A STOCK POND SIMULATION MODEL
FOR CHAPARRAL WATERSHEDS IN ARIZONA

by

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ABSTRACT

A previously developed methodology to model the hydrologic performance of stock ponds is modified and tested using data from Arizona chaparral watersheds. The modified method uses stochastic computer models to generate time series' of daily precipitation and temperatures, then transforms this synthetic data into daily streamflow using a soil moisture accounting model. The streamflow model, called a Generalized Streamflow Simulation System, is used to simulate the long "baseflow" recessions typical of chaparral watersheds. Generated streamflow is routed through a set of standard stock ponds to yield statistics and probability distributions for the following annual pond performance criteria: runoff retention, spillage, and pond dry days.

A case study of pond performance on a chaparral watershed is performed using the calibrated simulation model. Simulation results are discussed in the context of previous case studies for other areas of Arizona. Simulation results, computer program listings, and sample outputs are included in the report.

CHAPTER ONE

INTRODUCTION

Stock ponds are small, earth-dam reservoirs built to provide water for livestock. In Arizona, stock ponds generally are built in ephemeral channels of small rangeland watersheds. The quantity of runoff water retained by these ponds varies considerably from year to year, and is difficult to predict.

In 1982, the Arizona Department of Water Resources, the U.S. Forest Service, and the Salt River Project asked the University of Arizona to develop methods for predicting the effect of stock ponds on downstream water yield. The first phase of the project resulted in the development of PONDS, a computer model to simulate the hydrologic performance of stock ponds on a daily basis (Almestad, 1984).

The PONDS model uses stochastic models to simulate daily precipitation and temperature data, a modified U.S. Soil Conservation Service (SCS) method to create daily runoff events, and a pond routing model which utilizes the conservation of mass principle. Model output is statistics on pond retention, pond spillage, and pond dry days for a variety of standard pond shapes, sizes, and seepage rates, as well as various sizes for the contributing watershed.

It was suggested by the project sponsors that the PONDS model be calibrated and tested with data from three different areas of Arizona to demonstrate its versatility, and to provide initial estimates of stock pond performance on watersheds of various cover types. The model was first tested using precipitation and runoff data from a pinyon-juniper area of the Beaver Creek Experimental Watersheds in northern Arizona (Almestad, 1983). Subsequently, the model was recalibrated and tested using data from the Walnut Gulch Experimental Watershed in semidesert grassland at Tombstone, Arizona (Kiyose, 1984).

This study describes the development, calibration, and testing of POND3, a version of the PONDS model designed for use in chaparral zone watersheds in Arizona.

Objectives

The objectives of this study are: to modify the PONDS model for use in the chaparral cover type in Arizona; to calibrate and test the revised model, hereafter called POND3, using precipitation, temperature, and streamflow data from experimental watersheds in the chaparral zone; and to report and discuss the results of stock pond simulations using the calibrated POND3 model.

The original PONDS model was developed primarily for use in the adjudication of surface water rights, and secondarily as an aid in stock pond design. The POND3 model is designed for the same uses, and, as such, retains the structure and operational method as the original model. The input requirements for operation of POND3 are limited to records of daily precipitation and maximum temperatures. Model output is a series of probability statements and statistics concerning three pond performance criteria:

1) Pond retention, or the volume of runoff withheld from downstream flow by the pond. Retention is defined as water lost to evaporation, seepage, and livestock consumption while in the pond.

2) Pond spillage, or the volume of runoff water which spills over the dam or pond spillway and enters downstream flow.

3) Dry days, or days on which the pond is empty. Dry days are counted on a monthly and an annual basis, and serve mainly as an aid in stock pond design.

Approach

The approach of the POND3 model is to stochastically simulate a series of daily streamflow volumes, route the flows through a hypothetical stock pond, and then statistically evaluate the pond's performance in terms of retention, spillage, and dry days. Simulation is used because existing runoff records for rangeland watersheds in Arizona are too few and too short to permit a useful evaluation of stock pond impacts on surface water regimes. Furthermore, runoff records which do exist cannot be expected to repeat themselves, and therefore do not serve as a good basis for future predictions.

In the POND3 computer program a stochastic precipitation submodel is used to generate daily precipitation input to a deterministic streamflow generation submodel. Direct stochastic simulation of small watershed runoff flows is not feasible, due to the limitations mentioned above, but stochastic simulation of daily precipitation, and its use as input to a runoff model is well precedented in Arizona (see Fogel,1981, for a review).

The POND3 model uses the same stochastic precipitation submodel as the original PONDS program. The main modification in POND3 is the insertion of a more complex streamflow generation submodel in place of the SCS formula. The new streamflow generation model is necessary in order to effectively simulate the baseflow processes common in small chaparral watersheds.

In summary, the approach of the POND3 model is as follows:

1) to generate a time series of daily precipitation data using a stochastic, event-based model,

2) to generate a time series of daily maximum temperature data, using a simple Markovian stochastic model,

3) to transform the synthetic precipitation and temperature data into sequences of daily streamflow events using a soil moisture accounting model, and

4) to route the synthetic streamflow through a standard stock pond on a daily basis, and tabulate statistics on retention, spillage, and dry days. The same synthetic streamflow sequence is routed through a variety of different standard pond sizes and pond types for the purposes of comparison.

Each of the tasks described above is accomplished with a separate submodel within the POND3 program. The development, calibration, and testing of each submodel is discussed in chapters two through five of this study.

Study Area

The data used in the calibration and testing of the POND3 model were collected by the Rocky Mountain Experiment Station of the U.S.D.A. Forest Service at the Whitespar Experimental Watersheds near Prescott, Arizona. The Whitespar watersheds were used here because their hydrologic data records are of excellent quality, and because their hydrologic characteristics are typical of chaparral watersheds in Arizona (Hibbert, 1983).

Twenty years of data from Whitespar Watershed A are used in calibrating and testing the precipitation, temperature, and runoff components of the model. Six years of data from Whitespar Watershed B are used in further tests of the model.

Whitespar Watershed A is 303 acres, varying in elevation from 6,000 ft. to 7,000 ft. above sea level. Watershed B is 246 acres, ranging in elevation from 5,800 ft. to 6,800 ft. Soils in this area are derived from Bradshaw granite, which intruded into Yavapai schist (Ingebo, 1972). Surface horizon soils are fine gravelly loams or gravelly sandy loam. Soil depths are from 19 to greater than 42 inches. Depth to firm bedrock is unknown. Infiltration rates are high, and there is little evidence of overland flow (Ingebo, 1972).

The vegetative cover at Whitespar is interior chaparral, a plant community dominated by evergreen, sclerophyllous shrubs (Brown, 1982). Shrub live oak (**Quercus turbinella**) and true mountain mahogany (**Cercocarpus montanus**) are the most abundant shrubs at Whitespar, and the crown cover by vertical projection is 51 percent (Ingebo, 1972).

The 23-year mean annual precipitation at Whitespar A is 25.06 inches (1958-1980). Snow is uncommon, but occasional heavy snowfalls do occur. The mean annual runoff for 20 years is 3.45 inches at Whitespar A, with a low of 0.01 inch and a high of 15.25 inches (1961-1980). Fourty-eight percent of the precipitation falls in the period December through April, while nearly all the runoff occurs during this winter period. Winter runoff at Whitespar generally occurs as continuous streamflow which begins in December or January and continues through April or May. Summer runoff consists of infrequent, small events of short duration.

The winter baseflow of small chaparral watersheds suggested their separate treatment in the PONDS stock pond modeling effort. Small watersheds with a similar elevation and annual mean precipitation in the pinyon-juniper cover type generally exhibit more snowfall, intermittent winter runoff, and significant runoff from summer storms.

The vegetative and hydrologic differences between chaparral and pinyon-juniper watersheds apparently are due to their geologic substrate. Chaparral cover type is found on deeply weathered and fractured granite, schist, diabase, and sandstone, while pinyon-juniper watersheds are generally derived from basalt, limestone, and quartzite weathered to a fine-textured, shallow regolith (Hibbert, et.al.,1974).

Chaparral vegetation covers about 3.2 million acres in Arizona, including large areas of the Prescott and Tonto National Forests and the Salt and Verde River watersheds (Hibbert, et.al.,1974). See Figure 1 for a map of chaparral vegetation in Arizona.

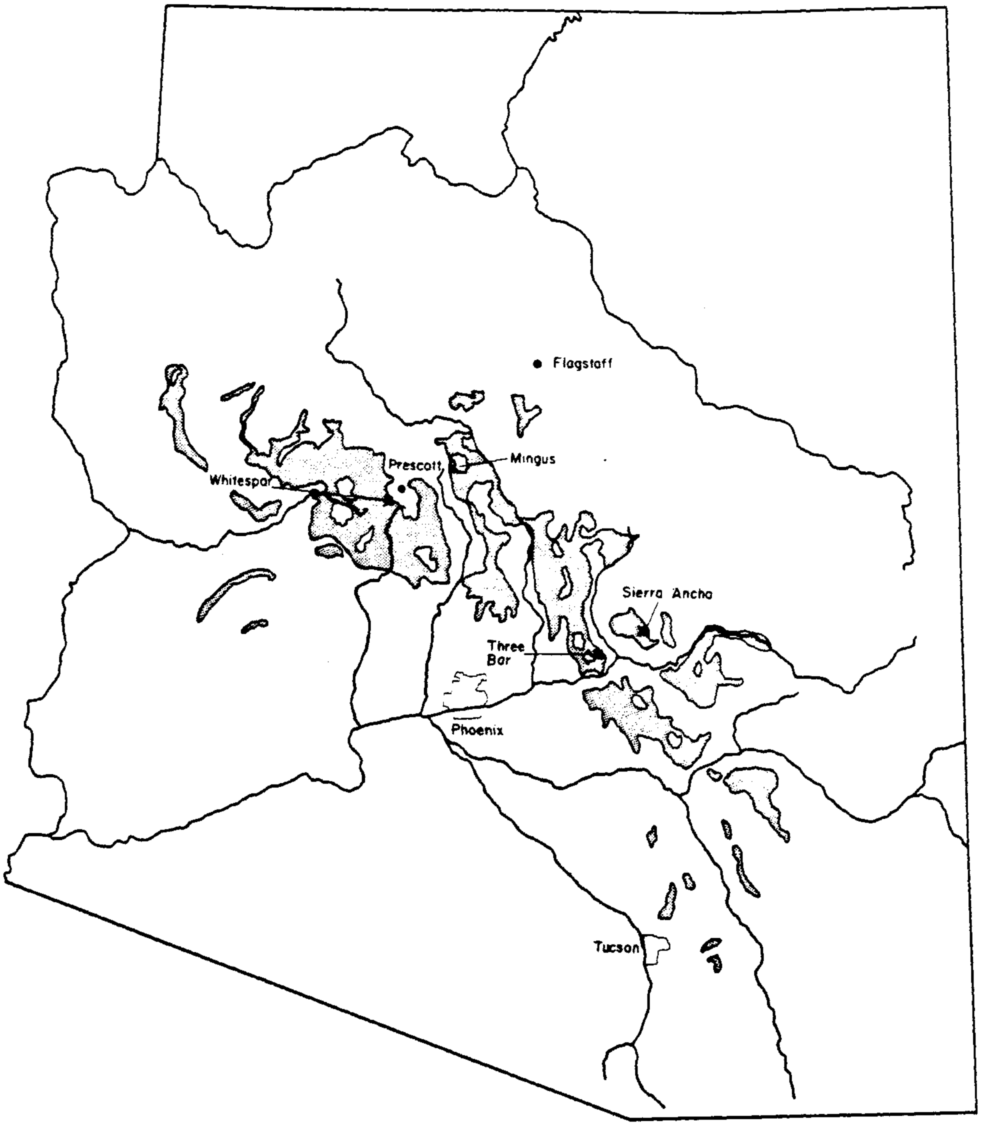


Figure 1. Distribution of Chaparral Vegetation In Arizona And Location of Some Experimental Watersheds (From Hibbert, et al., 1974).

CHAPTER TWO

PRECIPITATION MODEL

The precipitation simulation model used in PONDS, and also used in this study, is a stochastic, event-based daily model. This model actually includes two related seasonal models, one for summer precipitation and one for winter precipitation (Duckstein, Fogel, and Kisiel, 1972; Duckstein, Fogel, and Davis, 1975). These precipitation models presume that there are two different types of runoff-producing storms prevalent in the southwestern United States: convective-type summer thunderstorms and frontal-type winter storms.

In the POND3 simulation effort, summer season storms are modeled as single day events, which occur independently of each other. Winter season storms are modeled as multi-day events which occur in linked sequences. Each of these models, hereafter called the summer model and the winter model, have been used successfully in simulating Arizona precipitation patterns (Fischer, 1976; Hekman, 1977; Almestad, 1983; Kiyose, 1984).

Computer programs developed by Jones (1981) and Almestad (1983) are used for the precipitation data analysis necessary to calibrate these models. The two following sections briefly describe the data analysis, calibration, and operation of the summer and winter precipitation models.

Summer Precipitation Model

The two parameters used in simulating a sequence of summer precipitation events are: interarrival days, or the number of days between precipitation events; and the amount of precipitation per event.

The event-based method of precipitation simulation requires the development of empirical frequency distributions for these two parameters. Theoretical probability distributions are fit to these empirical distributions to calibrate the model. In actual model operation, the theoretical distributions are randomly sampled using Monte Carlo simulation to generate first, an interarrival interval, and second, a precipitation event. This process creates a realistic sequence of synthetic precipitation data for the summer season.

The data analysis procedures used in developing the necessary empirical frequency distributions, as well as in estimating parameters for the theoretical distributions, are as follows:

1) The historical precipitation record, 23 years long at Whitespar, was broken into calendar months. Monthly means for each parameter were compared separately using Students T-test at the 0.05 level. Months whose means appeared to represent the same population, or "season", were grouped together.

For example, April, May, and June were classified as one group in terms of the interarrival parameter, but April was given its own group for the precipitation per event parameter. These group designations ultimately were subjective, but were based on the T-test results and the continuity of grouped months. The reasons for grouping the data are to simplify the structure of the final simulation program, and also to increase the amount of data in each season to facilitate better fits between the empirical and theoretical distributions.

2) At this point the data from the months of December, January, February, and March were grouped together, and put aside for analysis by the winter model.

3) The grouped summer month data was reanalyzed in terms of interarrival days and precipitation per event for each group. Empirical cumulative frequency distributions for each parameter were compared to theoretical geometric, exponential, and gamma cumulative distribution functions. These theoretical functions were generated using parameters estimated, using the method of moments, from the empirical data (see Almestad, 1983, pp.59-61).

4) The Kolmogorov-Smirnov test was used to indicate the best fit between the frequency distributions of actual data and the theoretical distributions (Benjamin and Cornell, 1970).

The procedure described above constitutes the calibration of the summer model for the Whitespar data set. The monthly groupings for the Whitespar data, their best-fit theoretical distributions, and the estimated parameters for the theoretical distributions are listed in Table 1. Examples of the empirical frequency distributions and their fitted theoretical distributions for September, October, and November are shown in Figure 2 and Figure 3.

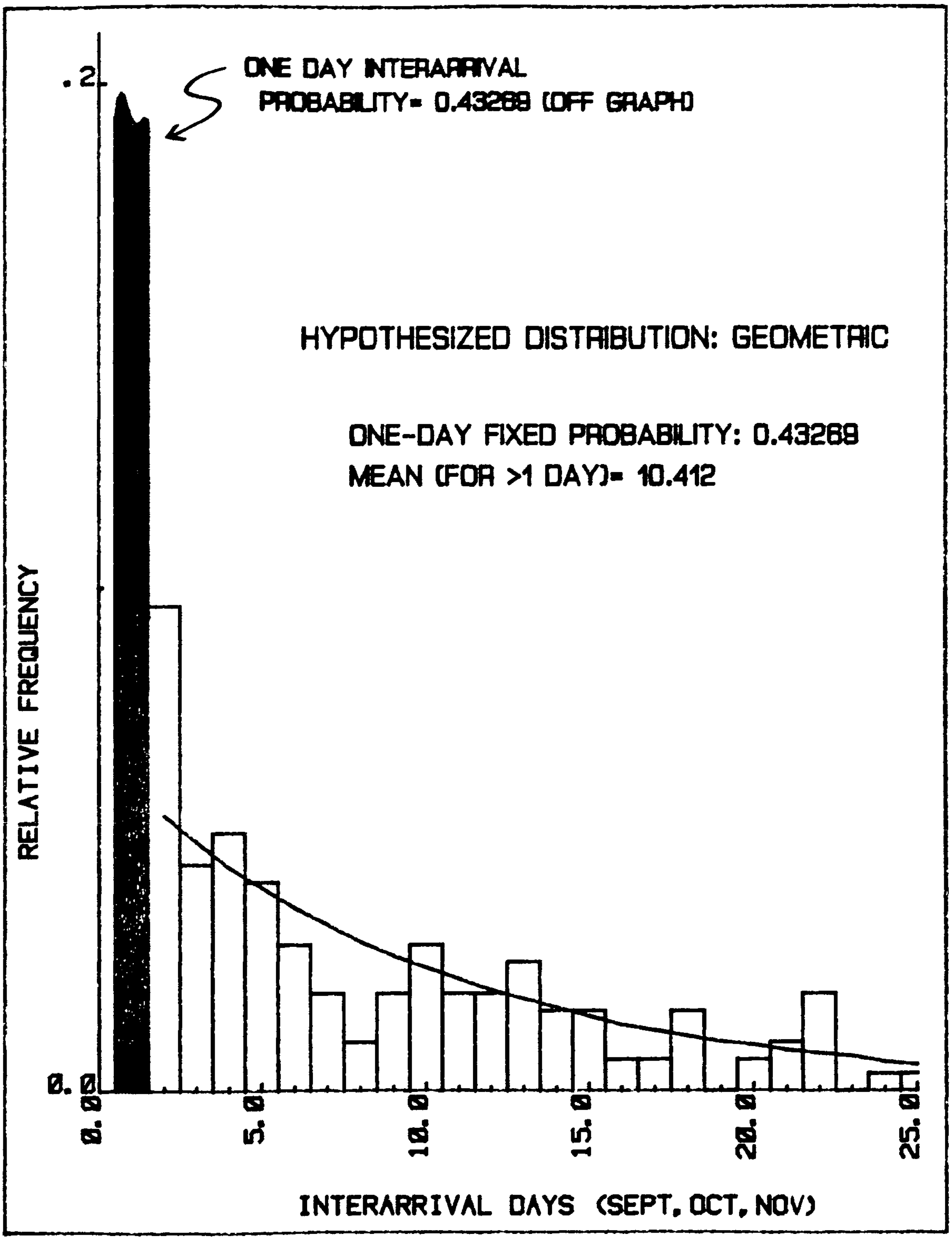


Figure 2. Frequency Distribution of Interarrival Days For September, October, and November at Whitespar, With The Theoretical Geometric Distribution Used In The Model.

