.1	50.0	.42
28	4.9	2.1	.08
29	4.4	163.0	.36
30	3.8	105.0	0.00
31	3.3	3.2	0.00

AUG-SEP 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

AUG-SEP	SIM.	OBS.	RAIN+MELT
1	3.0	1.7	0.00
2	2.8	1.3	0.00
3	2.6	1.0	0.00
4	2.5	.7	0.00
5	2.4	.4	0.00
6	2.3	.2	0.00
7	2.2	.1	0.00
8	2.2	.1	.02
9	2.1	.1	0.00
10	2.1	.1	.01
11	2.0	0.0	0.00
12	2.0	0.0	0.00
13	1.9	0.0	0.00
14	1.9	0.0	0.00
15	1.9	0.0	0.00
16	1.8	0.0	0.00
17	4.1	0.0	.63
18	44.2	0.0	.32
19	6.9	.1	0.00
20	4.6	.1	.00
21	3.8	0.0	.01
22	3.3	0.0	0.00
23	2.9	0.0	0.00
24	18.6	0.0	.77
25	10.2	0.0	0.00
26	246.3	55.0	1.64
27	20.9	2.1	0.00
28	11.9	.6	0.00
29	9.2	.2	0.00
30	7.3	.1	0.00
31	6.0	0.0	0.00
1	5.0	0.0	0.00
2	4.2	0.0	0.00
3	3.7	0.0	0.00
4	3.3	0.0	0.00
5	2.9	0.0	0.00
6	2.7	0.0	0.00
7	2.5	0.0	0.00
8	2.4	0.0	0.00
9	2.3	0.0	.03
10	2.2	0.0	0.00
11	2.1	0.0	0.00
12	2.1	0.0	0.00
13	2.0	0.0	0.00
14	2.0	0.0	0.00
15	1.9	0.0	0.00
16	1.9	0.0	0.00
17	1.8	0.0	0.00
18	1.8	0.0	0.00
19	1.8	0.0	.03
20	1.8	0.0	.07
21	1.8	0.0	.09
22	1.7	0.0	0.00
23	1.8	.2	.30
24	1.7	7.9	.03
25	1.6	.1	.00
26	1.7	0.0	.13
27	1.6	0.0	0.00
28	1.5	0.0	0.00
29	1.5	0.0	0.00
30	1.5	0.0	0.00

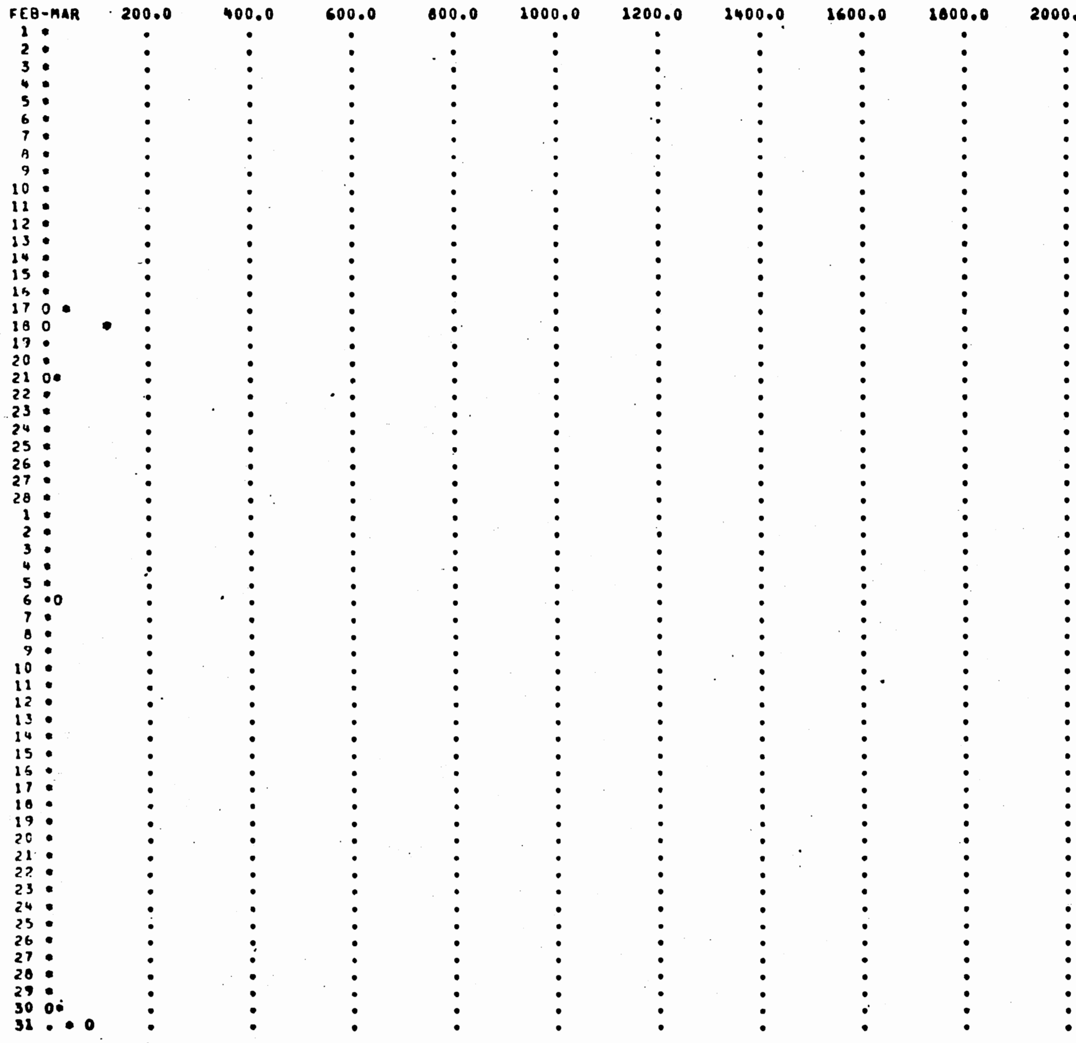
MEAN DAILY FLOW PLOT   COUNCIL CR   WATER YEAR 1961   *=SIMULATED   O=OBSERVED   UNITS-CFSD

OCT-NOV 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

OCT-NOV	SIM.	OBS.	RAIN+MELT
1	1.5	0.0	0.00
2	1.4	0.0	0.00
3	1.4	0.0	0.00
4	1.4	0.0	0.00
5	1.4	0.0	0.00
6	1.4	0.0	0.00
7	1.3	0.0	0.00
8	1.3	0.0	0.00
9	1.3	0.0	0.00
10	1.3	0.0	0.00
11	1.3	0.0	0.00
12	1.2	0.0	0.00
13	1.5	0.0	.49
14	1.3	0.0	0.00
15	1.2	0.0	0.00
16	1.2	0.0	0.00
17	1.2	0.0	.03
18	201.7	83.0	2.59
19	52.2	4.3	.01
20	15.2	.6	.00
21	11.3	.3	0.00
22	8.8	.2	0.00
23	7.0	.1	0.00
24	5.6	.1	0.00
25	4.9	.1	.31
26	4.0	.2	0.00
27	3.4	.4	.00
28	3.1	.4	.10
29	256.5	252.0	2.22
30	266.8	27.0	.31
31	45.5	5.1	0.00
1	14.2	2.5	0.00
2	10.6	1.5	0.00
3	8.4	1.5	0.00
4	6.8	1.8	0.00
5	5.7	1.5	0.00
6	4.8	1.7	0.00
7	4.2	1.5	0.00
8	3.7	1.7	0.00
9	3.3	1.7	0.00
10	3.1	1.4	0.00
11	2.9	1.5	0.00
12	2.7	1.3	0.00
13	2.6	.9	0.00
14	2.5	1.0	.01
15	2.7	3.0	.36
16	2.4	4.8	0.00
17	2.3	1.8	0.00
18	2.2	1.4	0.00
19	2.2	1.3	0.00
20	2.1	1.1	0.00
21	2.1	1.1	0.00
22	2.1	1.1	0.00
23	2.0	1.3	0.00
24	2.0	1.3	0.00
25	2.0	1.1	0.00
26	1.9	1.1	0.00
27	1.9	1.1	.16
28	2.0	1.5	0.00
29	1.8	1.8	0.00
30	1.8	1.3	0.00

DEC-JAN 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

DEC-JAN	SIM.	OBS.	RAIN+MELT
1	1.8	1.0	0.00
2	1.8	.6	0.00
3	1.7	.6	0.00
4	18.7	10.0	.56
5	10.5	15.0	0.00
6	3.1	1.7	0.00
7	2.6	1.0	0.00
8	2.4	.8	.01
9	2.2	.7	.04
10	153.6	98.0	1.02
11	90.3	59.0	.09
12	10.9	18.0	0.00
13	6.6	3.8	.00
14	5.3	2.9	.05
15	4.4	2.7	0.00
16	3.7	2.0	0.00
17	3.2	1.7	0.00
18	2.8	1.5	0.00
19	2.5	1.4	0.00
20	2.3	1.3	0.00
21	2.1	1.1	0.00
22	2.0	1.1	.01
23	1.9	1.1	0.00
24	1.8	1.4	0.00
25	1.8	1.4	0.00
26	1.7	1.4	0.00
27	1.7	1.3	.05
28	1.7	1.3	.03
29	1.6	1.4	.01
30	1.6	1.4	0.00
31	1.8	1.8	.28
1	1.5	2.0	0.00
2	1.5	1.5	0.00
3	1.5	1.3	0.00
4	1.4	1.3	0.00
5	1.4	1.3	0.00
6	1.4	1.4	0.00
7	1.4	1.4	0.00
8	1.3	1.3	0.00
9	1.3	1.3	0.00
10	1.3	1.4	0.00
11	1.3	1.4	0.00
12	1.3	1.4	0.00
13	1.2	1.4	0.00
14	1.2	1.5	.01
15	1.2	1.5	0.00
16	1.2	1.4	0.00
17	1.2	1.3	0.00
18	1.1	1.3	0.00
19	1.1	1.1	0.00
20	1.1	1.1	0.00
21	1.1	.9	0.00
22	1.1	1.0	0.00
23	1.0	1.1	0.00
24	1.0	1.1	0.00
25	1.0	.9	0.00
26	1.0	.9	0.00
27	1.0	.9	0.00
28	1.0	.9	0.00
29	1.0	1.0	0.00
30	.9	1.1	0.00
31	.9	1.3	0.00