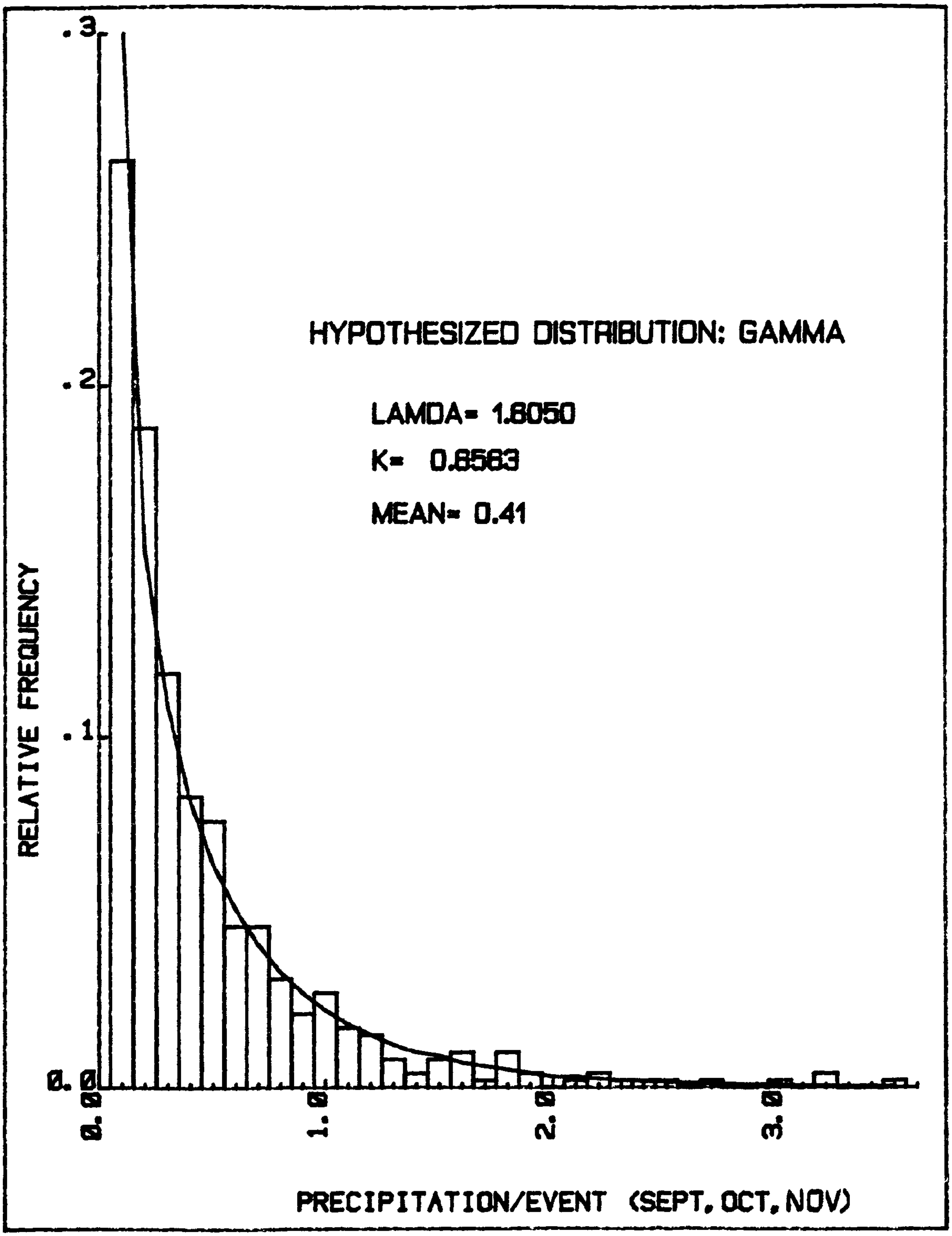


Figure 3. Frequency Distribution of Precipitation Per Event for September, October, and November at Whitespar, With The Theoretical Distribution Used In The Model.

As in the previous stock pond simulation studies some of the Whitespar interarrival day distributions were fit by fixing the probability of one-day interarrival (consecutive rainy days), and fitting a theoretical probability distribution to the remaining data (Almestad, 1983; Kiyose, 1984). The July, August interarrival day distribution also required the use of a three-parameter gamma distribution for effective curve-fitting. This type of theoretical distribution was not used in previous work on the PONDS model, but its use in modeling probability distributions in hydrology and civil engineering is well-precedented (Benjamin and Cornell, 1970).

Winter Precipitation Model

Winter precipitation was simulated using a five-parameter modification of the basic summer model (Duckstein, Fogel, et.al.,1975). This model presumes that winter storms in the mountainous southwest occur as multi-day events, called groups, which themselves occur in linked sequences. The five parameters of interest are:

1) interarrival time between sequences,
2) number of groups per sequence,
3) length of group (in days),
4) days between groups, and
5) precipitation amount per group.

The structure and operation of the model is described in detail elsewhere (Hekman, 1977; Almestad, 1983), but the essential features of the winter model are as in the summer version: theoretical probability distributions which represent each of the five parameters are sampled by

Monte Carlo simulation to create a sequence of synthetic precipitation events. The main difference from the summer model is that the additional parameters for describing interarrival days tend to create storm "persistence," or a high probability of sequential wet days, in the synthetic record.

To calibrate the winter model, each of the above parameters was analyzed in the historical precipitation record for the grouped winter months, and each empirical frequency distribution was fit with a theoretical cumulative distribution function.

The theoretical distribution types for each precipitation model parameter, together with their parameter estimates, are listed in Table 1 and Table 2.

Precipitation Model Operation and Testing

The two precipitation submodels for summer- and winter-type storms are combined in subroutine TRAB1 as an event-based stochastic model of daily precipitation at Whitespar (see Appendix A). The TRAB1 subroutine generates a one-year time series of precipitation data beginning on the first day of the water year, October 1st. The model operates by a series of Monte Carlo simulations, using uniform random numbers generated by the computer to sample the appropriate theoretical cumulative distribution function for each month and model parameter. This generates a series of interarrival days and precipitation events which conform to the probability distributions defined for each season.

Table 1. Summary of monthly groupings and parameter estimates for summer precipitation model

Parameter: Interarrival Days

Group	Months	Distribution Type	Parameter Estimates
1	4,5,6	fixed geometric	1-day fix: 0.36522 $\bar{x}$ = 12.144
2	7,8	fixed shifted gamma	1-day fix: 0.50737 shift = -0.5 λ = 0.2210 k = 0.7876
3	9,10,11	fixed geometric	1-day fix: 0.4327 $\bar{x}$ = 10.4120
		Parameter: Precipitation Per Event	
1	4	gamma	λ = 2.8746 k = 0.8921
2	5,6	gamma	λ = 5.7508 k = 1.1126
3	7	gamma	λ = 3.1380 k = 0.9032
4	8,9,10,11	gamma	λ = 1.6050 k = 0.6563

Table 2. Summary of monthly groupings and parameter estimates for winter precipitation model

Parameter	Distribution Type	Parameter Estimates
1. Days between sequences	geometric	$\bar{x}$ = 7.203
2. Groups per sequence	geometric	$\bar{x}$ = 1.589
3. Days per group	geometric	$\bar{x}$ = 2.162
4. Days between groups	geometric	$\bar{x}$ = 1.698
5. Precip. per group	gamma	λ = 0.5178 k = 0.4931

The interarrival days generated by the model are counted, so that each precipitation event is assigned to a particular date, and new seasonal parameters are invoked as the simulation progresses. If an interarrival sequence spans the transition from one seasonal group to the next, the overlapping portion of the interarrival sequence is carried into the next seasonal group. The only exception is the transition from the April, May, June group to the July, August monsoon season. In this case, the day counter is reassigned to July 1st every year as an arbitrary beginning to the summer rainy season. Otherwise, the simulated number of events for July is far below the actual. The program saves the last interarrival value each year and applies it toward the initiation of the next year's simulation.

A test was carried out to verify the calibrated model's ability to duplicate the seasonal precipitation patterns at Whitespar. Two hundred years of precipitation events were simulated, and the mean precipitation per event and mean number of events per season were calculated for each season. The results of this test are reported in Table 3, and compared to the actual precipitation statistics for 23 years at Whitespar.

The errors in simulated mean annual precipitation and mean number of events per year are each less than two percent of the actual. In winter, the most critical season for runoff generation, the errors in mean seasonal precipitation, mean precipitation per event, and mean number of events per season are four percent, three percent, and two percent respectively.

Table 3. Comparison of Actual and Simulated Precipitation Data For Whitespar Watershed "A", Prescott, Arizona.

Length of data record: 23 years (1958 - 1980)

Length of simulation: 200 years

	All Data in Inches					
	Mean Monthly PPT		Mean PPT/Event		Events/Month	
Month	Actual	Simulated	Actual	Simulated	Actual	Simulated
April	1.24	0.87	.31	.30	4.0	2.9
May	0.61	0.72	.20	.20	3.0	3.6
June	0.38	0.72	.18	.20	2.1	3.6
July	2.89	3.06	.29	.30	10.0	10.2
August	3.71	3.87	.38	.38	9.8	10.2
September	2.10	1.68	.42	.43	5.0	3.9
October	1.48	1.68	.38	.43	3.9	3.9
November	1.88	1.68	.51	.43	3.7	3.9
Winter : (Dec-March)	10.77	11.25	.95	.98	11.3* (24.3)	11.5* (24.8)
Total	25.06	25.46			65.8	67.0

* Events in winter = groups. Average length of group = 2.16 days.

Therefore, Winter days w/precip = 11.3* 2.16 = 24.3 per year.

Examination of the daily simulated precipitation record revealed a higher than expected incidence of large daily precipitation events (events of four or more inches in magnitude). This discrepancy is caused by the independent simulation of days per group and precipitation per group parameters in the winter model. An attempt to correct this unrealistic aspect of the model by simulating winter precipitation by the day rather than by the group did not succeed--instead, the 200-year simulation produced fewer large daily events than the actual 23-year record.

Simulation of precipitation per group, rather than per day, is required by the theory of the winter model (Duckstein, Fogel, et.al., 1975). Those authors suggest the development of joint probability distributions to handle this problem, but at Whitespar there is an insufficient quantity of data to develop such a distribution for days per group and precipitation per group. Therefore the unrealistic independence of these parameters in the winter model is maintained. Winter season error in precipitation per group caused by this assumption is three percent of the actual winter season mean.

CHAPTER THREE

DAILY TEMPERATURE MODEL

The POND3 streamflow generation model requires daily maximum temperatures as input in the separation of snow from rain and in the snowmelt routine. Daily maximum temperatures were simulated in this study, using the same stochastic temperature model used in previous work on the PONDS model (Almestad, 1983; Kiyose, 1984). This model, originally developed by Hekman (1977), has two components: a simulated set of 366 daily mean maximum temperatures; and a lag-one Markov model which generates a daily maximum temperature as a random but serially correlated variation from the simulated daily mean.

Temperature Model Operation and Calibration

A plot of mean daily maximum temperatures for 20 years of data at Whitespar showed the same erratic fluctuations, as noted in the Beaver Creek data (Almestad, 1983), even if plotted as five-day averages (see Figure 4). Making the assumption that a longer historical record would show progressively less fluctuation and approach a smooth curve, mean daily maximum temperatures used in this model were simulated. This approach also removes the necessity for storing 366 temperature means in the computer memory.

The equation used to simulate the mean daily maximum temperatures is a simple cosine function:

$$T_{day} = X + AMP * COS(2 \quad *(DAY-PEAK)/366) \qquad (1)$$

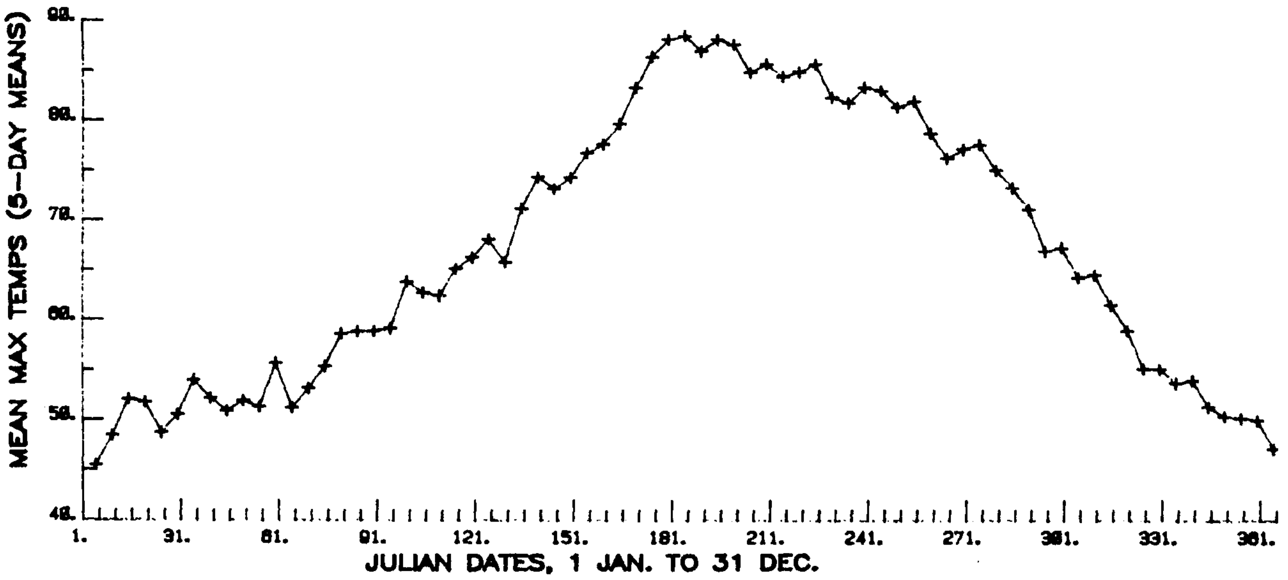


Figure 4. Mean Daily Maximum Temperatures For 20 Years of Whitespar Data,
Plotted as 5-Day Averages

where: T_{day}= the maximum temperature on a given day,
X= the mean annual maximum daily temperature,
AMP= amplitude of the mean daily maximum temperature rise above the annual mean,
DAY= day of the year (1-366, starting 1 October),
PEAK= the day of the year on which the peak amplitude of the mean daily maximum temperature curve occurs.

The program &MAXTM, written by Almestad (1983), was used to analyze the historical data, and produce the necessary estimates of X, AMP, and PEAK, as well as means, standard deviations, and skew for each day and month of the historical temperature record. The parameters AMP and PEAK are estimated in &MAXTM by testing each summer day as a possible peak, and minimizing the sum of the square error between the actual and simulated daily means.

Once the simulated cosine curve of mean daily maximum temperatures was fit to the actual data, the stochastic serial correlation model was applied. This model uses the lag-one Markov formula:

$$T_i = T_{day} + r(T_{i-1} - T_i) + G * S_j (1-r^2)^{.5}$$

where: T_{day}= simulated mean maximum temperature for that day
T_{i-1}= simulated maximum temperature for the previous day, using the October monthly mean to start the simulation,
r= the lag one serial correlation coefficient of actual daily temperature data,

G= a gamma distributed random variate (mean=0, s^2=1) with skew equal to skew of the actual data.

s_j= standard deviation of daily maximum temperatures about their monthly mean (month=j),

to generate synthetic daily temperatures.

The lag one serial correlation coefficient was calculated from the actual data using the program &CORR2 written by Almestad. The gamma distributed random variate is generated by the transformation described in Almestad (1983, p.24) given a normally distributed random number from the computer. A gamma distributed random variate is used to account for the consistently negative skew of daily maximum temperatures about their long term mean.

Temperature Model Testing

The calibrated temperature model was verified by simulating 100 years of daily maximum temperature data, and comparing the statistics of the simulated data to those of the actual data. The annual mean daily maximum temperature calculated from the simulated data was less than one percent different from the actual. Monthly mean maximum temperatures, monthly variances about the means, and the serial correlation coefficients for the simulated data also closely match the statistics for the actual data. These comparisons are presented in Table 4.

The calibrated temperature model is listed in Appendix A as subroutine JOTSS.

Table 4. Comparison of Actual and Simulated Maximum Daily Temperature Data for Whitespar Watershed "A", Prescott, Arizona

Length of data record: 20 years (1960 - 1980)

Length of simulation: 100 years

Data in Degrees Fahrenheit

	Mean		Variance	
Month	Actual	Simulated	Actual	Simulated
January	49.62	50.53	93.78	98.35
February	52.50	50.02	95.31	96.73
March	56.10	54.37	123.90	122.50
April	63.44	64.36	119.01	126.67
May	71.53	72.79	91.97	100.21
June	82.82	80.17	72.19	76.30
July	86.63	84.72	44.31	44.02
August	83.63	83.99	42.30	42.68
September	79.03	79.13	58.62	65.05
October	69.91	69.77	101.73	112.81
November	58.18	61.67	95.56	101.70
December	50.37	53.43	110.21	116.19
Annual	67.03	67.08		

Serial Correlation Coefficients (r)

	Actual	Simulated
lag 1	.772	.776
2	.602	.570
3	.470	.427
4	.367	.337

CHAPTER FOUR

STREAMFLOW GENERATION MODEL

The previous versions of the PONDS model used the SCS runoff formula, in modified form, to transform synthetic precipitation and temperature data into daily streamflow. The SCS formula could not be successfully adapted for use on chaparral watersheds at Whitespar due to its inability to simulate baseflow. Runoff from winter storms at Whitespar takes the form of long recession flows, which combine to create four to seven months of continuous streamflow. These conditions can best be simulated by a soil moisture accounting model which slowly releases soil water to streamflow over a period of days.

The criteria used in selecting a streamflow generation model for the chaparral zone were: input requirements for calibration and operation of the model must be limited to daily precipitation, daily temperatures, and daily runoff volumes; calculated parameters must be minimized; the model must be capable of accurately modeling baseflow recessions; it should be a model developed for use on wildland watersheds; and, if possible, there should be a precedent for its use in Arizona.

The model selected was the Generalized Streamflow Simulation System (GSSS) developed by the Joint State-Federal River Forecast Center in Sacramento, California (Burnash and Ferral, 1973). GSSS is a fitted-parameter conceptual model which uses a system of soil moisture storage and drainage components to simulate perennial streamflow. It claims to simulate the processes of surface flow, interflow, baseflow, percolation, and evapotranspiration in a simple, but "physically consistent" manner.

The structure and principal components of the GSSS model are illustrated in Figures 5 and 6. In brief, the model operates by routing precipitation input into a series of cascading soil moisture storage compartments, then slowly drains this soil water to form interflow and baseflow. The rate of drainage depends on the proportion of maximum soil moisture storage capacity which is currently filled, with drainage slowing as moisture is depleted.

The important parameters of the GSSS model are the sizes of the soil moisture storage compartments and their various maximum drainage rates. These parameters are estimated by inference from the historical precipitation and streamflow records. Burnash and Ferral (1973) provided excellent documentation of the methods used to make initial parameter estimates for this model.