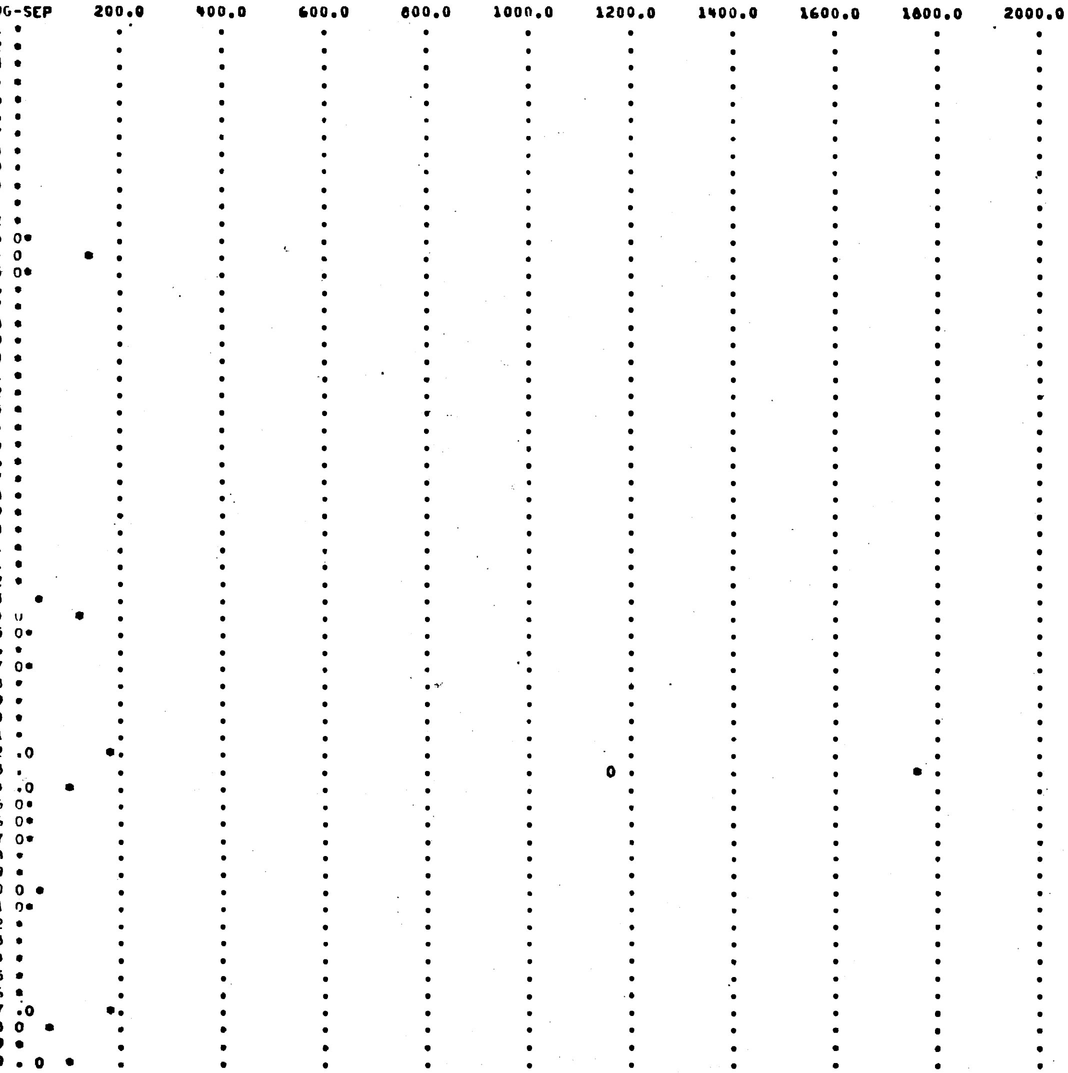
FEB-MAR	SIM.	OBS.	RAIN+MELT
1	.9	1.5	0.00
2	.9	1.5	0.00
3	.9	1.4	0.00
4	.9	1.3	.01
5	.9	1.1	.03
6	.9	1.3	.11
7	.9	1.5	.08
8	.8	1.5	.00
9	.8	1.5	0.00
10	.8	1.4	0.00
11	.8	1.4	0.00
12	.8	1.4	0.00
13	.8	1.4	0.00
14	.7	1.4	0.00
15	.7	1.3	0.00
16	.7	1.4	0.00
17	40.1	2.0	1.29
18	112.1	4.7	0.00
19	8.6	2.3	0.00
20	5.3	1.7	.11
21	13.4	2.0	.13
22	4.3	2.1	.00
23	3.1	2.1	0.00
24	2.5	1.8	.01
25	2.1	1.5	0.00
26	1.8	1.7	0.00
27	1.6	1.7	0.00
28	1.4	1.4	0.00
1	1.3	1.4	0.00
2	1.2	1.4	0.00
3	1.1	1.5	0.00
4	1.0	1.7	0.00
5	1.0	1.8	.05
6	1.0	15.0	0.00
7	.9	2.5	0.00
8	.9	1.8	0.00
9	.9	1.4	0.00
10	.8	1.4	0.00
11	.8	1.4	0.00
12	.8	1.7	0.00
13	.8	1.7	0.00
14	.8	1.4	0.00
15	.8	1.4	0.00
16	.8	1.5	.04
17	3.6	2.3	.63
18	8.7	6.5	.03
19	1.9	2.9	.03
20	1.6	2.5	.21
21	1.3	3.5	0.00
22	1.1	2.5	0.00
23	1.0	2.0	0.00
24	.9	1.8	0.00
25	.9	1.8	.04
26	1.5	2.0	.45
27	2.1	2.3	0.00
28	.9	2.1	0.00
29	3.3	2.0	.37
30	13.2	5.4	.44
31	48.0	75.0	.26

APR-MAY 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

APR-MAY	Plot	SIM.	OBS.	RAIN+MELT
1	*O	6.2	14.0	.00
2	*	4.1	5.6	.00
3	*	3.2	3.5	0.00
4	*	2.6	2.9	0.00
5	*	2.1	2.9	0.00
6	*	1.8	2.7	0.00
7	*	1.5	2.5	0.00
8	*	1.5	2.9	.25
9	*	1.2	4.2	0.00
10	*	1.1	3.2	0.00
11	*O	1.1	13.0	.21
12	*O	1.0	27.0	0.00
13	*	.9	4.2	0.00
14	*	.8	3.2	.01
15	*	.8	2.5	.05
16	*	.8	2.1	0.00
17	*	.7	2.1	0.00
18	*	.7	2.0	0.00
19	*	.7	2.0	0.00
20	*	.7	2.0	0.00
21	*	.7	2.0	0.00
22	*	.6	1.8	0.00
23	*	.6	1.7	0.00
24	*	.6	1.7	0.00
25	*	.6	1.7	0.00
26	*	.6	1.5	0.00
27	*	.6	1.5	0.00
28	*	.6	1.5	0.00
29	*	.5	1.4	0.00
30	*	.5	1.4	0.00
1	*	.5	1.5	0.00
2	*	.5	1.5	0.00
3	*	.6	1.5	.18
4	. *O	10.9	32.0	1.10
5	. * O	32.3	76.0	.01
6	*	6.2	5.6	.00
7	*	4.7	2.9	.24
8	. *O	84.2	91.0	1.10
9	. *	18.9	15.0	0.00
10	*	7.7	4.7	0.00
11	*	5.9	2.7	0.00
12	*	4.6	2.0	0.00
13	*	3.7	1.7	0.00
14	*	3.0	1.4	0.00
15	*	2.5	1.0	0.00
16	*	2.1	1.0	.10
17	*	1.9	1.3	.02
18	*	1.6	1.4	0.00
19	*	1.5	1.1	.02
20	*	1.4	.9	0.00
21	. O*	132.3	127.0	2.13
22	. *	88.0	89.0	0.00
23	O*	12.4	8.1	0.00
24	*	8.7	4.2	0.00
25	* O	6.8	45.0	.01
26	* O	5.4	40.0	0.00
27	*	4.4	4.2	0.00
28	*	3.6	2.7	0.00
29	*	3.1	2.3	0.00
30	*	2.7	1.8	0.00
31	*	2.4	1.5	0.00