The critical parameters of the GSSS runoff model are defined below:

Soil Moisture Storage Capacities

UZTWM= Upper zone tension water capacity
UZFWM= Upper zone free water capacity
LZTWM= Lower zone tension water capacity
LZFSM= Lower zone free supplementary water capacity
LZFPM= Lower zone free primary water capacity

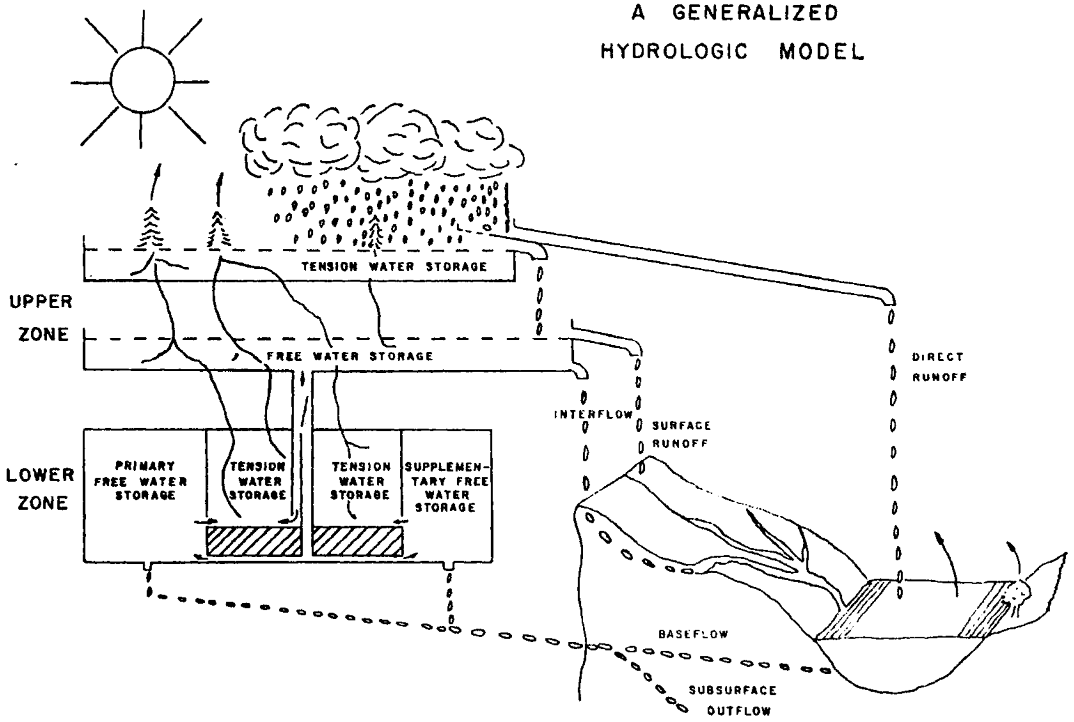


Figure 5. Conceptual Structure of The Hydrologic Cycle Used In The Generalized Streamflow Simulation System (From Burnash and Ferral, 1973)

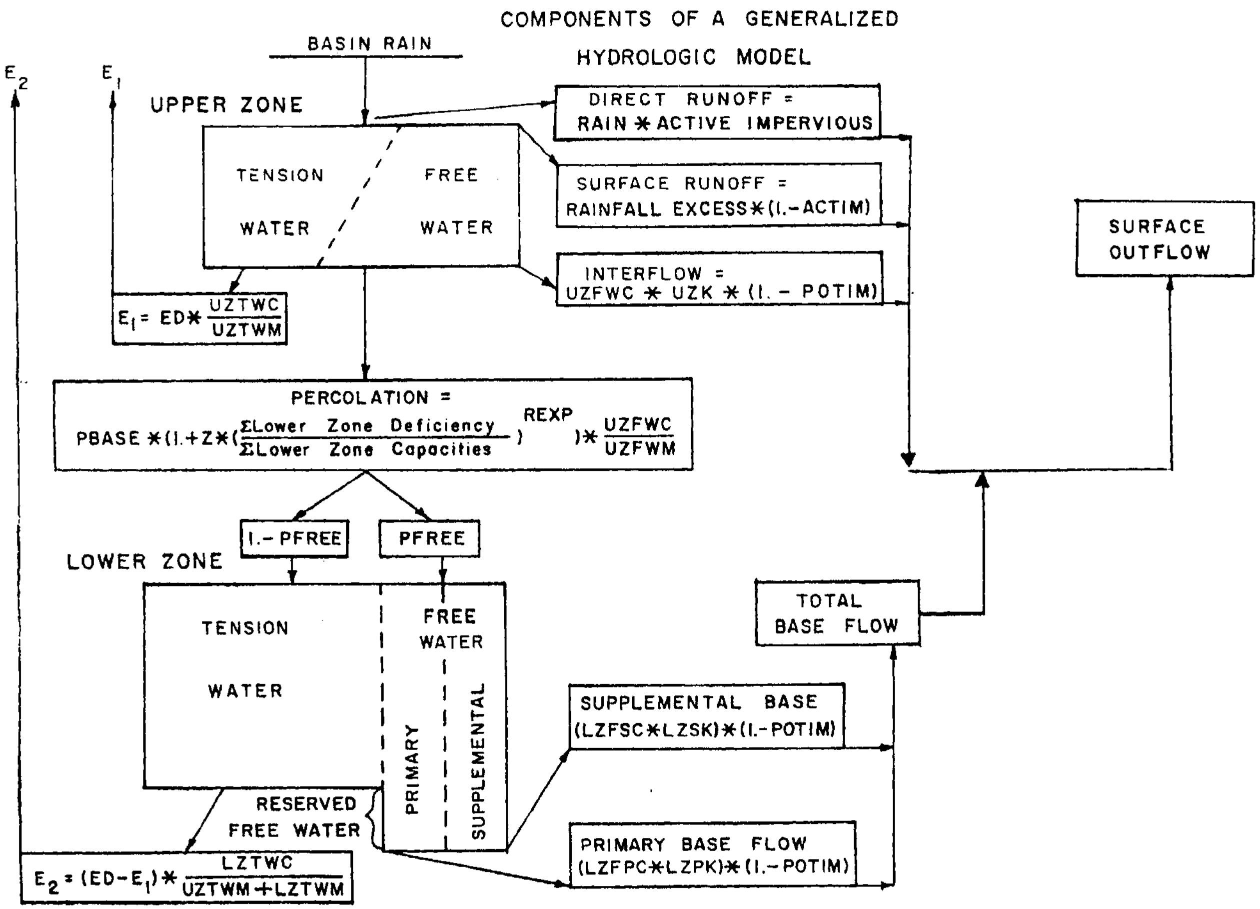


Figure 6. Principal Components of The Generalized Streamflow Simulation System As Used in POND3 (From Burnash and Ferral, 1973).

Soil Moisture Drainage Rates

UZK= Drainage rate for upper zone free water

LZSK= Drainage rate for lower zone supplementary water

LZPK= Drainage rate for lower zone primary water

Percolation Rate

ZPERC= Controls the percolation rate from upper to lower zone water

REXP= Exponent which controls change in the percolation rate

There are fourteen other parameters in the GSSS runoff algorithm, but all are either self-adjusting or unimportant in application of the model to a small watershed.

Initial Parameter Estimates for GSSS

Examples of the procedures used for making initial parameter estimates are explained here for the case of soil moisture drainage rates LZPK and LZSK, and for upper zone tension water capacity, UZTWC.

The soil moisture drainage parameters LZPK and LZSK are used to calibrate the simulated streamflow recession curves to recession curves from the historical record. These parameters are based on the assumption that long-term recession curves can be modeled as the sum of drainage from two lower zone soil moisture storage compartments, such that:

$$\text{Baseflow} = \text{LZPK}*\text{LZFPC} + \text{LZSK}*\text{LZFSC}$$

where LZFPC and LZFSC are the current contents of the lower zone soil moisture storage compartments, and the other variables are as defined above. Contents of the soil moisture storage compartments are updated daily.

The mathematical model of baseflow recession used to derive these drainage rates is a simple exponential decay function:

$$Q_t = Q_0 * K^t \qquad (1)$$

where: Q_t= the flow volume on a designated day,
Q_0= the flow volume from a previous day,
t= the time step in days,
K= an empirical decay constant.

Solving for K,

$$K = (Q_t/Q_0)^{1/t} \qquad (2)$$

The lower zone primary soil moisture drainage factor is simply:

$$LZPK = 1 - K \qquad (3)$$

An initial estimate of this parameter is derived by substituting actual runoff data for Q_t and Q_0 in equation two, then using equation three. Because these drainage rate parameters are supposed to represent maximum baseflow capacity for the watershed, the recession curves chosen for this analysis are those from the largest winter flow events in the historical record.

In this study, eight winter rainstorm flow recessions were plotted on semi-logarithmic paper and each fit with three straight lines representing early, middle, and late streamflow responses. These linear recessions were combined to form composite recession curves (see Figure 7).

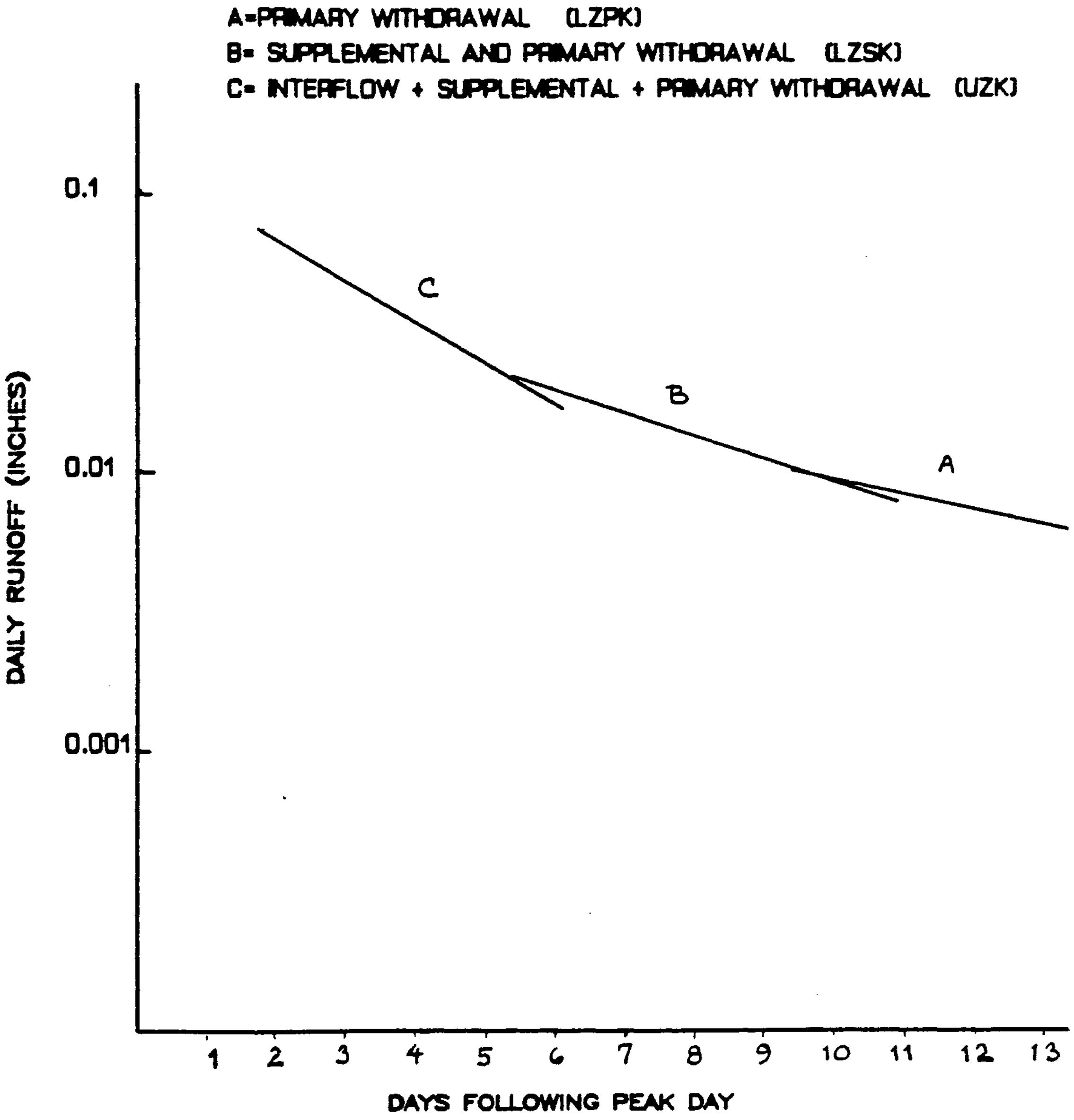


Figure 7. Composite Recession Curves Developed From Eight Winter Rainstorm Streamflow Recessions At Whitespar.

The early recession represents streamflow from upper zone soil moisture storage plus that from the two lower zone compartments, the middle zone represents streamflow from the two lower zone compartments, and the late recession curve represents streamflow from lower zone primary storage alone.

Data from the late recession curve were substituted into equations two and three to yield an initial estimate of LZPK= 0.08/day. This value was later adjusted to 0.04/day after repeated calibration trials of the model.

Estimates for the lower zone supplementary compartment drainage rate were derived by extending the late recession curve backwards underneath the middle curve, then subtracting the primary flow from the supplementary. Then equations two and three are used to calculate LZSK from the adjusted middle curve. The method is fully described in Burnash and Ferral (1973, pp. 44-45). This analysis yielded an initial estimate for LZSK of 0.40/day. This value did not need to be further adjusted during calibration runs of the model.

Comparing the initial and final estimates of the baseflow parameters LZPK and LZSK indicates that the parameter estimation methods provided by Burnash and Ferral (1973) were effective in this case.

The upper zone soil moisture storage capacity parameter UZTWM is critical for determining both the timing of initial winter runoff, and the volume of peak one-day flows. This parameter simulates an upper soil layer which absorbs precipitation or snowmelt until its moisture storage capacity is filled, then spills the excess as "surface" runoff.

Each day a certain portion of this moisture storage volume is lost to evapotranspiration, percolation, and interflow.

Initial estimation of UZTWM was made using a portion of the historical record, which includes an extended dry period followed by several consecutive days of heavy rain. The UZTWM parameter is estimated as that volume of rainfall which occurs before any appreciable peak (surface runoff) shows up in the streamflow record. On Whitespar A, the following sequence was used:

	Rain (inches)	Runoff (inches)
9 January, 1980	1.52	0.000
10 January, 1980	2.07	0.018
11 January, 1980	1.42	0.110

The sudden large flow on 11 January, 1980, indicates that soil moisture storage was full, and "surface" runoff was occurring. The estimation of UZTWM was:

Rain (day one) + Rain (day two) = UZTWM

1.52 + 2.07 = 3.59 inches= UZTWM

This is a minimum estimate for UZTWM, because it is not known what portion of the third day's rain should be added in to the estimate. After many calibration runs of the model, the UZTWM parameter was optimized at 4.2 inches, indicating that the initial estimation method was effective in this case.

The remaining soil moisture parameters in the GSSS runoff model are either estimated using similar techniques to those described above, or optimized by trial and error during successive calibration runs of the model. Suggested starting values for trial and error parameters are provided in the GSSS program documentation (Burnash and Ferral, 1973).

Evapotranspiration Estimates

The GSSS model requires as input a daily estimate for potential evapotranspiration (PET). No pan evaporation data were available for the Whitespar area, therefore the Blaney-Criddle equation was used to estimate monthly evapotranspiration demand (Dunne and Leopold, 1978). This equation estimates mean monthly potential evapotranspiration from mean monthly temperatures, the latitude of the site, and a crop factor estimated from a table:

$$PET= (0.142T^a+1.095)*(T^a+17.8)*K*D$$

where: T^a= mean air temperature for the month,

K= a crop factor chosen from a table of suggested values (K= 2.0 was used for chaparral),

D= monthly fraction of annual hours of daylight, which is provided in a table.

The results of the Blaney-Criddle method for estimating potential evapotranspiration are reported in Table 5. The total annual PET calculated by this method is 62.5 inches. Hibbert, Davis, and Scholl (1974) estimate that total annual PET in Arizona chaparral averages 45 to 60 inches. The same authors report that class A pan evaporation at Sierra Ancha, a chaparral site at 5,100 ft. elevation, is 74 inches. Using a pan to actual PET conversion of 0.7, this pan evaporation value at Sierra Ancha represents a PET of approximately 52 inches. Whitespar is 900 ft. higher in elevation than Sierra Ancha, and would be expected

Table 5. Potential Evapotranspiration Estimates for Whitespar Watersheds, Prescott, Arizona

	All Data in Inches			
Month	Blaney-Criddle Eq. Monthly	Adjustment Factor for GSSS Model	Adjusted PET Monthly	Adjusted PET Daily Fraction
January	2.0	.75	1.5	.0484
February	2.4	.75	1.8	.0638
March	3.2	.75	2.4	.0774
April	4.3	.75	3.2	.1075
May	6.1	.75	4.6	.1476
June	8.1	.75	6.1	.2025
July	10.9	.75	8.2	.2637
August	9.4	.75	7.1	.2274
September	7.9	.75	5.9	.1975
October	3.1	.75	2.3	.0750
November	2.8	.75	2.1	.0700
December	2.3	.75	1.7	.0557
Total	62.5 inches		46.9 inches	

to have a correspondingly lower PET; hence, the PET estimate using the Blaney-Criddle technique appears high.

The GSSS model suggests that weighting factors for monthly PET rates be employed to account for seasonal plant growth characteristics. The suggested monthly factors range from 0.4 to 0.9 for March and August, respectively. For this study, 0.75 was chosen as a constant weighting factor. This choice is based on several calibration runs of the model. In physical terms, it assumes that the chaparral shrubs transpire in both winter and summer, provided sufficient moisture, and that these shrubs can effectively stop transpiration in summer droughts. This assumption obviates the need for a seasonal adjustment to PET weighting factors.

Daily fractions of adjusted monthly PET estimates are used in the POND3 model. The runoff program calculates evapotranspiration loss from both upper and lower zone soil moisture storage. For each zone, daily evapotranspiration loss is calculated as the product of the adjusted PET value and a soil moisture volume to soil moisture capacity ratio.

Snow and Snowmelt Model

The GSSS runoff model has a daily moisture input parameter, PLIQ, which was adapted in this study to serve for both rain and snowmelt. Snow is uncommon in Arizona chaparral, but the presence of significant snowfall events in the historical record at Whitespar demanded methods for distinguishing snow from rain, and for melting snow.

The snow/snowmelt model used in this study depends on daily maximum temperatures for distinguishing precipitation type and for melting snow. This simple temperature-based approach was used previously in mountainous areas of Arizona by Beschta (1974), Hekman (1977), and Almestad (1983).

The snow/rain separation technique uses a designated maximum temperature variable called BASESNOW to distinguish precipitation type. Any precipitation generated on a day with maximum temperature equal to or below BASESNOW is called snow and is accumulated; otherwise the precipitation is called rain.

Calibration of the BASESNOW parameter at Whitespar was complicated by the lack of snow/rain designations in the historical precipitation record. Instead, this distinction was inferred from the data by using a graphics program to plot daily precipitation vs. daily runoff for 20 years of record. First, snowmelt peaks were identified as those winter runoff events which occurred apart from any precipitation. The precipitation events immediately preceeding "snowmelt" were classified as snow. The snowmelt events could generally be recognized by a distinctive slow rising limb on the daily flow sequence (see Figure 8).

Fifty-six "snowfall" events were tabulated. The mean maximum daily temperature on these days was 36.7 degrees Fahrenheit, with a range of 25 degrees to 44 degrees Fahrenheit. Fourty-three degrees was first chosen as a BASESNOW temperature, because it encompassed greater than an arbitrarily chosen 90 percent of the "snowfall" events. In calibration runs of the entire model, this value was later lowered to 40 degrees to account for several major winter rainstorms in the historical record when the daily temperature never rose above 41 degrees.