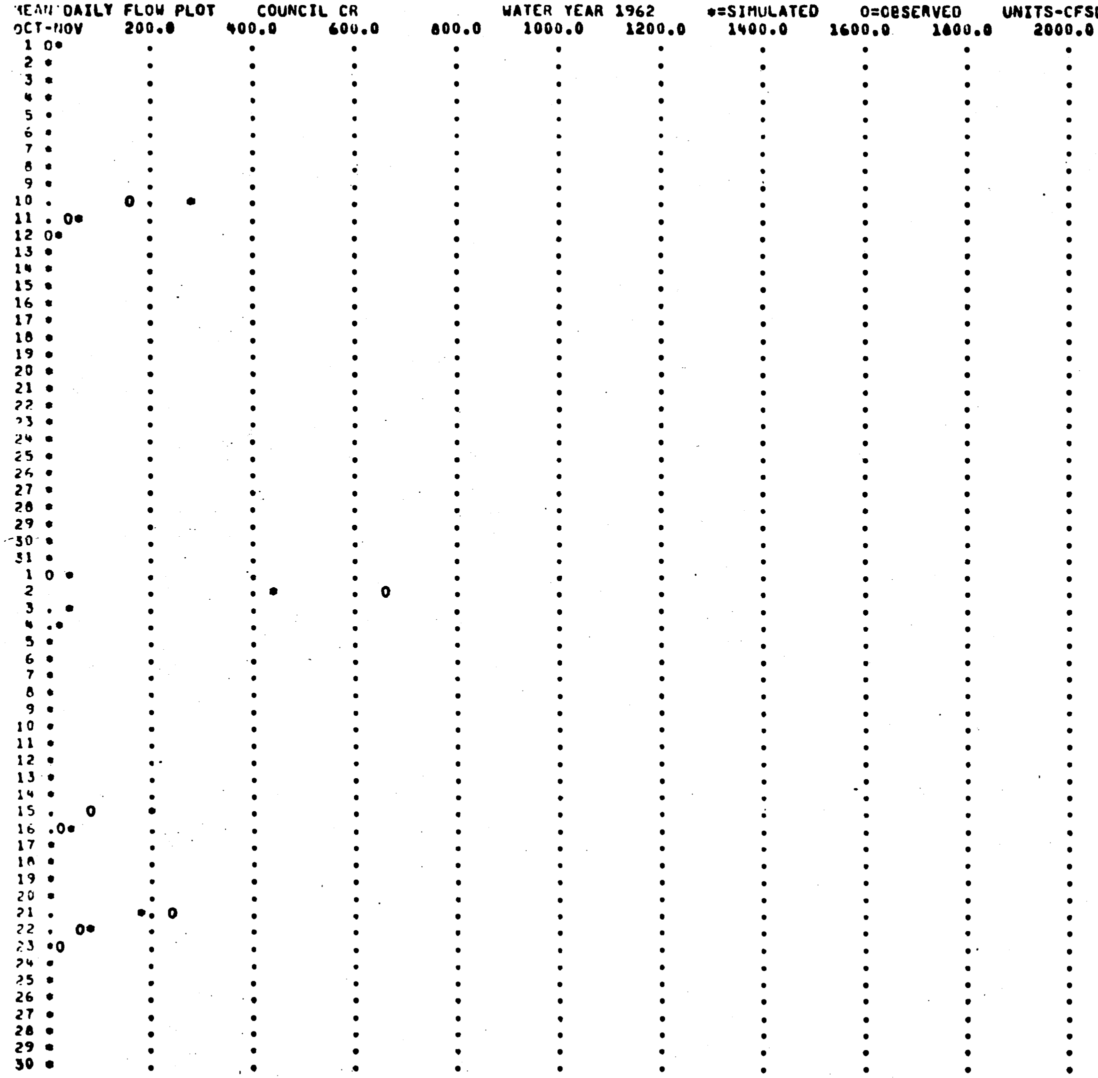
JUN-JUL 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

JUN-JUL	SIM.	OBS.	RAIN+MELT
1	2.1	1.3	0.00
2	35.7	5.0	1.42
3	123.2	137.0	.12
4	638.1	705.0	2.45
5	107.2	40.0	.04
6	19.0	18.0	.07
7	22.6	74.0	.35
8	25.8	66.0	.24
9	9.7	13.0	0.00
10	7.2	7.6	0.00
11	5.9	5.6	0.00
12	5.0	4.2	0.00
13	4.3	3.5	0.00
14	452.8	835.0	1.90
15	47.0	32.0	0.00
16	11.7	15.0	0.00
17	8.6	10.0	0.00
18	7.0	8.7	0.00
19	5.8	7.0	0.00
20	5.0	6.0	0.00
21	4.3	5.1	0.00
22	3.8	4.2	0.00
23	3.5	3.5	0.00
24	3.2	2.9	0.00
25	3.0	2.9	.01
26	2.8	2.7	0.00
27	2.7	2.5	0.00
28	2.6	2.3	0.00
29	2.5	2.1	0.00
30	2.4	2.5	0.00
1	2.3	2.0	0.00
2	2.3	1.8	0.00
3	2.2	1.8	0.00
4	2.2	1.7	0.00
5	2.1	1.5	0.00
6	65.3	2.5	1.90
7	401.7	149.0	.76
8	35.1	6.0	0.00
9	14.2	2.7	0.00
10	10.9	2.0	0.00
11	8.6	1.7	.01
12	44.5	5.7	.72
13	84.2	126.0	1.23
14	306.6	272.0	.54
15	69.0	215.0	.17
16	15.8	26.0	0.00
17	10.0	7.6	0.00
18	8.1	4.7	0.00
19	6.7	3.2	0.00
20	5.8	3.5	.24
21	84.9	30.0	.84
22	58.5	28.0	.46
23	24.7	19.0	0.00
24	7.2	6.0	0.00
25	5.7	3.5	0.00
26	4.9	2.7	0.00
27	4.3	2.1	0.00
28	3.9	2.0	0.00
29	3.5	1.7	0.00
30	3.3	1.4	0.00
31	3.1	1.1	0.00



AUG-SEP	SIM.	OBS.	RAIN+MELT
1	2.9	1.1	0.00
2	2.8	.9	0.00
3	2.7	.9	.04
4	2.6	1.0	0.00
5	2.6	1.1	.05
6	2.5	1.3	.01
7	2.4	.7	0.00
8	2.4	.6	0.00
9	2.3	.5	0.00
10	2.3	.4	0.00
11	2.3	.3	0.00
12	2.3	.5	.21
13	21.2	.8	.75
14	139.9	1.3	.85
15	25.0	1.3	.16
16	9.5	1.1	0.00
17	7.4	.9	0.00
18	6.1	.6	0.00
19	5.1	.4	0.00
20	4.3	.4	0.00
21	3.8	.2	.03
22	3.6	.4	.24
23	3.1	.4	0.00
24	2.8	.3	0.00
25	2.6	.2	0.00
26	2.5	.1	0.00
27	2.4	.1	0.00
28	2.3	0.0	0.00
29	2.2	0.0	0.00
30	2.2	0.0	.11
31	2.1	0.0	0.00
1	2.0	0.0	0.00
2	2.0	0.0	0.00
3	33.7	0.0	1.41
4	124.4	4.7	.18
5	13.1	1.0	0.00
6	8.1	.4	0.00
7	12.6	.9	.47
8	8.6	2.4	0.00
9	5.1	.4	0.00
10	4.3	.1	0.00
11	3.7	.1	.00
12	170.7	20.0	2.33
13	1766.7	1170.0	2.62
14	105.9	22.0	0.00
15	21.2	6.7	0.00
16	14.7	6.0	0.00
17	11.5	5.1	0.00
18	9.2	4.2	0.00
19	7.5	3.5	0.00
20	40.8	5.6	.73
21	14.2	5.6	0.00
22	6.0	3.2	0.00
23	5.1	2.5	0.00
24	4.5	2.7	.22
25	4.1	4.8	0.00
26	3.7	2.3	0.00
27	184.6	11.0	1.20
28	64.0	8.3	0.00
29	9.4	3.2	0.00
30	98.4	43.0	.59

MEAN DAILY FLOW PLOT   COUNCIL CR   WATER YEAR 1962   *=SIMULATED   O=OBSERVED   UNITS-CFSD

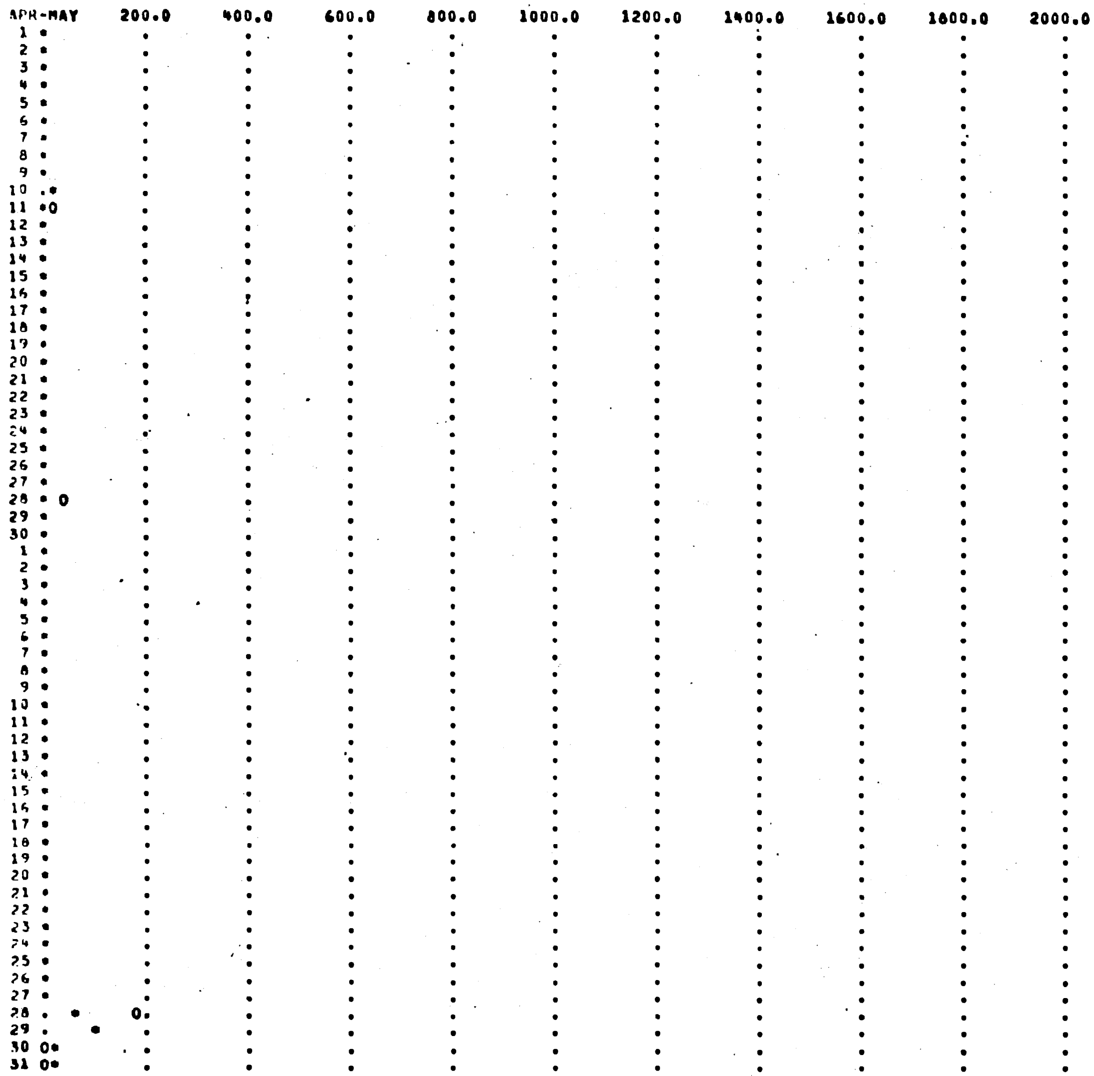


OCT-NOV	SIM.	OBS.	RAIN+MELT
1	23.8	5.1	.00
2	7.2	2.5	.07
3	5.7	2.1	0.00
4	4.9	2.0	0.00
5	4.3	1.8	0.00
6	3.9	1.7	0.00
7	3.5	1.5	0.00
8	3.3	1.4	0.00
9	3.2	1.5	.48
10	282.2	164.0	1.12
11	67.8	39.0	0.00
12	10.4	7.6	0.00
13	7.2	5.6	0.00
14	6.0	4.2	0.00
15	5.1	3.2	0.00
16	4.4	2.7	0.00
17	3.9	2.7	0.00
18	3.5	2.5	0.00
19	3.3	2.3	0.00
20	3.0	2.3	0.00
21	2.9	2.3	0.00
22	2.7	2.3	0.00
23	2.6	2.3	.00
24	2.6	2.3	0.00
25	2.5	2.5	.00
26	2.4	2.1	0.00
27	2.4	2.0	0.00
28	2.3	2.3	0.00
29	2.3	2.5	.03
30	2.4	2.5	.29
31	2.4	2.5	.12
1	44.1	2.7	.86
2	439.4	661.0	1.05
3	44.0	31.0	0.00
4	11.8	11.9	0.00
5	8.8	8.1	0.00
6	7.1	7.0	0.00
7	5.8	6.5	0.00
8	4.9	6.0	0.00
9	4.2	6.0	0.00
10	3.8	6.0	.04
11	3.4	6.0	0.00
12	3.1	5.6	0.00
13	2.9	5.1	0.00
14	2.7	4.7	.00
15	202.6	80.0	1.16
16	46.4	25.0	0.00
17	7.6	7.6	0.00
18	5.5	6.5	.07
19	4.7	6.5	.01
20	4.0	5.6	.00
21	181.3	241.0	.84
22	70.7	61.0	.01
23	9.0	18.0	0.00
24	5.7	10.0	0.00
25	4.8	8.7	0.00
26	4.1	8.1	0.00
27	3.6	7.6	0.00
28	3.2	7.0	0.00
29	3.0	6.5	0.00
30	2.8	6.5	0.00

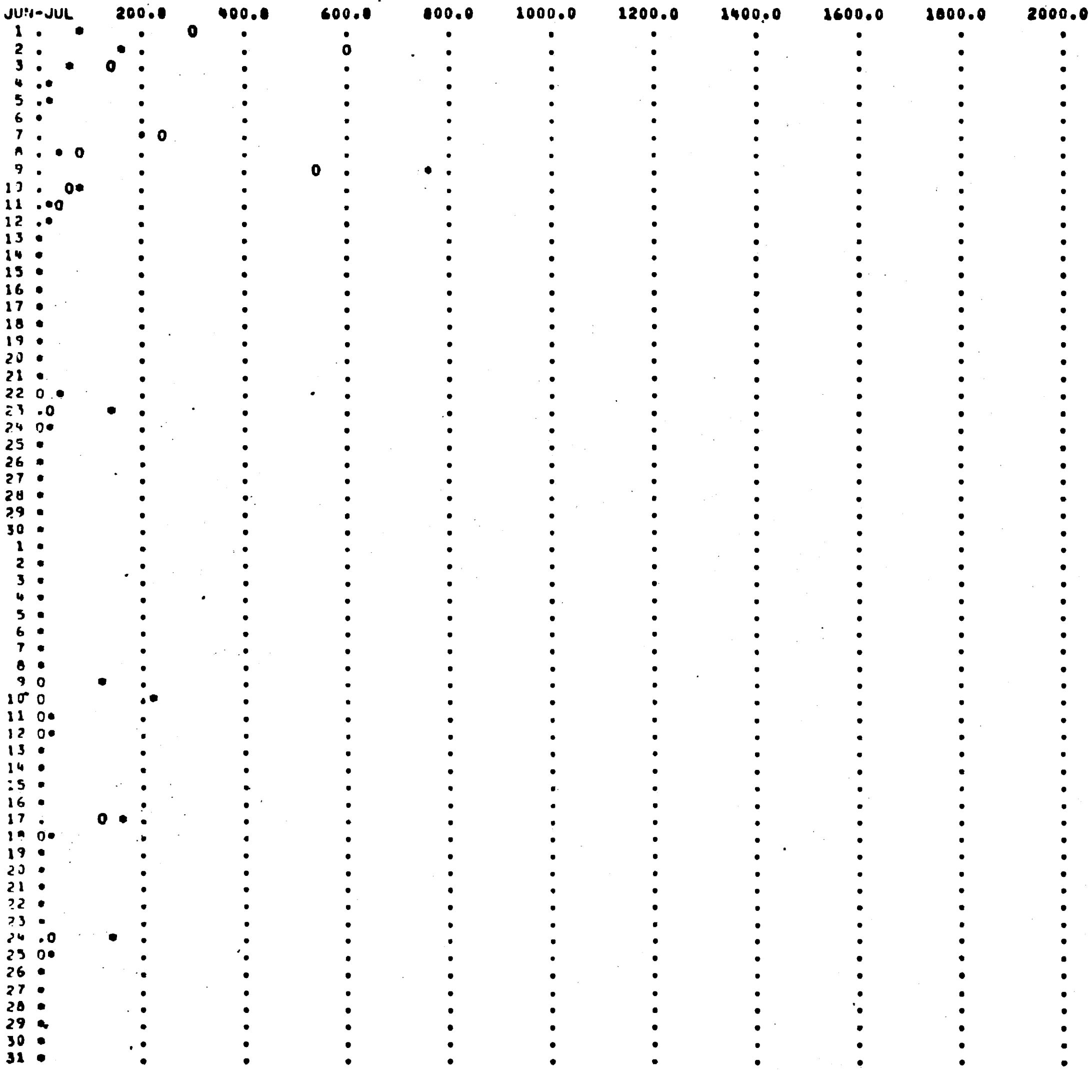
DEC-JAN 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

DEC-JAN	Plot	SIM.	OBS.	RAIN+MELT
1	*	2.6	6.5	0.00
2	*	2.5	6.5	0.00
3	*	2.4	6.5	0.00
4	*	2.3	6.5	.07
5	*	2.2	6.0	0.00
6	*	2.2	5.6	0.00
7	*	2.1	4.7	0.00
8	.O*	45.1	21.0	.64
9	. *	73.4	83.0	.03
10	.*	10.7	16.0	.15
11	O*	23.4	8.1	.10
12	*	7.1	6.5	0.00
13	*	3.3	5.1	0.00
14	*	2.9	6.5	0.00
15	*	2.6	7.0	0.00
16	. O*	152.9	137.0	.52
17	.*O	26.9	32.0	.00
18	*O	5.2	16.0	0.00
19	*	3.8	9.3	0.00
20	*	3.3	7.6	0.00
21	*	2.9	7.6	0.00
22	*	2.6	7.0	0.00
23	*	2.4	6.0	0.00
24	*	2.2	5.6	0.00
25	*	2.1	6.0	0.00
26	*	2.0	6.5	0.00
27	*	1.9	5.6	0.00
28	*	1.9	4.7	0.00
29	*	1.8	4.2	0.00
30	*	1.8	4.7	0.00
31	*	1.7	4.7	0.00
1	*	1.7	4.7	0.00
2	*	1.6	4.7	0.00
3	*	1.6	5.1	0.00
4	*	1.6	6.0	.00
5	*	1.7	8.1	.25
6	*	1.5	5.6	0.00
7	*	1.5	6.0	0.00
8	*	1.5	5.6	.03
9	*	1.5	4.2	.00
10	*	1.4	2.9	0.00
11	*	1.4	2.9	0.00
12	*	1.4	3.2	0.00
13	*	1.4	4.2	0.00
14	*	1.3	6.0	.01
15	*	1.3	5.1	0.00
16	*	1.3	4.2	0.00
17	*	1.3	3.5	0.00
18	*	1.4	4.7	.21
19	*	1.3	4.2	0.00
20	*	1.2	3.5	0.00
21	*	1.2	4.2	0.00
22	*	1.2	4.2	0.00
23	*	1.1	3.2	0.00
24	*	1.1	5.1	0.00
25	*	1.2	7.6	.13
26	*O	1.2	13.0	0.00
27	*	1.1	8.1	0.00
28	*	1.1	5.6	0.00
29	*	1.0	5.1	0.00
30	*	1.0	5.1	0.00
31	*	1.0	4.7	0.00