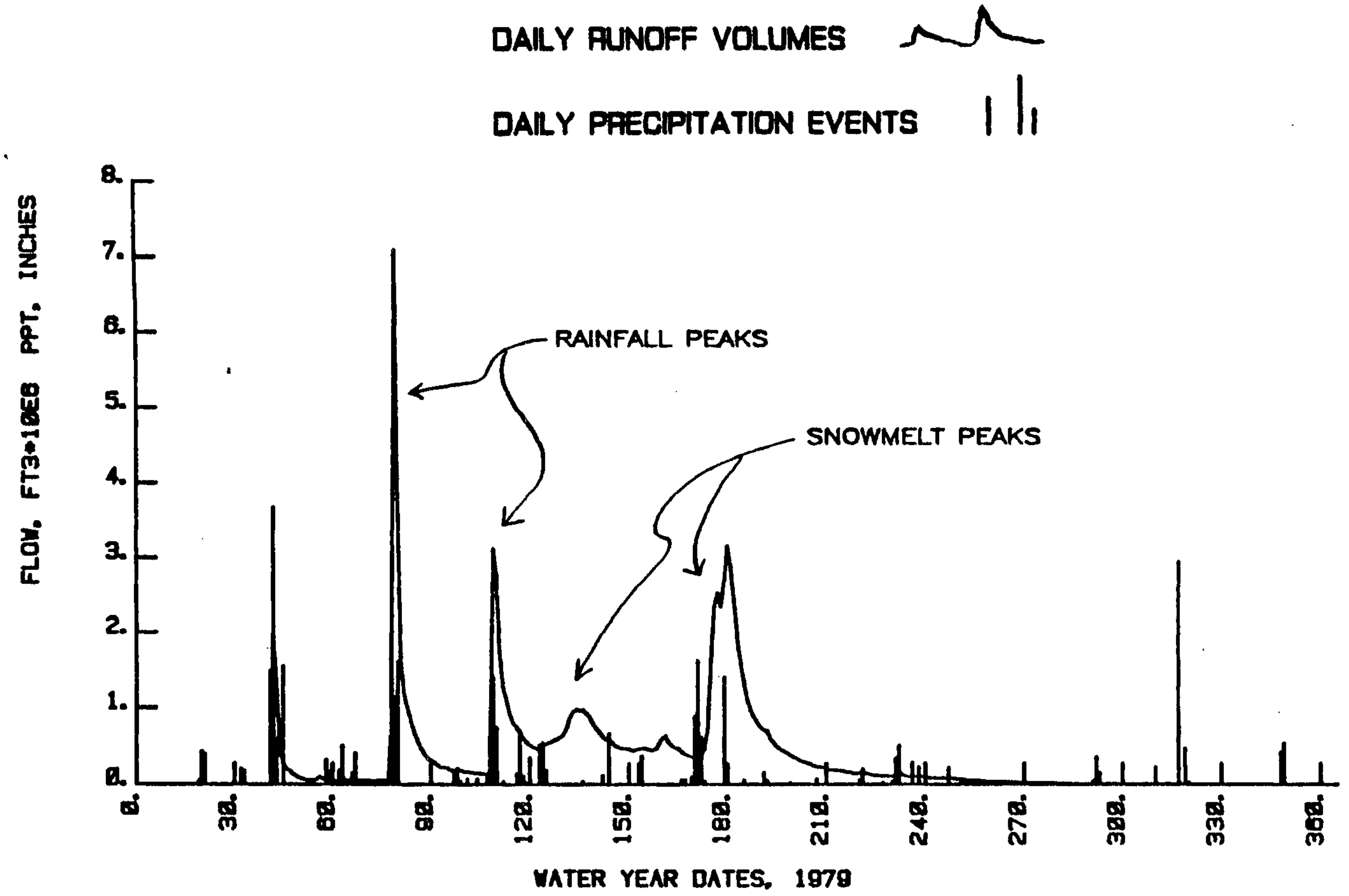


Figure 8. Rainfall-Runoff Relations at Whitespar Watershed A For The Year 1979

"Snowmelt" days in the historical record were tabulated from the graphics plots mentioned above. An array of 105 snowmelt day maximum temperatures from this tabulation showed that obout 90 percent were at 45 degrees or above. This value was used in the variable BASEMELT of the degree-day snowmelt model:

MELT= (TEMP-BASEMELT)* K

where:
MELT= the daily snowmelt in inches,
TEMP= simulated maximum temperature for the day,
BASEMELT= the minimum temperature at which significant snowmelt occurs, and
K= snowmelt constant (inches per degree per day), equals 0.05 in this study.

This model was developed by Beschta (1974) from empirical data for northern Arizona, and was also used in the first PONDS simulation. In these previous cases, BASEMELT was set at 48 degrees, probably because snowpacks are greater in those sites.

This simple degree-day model is used in POND3 because the input data requirements are widely available for wildland watersheds. In general, this model performed adequately in the runoff simulation, however, simulated snowmelt flows tended to have higher peaks and shorter base times than actual snowmelt sequences.

Runoff Model Calibration and Testing

The GSSS runoff model is calibrated by a series of trial simulation runs in which the model parameters are adjusted until the simulated daily runoff sequence approachs the actual daily runoff record. The input to each computer simulation run is the actual daily precipitation and maximum temperature data for that sequence.

In this study, one-year sequences of climatological and runoff data were used for calibration. The seven calibration years were 1966, and 1975-1980 from Whitespar Watershed A. Simulated and actual streamflow records for each year were compared uising digital and graphical displays on a HP-1000 computer and a HP-7221B graphics plotter, respectively. Criteria for the comparison of daily streamflow records included volume of peak flow days, shape and duration of recession flows, and total annual flow volumes. All comparisons were evaluated subjectively.

An interactive version of the GSSS runoff subroutine STREB was written to facilitate rapid parameter adjustment at the computer terminal. Parameters were adjusted by trial and error, using the initial parameter estimates described in the preceeding sections as a first trial. Thereafter, parameters were adjusted using the conceptual structure of the GSSS model as a guide.

For example, if a simulated streamflow sequence exhibited low peak flows and exaggerated baseflow, percolation and/or lower zone soil moisture storage parameters were reduced. This adjustment increases the amount of water in the upper zone available for surface runoff and evapotranspiration, and reduces the water in the lower zone available for baseflow. An example calibration procedure provided in the GSSS model documentation describes the effect of each parameter on simulated streamflow.

When model calibration was completed, the runoff model was tested on a continuous 20-year sequence of data from Whitespar Watershed A (1961-1980). It was considered important to test the model on a continuous multi-year data sequence in order to check for long term trending errors.

The results of the twenty-year test of the calibrated model are displayed in Table 6. The cumulative annual error for the entire twenty-year sequence was one percent. Predictions for the high flow years (greater than two inches of runoff) have a small mean annual error, about 16 percent. Accurate prediction for high flow years was considered crucial to the successful modeling of stock pond performance. Predictions for the low flow years were sometimes in considerable error if evaluated as a percent error. However, the actual quantity of runoff water involved in these low flow year errors is small. Errors in the simulation of low flow years are not expected to significantly affect stock pond performance.

Examples of daily simulated runoff plotted against actual runoff records are provided in figures 9 and 10 to illustrate the daily performance of the calibrated runoff model.

A further test of the calibrated watershed runoff model was carried out to gain a preliminary indication of its wider applicability. Six years of precipitation and runoff data from Whitespar Watershed B, a chaparral watershed located adjacent to the original test site, was used in the test. Only six years of data were available, because this watershed was subjected to vegetation conversion treatment in 1967.

Table 6. Comparison of Actual and Simulated Annual Runoff From Whitespar Watershed "A", Prescott, Arizona.

Length of data record: 20 years

Length of simulation*: 20 years

All Data in Watershed Inches							
Year**	Actual	Simulated	% Error	Year**	Actual	Simulated	% Error
1961	.014	.002	- 86%	1971	.051	.002	- 96%
1962	.418	.935	+124%	1972	1.529	3.660	+139%
1963	.605	1.075	+ 78%	1973	9.961	9.384	- 6%
1964	.303	.569	+ 88%	1974	.172	.292	+ 70%
1965	8.294	7.473	- 10%	1975	.243	.142	- 42%
1966	3.539	5.141	+ 45%	1976	2.346	2.099	- 11%
1967	.177	.379	+114%	1977	.088	.089	+ 1%
1968	2.639	2.942	+ 11%	1978	11.358	12.857	+ 13%
1969	2.641	2.792	+ 6%	1979	9.051	6.918	- 24%
1970	.304	.840	+176%	1980	15.251	10.577	- 31%
				TOTAL	68.980	68.160	
				MEAN	3.449	3.408	- 1%
				VARIANCE	21.513	15.821	

* Simulation uses actual precipitation and temperature as input.

** Years here are calendar years, 1 Jan - 31 Dec.

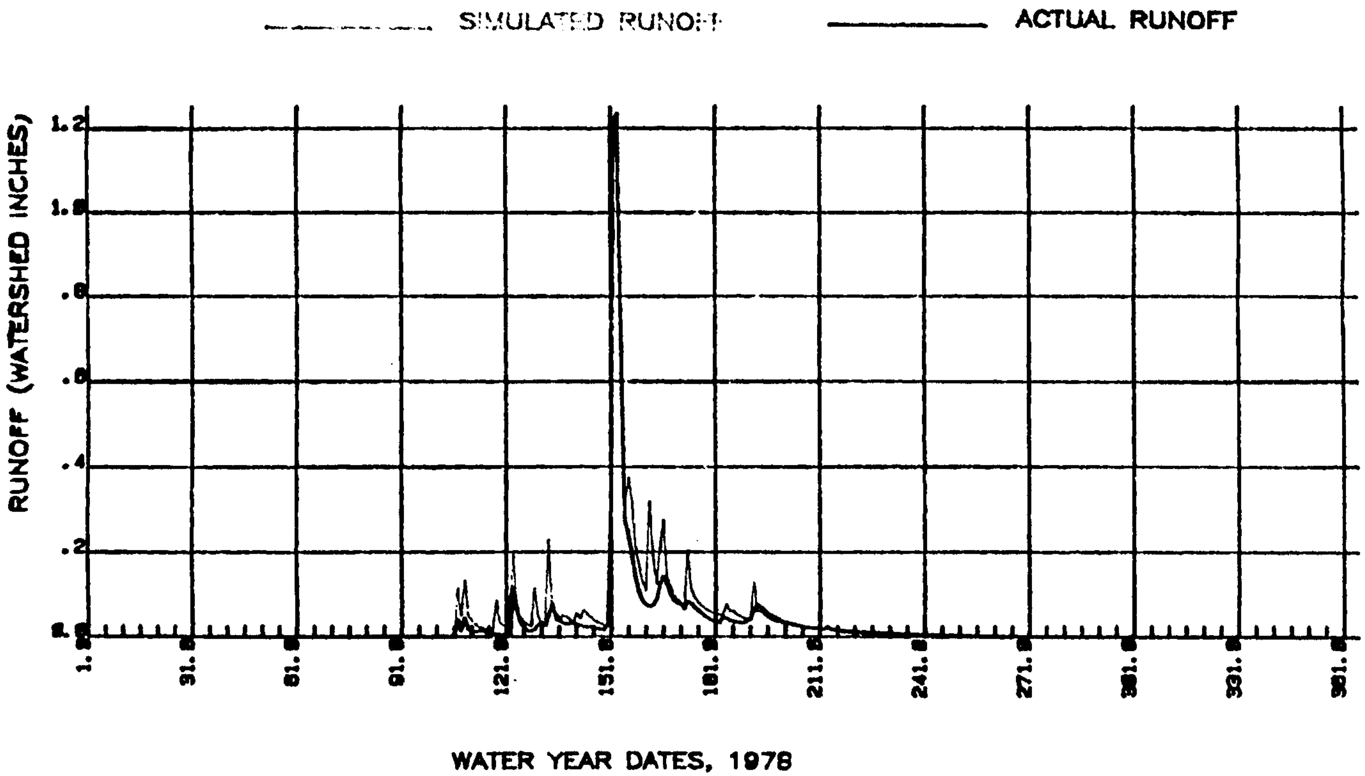


Figure 9. Comparison of Simulated and Actual Daily Runoff at Whitespar for 1978.

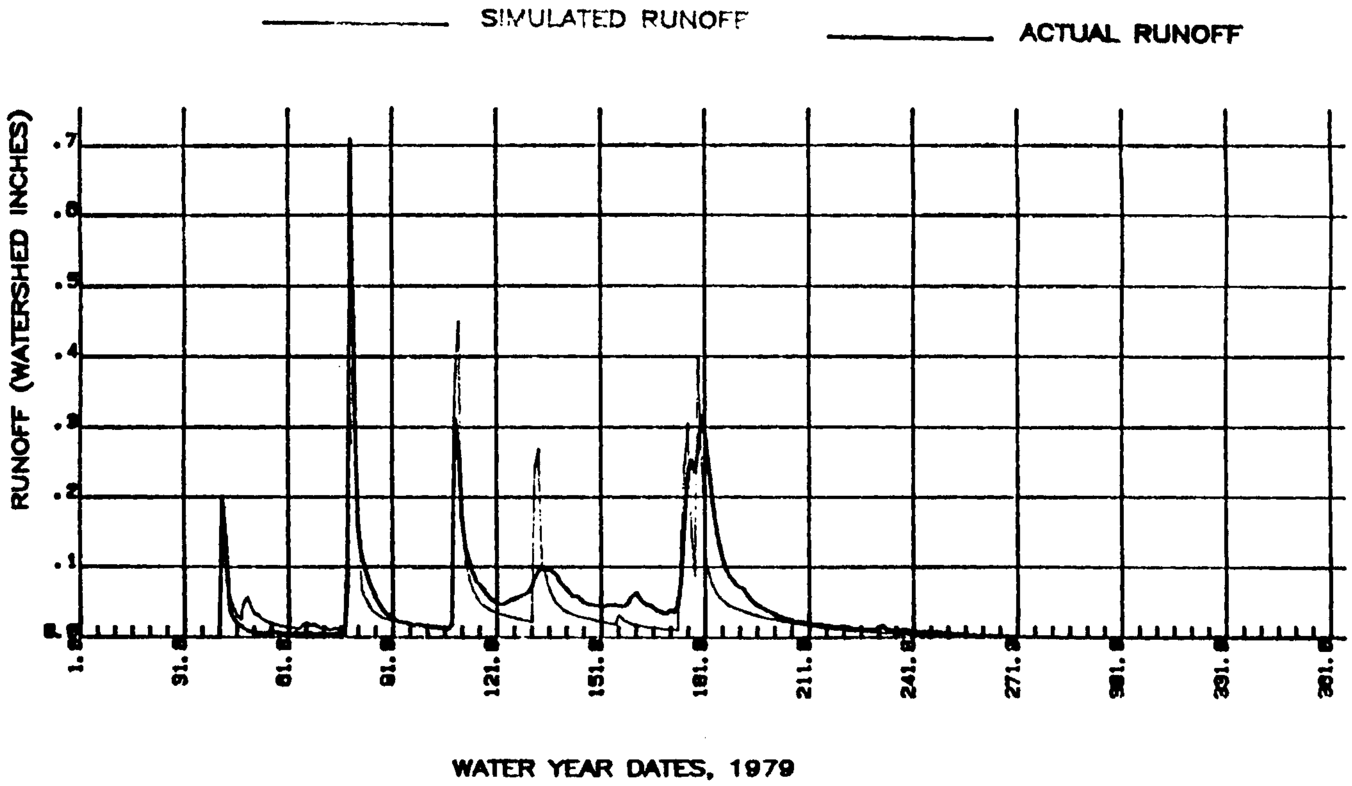


Figure 10. Comparison of Simulated and Actual Daily Runoff at Whitespar for 1979.

The results of the second test are shown in Table 7. The cumulative annual error for the six-year sequence was 25 percent. Most low flow year predictions were far higher than the actual. The calibrated model performed well for the one high flow year in the data record (1965).

The two tests of the calibrated runoff model constitute a subjective validation of the model. The calibrated version of the GSSS runoff model is used in POND3, and listed in subroutine STRBB in Appendix A. This calibrated model appears to simulate the basic processes of daily runoff on the Whitespar Experimental Watersheds. The model performs less well on Watershed B, which was not used in calibration, than on Watershed A. This particular calibrated version of the model is not necessarily expected to perform well for ungaged chaparral watersheds in Arizona. However, given the data necessary for calibration, the GSSS runoff model appears to be a useful tool in the simulation of daily streamflows from small chaparral watersheds.

Table 7. Comparison of Actual and Simulated Annual Runoff for Whitespar Watershed "B", Prescott, Arizona

Length of record: 6 years

Length of simulation*: 6 years

	All Data in Inches		
Year	Actual	Simulated	% Error
1961	.044	.002	- 50%
1962	.253	.897	+255%
1963	.209	.522	+150%
1964	.186	.430	+131%
1965	6.225	6.325	+ 2%
1966	1.996	2.873	+ 44%
TOTAL	8.873	11.049	+ 25%
MEAN	1.479	1.842	
VARIANCE	2.439	2.416	

* Simulation used actual precipitation for watershed "B" and temperature from watershed "A" (adjacent) as input.

CHAPTER FIVE

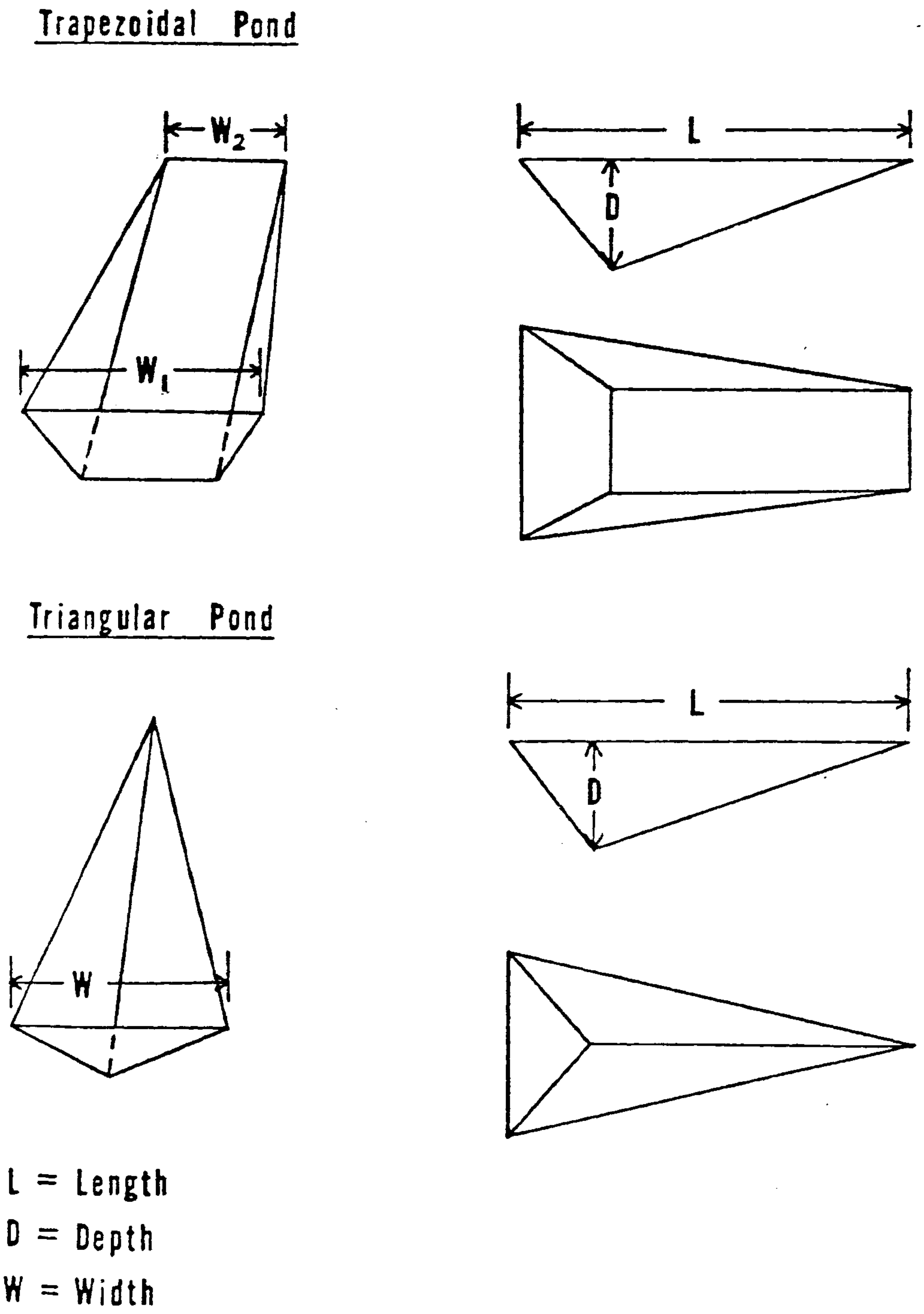
STOCK POND ROUTING MODEL

The stock pond routing model used in this study uses hypothetical ponds of standard shapes to evaluate pond performance. This model is essentially the same as that developed by Almestad (1983). Pond shapes used are triangular and trapezoidal. The dimensions are standardized so that ponds of different sizes all have the same ratios of depth to width and width to length (see Figure 11). Stage-storage relationships are linear and approximately equal for all ponds of the same shape. Each pond shape is evaluated for nine pond sizes--0.25, 0.5, 0.75, 1, 2, 3, 4, 5, and 10 acre-feet.