FEB-MAR	200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0	SIM.	OBS.	RAIN+MELT
1	*	1.0	4.7	0.00
2	*	1.0	4.2	0.00
3	*	1.0	4.2	0.00
4	*	.9	4.2	0.00
5	*	.9	3.8	0.00
6	*	.9	3.2	0.00
7	*	.9	3.5	0.00
8	*	.9	3.9	0.00
9	*	.9	4.2	0.00
10	*	.9	3.8	0.00
11	*	.8	4.2	0.00
12	*	.8	4.2	0.00
13	*	.8	4.2	0.00
14	*	.8	3.8	0.00
15	*	1.1	6.0	.33
16	*	.8	5.1	0.00
17	*	.8	4.7	0.00
18	*	.7	3.8	0.00
19	*	.7	3.2	0.00
20	*	.7	2.9	.01
21	*	.7	3.8	0.00
22	*	.7	3.2	0.00
23	*	.7	3.5	.06
24	*	.7	3.2	0.00
25	*	.7	2.9	.03
26	*	.7	3.5	0.00
27	*	.8	2.9	.18
28	*	.6	2.5	0.00
1	*	.6	2.7	0.00
2	*	.6	3.2	0.00
3	*	.6	4.2	0.00
4	*	.6	4.2	0.00
5	*	.5	2.9	0.00
6	*	.5	2.7	0.00
7	*	.5	3.2	0.00
8	*	.5	3.5	0.00
9	*	.5	3.2	0.00
10	*	.5	2.9	0.00
11	*	.5	2.9	0.00
12	*	.5	2.5	0.00
13	*	.5	2.1	0.00
14	*	.4	2.1	0.00
15	*	.4	2.1	0.00
16	*	.4	2.5	0.00
17	*	.4	2.5	0.00
18	*	.4	2.7	0.00
19	*	.4	2.9	0.00
20	*	3.6	6.0	.59
21	*	1.0	6.0	0.00
22	*	.7	3.5	0.00
23	*	.6	3.2	0.00
24	.*0	23.0	45.0	.73
25	. *0	43.4	61.0	.27
26	*0	6.1	14.0	0.00
27	*	4.0	7.6	0.00
28	*	3.1	6.0	0.00
29	*	2.4	5.1	0.00
30	*	1.9	4.2	0.00
31	*	1.6	3.8	0.00



APR-MAY	SIM.	OBS.	RAIN+MELT
1	1.3	3.5	0.00
2	1.1	3.2	0.00
3	1.0	3.2	0.00
4	.9	3.5	.10
5	.9	4.7	.08
6	.8	5.1	.05
7	.7	4.7	0.00
8	.8	5.1	.17
9	.6	4.2	0.00
10	15.9	24.0	.65
11	3.9	15.0	.03
12	2.2	7.0	.00
13	1.7	5.6	0.00
14	1.4	5.1	0.00
15	1.2	5.1	0.00
16	1.0	4.2	0.00
17	.9	3.8	0.00
18	.8	3.5	0.00
19	.7	3.5	0.00
20	.8	3.2	.10
21	.6	2.9	.00
22	.7	2.9	.10
23	.6	2.9	0.00
24	.6	2.9	0.00
25	.5	3.2	0.00
26	.5	2.9	.04
27	.7	7.5	.27
28	.5	32.0	.03
29	.5	5.1	0.00
30	.4	3.2	0.00
1	.4	2.7	.03
2	.4	2.3	0.00
3	.4	2.1	0.00
4	.4	2.0	0.00
5	.4	1.8	0.00
6	.3	1.7	0.00
7	.3	1.8	0.00
8	.3	1.7	0.00
9	.3	1.5	0.00
10	.3	1.4	0.00
11	.3	1.3	0.00
12	.3	1.3	0.00
13	.3	1.1	0.00
14	.3	1.0	0.00
15	.3	.9	0.00
16	.3	.8	0.00
17	.3	.8	0.00
18	.3	.7	0.00
19	.3	.6	0.00
20	.3	.5	0.00
21	.3	.4	0.00
22	.3	.3	0.00
23	.2	.2	0.00
24	.2	.2	0.00
25	.3	.2	.32
26	.4	.4	.03
27	.3	.4	.05
28	51.5	186.0	2.42
29	99.0	94.0	.00
30	15.3	3.5	0.00
31	10.6	1.8	0.00



JUN-JUL	SIM.	OBS.	RAIN+MELT
1	84.7	300.0	1.45
2	164.8	591.0	.87
3	56.3	132.0	0.00
4	14.3	22.0	0.00
5	10.6	11.0	0.00
6	8.2	6.5	.00
7	202.4	242.0	1.27
8	46.5	76.0	.36
9	758.1	539.0	2.15
10	76.4	57.0	.01
11	17.9	31.0	.01
12	12.6	11.0	0.00
13	9.9	9.3	0.00
14	8.0	8.1	0.00
15	6.5	8.7	0.00
16	5.5	7.6	0.00
17	4.7	5.6	0.00
18	4.2	4.2	.05
19	3.7	2.9	.01
20	3.4	2.5	0.00
21	3.3	2.3	.22
22	30.6	3.5	.79
23	144.6	23.0	.37
24	14.4	2.9	0.00
25	6.6	2.5	0.00
26	5.4	2.3	0.00
27	4.6	2.5	.01
28	4.0	2.3	0.00
29	3.6	2.1	.02
30	3.3	2.1	0.00
1	3.0	2.0	0.00
2	2.8	1.7	0.00
3	2.7	1.4	0.00
4	2.5	1.1	0.00
5	2.5	1.3	.02
6	2.4	1.0	0.00
7	2.3	.7	0.00
8	2.4	.6	.29
9	123.4	5.7	1.49
10	217.2	9.9	.43
11	21.3	1.5	0.00
12	11.0	1.0	0.00
13	8.6	.8	0.00
14	7.0	.5	0.00
15	5.8	1.0	.11
16	4.8	9.9	.00
17	159.9	128.0	1.13
18	17.1	2.9	0.00
19	7.8	1.7	0.00
20	6.3	1.1	0.00
21	5.3	1.0	0.00
22	4.5	.7	0.00
23	3.9	.7	0.00
24	131.9	19.0	1.28
25	27.7	5.0	0.00
26	7.8	1.4	0.00
27	6.2	1.0	.03
28	5.2	1.1	.09
29	4.4	1.4	0.00
30	3.9	1.7	.06
31	3.6	2.7	.23

AUG-SEP 200.0 400.0 600.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 2000.0

AUG-SEP	SIM.	OBS.	RAIN+MELT
1	46.0	20.0	.61
2	7.0	4.0	0.00
3	4.6	2.0	0.00
4	4.0	1.8	0.00
5	3.5	1.7	0.00
6	3.2	1.0	0.00
7	2.9	.9	0.00
8	2.7	.9	0.00
9	2.6	.9	0.00
10	2.4	.8	0.00
11	2.3	.6	0.00
12	2.2	.5	0.00
13	2.2	.4	0.00
14	2.1	.4	0.00
15	2.1	.4	0.00
16	2.0	.3	0.00
17	2.0	.3	0.00
18	1.9	.2	0.00
19	1.9	.2	0.00
20	1.9	.2	0.00
21	1.8	.2	0.00
22	1.8	.1	0.00
23	1.8	.1	0.00
24	2.1	.1	.49
25	1.8	.1	0.00
26	1.7	.1	0.00
27	1.7	0.0	0.00
28	1.7	0.0	0.00
29	1.6	0.0	0.00
30	1.6	0.0	0.00
31	1.7	0.0	.14
1	1.6	0.0	0.00
2	1.6	0.0	.03
3	309.2	114.0	2.86
4	48.9	4.1	.12
5	16.7	.9	0.00
6	12.6	.4	.03
7	13.1	.6	.42
8	27.0	1.0	.12
9	12.6	.8	.12
10	6.8	.7	0.00
11	5.5	.8	0.00
12	4.6	.7	0.00
13	4.0	.5	0.00
14	3.6	.2	.03
15	470.0	257.0	2.14
16	43.0	5.1	.00
17	13.3	1.5	.01
18	10.1	.9	0.00
19	43.2	.7	.76
20	117.5	10.0	.05
21	12.5	1.8	.06
22	7.5	1.0	0.00
23	6.2	.9	0.00
24	5.3	1.3	.11
25	4.6	1.7	0.00
26	4.0	1.4	0.00
27	3.6	1.4	0.00
28	3.4	1.3	0.00
29	3.1	1.1	0.00
30	3.0	1.1	.11

MULTIYEAR STATISTICAL SUMMARY

FLOWPOINT = COUNCIL CR WATER YEARS 1959 TO 1962

MONTH	SIMULATED MEAN	OBSERVED MEAN	BIAS (SIM MEAN -OBS MEAN)	PERCENT BIAS	1ST MOMENT (SIM)-1ST MOMENT(OBS)	MAXIMUM ERROR	STANDARD ERROR	PERCENT STANDARD ERROR	CORREL. COEFF	BEST FIT LINE OBS = A + B *SIM A	B
OCTOBER	2.322	3.186	-.865	-27.132	1.016	-147.587	4.777	145.927	.985	-1.056	1.827
NOVEMBER	.327	.345	-.018	-5.337	.283	-6.275	.569	164.981	.949	-.077	1.293
DECEMBER	.247	.237	.011	4.575	-.822	1.574	.135	57.009	.975	.050	.755
JANUARY	.057	.082	-.025	-30.948	-.767	1.481	.065	78.945	.382	.074	.142
FEBRUARY	.168	.158	.010	6.256	2.179	3.040	.317	200.702	.802	.021	.818
MARCH	.077	.203	-.126	-51.950	1.257	-3.388	.378	186.320	.456	.133	.911
APRIL	.053	.171	-.118	-58.930	-.781	-4.493	.423	248.069	.206	.125	.664
MAY	.475	.886	-.411	-46.412	4.531	-27.509	2.684	303.006	.490	.188	1.470
JUNE	.869	1.267	-.398	-31.436	1.290	-12.069	2.091	165.053	.031	.320	1.090
JULY	1.777	1.148	.629	54.759	-1.135	15.656	2.251	196.131	.032	-.112	.709
AUGUST	.412	.252	.160	63.332	4.985	9.920	1.269	503.079	.591	-.009	.634
SEPTEMBER	1.608	1.218	.390	31.987	-3.015	16.897	2.462	202.103	.909	-.252	.914
WATER YEAR	.703	.767	-.064	-8.390	81.935	-147.587	2.939	382.907	.940	-.351	1.591