Routing of runoff water through the pond is accomplished by a daily water budget:

STORAGE= STORAGE^{i-1}+ INFLOW+ PRECIP- SPILLAGE- SEEPAGE
-EVAPORATION-COW CONSUMPTION

where: STORAGE= volume of water in the pond on day i,
STORAGE$_{i-1}$= volume of water in the pond on the previous day,
INFLOW= watershed runoff, or streamflow, on day i, translated to cubic feet,
PRECIP= precipitation falling directly on the pond surface (a function of pond area on day i),



Trapezoidal Pond

Triangular Pond

L = Length

D = Depth

W = Width

Figure 11. Standardized Stock Pond Shapes Used In The POND3 Model.

Figure 11a. Trapezoidal-Shaped Pond Dimensions.

Pond Capacity acre feet)	Maximum Depth (feet)	Length (feet)	Minimum Width (feet)	Maximum Width (feet)	Maximum Water Surface Area (acre)
0.25	3.15	113.47	57.74	69.34	0.16
0.50	3.97	142.97	71.48	87.36	0.26
0.75	4.54	163.66	81.83	100.00	0.34
1.00	5.00	180.13	90.06	110.06	0.41
2.00	6.30	226.95	113.47	138.67	0.66
3.00	7.21	259.79	129.90	158.74	0.86
4.00	7.94	285.94	142.97	174.72	1.04
5.00	8.55	308.02	154.01	188.21	1.21
10.00	10.77	388.08	194.04	243.13	1.92

Figure 11b. Triangular-Shaped Pond Dimensions

Pond Capacity (acre feet)	Maximum Depth (feet)	Length (feet)[1/]	Maximum[1/] Width (feet)	Maximum Water Surface Area (acre)
0.25	3.15	204.49	102.25	0.24
0.50	3.97	257.32	128.66	0.38
0.75	4.54	295.16	147.58	0.50
1.00	5.00	323.33	161.67	0.60
2.00	6.30	406.43	203.43	0.95
3.00	7.21	466.43	233.35	1.25
4.00	7.94	512.94	256.47	1.51
5.00	8.55	552.20	276.10	1.75
10.00	10.77	695.98	347.99	2.78

[1/] Ratios of length to width are 2 to 1.

SPILLAGE= volume of water spilling over into the downstream channel, in cubic feet,

SEEPAGE= volume of water lost to infiltration into the pond sediments,

EVAPORATION= the volume of water lost to evaporation from the pond surface, and

COW CONSUMPTION= the volume of water consumed by livestock or wildlife (a constant).

The storage, inflow, precipitation and spillage terms in the pond water budget are self-explanatory. The methods used for estimating seepage losses, evaporation, and livestock water consumption are explained below.

Seepage Losses

Seepage losses were estimated in this model as a constant daily loss rate. Daily seepage loss was calculated as the product of the seepage rate, in feet per day, and the pond surface area on that day. Seepage was assumed to occur only in a vertical direction. Seepage loss rates used were 0.00 ft/day, 0.02 ft/day, and 0.05 ft/day.

Field measurements of stock pond seepage indicate that seepage rates vary according to pond stage and time elapsed since the latest inflow (Langbein,et.al., 1951; Sale, 1985). Actual seepage rates are highest immediately after a large inflow, due to the large surface area and high infiltration rate of dry pond-margin soils. Actual seepage rates decline due to the reduced infiltration capacity of saturated soils and, as pond stage falls, the presence of fine, impermeable sediments in the pond bottom.

The constant rate seepage model used in this study partly accounts for these seepage rate variations by maximizing seepage losses at the highest pond stage. A more sensitive and realistic model was developed by Sale (1985). This model could not be incorporated into the current study due to time constraints, but it is expected to offer improved predictions of pond performance once calibrated.

Pond Evaporation

Pond evaporation estimates in this study were modeled using monthly lake evaporation estimates for Arizona from Cooley (1970). The monthly values, and their daily fractions, are reported in Table 8.

Previous work on the PONDS model used a linear regression of monthly lake evaporation versus monthly mean maximum temperatures to adjust evaporation rates on a daily basis. This approach was not used in this study for two reasons: regression of actual daily pan evaporation against daily maximum temperatures yielded a low coefficient of determination ($r^2 = 0.38$) for Sale (1984); and estimation of daily evaporation using a regression line based on monthly data is not reasonable.

Livestock Water Consumption

The livestock water consumption estimate for the POND3 model is the same as that previously used in the PONDS effort. Each cow is estimated to drink 10 gallons, or 1.34 cubic feet, of water per day. Options are provided in the POND3 model to enter the number of cattle and the length of the grazing season into the program interactively.

Table 8. Monthly Lake Evaporation Estimates for Whitespar Watersheds, Prescott, Arizona. Developed from Cooley (1970).

Month	All Estimates in Inches Monthly Evaporation	Daily Fraction of Monthly Evaporation
January	2.0	.065
February	2.8	.100
March	4.5	.145
April	5.9	.197
May	8.1	.270
June	8.9	.297
July	8.9	.287
August	8.1	.261
September	6.2	.207
October	4.8	.155
November	3.0	.100
December	2.0	.065
TOTAL	65.2 inches	

CHAPTER SIX

STRUCTURE AND OPERATION OF THE POND3 MODEL

The POND3 stock pond performance model links together the previously described component models of precipitation, temperature, runoff, and pond routing. This linked model is driven by the component models for stochastic precipitation and temperature simulation. The runoff model transforms this synthetic climatological input into streamflow, or pond inflow. The pond routing model manages the daily pond water budget and calculates output statistics.

The POND3 model operates as a series of one year simulations. Each year of runoff is routed through each pond size independently. After the simulation is completed for its entire duration (200 years in the case study reported here), a new watershed size is chosen and the entire process repeated. This rather inefficient structure was necessary because the HP-1000 computer could not store larger sequences of synthetic data.

A flow chart describing the logical structure of the POND3 model is given in Figure 12. This structure is basically the same as that used by Almestad and Kiyose in previous work on this project. Structural differences between POND3 and previous model versions include:

1) The use of an interactive input routine for entering the number of watershed sizes, the number of stock pond sizes, the pond seepage rate, the pond shape, and the livestock use factors without recompiling the program.

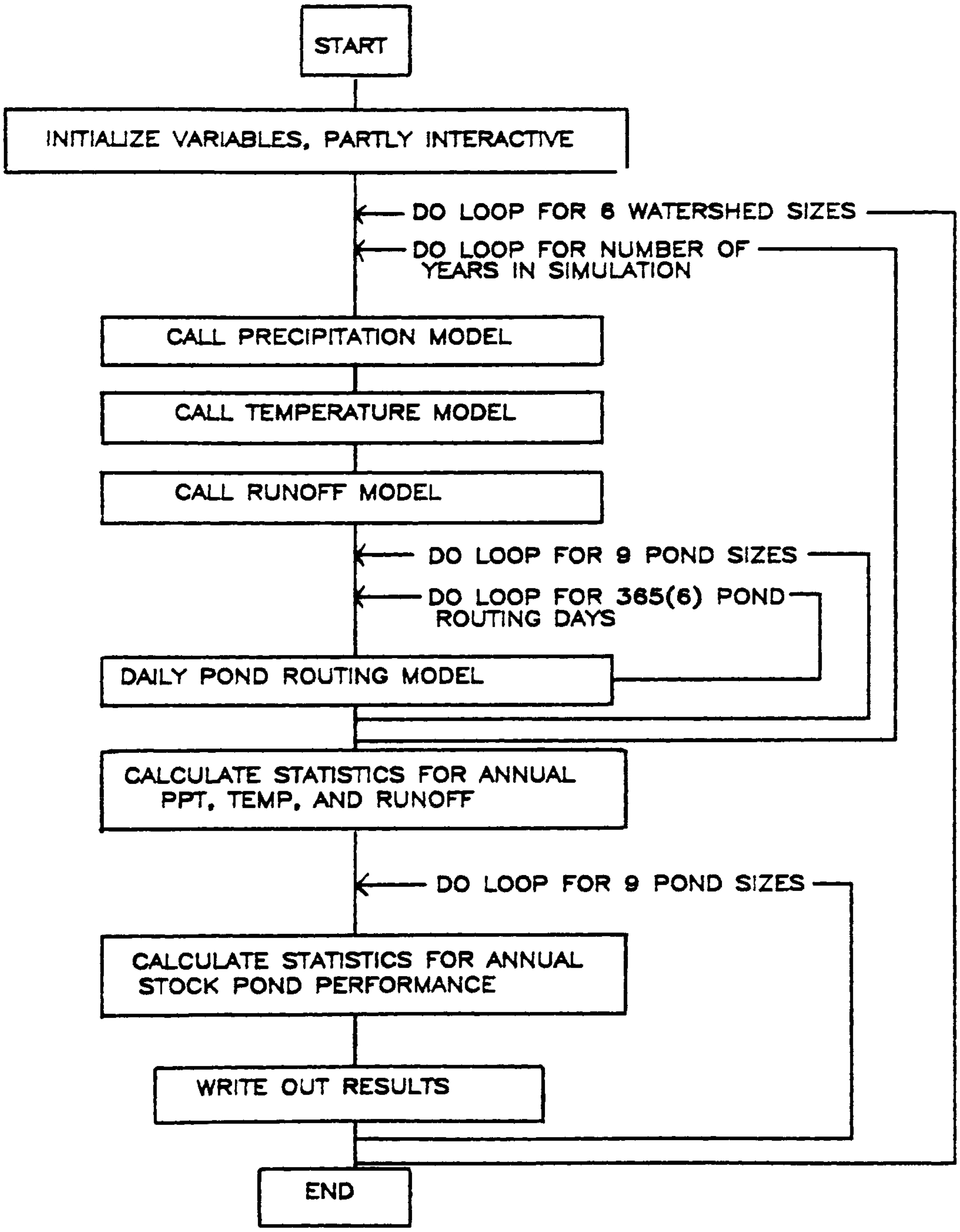


Figure 12. Flow Chart of The POND3 Model's Logical Structure And Operation.

2) Three new output options are included in POND3: a) Daily precipitation, runoff, stage, storage, and spillage. This is useful for checking the daily operation of the model. b) Annual totals for precipitation, runoff, spillage, retention, and dry days. This displays the range of annual values for each factor. c) Probability distributions for annual retention, spillage and dry days. These distributions, useful in any stochastic interpretation of modeling results, were not included in previous versions of the main program.
3) The POND3 model uses called subroutines for simulating annual sequences of precipitation, temperature, and runoff. This allows a clearer view of how each component model functions.

The standard output of the POND3 model is like that of the original PONDS model: means and standard deviations for the annual precipitation, temperature, runoff, pond retention, pond spillage, and pond dry days, as well as the median of retention, the fill factor, and a monthly breakdown of dry days for each pond type.

The model is presently capable of producing these statistics for two pond shapes, nine pond sizes, and six watershed sizes, with seepage rates and livestock factors being completely interactive.

CHAPTER SEVEN

RESULTS OF A CASE STUDY WITH POND3

To provide a preliminary estimate of stock pond performance on a chaparral watershed, the POND3 model, calibrated for Whitespar conditions, was run for a 200-year simulation period. Three hundred and twenty-four standardized stock ponds were evaluated in this case study.

The simulation results presented and discussed here are restricted to mean annual retention as a percentage of runoff and the mean annual number of dry days. These data were chosen for detailed discussion because of their relevance to the problems of downstream water yield and stock pond design.

Stock Pond Retention

Stock pond retention, or water lost to seepage, evaporation, and livestock consumption, can be visualized as water lost to downstream water yield. Mean annual retention for the 200-year simulation is listed for six stock pond types in Tables 10 through 15.

Examination of the tabulated retention statistics reveals the following general trends:

1) Percent retention is greater in triangular than in trapezoidal ponds. The higher water surface to volume ratio of standard triangular ponds promotes proportionally greater evaporation and seepage for this pond shape.

2) Percent retention increases as seepage rates and pond sizes increase,

and decreases as watershed size, and hence total inflow, increases.
3) The range of seepage rates used in this study had a minor effect on retention compared to the effect of pond size and pond shape.
Each of these trends is an expected result because the causitive factors are related to standard pond geometries.

POND3 simulation results show a consistently higher percentage of runoff retained by hypothetical ponds at Whitespar than was reported at Beaver Creek by Almestad (1983). Retention statistics from a sample pond in the POND3 simulation are plotted in Figure 13 against data from earlier PONDS simulations for the same pond type.

Results shown in Figure 13 are representative of of the percent retention results for all simulated ponds at Beaver Creek, Walnut Gulch, and Whitespar. Retention percentages for each case vary in accordance with the locally different volumes and timing of simulated pond inflow. The greater volume of annual runoff at Beaver Creek forces proportionally more spillage and less retention at that watershed than at Whitespar or Walnut Gulch. Whitespar retention statistics are somewhat similar to those at Walnut Gulch because Whitespar runoff, though greater in volume, is much more evenly distributed over time than that at Walnut Gulch; this more even distribution of annual runoff allows proportionally more of it to be lost to evaporation and seepage.

Spillage over the dam or spillway when the pond is full constitutes water available for further use downstream. Spillage in the POND3 model is that portion of watershed runoff not retained by the pond. Spillage as a percentage of runoff is simply: 100 - retention = spillage.

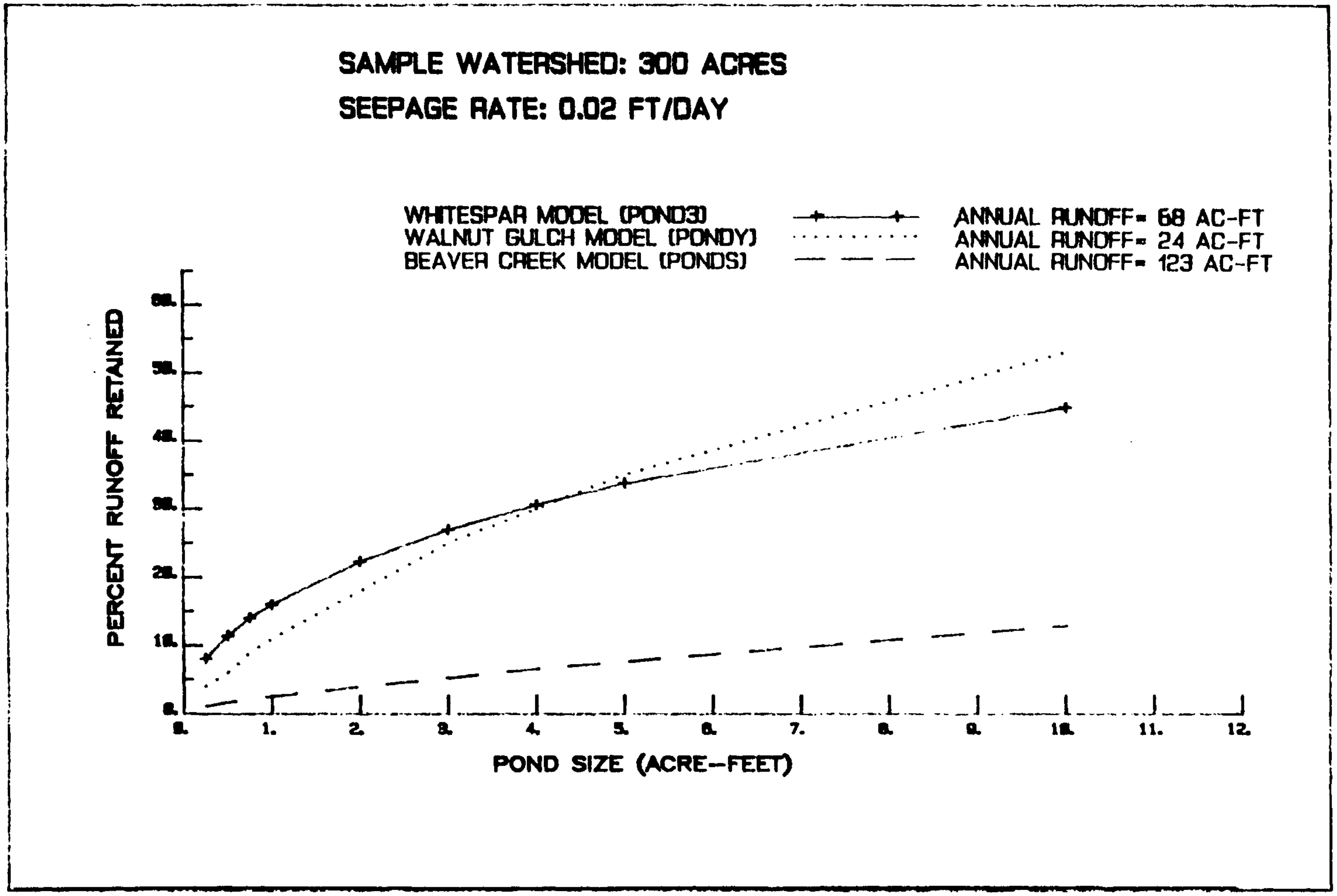


Figure 13. Comparison Of Simulated Percent Runoff Retention vs. Pond Size For Three Different Watershed Models

No spillage statistics are reported for the POND3 case study because they can be so easily derived from retention statistics.

Stock Pond Dry Days

Dry days are those days when the stock pond is empty. Dry day statistics serve as an indication of how well the stock ponds perform as water sources for livestock. The mean annual number of dry days at Whitespar for a 200-year simulation is reported in Tables 16 and 17 for six pond types.

The tabulated results show that higher seepage rates increase the number of dry days, and that the trapezoidal ponds, with a lower surface to volume ratio, show fewer dry days than the triangular ponds. Both pond shape and seepage rates exert small effects on dry day statistics.

The POND3 simulation indicates that increasing pond size does not significantly reduce the number of dry days. One would expect that greater pond storage capacity would delay pond drying, and reduce the number of dry days at Whitespar just as it did in previous simulations at Beaver Creek and Walnut Gulch (Almestad, 1983; Kiyose, 1984). Instead, pond dry days for Whitespar conditions are almost identical for all pond sizes.

Examination of daily pond stages and losses simulated by POND3 indicates that the insensitivity of dry day results to the pond size parameter is a product of semi-perennial baseflow and the use of a standard stage-storage relationship.

The winter baseflow typical of Whitespar conditions assures that every pond, no matter how small, will contain water throughout the winter and spring. By late spring, the large ponds have lost most of their once greater volume to evaporation and seepage, and often contain the same volume of water as small ponds. When inflows cease the ponds tend to dry up rapidly, and at about the same time regardless of their size. The key factor here is the proportionally more rapid evaporation and seepage losses of large ponds in this model (see Figure 14).

The POND3 simulation results for Whitespar show a greater number of annual dry days, and a different seasonal distribution of dry days, than either previous stock pond simulation with PONDS. Dry days at Whitespar are concentrated in the months of July, August, September, and October, when the proportion of dry days was consistently high. This is due to the scarcity of summer runoff events, especially large runoff events, at Whitespar. In many other areas of Arizona, including Beaver Creek and Walnut Gulch, late summer runoff is common, and sometimes is the season which provides a majority of annual runoff.

The stock ponds simulated by Almestad (1983) and Kiyose (1984) apparently had relatively fewer dry days than those at Whitespar because summer and fall runoff kept the ponds wet during those seasons. At Walnut Gulch, where winter runoff is rare, stock ponds depend on retaining summer inflows through the fall and winter. Whitespar stock ponds do not retain spring runoff during the summer, because hot season evaporation rates are so high, and replenishing inflows so few.