NOTE...SUM OF (SIM-OBS)2 = 25809......ROOT MEAN OF SUM OF (SIM-OBS)**2 = 4.203...**

FLOW INTERVAL	NUMBER OF CASES OBSERVED	OBSERVED MEAN	SIMULATED MEAN	BIAS	PERCENT BIAS	MAXIMUM ERROR	STANDARD ERROR	PERCENT STANDARD ERROR	CORREL. COEFF	BEST FIT LINE OBS = A + B *SIM A	B
0 - 1	1369	.105	.191	.086	82.640	9.920	.132	126.653	.330	.090	.074
1 - 1	4	1.076	2.332	1.256	116.606	2.907	.015	1.361	-.602	1.106	-.013
1 - 1	9	1.290	1.727	.437	33.874	2.230	0.000	0.000	1.000	1.279	.006
1 - 2	14	1.877	2.215	.338	17.982	5.417	.273	14.548	-.236	1.951	-.033
2 - 4	22	3.238	4.357	1.119	34.550	15.656	.528	16.309	-.180	3.336	-.022
4 - 7	15	5.195	4.417	-.778	-14.979	7.249	.930	18.059	-.215	5.459	-.060
7 - 11	12	8.750	7.674	-1.076	-12.297	18.091	1.483	16.945	.201	8.436	.041
11 - 19	6	15.758	11.414	-4.344	-27.568	-12.069	1.924	12.211	.419	14.359	.123
19 - 30	5	26.034	18.191	-7.843	-30.126	-27.509	3.863	14.838	-.163	27.055	-.056
ABOVE 30	5	91.407	59.249	-32.158	-35.181	-147.587	20.332	22.244	.983	-29.333	2.038
ABOVE 4	43	20.109	14.280	-5.829	-28.988	-147.587	14.598	72.597	.948	-4.300	1.709

CHAPTER VI

CONCLUSION

The derivation of the initial NWSRFS soil moisture accounting parameters by the use of SCS estimated engineering soil properties is a practical and useful solution. The SCS soil properties are readily available and the NWSRFS Verification computer program can quickly check the validity of the derived parameters. The derivation method will be readily adaptable to a computer solution, hence the total parameter set could easily be computed. It has been found that the computed zone parameters have a definite bias toward being larger than the optimum value, hence all values should always be evaluated as to rationality. The derived parameters will be closely related to the physical characteristics of the basin and the substitution of the parameters to basins with similar characteristics should be valid. The use of this procedure should result in a considerable savings in man-hours and computer time.

As operational rainfall measurements from radar, automated gages and high density networks come into being, the need for procedures to delineate changes in runoff producing characteristics will be in demand and SCS soil properties will be available for as small an areal distribution as is required. The procedure for parameter derivations presented in this thesis could be the answer.

Recommendations for Future Work

Since there are many possible combinations of soil characteristics within a soil profile as well as aerally across a basin, the derivation procedures should be tested on a large number of widely scattered basins. Adjustments and additional variations in the rules for the computation of parameters will most likely be needed. An investigation of soil properties available from other sources should be pursued. After the procedures are widely tested and finalized, a computer program to reference a data file of Soil Conservation Service soil properties for all soils in a region will be a step toward greater efficiency.

SELECTED BIBLIOGRAPHY

1. Burnash, R.J.C., R. L. Ferrel and R. A. McGuire, A Generalized Streamflow Simulation System, Conceptual Modeling for Digital Computers. U. S. Department of Commerce, National Weather Service and State of California, Department of Water Resources (1973).

2. George, E. J., R. A. Reed, E. W. Johnson and A. E. Ferber, "Shelterbelts and Windbreaks." Soil-The 1957 Yearbook of Agriculture, United States Government Printing Office, pp. 715-721, Washington, D.C. (1957).

3. Green, D. W., H. Dabri, C. F. Weinang and R. Prill, "Numerical Modeling of Unsaturated Groundwater Flow and Comparison of the Model to a Field Experiment." Water Resources Research, Vol. 6, No. 3, pp. 862-874 (1970).

4. Hanks, R. J., A. Klute and E. Brester, "A Numerical Method for Estimating Infiltration, Redistribution, Drainage and Evaporation of Water from Soil." Water Resources Research, Vol. 5, No. 5, pp. 1064-1069 (1969).

5. "Hydrology." SCS National Engineering Handbook, Soil Conservation Service, United States Department of Agriculture (1964).

6. Linsley, R. K., M. A. Kohler and J.L.H. Paulhus, Hydrology for Engineers. McGraw-Hill Cook Company, Inc., New York (1958).

7. National Weather Service River Forecast System, Forecast Procedures. NOAA Technical Memorandum NWS Hydro-14, United States Department of Commerce (1972).

8. Peck, Eugene L., Catchment Modeling and Initial Parameter Estimation for the National Weather Service River Forecast System, NOAA Technical Memorandum NWS Hydro-31, United States Department of Commerce (1976).

9. Richard, L. A., and S. J. Richards, "Soil Moisture." Soil-The 1957 Yearbook of Agriculture, United States Government Printing Office, pp. 49-66, Washington, D.C. (1957).

10. Swafford, B., Soil Survey of Garfield County, Oklahoma, United States Department of Agriculture, Soil Conservation Service (1967).