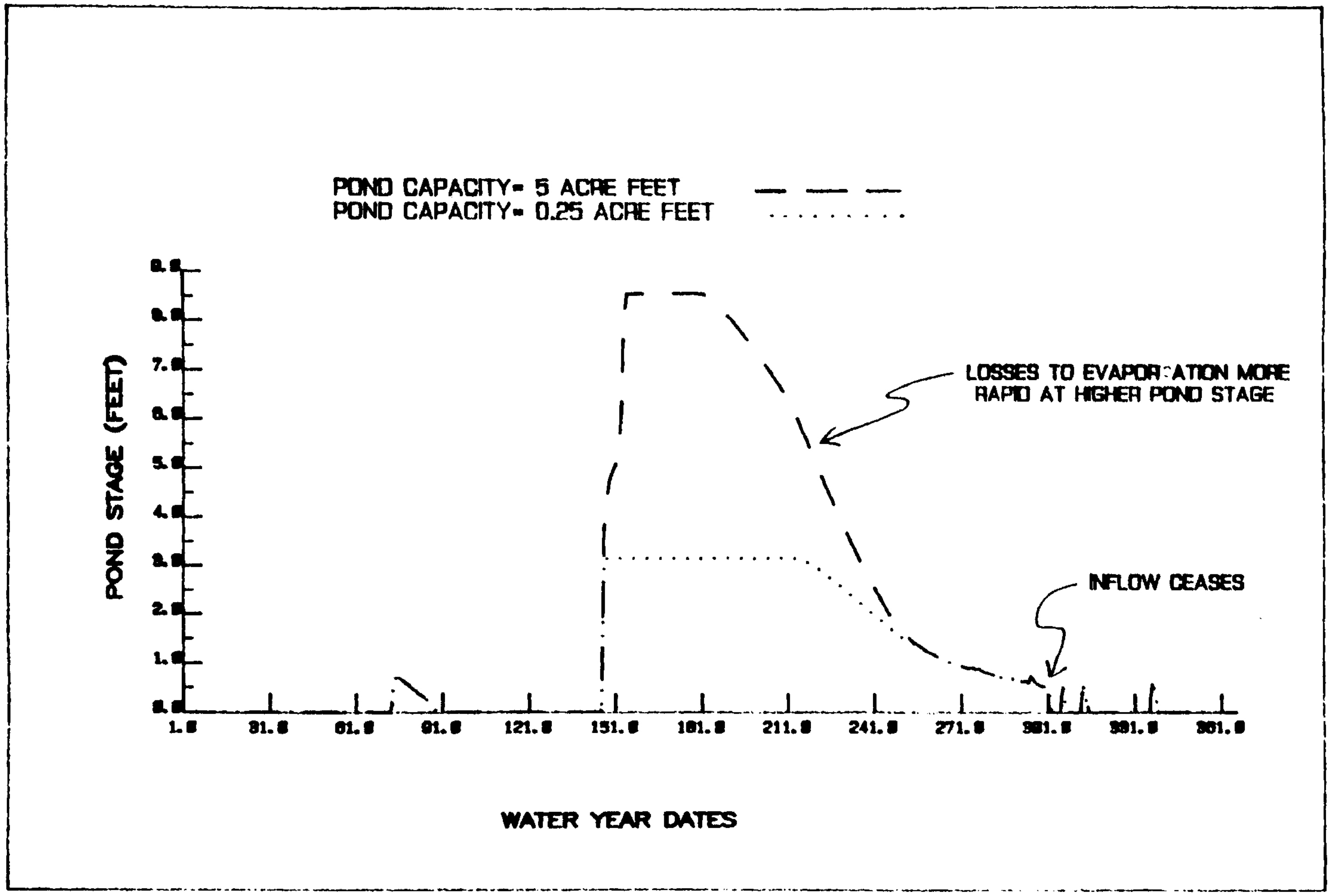


Figure 14. Simulated Pond Stage Data For Two Pond Sizes. Showing Similarity of Pond Dry Day Performance For All Pond Sizes At Whitespar.

In summary, the coincidence of scarce summer runoff and high summer evaporation rates causes a high incidence of summer and fall dry days in stock ponds simulated for Whitespar conditions. The low correlation of pond size to pond performance as a livestock water source in this study reflects Langbein's conclusion that stock pond performance in Arizona is more often a factor of pond depth than pond volume (Langbein,et.al.,1951).

CHAPTER EIGHT

SUMMARY AND CONCLUSIONS

This study describes the development of a computer program for modeling stock pond performance in Arizona chaparral watersheds. This computer model, called POND3, is a modification and extension of a previously developed stock pond simulation model called PONDS or PONDY (Almestad, 1983; Kiyose, 1984). The POND3 model, like its predecessors, is designed to assist concerned Arizona agencies in the determination of stock pond impacts on downstream water yields, and in evaluating the performance of ponds as water sources for livestock.

The POND3 model is a combination of two stochastically driven climatological submodels with two separate deterministic submodels for streamflow generation and pond routing. The model operates as follows: 1) a daily time series of precipitation is simulated by an event-based stochastic model, 2) an independent time series of daily maximum temperatures is simulated by a lag-one Markov model, 3) snowmelt and rainfall runoff are simulated by a daily soil moisture accounting model using the synthetic precipitation and temperature data as input, 4) generated streamflow is routed through specified types of stock ponds, one at a time, and annual stock pond performance statistics are compiled for each pond type.

Major modifications in the POND3 version of the stock pond simulation model, as compared to previous versions, are as follows: 1) The submodels for precipitation, temperature and streamflow synthesis are each separate subroutines called from the main computer program.

2) The precipitation submodel incorporates a new, more efficient subroutine for the generation of gamma distributed random variables. This new subroutine substantially reduces the time required for generation of synthetic precipitation data.

3) Streamflow generation is handled by a soil moisture accounting model instead of the modified SCS runoff formulae used in the previous stock pond models. This new streamflow submodel, though more lengthy and more complex than the previous technique, was necessary to simulate the baseflow on chaparral watersheds.

4) The pond routing model uses mean monthly evaporation estimates instead of the previously employed regression equations to estimate evaporation from the ponds. Regression of actual pan evaporation data against daily maximum temperatures indicated that the correlation between these two variables was too low to be of use in this model.

5) The output options were expanded to provide probability distributions for annual pond retention, spillage, and dry days. In previous models, these data were calculated in a separate, unlisted program.

6) The main program is made partly interactive so that users can specify several pond parameters, as well as the various output options, from the computer terminal.

All the component submodels were calibrated, verified, and validated so far as possible using data from the Whitespar Experimental Watersheds near Prescott, Arizona. These watersheds were chosen to represent the chaparral cover type in Arizona.

Model Operation

Conclusions regarding the suitability and performance of the component submodels follow:

1) The stochastic event-based precipitation submodel was verified as capable of reproducing the mean monthly number of events and the precipitation per event with good accuracy for all seasons. Simulation errors in mean annual precipitation and mean number of events per year were less than two percent.

As in previous work on this project, the precipitation routine used in the winter months simulates the length of a precipitation group (in days) independently from the amount of precipitation in that group. Although this is an unrealistic approach, no better method could be found, and the winter precipitation simulation was not greatly affected.

3) The stochastic temperature model was verified to function well in simulating daily maximum temperatures with monthly and annual statistics similar to those of the actual data.

4) The calibrated GSSS runoff model used in this study was verified using 20 years of actual precipitation and temperature data as input. Only seven of the verification years were also used in model calibration. The mean annual streamflow volume error for the twenty year test was one percent. Individual annual errors in the test were sometimes large for low flow years, but simulation of high flow years was consistently good.

Using 200 years of simulated precipitation input, the runoff model yielded 21 percent less mean annual runoff than the annual mean of actual runoff data. The standard deviation for 200 years of simulated runoff was 32 percent lower than the standard deviation of the actual data. Insofar as the verifications of the precipitation and runoff submodels can be respected, this indicates that the actual 20 year runoff record is higher and more varied than would be expected for a longer record. Indeed, if 1980, the extreme runoff year, is subtracted from the record, the actual and simulated runoff statistics are very similar. On the other hand, the discrepancies discussed could indicate a flaw in the simulation models.

5) The pond routing model was not verified because no pond stage data were available for Whitespar. This submodel has several naive assumptions, for example, the use of a constant seepage rate, and the assumption that all seepage losses occur through the pond bottom instead of the dam. Considering the complexity of stage-storage relationships and seepage characteristics for actual stock ponds, this submodel is expected to be the most problematic in actual use of the model. A pond seepage model developed by Sale (1984), but not incorporated here due to time constraints, is designed to handle some of these problems.

Trial Stock Pond Simulations

The results of the trial stock pond simulations from this study (see chapter seven) illustrate how the general precipitation and runoff patterns of small chaparral watersheds are translated into stock pond performance. These trial simulations also provide quantitative estimates of important pond performance criteria.

The trial simulation results provided by POND3 are probably most useful when used in comparison to previous stock pond simulations for Beaver Creek, Arizona, and Walnut Gulch, Arizona. These estimates indicate that stock pond performance in chaparral watersheds will differ significantly from pond performance on pinyon-juniper and semidesert grassland watersheds, respectively.

The key for opening the full potential of POND3 and the previous versions of the stock pond model is proper calibration of the precipitation and runoff submodels. Calibration is a time-consuming process requiring good data sets for daily precipitation and temperature, as well as for daily runoff volumes if the model is to be fine-tuned.

Output statistics for a POND3 case study at Whitespar are provided here as a preliminary indication of how stock ponds are expected to perform on small chaparral watersheds in Arizona. The precipitation, temperature, and runoff submodels used to make these predictions are calibrated specifically for Whitespar conditions. Use of the model outside this area will require recalibration of the submodels, or a readiness to accept the reduced reliability of model results outside the original calibration area.