11. Todd, D. K., Ground Water Hydrology, John Wiley and Sons, Inc., New York (1960).

12. Walton, W. C., Groundwater Resource Evaluation, McGraw-Hill Book Company, Inc., New York (1970).

APPENDIX

COMPUTER PROGRAM LISTING OF NWSRFS SOIL
MOISTURE ACCOUNTING SUBROUTINE

```
      SUBROUTINE LAND(ID1,IP1,ID2,IP2,MOSM,ICOUNT,IRG)
C
C
C**********************************************************************
C
C
C      NWSRFS SOIL MOISTURE ACCOUNTING PROCEDURE
C      BASED ON SOIL MOISTURE ACCOUNTING IN THE SACRAMENTO MODEL
C
C
C**********************************************************************
C
C
C      LAND VARIABLES
C
      REAL LZTWC,LZFPC,LZFSC,LZTWC1,LZFPC1,LZFSC1,LZTWM,LZFPM,LZFSM,LZPK
     1,LZSK
C
      DIMENSION MOSM(8,2),EPDIST(4)
C
C GENERAL PROGRAM VARIABLES
C
      INTEGER ROUTE,SNOW,SNOWA,YRIN,YR1,STORE,YEAR,PLT6HR,SAVEFW,COMPAR,
     1PTEST,PLOT,CTEST,SIXIN,OBSER,STDA,STP6,YR2,STAT,PEG
      REAL INFRO
C
      COMMON /G/ MONTH,MOIN,LAST,ROUTE,NGAGES,SNOW,SNOWA(12),YRIN,IREGS,
     1YR1,NPTS,STORE,BASIN(20),YEAR,SSF(3,12),SPF(3,12),PLT6HR,SAVEFW,
     2COMPAR(3),PTEST,PLOT(3),LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),
     3PEG(5),STAT,YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),
     4IYEAR1(3),IPT,METRIC(3),NO24,NO6,NPTSOP,IO24IN(3),IO6IN(3)
C
C  SOIL MOISTURE ACCOUNTING VARIABLES.
C
      COMMON/SOIL/BAL(5),BL(5,18),VL(5,6),SL(5,10),E(5,12,31)
C
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
C
      COMMON /TSID/ AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(3,5),FPID(3,3),
     1O24ID(3,3),O6ID(3,3),UPEWID(3,3),PXID(5,3)
C
C BASIC DATA ARRAYS
C
      COMMON /BD/ PX(5,4,31),TA(5,4,31),PE(3,31),RO(5,4,31),OFW6(3,4,31)
     1,SFW6(3,4,31),UFW6(3,4,31),OFW24(3,31)
C
C SNOW AND LAND COMMON BLOCK
C
      COMMON/SL/COVER(5,31),EFC(5),PXADJ(5),NTAG,NWEG
      DATA EPDIST/0.0,0.33,0.67,0.0/
C
C**********************************************************************
C
C
      IPRINT=0
      IF((MONTH.EQ.MOSM(ICOUNT,1)).AND.(YEAR.EQ.MOSM(ICOUNT,2)))IPRINT=1
      IF(IPRINT.EQ.0) GO TO 200
C
      PRINT 900,MONTH,YEAR,(ANAME(IRG,I),I=1,5)
  900 FORMAT(1H1,33HSIX-HOUR SOIL MOISTURE OUTPUT FOR,1X,I2,1H/,I4,2X,5A
     14,20X,39HUNITS OF ALL QUANTITIES ARE MILLIMETERS)
C
      PRINT 902
  902 FORMAT(1H ,5X,19HPERC IS PERCULATION,5X,31HBASEFW IS THE CHANNEL C
     1OMPONENT,5X,67HTOTAL-RO IS CHANNEL INFLOW MINUS ET FROM THE AREA D
     2EFINED BY SARVA.)
C
      PRINT 901
  901 FORMAT(1H ,3HDAY,1X,2HPD,2X,5HUZTWC,2X,5HUZFWC,2X,5HLZTWC,2X,5HLZF
     1SC,2X,5HLZFPC,2X,5HADIMC,4X,4HPERC,1X,7HIMPV-RO,2X,6HDIRECT,2X,6HS
     2UR-RO,1X,7HINTERFW,2X,6HBASEFW,1X,8HTOTAL-RO,1X,7HET-DEMD,1X,6HACT
     3-ET,2X,9HRAIN+MELT)
C
```

```
C.......................................................................
C
  200 SROT=0.0
      SIMPVT=0.0
      SROOT=0.0
      SROST=0.0
      SINTFT=0.0
      SGWFT=0.0
      SRECHT=0.0
      SETT=0.0
      SPRT=0.0
      SPET=0.0
C
C     INTIAL VALUES OF VARIABLES
C
      UZTWC=VL(IRG,1)
      UZFWC=VL(IRG,2)
      LZTWC=VL(IRG,3)
      LZFPC=VL(IRG,5)
      LZFSC=VL(IRG,4)
      ADIMC=VL(IRG,6)
      UZTWC1=UZTWC
      UZFWC1=UZFWC
C
      LZTWC1=LZTWC
      LZFPC1=LZFPC
      LZFSC1=LZFSC
C
      ADIMC1=ADIMC
C
C     INITIAL VALUES OF PARAMETERS
C
      PPADJ=PL(IRG,1)
      PEADJ=PL(IRG,2)
      UZTWM=PL(IRG,3)
      UZFWM=PL(IRG,4)
      UZK=PL(IRG,5)
      ZPERC=PL(IRG,9)
      REXP=PL(IRG,10)
      PCTIM=PL(IRG,6)
      ADIMP=PL(IRG,7)
      SARVA=PL(IRG,8)
      LZTWM=PL(IRG,11)
      LZFPM=PL(IRG,13)
      LZFSM=PL(IRG,12)
      LZPK=PL(IRG,15)
      LZSK=PL(IRG,14)
      PFREE=PL(IRG,16)
      RSERV=PL(IRG,17)
      SIDE=PL(IRG,18)
C
      WATSF=SARVA
      SARRA=0.0
C
      IF(SARVA.LE.PCTIM) GO TO 201
      WATSF=PCTIM
      SARRA=SARVA-PCTIM
C
  201 IGPE=PEG(IRG)
      EFCT=EFC(IRG)
      SAVED=RSERV*(LZFPM+LZFSM)
      PAREA=1.0-PCTIM-ADIMP
      IP6=IP1
      IDA=ID1
      GO TO 204
C
C***********************************************************************
```

```
C
C     BEGINNING OF 6 HOUR AND DAY LOOP
C
C*************************************************************************
C
  205 IF(IP6.NE.1) GO TO 210
  204 IF(IGPE.GT.0) GO TO 206
C
C     NO PE INPUT. THUS PE IS OBTAIN FROM MEAN SEASONAL CURVE.
C
      EP=E(IRG,MONTH,IDA)
      GO TO 207
C
C     DAILY PE TIME SERIES IS AVAILABLE
C
  206 EP=PE(IGPE,IDA)
      EP=EP*E(IRG,MONTH,IDA)
  207 EP=EP*PEADJ
      SPET=SPET+EP
C
      IF(SNOW.EQ.1) EP=EFCT*EP+(1.0-EFCT)*(1.0-COVER(IRG,IDA))*EP
  210 IF((SNOW.EQ.1).AND.(SNOWA(MONTH).EQ.1)) GO TO 219
      PX6 = PX(IRG,IP6,IDA)*PPADJ
      GO TO 215
C
C     IF SNOW IS BEING CONSIDERED, PXADJ HAS ALREADY BEEN APPLIED
C
  219 PX6 = PX(IRG,IP6,IDA)
  215 SPRT=SPRT+PX6
C
C     PX6 IS THE SIX HOUR RAINFALL OR SNOW COVER OUTFLOW
C
C*************************************************************************
C
C
C     EDMND IS SIX-HOUR EVAPORATION DEMAND
C
      EDMND=EP*EPDIST(IP6)
C
C.........................................................................
C
      E1=EDMND*(UZTWC/UZTWM)
      RED=EDMND-E1
C
C     RED IS RESIDUAL EVAP DEMAND
C
      UZTWC=UZTWC-E1
      E2=0.0
      IF(UZTWC.GE.0.) GO TO 220
C
C     E1 CAN NOT EXCEED UZTWC
C
      E1=E1+UZTWC
      UZTWC=0.0
      RED=EDMND-E1
      IF(UZFWC.GE.RED) GO TO 221
C
C.........................................................................
C
C     E2 IS EVAP FROM UZFWC.
C
      E2=UZFWC
      UZFWC=0.0
      RED=RED-E2
      GO TO 225
C
  221 E2=RED
      UZFWC=UZFWC-E2
      RED=0.0
C
  220 IF((UZTWC/UZTWM).GE.(UZFWC/UZFWM)) GO TO 225
```

```
C.......................................................................
C
C     UPPER ZONE FREE WATER RATIO EXCEEDS UPPER ZONE
C     TENSION WATER RATIO, THUS TRANSFER FREE WATER TO TENSION
C
      UZRAT=(UZTWC+UZFWC)/(UZTWM+UZFWM)
      UZTWC=UZTWM*UZRAT
      UZFWC=UZFWM*UZRAT
C
C.......................................................................
C
C     COMPUTE ET FROM ADIMP AREA.-E5
C
  225 E5=E1+(RED+E2)*((ADIMC-E1-UZTWC)/(UZTWM+LZTWM))
C
C.......................................................................
C
C     COMPUTE ET FROM LZTWC (E3)
C
      E3=RED*(LZTWC/(UZTWM+LZTWM))
      LZTWC=LZTWC-E3
      IF(LZTWC.GE.0.0) GO TO 226
C
C     E3 CAN NOT EXCEED LZTWC
C
      E3=E3+LZTWC
      LZTWC=0.0
C
C.......................................................................
C
  226 RATLZT=LZTWC/LZTWM
      RATLZ=(LZTWC+LZFPC+LZFSC-SAVED)/(LZTWM+LZFPM+LZFSM-SAVED)
      IF(RATLZT.GE.RATLZ) GO TO 230
C
C     RESUPPLY LOWER ZONE TENSION WATER FROM LOWER
C     ZONE FREE WATER IF MORE WATER AVAILABLE THERE.
C
      DEL=(RATLZ-RATLZT)*LZTWM
C
C     TRANSFER FROM LZFSC TO LZTWC.
C
      LZTWC=LZTWC+DEL
      LZFSC=LZFSC-DEL
      IF(LZFSC.GE.0.0) GO TO 230
C
C     IF TRANSFER EXCEEDS LZFSC THEN REMAINDER COMES FROM LZFPC
C
      LZFPC=LZFPC+LZFSC
      LZFSC=0.0
C
C.......................................................................
C
  230 ROIMP=PX6*PCTIM
C
C      ROIMP IS RUNOFF FROM THE MINIMUM IMPERVIOUS AREA.
C
      SIMPVT=SIMPVT+ROIMP
C
C      ADJUST ADIMC,ADDITIONAL IMPERVIOUS AREA STORAGE, FOR EVAPORATION.
C
      ADIMC=ADIMC-E5
      IF(ADIMC.GE.0.0) GO TO 231
C
C.......................................................................
C
C     E5 CAN NOT EXCEED ADIMC.
C
      E5=E5+ADIMC
      ADIMC=0.0
  231 E5=E5*ADIMP
C
C     E5 IS ET FROM THE AREA ADIMP.
C
      PAV=PX6+UZTWC-UZTWM
C
C     PAV IS THE PERIOD AVAILABLE MOISTURE IN EXCESS
C     OF UZTW REQUIREMENTS.
C
```

```
      IF(PAV.GE.0.0) GO TO 232
C
C     ALL MOISTURE HELD IN UZTW--NO EXCESS.
C
      UZTWC=UZTWC+PX6
      PAV=0.0
      GO TO 233
C
C      MOISTURE AVAILABLE IN EXCESS OF UZTW STORAGE.
C
  232 UZTWC=UZTWM
  233 ADIMC=ADIMC+PX6-PAV
C
C
C***************************************************************
C
      SBF=0.0
      SSUR=0.0
      SIF=0.0
      SPERC=0.0
      SDRO=0.0
C
      NINC=1.0+0.2*(UZFWC+PAV)
C
C     NINC=NUMBER OF TIME INCREMENTS THAT THE SIX
C     HOUR PERIOD IS DIVIDED INTO FOR FURTHER
C     SOIL-MOISTURE ACCOUNTING.  NO ONE PERIOD
C     WILL EXCEED 5.0 MILLIMETERS OF UZFWC+PAV
C
      DINC=(1.0/NINC)*0.25
C
C     DINC=LENGTH OF EACH INCREMENT IN DAYS.
C
      PINC=PAV/NINC
C
C     PINC=AMOUNT OF AVAILABLE MOISTURE FOR EACH INCREMENT.
C      COMPUTE FREE WATER DEPLETION FRACTIONS FOR
C     THE TIME INTERVAL BEING USED-BASIC DEPLETIONS
C      ARE FOR ONE DAY
C
      DUZ=1.0-((1.0-UZK)**DINC)
      DLZP=1.0-((1.0-LZPK)**DINC)
      DLZS=1.0-((1.0-LZSK)**DINC)
C
C
C..............................................................
C
C
      DO 240 IC=1,NINC
C
      PAV=PINC
      ADSUR=0.0
      RATIO=(ADIMC-UZTWC)/LZTWM
      ADDRO=PINC*(RATIO**2)
      SDRO=SDRO+ADDRO*ADIMP
C
C     ADDRO IS THE AMOUNT OF DIRECT RUNOFF FROM
C     THE AREA ADIMP-SDRO IS THE SIX HOUR SUMMATION
C     COMPUTE BASEFLOW AND KEEP TRACK OF SIX-HOUR SUM.
C
      BF=LZFPC*DLZP
      LZFPC=LZFPC-BF
C
      IF (LZFPC.GT.0.0001) GO TO 234
C
      BF=BF+LZFPC
      LZFPC=0.0
C
  234 SBF=SBF+BF
      BF=LZFSC*DLZS
      LZFSC=LZFSC-BF
C
      IF(LZFSC.GT.0.0001) GO TO 235
```

```
      BF=BF+LZFSC
      LZFSC=0.0
C
  235 SBF=SBF+BF
C
C.................................................................
C
C      COMPUTE PERCOLATION-IF NO WATER AVAILABLE THEN SKIP
C
      IF((PINC+UZFWC).GT.0.01) GO TO 251
C
      UZFWC=UZFWC+PINC
      GO TO 249
C
  251 PERCM=LZFPM*DLZP+LZFSM*DLZS
      PERC=PERCM*(UZFWC/UZFWM)
      DEFR=1.0-((LZTWC+LZFPC+LZFSC)/(LZTWM+LZFPM+LZFSM))
C
C     DEFR IS THE LOWER ZONE MOISTURE DEFICIENCY RATIO
C
      PERC=PERC*(1.0+ZPERC*(DEFR**REXP))
C
C     NOTE...PERCOLATION OCCURS FROM UZFWC BEFORE PAV IS ADDED.
C
      IF(PERC.LT.UZFWC) GO TO 241
C
C      PERCOLATION RATE EXCEEDS UZFWC.
C
      PERC=UZFWC
      UZFWC=0.0
      GO TO 247
C
C     PERCOLATION RATE IS LESS THAT UZFWC.
C
  241 UZFWC=UZFWC-PERC
C
C     CHECK TO SEE IF PERCOLATION EXCEEDS LOWER ZONE DEFICIENCY.
C
      CHECK=LZTWC+LZFPC+LZFSC+PERC-LZTWM-LZFPM-LZFSM
C
      IF(CHECK.LE.0.0) GO TO 242
      PERC=PERC-CHECK
      UZFWC=UZFWC+CHECK
  242 SPERC=SPERC+PERC
C
C     SPERC IS THE SIX HOUR SUMMATION OF PERC
C
C.................................................................
C
C     COMPUTE INTERFLOW AND KEEP TRACK OF SIX HOUR SUM.
C     NOTE...PAV HAS NOT YET BEEN ADDED.
C
      DEL=UZFWC*DUZ
      SIF=SIF+DEL
      UZFWC=UZFWC-DEL
C
C.................................................................
C
C     DISTRIBE PERCOLATED WATER INTO THE LOWER ZONES
C     TENSION WATER MUST BE FILLED FIRST EXCEPT FOR THE PFREE AREA.
C
  247 VPERC=PERC
      PERC=PERC*(1.0-PFREE)
C
      IF((PERC+LZTWC).GT.LZTWM) GO TO 243
      LZTWC=LZTWC+PERC
      PERC=0.0
      GO TO 244
C
  243 PERC=PERC+LZTWC-LZTWM
      LZTWC=LZTWM
C
C      DISTRIBUTE PERCOLATION IN EXCESS OF TENSION
C      REQUIREMENTS AMONG THE FREE WATER STORAGES.
C
```

```
  244 PERC=PERC+VPERC*PFREE
      IF(PERC.EQ.0.0) GO TO 245
      HPL=LZFPM/(LZFPM+LZFSM)
C
C     HRL IS THE RELATIVE SIZE OF THE PRIMARY STORAGE
C     AS COMPARED WITH TOTAL LOWER ZONE FREE WATER STORAGE.
C
      RATLP=LZFPC/LZFPM
      RATLS=LZFSC/LZFSM
C
C     RATLP AND RATLS ARE CONTENT TO CAPACITY RATIOS. OR
C     IN OTHER WORDS, THE RELATIVE FULLNESS OF EACH STORAGE
C
C
      PERCP=PERC*((HPL*2.0*(1.0-RATLP))/((1.0-RATLP)+(1.0-RATLS)))
      PERCS=PERC-PERCP
C
C     PERCP AND PERCS ARE THE AMOUNT OF THE EXCESS
C     PERCOLATION GOING TO PRIMARY AND SUPPLEMENTAL
C      STORGES,RESPECTIVELY.
C
      LZFSC=LZFSC+PERCS
C
      IF(LZFSC.LE.LZFSM) GO TO 246
      PERCS=PERCS-LZFSC+LZFSM
      LZFSC=LZFSM
C
  246 LZFPC=LZFPC+(PERC-PERCS)
C
C.................................................................
C
C      DISTRIBUTE PAV BETWEEN UZFWC AND SURFACE RUNOFF.
C
  245 IF(PAV.EQ.0.0) GO TO 249
C
C     CHECK IF PAV EXCEEDS UZFWM
C
      IF((PAV+UZFWC).GT.UZFWM) GO TO 248
C
C     NO SURFACE RUNOFF
C
      UZFWC=UZFWC+PAV
      GO TO 249
C
C.................................................................
C
C     COMPUTE SURFACE RUNOFF AND KEEP TRACK OF SIX HOUR SUM
C
  248 PAV=PAV+UZFWC-UZFWM
      UZFWC=UZFWM
      SSUR=SSUR+PAV*PAREA
      ADSUR=PAV*(1.0-ADDRO/PINC)
C
C     ADSUR IS THE AMOUNT OF SURFACE RUNOFF WHICH COMES
C     FROM THAT PORTION OF ADIMP WHICH IS NOT
C     CURRENTLY GENERATING DIRECT RUNOFF.  ADDRO/PINC
C     IS THE FRACTION OF ADIMP CURRENTLY GENERATING
C     DIRECT RUNOFF.
C
      SSUR=SSUR+ADSUR*ADIMP
  249 ADIMC=ADIMC+PINC-ADDRO-ADSUR
C
  240 CONTINUE
C
C.................................................................
C
C     END OF INCREMENTAL DO LOOP.
C
C
C*****************************************************************
C
```

```
C       COMPUTE SUMS AND ADJUST RUNOFF AMOUNTS BY THE AREA OVER
C       WHICH THEY ARE GENERATED.
C
        EUSED=E1+E2+E3
C
C       EUSED IS THE ET FROM PAREA WHICH IS 1.0-ADIMP-PCTIM
C
        SIF=SIF*PAREA
C
C       SEPARATE CHANNEL COMPONENT OF BASEFLOW
C       FROM THE NON-CHANNEL COMPONENT
C
        TBF=SBF*PAREA
C
C       TBF IS TOTAL BASEFLOW
C
        BFCC=TBF*(1.0/(1.0+SIDE))
C
C       BFCC IS BASEFLOW, CHANNEL COMPONENT
        BFNCC=TBF-BFCC
C
C       BFNCC IS BASEFLOW,NON-CHANNEL COMPONENT
C
C
C.......................................................................
C
C       ADD TO MONTHLY SUMS.
C
        SINTFT=SINTFT+SIF
        SGWFT=SGWFT+BFCC
        SRECHT=SRECHT+BFNCC
        SROST=SROST+SSUR
        SRODT=SRODT+SDRO
C
C
C       COMPUTE TOTAL CHANNEL INFLOW FOR THE SIX-HOUR PERIOD.
C
        TCI=ROIMP+SDRO+SSUR+SIF+BFCC
C
C       COMPUTE E4-ET FROM STREAM SURFACES AND RIPARIAN VEGETATION.
C
        E4=EDMND*WATSF+(EDMND-EUSED)*SARRA
C
C       SUBTRACT E4 FROM CHANNEL INFLOW
C
        TCI=TCI-E4
        IF(TCI.GE.0.0) GO TO 250
        E4=E4+TCI
        TCI=0.0
C
C       COMPUTE TOTAL EVAPOTRANSPIRATION-TET
C
  250   EUSED=EUSED*PAREA
        TET=EUSED+E5+E4
        SETT=SETT+TET
C
C
C.......................................................................
C
        RO(IRG,IP6,IDA) = TCI
C
C.......................................................................
C
        SROT=SROT+TCI
C
C        PRINT SIX-HOUR ACCOUNTING VALUES IF REQUESTED.
C
        IF(IPRINT.EQ.1) PRINT 903,IDA,IP6,UZTWC,UZFWC,LZTWC,LZFSC,LZFPC,AD
       1IMC,SPFRC,ROIMP,SDRO,SSUR,SIF,BFCC,TCI,EDMND,TET,PX6
  903   FORMAT(1H ,2I3,6F7.1,7F8.2,3F8.1)
C
        IF((IDA.EQ.ID2).AND.(IP6.EQ.IP2)) GO TO 270
        IP6=IP6+1
C
```

```
      IF(IP6.LE.4) GO TO 205
C
      IP6=1
      IDA=IDA+1
      GO TO 205
C
C
C*********************************************************************
C
C       END OF SIX HOUR AND DAY LOOP
C
C*********************************************************************
C
  270 IF(IRG.NE.NGAGES) GO TO 271
      IF((IPRINT.EQ.1).AND.(ICOUNT.LT.8)) ICOUNT=ICOUNT+1
  271 IPRINT=0
C
C
C     COMPUTE MONTHLY WATER BALANCE FOR AREAL SOIL MOISTURE ACCOUNTING.
C
      BAL(IRG)=(UZTWC+UZFWC+LZTWC+LZFPC+LZFSC-UZTWC1-UZFWC1-LZTWC1-LZFPC
     11-LZFSC1)*PAREA+(ADIMC-ADIMC1)*ADIMP+SROT+SRECHT+SETT-SPRT
C
C
C....................................................................
C
      SL(IRG,1)=SROT
      SL(IRG,2)=SIMPVT
      SL(IRG,3)=SRODT
      SL(IRG,4)=SROST
      SL(IRG,5)=SINTFT
      SL(IRG,6)=SGWFT
      SL(IRG,7)=SRECHT
      SL(IRG,8)=SPRT
      SL(IRG,9)=SPET
      SL(IRG,10)=SETT
      VL(IRG,1)=UZTWC
      VL(IRG,2)=UZFWC
      VL(IRG,3)=LZTWC
      VL(IRG,5)=LZFPC
      VL(IRG,4)=LZFSC
      VL(IRG,6)=ADIMC
C
C
      RETURN
C
      END
```