APPENDIX A

PROGRAM LISTING OF POND3 SIMULATION MODEL, INCLUDING SUBROUTINES

```
FTN7X,L
$FILES 2,2
      PROGRAM POND3
C THIS IS THE MAIN POND ROUTING PROGRAM FOR THE STOCKPOND PROJECT,
C SMALL WATERSHED HYDROLOGIC SIMULATION. THIS PROGRAM WAS CALIBRATED
C WITH 20+YEARS OF PPT,TEMP, AND FLOW DATA FROM WHITESPAR WATERSHED
C 'A' ON THE PRESCOTT NATIONAL FOREST.
C THE STRUCTURE OF THE PROGRAM IS BASED ON PROGRAM 'PONDS' DEVELOPED
C BY C. ALMESTAD. THE RAINFALL SIMULATION SUBROUTINE IS A STOCHASTIC
C SEASONAL MODEL BASED ON THOSE OF HEKMAN,JONES, AND ALMESTAD. THE
C MAXIMUM DAILY TEMPERATURE MODEL IS BASED ON HEKMAN AND ALMESTAD. THE
C RUNOFF SUBROUTINE IS A SLIGHTLY MODIFIED 'STREB' SOIL MOISTURE ACCOUNT-
C ING MODEL TAKEN FROM THE US WEATHER SERVICE 'SACRAMENTO' RIVER FORECAST
C MODEL. STOCKPOND PROJECT. MCDOWELL, FEB. 1985.
C                    GENERAL VARIABLES
C    LP=       OUTPUT LOCATION LOGICAL UNIT NUMBER
C    NYEARS=  NUMBER OF YEARS TO SIMULATE
C    NPONDS=  NUMBER OF PONDS TO SIMULATE
C    NACRE=   NUMBER OF WATERSHED SIZES TO SIMULATE
C               STOCK POND PARAMETERS
C    PTYPE=   CODE FOR POND GEOMETRY (1=TRIANGULAR,2=TRAPEZOIDAL)
C    SRATE=   SEEPAGE RATE(FT/DAY)
C    EVAPOR=  DAILY FRACTION OF MONTHLY LAKE EVAPORATION (INCHES)
C    AREAF( )=AREA FACTORS (CONSTANTS) FOR PONDS
C    VOLF( )= VOLUME FACTORS (CONSTANTS) FOR PONDS
C    W( )=    MAXIMUM DEPTHS FOR EACH POND(FT)
C    PSIZE( )=POND SIZES IN ACRE FEET
C    ACRE( )= ACREAGES OF WATERSHEDS TO BE SIMULATED
C               LIVESTOCK PARAMETERS
C    COWS=    NUMBER OF LIVESTOCK USING POND
C    DRINK=   DAILY CONSUMPTION OF WATER BY LIVESTOCK (GALLONS)
C    NFD1=    FIRST DAY OF FIRST GRAZING PERIOD
C    NLD1=    LAST DAY OF FIRST GRAZING PERIOD
C   ******************************************************************

      REAL AREAF(9),VOLF(9),STLAST(9)
      REAL ACRE(6),PSIZE(9),W(9),RET(200),PRECIPT(200)
      REAL TOTALQT(200),EVAPOR(12),HLAST(9)
      REAL DISPILL(20),DISRET(20),DISDRY(20,9)
      INTEGER PEAK,MDRY(12,9),IMDRY(12),MON(13)
      INTEGER PTYPE
      EMA SPILL2,NDRY,SPL,ICDRY
      DIMENSION SPILL2(200,9),NDRY(200,9),SPL(200),ICDRY(12,9,12)
      CHARACTER ALPHA(12)*9,PGEO(2)*11
      COMMON/A/JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),TOTALQ
C*************NOTE THAT MONTH 1=OCTOBER,DAY 1=OCTOBER*FIRST*************
      DATA MON/0,31,61,92,123,151,182,212,243,273,304,335,365/
      DATA EVAPOR/.155,.100,.065,.065,.100,.145,.197,.270,.297,.287,
     $.261,.217/
      DATA ALPHA/'OCTOBER','NOVEMBER','DECEMBER','JANUARY','FEBRUARY',
     $'MARCH','APRIL','MAY','JUNE','JULY','AUGUST','SEPTEMBER'/
      DATA PGEO/'TRIANGULAR','TRAPEZOIDAL'/
      DATA AREAF/9*1045.4375/
      DATA VOLF/9*348.48/
      DATA W/3.1498026,3.9685026,4.5428015,5.0,6.2996052,7.2112479,
     +7.9370053,8.5498797,10.772173/
      DATA PSIZE/0.25,0.5,0.75,1.,2.,3.,4.,5.,10./
      DATA ACRE/50.,100.,200.,300.,400.,1000./
```

```
      WRITE(1,*)'WRITE THE PRINT OPTION FOR 1)DAILY TEMP,PRECIP,RUNOFF,
     $SPILL-STORE,  2) ANNUAL STATISTICS, AND  3) ANNUAL DISTRIBUTIONS,
     $WHERE 1=PRINT,0=SKIP,  E.G. 0,0,1.  CUMULATIVE STATISTICS FOR THE
     $ENTIRE SIMULATION APPEAR AUTOMATICALLY.'
      READ(1,*)LPRN1,LPRN5,LPRN6
      WRITE(1,*)'WRITE SEEPAGE RATE(FT/DAY),YEARS SIMULATED,
     $NUMBER OF PONDS(<9), AND NUMBER OF WATERSHED SIZES(<6).'
      READ(1,*)SRATE,NYEARS,NPOND,NACRE
      WRITE(1,*)'OUTPUT TO 1=TERMINAL, 6=PRINTER.'
      READ(1,*)LP
C  POND PARAMETERS  (ALSO DATA STATEMENTS U,V,W, AND PSIZE ABOVE)
      WRITE(1,*)'WHICH POND SHAPE? 1=TRIANGULAR, 2=TRAPEZOIDAL'
      READ(1,*)PTYPE
      IF(PTYPE.EQ.2)THEN
      DO 12, I=1,9
      AREAF(I)=714.38
   12 CONTINUE
      ELSE
      END IF
C  LIVESTOCK PARAMETERS
      COWS=0.
      WRITE(1,*)'HOW MANY CATTLE ARE USING THIS POND? WHAT ARE THE
     $FIRST AND LAST DAY OF THE GRAZING PERIOD(OCT.1=1,SEPT.30=365);
     $E.G., 25,1,174= 25 CATTLE FROM 1 OCT. TO 1 APRIL.'
      READ(1,*)COWS,NFD1,NLD1
      DRINK=10.0
      COWVOL=COWS*DRINK/7.48
      IF(NLD1.LT.NFD1)THEN
       COWDAYS=((365-NFD1)+NLD1)*COWS
      ELSE
       COWDAYS=(NLD1-NFD1)*COWS
      END IF
C END VARIABLE INITIALIZATION*******************************************

C HEADER FOR OUTPUT*****************************************************
      WRITE(LP,50)'STOCKPOND SIMULATION FOR',NYEARS,'YEARS','WATERSHED
     &SIZES,((1000 ACRES)=',NACRE,'STOCK POND SIZES,((10 ACRE-FEET)=',
     &NPOND,'SEEPAGE RATE=',SRATE,'FT/DAY','CATTLE*DAYS=',COWDAYS
   50 FORMAT(20X,A25,1X,I3,1X,A5,/,25X,A31,1X,I2,/,25X,A34,1X,I2,/,25X,
     &A14,F4.3,1X,A6,/,25X,A12,1X,F7.1,/)
      WRITE(LP,33)'POND TYPE=',PGEO(PTYPE)
   33 FORMAT(25X,A10,1X,A12,//,80(1H*),/,80(1H*),//)

C START SIMULATION, FIRST LOOP IS FOR WATERSHED SIZES*******************
      DO 4000 KKKK=1,NACRE
C RESEED RANDOM NUMBER GENERATOR TO DUPLICATE CLIMATE DATA**************
      CALL SSEED(12345)
C INITIALIZE ALL VARIABLES TO ZERO**************************************
      DO 75 LL=1,NPOND
      DO 65 N=1,12
      MDRY(N,LL)=0
      DO 60 I=1,12
      ICDRY(N,LL,I)=0
   60 CONTINUE
   65 CONTINUE
      DO 70 J=1,NYEARS
      SPILL2(J,LL)=0.0000
      NDRY(J,LL)=0.0000
   70 CONTINUE
      STLAST(LL)=0.0000
      HLAST(LL)=0.0000
   75 CONTINUE
      LDAY=0
      PAVE=0.000
      LCOUNT=0
      PTOTAL=0.
      GTOTAL=0.
      TTOTAL=0.
```

```

C START OF ANNUAL LOOP  *******************************************
      DO 3000 JJJJ=1,NYEARS
      JDAY=0
      DO 90 I=1,366
      PPT(I)=0.00
      TEMP(I)=0.00
      Q(I)=0.0000
   90 CONTINUE
C LEAP YEAR DETERMINATION
      ILEAP=0
      LCOUNT=LCOUNT+1
      IF(LCOUNT.EQ.4) ILEAP=1
      IF(LCOUNT.EQ.4) LCOUNT=0

C****PRECIPITATION MODEL *******************************************
      CALL TRAB1(JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),
     $TOTALQ)
      PRECIPT(JJJJ)=PRECIP
C *****************************************************************

C****TEMPERATURE MODEL**********************************************
      CALL JOTSS(JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),
     $TOTALQ)
C******************************************************************

C****WATERSHED RUNOFF MODEL ****************************************
      CALL STRBB(JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),
     $TOTALQ)
      TOTALQT(JJJJ)=TOTALQ
C*********************************************************************

C  STOCK POND ROUTING ***********************************************

C  LOOP FOR EACH POND SIZE******************************************
      DO 700 LL=1,NPOND
      C=AREAF(LL)
      D=VOLF(LL)
      DO 610 I=1,12
      IMDRY(I)=0
  610 CONTINUE
      PVOL=D*(W(LL)**3)
      IILEAP=ILEAP

C****DAILY STOCK POND ROUTING *************************************
      DO 670 I=1,365+ILEAP
      IF(I.EQ.1) STORE=STLAST(LL)
      IF(I.EQ.1) H=HLAST(LL)
      PT=0.00000
      VOL=(Q(I)/12.)*ACRE(KKKK)*43560.+(PPT(I)/12.)*C*(H**2)
      DO 580, KK=1,12
      IF(KK.GE.5)IILEAP=ILEAP
      IF(I.GT.MON(KK)+IILEAP.AND.I.LE.MON(KK+1)+IILEAP)EVAP=EVAPOR(KK)
  580 CONTINUE
      IF(EVAP.LT.0.000) EVAP=0.000
C CALCULATION OF DAILY EVAPORATION AND SEEPAGE VOLUMES USING POND AREA*******
      EVOL=EVAP*C*(H**2)
      SEEP=SRATE*C*(H**2)
      STOCK=0.0000
      IF(I.GE.NFD1.AND.I.LE.NLD1) STOCK=COWVOL
C POND WATER BALANCE CALCULATION*******************************************
      STORE=STORE+VOL-EVOL-SEEP-STOCK
      IF(STORE.GT.PVOL)THEN
       SPILL=STORE-PVOL
       STORE=PVOL
      ELSE
       SPILL=0.00000
      END IF

      IF(STORE.GT.0.) GO TO 620
      STORE=0.
      H=0.
      GO TO 630
  620 H=(STORE/D)**(1./3.)
```

```

  630 IF(I.EQ.365+ILEAP) STLAST(LL)=STORE
      IF(I.EQ.365+ILEAP) HLAST(LL)=H

C  CUMULATIVE SUMMARIES OF STOCK POND ROUTING  *****************************

      SPILL2(JJJJ,LL)=SPILL2(JJJJ,LL)+SPILL
      IF(STORE.GT.0.0000) GO TO 640
      NDRY(JJJJ,LL)=NDRY(JJJJ,LL)+1.

C ***COUNT DRY DAYS PER MONTH**********************************************
      DO 570, JJ=1,12
      IF(JJ.GE.5)IILEAP=ILEAP
      IF(I.GT.MON(JJ)+IILEAP.AND.I.LE.MON(JJ+1)+IILEAP)
     $IMDRY(JJ)=IMDRY(JJ)+1
  570 CONTINUE
  640 IF(LPRN1.EQ.0)GO TO 670
      IF(I.EQ.1) WRITE(LP,650)'DAY','TEMP','PPT','Q','STAGE','SPILL',
     &'RETAIN'
  650 FORMAT(A3,5X,A4,4X,A3,7X,A1,5X,A5,3X,A5,3X,A6,2X)
C CONVERT SPILL AND STORE TO WATERSHED INCHES FOR COMPARISON*********
      TSPILL=(SPILL/(43560.*ACRE(KKKK)))*12
      TSTORE=(STORE/(43560.*ACRE(KKKK)))*12
      WRITE(LP,660) I,TEMP(I),PPT(I),Q(I),H,TSPILL,TSTORE
  660 FORMAT(I3,6X,F3.0,5X,F5.2,3X,F7.5,1X,F5.2,3X,F7.5,1X,F7.5)
  670 CONTINUE

      DO 690 N=1,12
      MDRY(N,LL)=MDRY(N,LL)+IMDRY(N)
      IXX=1
      DO 680 I=2,12
      IXX2=IXX+3
      IF(IMDRY(N).GE.IXX.AND.IMDRY(N).LT.IXX2)
     +ICDRY(N,LL,I)=ICDRY(N,LL,I)+1
      IXX=IXX2
  680 CONTINUE
      IF(IMDRY(N).EQ.0) ICDRY(N,LL,1)=ICDRY(N,LL,1)+1
  690 CONTINUE
  700 CONTINUE

C   WRITE SIMULATION PROGRESS TO MONITOR
      WRITE(1,710) JJJJ,ACRE(KKKK)
  710 FORMAT(5X,"YEAR ",I3," SIMULATED",8X,F8.1," ACRE WATERSHED")

C ***PRECIP,TOTALT,AND TOTALQ PASSED FROM SUBROUTINES(ANNUAL TOTALS)******
      PTOTAL=PTOTAL+PRECIPT(JJJJ)
      QTOTAL=QTOTAL+TOTALQT(JJJJ)
      TTOTAL=TTOTAL+TAVE
 3000 CONTINUE

C  CALCULATION OF TEMPERATURE, PRECIPITATION, AND RUNOFF STATISTICS *********
      AA=0.0000
      AAA=0.0000
      AVE=QTOTAL/NYEARS
      AVE1=(AVE/12.)*43560.*ACRE(KKKK)
      AVE2=PTOTAL/NYEARS
      DO 740 I=1,NYEARS
      AA=AA+(TOTALQT(I)-AVE)**2
      AAA=AAA+((PRECIPT(I)-AVE2)**2)
  740 CONTINUE
      STD=SQRT(AAA/(NYEARS-1.))
      WRITE(LP,745)'CLIMATOLOGICAL SIMULATION SUMMARY:',ACRE(KKKK),
     $'ACRE','WATERSHED'
  745 FORMAT(///,80(1H*),/,5X,A36,2X,I4,2X,A4,1X,A9,/,80(1H*))
      WRITE(LP,750) NYEARS,AVE2,STD
  750 FORMAT(///,10X,I4," YEAR MEAN YEARLY PRECIPITATION = ",F5.2,
     +1X,"INCHES",2X,"STANDARD DEVIATION = ",F6.3,1X,"INCHES",)
      STD=SQRT(AA/(NYEARS-1.))
      AVE1A=AVE1/43560.
      WRITE(LP,760) AVE,AVE1A,STD
  760 FORMAT(10X,"MEAN RUNOFF = ",F5.2," INCHES",5X,F7.3," ACRE FEET",
     +5X,"STANDARD DEVIATION = ",F6.3," INCHES")
      AVE3=TTOTAL/NYEARS
      WRITE(LP,770) NYEARS,AVE3
  770 FORMAT(10X,I4," YEAR MEAN MAXIMUM TEMPERATURE = ",F6.2,/,80(1H*))
```

```

C  CALCULATION OF ANNUAL STOCK POND STATISTICS **************************
      DO 920 LL=1.NPOND

      SPILL3=0.0000
      DRYDAY=0.0000
      DO 790 I=1.NYEARS
      SPILL3=SPILL3+SPILL2(I.LL)
      DRYDAY=DRYDAY+NDRY(I.LL)
      SPL(I)=(SPILL2(I.LL)/(43560.*ACRE(KKKK)))*12.
  790 CONTINUE
      AVE4=((SPILL3/NYEARS)/(ACRE(KKKK)*43560.))*12.
      AVE5=SPILL3/NYEARS
      AVE5A=AVE5/43560.
      AVE6=DRYDAY/FLOAT(NYEARS)
      AVE8=AVE1-AVE5
      AVE9=(AVE8/(43560.*ACRE(KKKK)))*12.
      AVE10=AVE8/43560.
      AVE7=(AVE9/AVE)*100.
      FFACT=AVE8/(VOLF(LL)*(W(LL)**3))
      AA=0.0000
      AAA=0.0000
      AAAA=0.0000
      DO 800 I=1.NYEARS
      AA=AA+(SPL(I)-AVE4)**2
      AAA=AAA+((TOTALQT(I)-SPL(I))-AVE9)**2
      AAAA=AAAA+(NDRY(I.LL)-AVE6)**2
  800 CONTINUE
      STDSPL=SQRT(AA/(NYEARS-1.))
      STDSAF=(STDSPL/12.)*ACRE(KKKK)
      STDRET=SQRT(AAA/(NYEARS-1.))
      STDRAF=(STDRET/12.)*ACRE(KKKK)
      STDDRY=SQRT(AAAA/(NYEARS-1.))

C  WRITE OUT ANNUAL PPT.RUNOFF,SPILLAGE, DRY DAYS, AND RETENTION
      IF(LPRNS.EQ.0) GO TO 812
      WRITE(LP,810)'PPT','QTOTAL'.'SPILLAGE','RETAINED','DRY DAYS'
  810 FORMAT(A3.6X.A6.3X.A8.1X.A8.1X.A8.//)

C******INITIALIZE DISTRIBUTION COUNTERS TO ZERO*************************
  812 DO 815.J=1,20
       DISPILL(J)=0.
       DISRET(J)=0.
       DISDRY(J.LL)=0.
  815 CONTINUE

C CALCULATION OF ANNUAL RETENTION FROM ANNUAL RUNOFF AND SPILLAGE*********
  820 DO 860 I=1.NYEARS
      RET(I)=TOTALQT(I)-SPL(I)
      IF(LPRNS.EQ.0)GO TO 840

C WRITE OUTPUT SUMMARIES OF DATA FOR EACH YEAR***************************
      WRITE(LP.830)PRECIPT(I).TOTALQT(I).SPL(I).RET(I).NDRY(I.LL)
  830 FORMAT(F5.2,4X,F5.2,4X,F5.3,4X,F5.3,4X,I3)

C **CALCULATE DISTRIBUTION OF ANNUAL SPILLAGE.RETENTION,DRY DAYS*******
  840 ISPILL=INT(SPL(I)+1.)
      IF(ISPILL.GT.20)ISPILL=20
      IRET=INT(RET(I)+1.)
      IF(IRET.GT.20)IRET=20
      IDDRY=INT(NDRY(I.LL)/18.3+1.)
      IF(IDDRY.GT.20)IDDRY=20
      DISPILL(ISPILL)=DISPILL(ISPILL)+1
      DISRET(IRET)=DISRET(IRET)+1
      DISDRY(IDDRY.LL)=DISDRY(IDDRY.LL)+1
  860 CONTINUE
```

```

C  RETENTION MEDIAN CALCULATION*******************************************
      NY=NYEARS-1
      DO 880 I=1,NY
      J=I+1
      DO 870 II=J,NYEARS
      IF(RET(I).GE.RET(II)) GO TO 870
      TMPR=RET(I)
      RET(I)=RET(II)
      RET(II)=TMPR
  870 CONTINUE
  880 CONTINUE
      RTMED1=(RET(NYEARS/2)+RET(NYEARS/2+1))/2
      RTMED2=(RTMED1/12.)*ACRE(KKKK)

C  WRITE OUT STANDARD RESULTS ****ANNUAL MEANS, DEVIATIONS, ETC.************

      WRITE(LP,889)'STOCKPOND SIZE='.PSIZE(LL),'ACRE-FEET',
     &'WATERSHED SIZE='.ACRE(KKKK).'ACRES'
  889 FORMAT(//,80(1H*),//,9X,A15,1X,F5.2,1X,A9.10X,A15,1X,F5.0.1X,A5,/)
      WRITE(LP.890) AVE4.AVE5.AVE5A.STDSPL.STDSAF.AVE9.AVE8.AVE10.
     +STDRET,STDRAF,RTMED1,RTMED2,AVE7,FFACT,AVE6,STDDRY
  890 FORMAT(10X."MEAN ANNUAL SPILL = ".F7.4." INCHES".5X.F10.1." CUBIC
     +FEET",5X,F7.3," ACRE FEET",/,10X,"STANDARD DEVIATION OF SPILL = "
     +.F7.3." INCHES".5X.F7.3." ACRE FEET".//.10X,"MEAN ANNUAL RETENTION
     + = ",F7.4," INCHES",5X,F10.1," CUBIC FEET",5X,F7.3," ACRE FEET",
     +/.10X."STANDARD DEVIATION OF RETENTION = ".F7.4." INCHES".5X,F7.3.
     +" ACRE FEET",/,10X,"MEDIAN OF RETENTION = ",F7.4," INCHES",5X,
     +F7.3."ACRE FEET".//.10X."MEAN ANNUAL RETENTION AS A PERCENT OF RUN
     +OFF = ",F7.3,/,10X,"FILL FACTOR = "F7.2,//,10X,"MEAN ANNUAL NUMBER
     + OF DRY DAYS = ".F7.3.10X."STANDARD DEVIATION = ".F7.3.//)
C MONTHLY DRY DAY DISTRIBUTIONS ONLY WRITTEN FOR POND LL=1**************
      IF(LL.GT.1)GO TO 915
      WRITE(LP,895)
  895 FORMAT(40X,"MONTHLY DRY DAYS DISTRIBUTIONS",/,17X,"MONTH",6X,
     +'DRY DAY'.20X."NUMBER OF YEARS IN EACH DRY DAY CLASS",/.29X,
     +'MEAN',6X,"0",4X,"1-3",3X,"4-6",3X,"7-9",2X,"10-12",1X,"13-15",
     +1X.'16-18'.1X."19-21",1X."22-24",1X."25-27".1X."28-30".3X."31")
      DO 910 I=1,12
      DM=FLOAT(MDRY(I.LL))/NYEARS
      WRITE(LP,900) ALPHA(I),DM,(ICDRY(I,LL,N),N=1,12)
  900 FORMAT(15X.A10.1X.F6.3.4X.I3.11(3X.I3))
  910 CONTINUE
  915 CONTINUE

C***INITIALIZE DISTRIBUTIONS TO ZERO************************************
      CDF1=0.
      CDF2=0.
      CDF3=0.
      IF(LPRN6.EQ.0)GO TO 920
```

```

C**WRITE DISTRIBUTIONS OF ANNUAL SPILL.RETENTION.DRY DAYS TO OUTPUT******
C************************************************************************
      WRITE(LP,577)'DISTRIBUTION OF ANNUAL SPILLS (AC-FT)','INTERVAL',
     $'OCCURENCES','PDF','CDF'
  577 FORMAT(//,1X,A48,//,A8,5X,A10,5X,A3,8X,A3,/)
  666 FORMAT(1X.F5.1.A1.F5.1,4X.F4.0.5X.F8.6.5X.F8.6)
      DO 861,I=1,20
      CDF1=CDF1+DISPILL(I)/NYEARS
      WRITE(LP,666)(I-.999)*ACRE(KKKK)/12.,'-',I*ACRE(KKKK)/12.,
     $DISPILL(I).DISPILL(I)/NYEARS.CDF1
  861 CONTINUE
      WRITE(LP,577)'DISTRIBUTION OF ANNUAL RETENTION (AC-FT)',
     $'INTERVAL'.'OCCURENCES','PDF'.'CDF'
      DO 862, I=1,20
      CDF2=CDF2+DISRET(I)/NYEARS
      WRITE(LP,666)(I-.999)*ACRE(KKKK)/12.,'-',I*ACRE(KKKK)/12.,
     $DISRET(I).DISRET(I)/NYEARS.CDF2
  862 CONTINUE
      WRITE(LP,577)'DISTRIBUTION OF ANNUAL DRY DAYS','INTERVAL',
     $'OCCURENCES'.'PDF'.'CDF'
      DO 863,I=1,20
      CDF3=CDF3+DISDRY(I.LL)/NYEARS
      WRITE(LP,677)INT((I-.999)*18.3)+1,'-',INT(I*18.3),DISDRY(I,LL),
     $DISDRY(I.LL)/NYEARS.CDF3
  863 CONTINUE
  677 FORMAT(1X,I3,A1,I3,9X,F4.0,5X,F8.6,5X,F8.6)

  920 CONTINUE