VITA

Bobby Lloyd Armstrong

Candidate for the Degree of

Master of Science

Thesis: SELECTION OF INITIAL SOIL MOISTURE ACCOUNTING PARAMETERS FROM SOIL PROPERTIES FOR A CONCEPTUAL RUNOFF MODEL

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Wichita Falls, Texas, July 9, 1937, the son of Mr. and Mrs. Robert W. Armstrong, married to Sue Frances Black, the father of Elizabeth Sue Armstrong, Katherine Ann Armstrong, and Robert Lloyd Armstrong.

Education: Graduated from Wichita Falls Senior High, Wichita Falls, Texas, in 1955; received a Bachelor of Science Degree in Geology from Midwestern University in 1959; subsequently attended New Mexico Institute of Mining and Technology, Odessa College, and Texas Christian University; completed requirements for the Master of Science Degree at Oklahoma State University, May, 1977.

Professional Experience: Employed as a Petroleum Geologist from 1960 to 1963 with an oil company; employed in meterology with the National Weather Service from 1963 to 1968; when assigned as a Hydrologist with the National Weather Service River Forecast Center in Fort Worth, Texas, until 1974, when assigned as the Procedure Development Hydrologist at the National Weather Service River Forecast Center in Tulsa Oklahoma, where presently employed.

Professional Organizations: Member of Association of Engineering Geologists.