 4000 CONTINUE
      STOP
      END
C  *******************  END OF PROGRAM  ********************************
```

```
      SUBROUTINE TRAB1
C THIS IS THE PRECIPITATION SUBROUTINE FOR POND3, FEB.1985, MCDOWELL
C THIS PROGRAM SIMULATES DAILY RAINFALL FOR WHITESPAR WATERSHED.PRESCOTT
C NATL. FOREST, ARIZONA, USING PARAMETER DISTRIBUTIONS DERIVED FROM
C ANALYSIS OF 23 YEARS PRECIPITATION RECORDS.  THE OUTPUT IS MONTHLY
C RAINFALL STATISTICS. THE PROGRAM IS BASED ON THE RAINFALL SIMULATION
C SECTOR OF PROGRAM PONDS. WRITTEN BY C. ALMESTAD.
      COMMON/A/JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),TOTALQ
      REAL K(7),LAM(7),MEAN(10),RAIN,PPTMON(6),LNGP(25),DAYBG(3)
      REAL TEVENTS(12),DAY(12),CDF(46),DBS(70),NGS(15)
      CHARACTER MONTH(6)*12
      DATA LAM/2.8746,5.7508,3.1380,1.5101,.2210,.5178,1.7791/
      DATA K/.8921,1.1126,.9032,.6541,.7876,.4931,.6751/
      DATA MEAN/.310,12.144,.193,.288,.409,10.412,2.162,1.589,1.698,
     $11.203/
      DATA PPTMON/6*0./
      DATA TEVENTS/12*0./

C START THE RAINFALL SIMULATION*****************************
        JDAY=0
C INITIALIZE DAY COUNT ACCORDING TO PREVIOUS YEAR'S LAST INTERARRIVAL DAY****
        IF(JJJJ.EQ.1)DCOUNT=0
        IF(JJJJ.GE.2)DCOUNT=DCOUNT-365
        DO 111, I=1,6
        PPTMON(I)=0.
  111   CONTINUE
        RAIN=0.00
       ICHECK=0
C*****OCTOBER,NOVEMBER AND (SEPTEMBER) MODEL*****GEOM INTER,GAMMA RAIN*****
       JDAY=61
  86   ICHECK=ICHECK+1
       DO WHILE(DCOUNT.LE.JDAY)
C SAMPLE UNIFORM RANDOM NUMBER GENERATOR URAN()******************************
        X=URAN()
C FIXED ONE-DAY INTERARRIVAL PROBABILITY EQUALS 0.43269**********************
        IF(X.LE.0.43269)THEN
         NINT=1
        ELSE
         X=URAN()
         P=1./MEAN(6)
C SAMPLE THE CALIBRATED GEOMETRIC DISTRIBUTION*******************************
         NINT=INT(ALOG(1-X)/ALOG(1-P)+1)+1
        END IF
C COUNT INTERARRIVAL DAYS TO DETERMINE CURRENT DAY OF YEAR*******************
       DCOUNT=DCOUNT+NINT
       IF(DCOUNT.GT.JDAY)GO TO 6
C SAMPLE THE CALIBRATED GAMMA DISTRIBUTION TO GENERATE PPT AMOUNT***********
       PPT(DCOUNT)=GAMMA(K(4),1/LAM(4))
       IF(PPT(DCOUNT).LT.0.01)PPT(DCOUNT)=0.01
       PPTMON(5)=PPTMON(5)+PPT(DCOUNT)
       TEVENTS(5)=TEVENTS(5)+1
       IF(DCOUNT.GE.JDAY)GO TO 6
    6 END DO
       IF(DCOUNT.GE.365+ILEAP.AND.ICHECK.GE.2)GO TO 44
```

```
C ****WINTER(DEC,JAN,FEB,MARCH) MODEL*******************************
C ****GROUP DUR,GROUPS/SEQ,DRY DAYS/GROUP,DRY DAYS/SEQ:ALL GEOM,*****
C ****PRECIP/GROUP IS  GAMMA*********************************
      JDAY=182+ILEAP
      ITRANSIT=1
      DO WHILE(DCOUNT.LE.JDAY)
      IF(ITRANSIT.EQ.1)GO TO 11
C ***DAYS BETWEEN SEQUENCES*****
      X=URAN()
      P=1./(MEAN(10)-3.)
      NINT=INT(ALOG(1-X)/ALOG(1-P)+1)+3
      TNINT=TNINT+1
      DBS(NINT)=DBS(NINT)+1
      DCOUNT=DCOUNT+NINT
      IF(DCOUNT.GT.JDAY)GO TO 7
C **GROUPS PER SEQUENCE************
   11 ITRANSIT=0
      X=URAN()
      P=1./MEAN(8)
      NGRPS=INT(ALOG(1-X)/ALOG(1-P)+1)
      NGS(NGRPS)=NGS(NGRPS)+1
C **LOOP FOR DAYS/GROUP,RAIN/GROUP,DRY DAYS BETWEEN GROUPS***
      DO 60,JJ=1,NGRPS
C *DAYS/GROUP***************
      X=URAN()
      P=1./MEAN(7)
      LG=INT(ALOG(1-X)/(ALOG(1-P))+1)
      LNGP(LG)=LNGP(LG)+1
C **PPT/GROUP************
      GRAIN=GAMMA(K(6),1/LAM(6))
      DO 59, I=1,LG
      DCOUNT=DCOUNT+1
      PPT(DCOUNT)=GRAIN/LG
      IF(PPT(DCOUNT).LT.0.01)PPT(DCOUNT)=0.01
   59 CONTINUE
      PPTMON(6)=PPTMON(6)+GRAIN
      TEVENTS(6)=TEVENTS(6)+1
      IF(DCOUNT.GE.JDAY)GO TO 7
C***DAYS BETWEEN GROUPS**************
   53 X=URAN()
      P=1./MEAN(9)
      DBG=INT(ALOG(1-X)/(ALOG(1-P))+1)
      IF(DBG.GT.3)GO TO 53
      DAYBG(DBG)=DAYBG(DBG)+1
      DCOUNT=DCOUNT+DBG
      IF(DCOUNT.GE.JDAY)GO TO 7
   60 CONTINUE
    7 END DO
```

```
C APRIL,MAY,JUNE PRECIP MODEL***FIXED GEOM INTER,GAMMA RAIN**********
      JDAY=273+ILEAP
      DO WHILE(DCOUNT.LE.JDAY)
      X=URAN()
      IF(X.LE.0.36522)THEN
      NINT=1
      ELSE
      X=URAN()
      P=1./MEAN(2)
      NINT=INT(ALOG(1-X)/ALOG(1-P)+1)+1
      END IF
      DCOUNT=DCOUNT+NINT
      IF(DCOUNT.LE.212+ILEAP)THEN
C **APRIL PRECIP*******************
       PPT(DCOUNT)=GAMMA(K(1),1/LAM(1))
       IF(PPT(DCOUNT).LT.0.01)PPT(DCOUNT)=0.01
       PPTMON(1)=PPT(DCOUNT)+PPTMON(1)
       TEVENTS(1)=TEVENTS(1)+1
      ELSE IF(DCOUNT.GT.212+ILEAP.AND.DCOUNT.LE.JDAY)THEN
C **MAY,JUNE PRECIP ********************************************
       PPT(DCOUNT)=GAMMA(K(2),1/LAM(2))
       IF(PPT(DCOUNT).LT.0.01)PPT(DCOUNT)=0.01
       PPTMON(2)=PPTMON(2)+PPT(DCOUNT)
       TEVENTS(2)=TEVENTS(2)+1
      ELSE
      END IF
    3 END DO
C**INITIALIZE DCOUNT TO FIRST DAY OF MONTH TO START RAINY SEASON**
      DCOUNT=JDAY
C**JULY,AUGUST PRECIP MODEL***FIXED SHIFTED GAMMA INT,GAMMA RAIN******
      JDAY=335+ILEAP
      DO WHILE (DCOUNT.LE.JDAY)
      X=URAN()
      IF(X.LE.0.50737)THEN
      NINT=1
      ELSE
      NINT=INT(GAMMA(K(5),1/LAM(5)))+1+1
      END IF
      DCOUNT=DCOUNT+NINT
      IF(DCOUNT.LE.304+ILEAP)THEN
C***JULY RAIN**************************
       PPT(DCOUNT)=GAMMA(K(3),1/LAM(3))
       IF(PPT(DCOUNT).LT.0.01)PPT(DCOUNT)=0.01
       PPTMON(3)=PPTMON(3)+PPT(DCOUNT)
       TEVENTS(3)=TEVENTS(3)+1
      ELSE IF(DCOUNT.GT.304+ILEAP.AND.DCOUNT.LE.JDAY)THEN
C****AUGUST RAIN*******
       PPT(DCOUNT)=GAMMA(K(7),1/LAM(7))
       IF(PPT(DCOUNT).LT.0.01)PPT(DCOUNT)=0.01
       PPTMON(4)=PPTMON(4)+PPT(DCOUNT)
       TEVENTS(4)=TEVENTS(4)+1
      ELSE
      END IF
      END DO
      JDAY=365+ILEAP
      GO TO 86
   44 CONTINUE
      PRECIP=0.
      DO 99, I=1,6
      PRECIP=PRECIP+PPTMON(I)
   99 CONTINUE
```

```
C***OUTPUT OF SUMMARIZED MONTHLY STATISTICS****************
C     IF(JJJJ.LT.200)GO TO 1000
C     WRITE(6,77)'MONTH(S)','MEAN MONTHLY PPT','MEAN PPT/EVENT',
C    $'EVENTS/SEASON'
C  77 FORMAT(//,1X,A8,6X,A16,5X,A14,2X,A13,//)
C     DO 70,I=1,6
C     AVERAGE=PPTMON(I)/200
C     XEVENTS=TEVENTS(I)/200
C     WRITE(6,88)AVERAGE,AVERAGE/XEVENTS,
C    $TEVENTS(I)/200
C     SUMALL=SUMALL+AVERAGE
C  70 CONTINUE
C  88 FORMAT(15X,F5.2,10X,F5.2)
C     WRITE(6,*)'SUMALL=',SUMALL

 1000 RETURN
      END

C MATHEMATICAL GAMMA FUNCTION GENERATOR*************************************
      FUNCTION GAMMA(ALPHA,BETA)
      IF(ALPHA.GT.1.) GOTO 200
         B=1.+ALPHA/2.17828183
 100     U=URAN()
         P=B*U
         U=URAN()
         IF(P.GT.1.) THEN
            Y=-ALOG((B-P)/ALPHA)
            IF(U.LE.Y**(ALPHA-1.)) THEN
               GAMMA=Y*BETA
               RETURN
            ENDIF
         ELSE
            Y=P**(1./ALPHA)
            IF(U.LE.EXP(-Y)) THEN
               GAMMA=Y*BETA
               RETURN
            ENDIF
         ENDIF
         GOTO 100
  200    A=1./SQRT(2.*ALPHA-1.)
         B=ALPHA-ALOG(4.)
         Q=ALPHA+1./A
         E=4.5
         D=1.+ALOG(E)
  300    U1=URAN()
         U2=URAN()
         V=A*ALOG(U1/(1.-U1))
         Y=ALPHA*EXP(V)
         Z=U1*U1*U2
         W=B+Q*V-Y
         IF(W+D-E*Z.GE.0..OR.W.GE.ALOG(Z)) THEN
            GAMMA=Y*BETA
            RETURN
         ENDIF
         GOTO 300
      END
```

```
C***********************************************************************
      SUBROUTINE JOTSS
C THIS PROGRAM IS TEMPERATURE SIMULATION FOR PROGRAM POND3, FEB. 1985.
C THIS PROGRAM SIMULATES A SERIES OF 365 TEMPERATURE MEANS USING A
C COSINE CURVE, THEN USES A LAG ONE MARKOV MODEL TO SIMULATE DAILY MAXIMUM
C TEMPERATURES STOCHASTICALLY. THE PARAMETERS ARE FOR WHITESPAR
C WATERSHED IN THE PRESCOTT NATL. FOREST, ARIZONA (CHAPARRAL ZONE).
C THESE PARAMETERS WERE TAKEN FROM DATA ANALYSIS PROGRAMS &MAXTM AND
C &CORR2 WRITTEN BY C. ALMESTAD. MCDOWELL,1985.
C NOTE:MONTH 1 IS OCTOBER........WATER YEAR DATES USED.
      COMMON/A/JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),TOTALQ
      REAL STDEV(12),LAG1,STEMP(0:366),TMEAN(366)
      INTEGER MON(13)
      DATA STDEV/10.09,9.78,10.50,9.68,9.76,11.13,10.91,9.59,8.50,
     $6.66,6.50,7.66/
      DATA MON/0,31,61,92,123,151,182,212,243,273,304,335,365/
C PARAMETERS EXPLAINED IN TEXT, MCDOWELL (1985)************************
      TYEAR=67.0349
      AMP=18.004
      IPEAK=298
      LAG1=.776
      SKEW=-.289
      TLAST=79.05
      TSKW=((1-LAG1**3)/(1-LAG1**2)**1.5)*SKEW
      TTOT=0.
C DETERMINE WHICH MONTHLY STANDARD DEVIATION APPLIES ON THIS DAY OF YEAR****
      DO 25 I=1,365+ILEAP
       IILEAP=0
       DO 30 J=1,12
       IF(J.GE.5)IILEAP=ILEAP
       IF(I.GT.MON(J)+IILEAP.AND.I.LE.MON(J+1)+IILEAP)STDEVT=STDEV(J)
   30  CONTINUE
C TEMPERATURE SIMULATION FOR ONE YEAR************************************
C****TMEAN=MEAN,TYEAR=ANNUAL MEAN, AMP=MAX AMPLITUDE COSINE,IPEAK=PEAK DAY
C************************************************************************
      TMEAN(I)=TYEAR+AMP*COS(6.283185*(I-IPEAK)/365)
C****TNRN=NORMAL RANDOM NUMBER, GRN=GAMMA RANDOM NUMBER (TRANSFORMED).
      TNRN=GRAN()
      GRN=(2/TSKW)*((1+((TSKW*TNRN)/6)-(TSKW**2/36))**3)-2/TSKW
      IF(I.EQ.1.AND.JJJJ.EQ.1)STEMP(I-1)=TLAST
      IF(I.EQ.1.AND.JJJJ.GT.1)STEMP(I-1)=STEMP(365+ILEAP)
      STEMP(I)=TMEAN(I)+LAG1*(STEMP(I-1)-TMEAN(I))+GRN*STDEVT*
     $SQRT(1-LAG1**2)
      TTOT=TTOT+STEMP(I)
      TEMP(I)=STEMP(I)
   25 CONTINUE

   20 CONTINUE
      TAVE=TTOT/(365+ILEAP)

      RETURN
      END
```

```
C************************************************************************
      SUBROUTINE STRBB
C THIS IS THE SUBROUTINE VERSION OF &STREB USED IN POND3, FEB. 1985.
C THIS IS A MODIFICATION OF THE GENERALIZED STREAMFLOW SIMULATION SYSTEM
C DEVELOPED BY THE JOINT FEDERAL-STATE RIVER FORECAST CENTER IN
C SACRAMENTO, CALIFORNIA (BURNASH,FERRAL,AND MCGUIRE,1973). THIS
C PROGRAM CONSISTS OF THE GENERALIZED HYDROLOGIC MODEL (SUB-ROUTINE
C 'STREB') DEVELOPED BY BURNASH,ET.AL.,BUT,USING EVAPOTRANSPIRATION INPUT
C AS MONTHLY MEANS, AND A SIMPLE SNOW AND SNOWMELT ROUTINE USING BASE
C TEMPERATURES TO DISTINGUISH PRECIP. TYPE AND TO MELT SNOW BY INCHES
C PER DEGREE-DAY. INPUT IS ONE-YEAR SETS OF PPT,TEMP, AND RUNOFF DATA.

      COMMON/A/JJJJ,ILEAP,PPT(366),PRECIP,TEMP(366),TAVE,Q(366),TOTALQ
      REAL LZTWC,LZFSC,LZFPC,LZTWM,LZFPM,LZFSM,MELTRATE
      REAL ET(12),LZSK,LZPK,RAIN(366),TOTALP,TOTALET,TOTALFLO
      REAL SNOW(366),PLIQ(366),EVAP(366),MELT(366)
      INTEGER MON(13)
      CHARACTER *6 JOTOYR,MVUAYR,MAJIYR
      DATA MON/0,31,61,92,123,151,182,212,243,273,304,335,365/
      DATA ET/.0750,.0700,.0557,.0484,.0638,.0774,.1075,.1476,
     $.2025,.2637,.2274,.1975/
C *********VARIABLE INITIALIZATION ****************************
       UZTWM=4.2
       UZFWM=1.4
       LZTWM=5.2
       LZFSM=1.
       LZFPM=2.70
       UZK=.50
       LZSK=.40
       LZPK=.04
       ZPERC=20.
       REXP=2.2
       FRACT=1.0
       PFREE=.3
       IF(JJJJ.EQ.1)THEN
       UZTWC=0.
       UZFWC=0.
       LZTWC=2.0
       LZFSC=0.
       LZFPC=0.
       ELSE
       END IF
       SIDE=0.
       SSOUT=0.
       PCTIM=0.0002
       SARVA=0.
       RSERV=0.3
       IMPRT=0.
       ADIMP=0.
       MELTRATE=.05
       BASEMELT=45.
       BASESNOW=40.
C **********VARIABLE*INITIALIZATION*DONE,**READ*DATA*FILES********************
C @STREM IS FOR LISTING RUNOFF TO DATA FILE FOR PLOTTING**********************
C      OPEN(99,FILE='@STREM',STATUS='NEW')
       TOTALP=0.
      TOTALQ=0.
       TOTALET=0.
      PAV=0.
       DSNOW=0.
      DO 111,I=1,366
       MELT(I)=0.00
       RAIN(I)=0.00
  111 CONTINUE
```

```

C ***BEGIN ANNUAL LOOP*****************************************************
        DO 999, I=1,365+ILEAP
          IILEAP=0
C DETERMINE WHICH MONTHLY EVAPOTRANSPIRATION RATE APPLIES THIS DAY I*********
          DO 16, J=1,12
           IF(J.GE.5)IILEAP=ILEAP
           IF(I.GT.MON(J)+IILEAP.AND.I.LE.MON(J+1)+IILEAP)EDMND=ET(J)
    16    CONTINUE

C****SNOW & SNOWMELT ALGORITHM; SNOW IF(BASESNOW,SNOWMELT IF)BASEMELT.
         IF(TEMP(I).GT.BASEMELT.AND.DSNOW.GT.0.)THEN
          MELT(I)=MELTRATE*(TEMP(I)-BASEMELT)
          IF(MELT(I).GE.DSNOW)MELT(I)=DSNOW
          IF(MELT(I).LT.0)MELT(I)=0.
          DSNOW=DSNOW-MELT(I)
         ELSE
         END IF
        IF(TEMP(I).GT.BASESNOW)RAIN(I)=PPT(I)
        PLIQ=RAIN(I)+MELT(I)
        IF(TEMP(I).LE.BASESNOW)THEN
         SNOW(I)=PPT(I)
         DSNOW=DSNOW+SNOW(I)
        ELSE
        END IF

C COMPUTE TRANSPIRATION LOSS FROM UPPER ZONE TENSION WATER.
C THE RAINY DAY NORMAL IS ASSUMED TO BE ONE INCH OF RAIN. THIS IS PDNOR.
        PDNOR=1.
        PDN20=PDNOR*.20
        E2=0.
        E1=EDMND*UZTWC/UZTWM
        RED=EDMND-E1
        UZTWC=UZTWC-E1
        IF(UZTWC)100,155,155
   100  E1=EDMND+UZTWC
        UZTWC=0.
        RED=EDMND-E1
C  COMPUTE TRANSPIRATION LOSS FROM UPPER ZONE FREE WATER.
        IF(UZFWC-RED)130,140,140
   130  E2=UZFWC
        UZFWC=0.
        GO TO 170
   140  E2=RED
        UZFWC=UZFWC-E2

C  IF UPPER ZONE FREE WATER RATION EXCEEDS UPPER ZONE
C  TENSION CONTENT RATIO, TRANSFER FREE WATER INTO TENSION.
   155  CONTINUE
        A=UZTWC/UZTWM
        B=UZFWC/UZFWM
        IF(A-B)160,170,170
   160  A=(UZTWC+UZFWC)/(UZTWM+UZFWM)
        UZTWC=UZTWM*A
        UZFWC=UZFWM*A
   170  CONTINUE
C EVAPORATION FROM ADIMP AREA
        E5=E1+RED*(ADIMC-E1-UZTWC)/(UZTWM+LZTWM)
C  COMPUTE TRANSPIRATION LOSS FROM LOWER ZONE TENSION WATER.
        E3=(RED-E2)*LZTWC/(UZTWM+LZTWM)
        LZTWC=LZTWC-E3
        IF(LZTWC)180,185,185
   180  E3=E3+LZTWC
        LZTWC=0.
```

```
C RESUPPLY LOWER ZONE TENSION WATER FROM LOWER ZONE FREE IF MORE
C WATER AVAILABLE THERE.
  185 CONTINUE
      A=LZTWC/LZTWM
      B=(LZFPC+LZFSC-SAVED+LZTWC)/(LZFPM+LZFSM-SAVED+LZTWM)
      IF(A-B)190,210,210
  190 DEL=(B-A)*LZTWM
C TRANSFER WATER FROM LOWER ZONE SECONDARY FREE WATER TO LOWER
C ZONE TENSION
      LZTWC=LZTWC+DEL
      LZFSC=LZFSC-DEL
      IF(LZFSC)200,210,210
C TRANSFER PRIMARY FREE WATER IF SECONDARY FREE WATER INADEQUATE.
  200 LZFPC=LZFPC+LZFSC
      LZFSC=0.
  210 CONTINUE
C RUNOFF FROM IMPERVIOUS OR WATER-COVERED AREA
      ROIMP=PLIQ*PCTIM
C ADJUST ADIMC STORAGE FOR EVAPORATION
      ADIMC=ADIMC-E5
      IF(ADIMC)211,212,212
  211 E5=E5+ADIMC
      ADIMC=0
  212 E5=E5*ADIMP
C REDUCE RAIN BY AMOUNT OF UPPER ZONE TENSION WATER DEFICIENCY.
      PAV=PLIQ+UZTWC-UZTWM
      IF(PAV)220,230,230
C FILL UPPER ZONE TENSION WATER AS MUCH AS RAIN PERMITS
  220 UZTWC=UZTWC+PLIQ
      PAV=0.
      GO TO 240
  230 UZTWC=UZTWM
C DETERMINE NUMBER OF INCREMENTS.

  240 NINC=1.+5.*(UZFWC*FRACT+PAV)
      ADIMC=ADIMC+PLIQ-PAV
      DINC=NINC
      DINC=1./DINC
      PINC=PAV*DINC
      FLOBF=0.
      FLOSF=0.
      FLOIN=0.
      DINC=DINC*FRACT
C MODIFICATIONS THIS DATE TO LUMP RAINFALL IN LESS THAN THE  7-14-71
C TOTAL PERIOD TO APPROXIMATE SOMEWHAT THE INTENSITY VARIATION EFFECT.
      DUZ=UZK
      DLZP=LZPK
      DLZS=LZSK
      ITIME=2
      ADJ=1.
      IF(PAV-PDN20)246,246,242
  242 IF(PAV-PDNOR)243,244,244
C  THE EFFECTIVE LENGTH OF RAIN IN A PERIOD IS ASSUMED TO BE HALF
C  PERIOD LENGTH FOR RAIN EQUAL TO THE RAINY PERIOD NORMAL.
  243 ADJ=.5*SQRT(PAV/PDNOR)
      GO TO 245
  244 ADJ=1.-.5*PDNOR/PAV
  245 CONTINUE
      ITIME=0
```

```
C SECTIONAL ANALYSIS****************************************
  400 ITIME=ITIME+1
      NINC=1.+5.*(UZFWC*FRACT*ADJ+PAV)
      DINC=NINC
      DINC=1./DINC
      PINC=PAV*DINC
      DINC=DINC*FRACT*ADJ
C ADJUSTMENT OF FREE-WATER STORAGE DEPLETION COEFFICIENTS FOR
C PERIODS DIFFERENT FROM ONE DAY WHEN COEFFICIENTS WERE DERIVED FOR
C DAILY DISCHARGE. DC(X DAYS)=1.-(1.-DC(ONE DAY))**X
      GO TO 247
  246 IF(DINC-1.)247,248,248
  247 CONTINUE
      DUZ=1.-(1.-UZK)**DINC
      DLZP=1.-(1.-LZPK)**DINC
      DLZS=1.-(1.-LZSK)**DINC
  248 CONTINUE

C BEGIN DRAINAGE AND PERCOLATION LOOP
      DO 385 INC=1.NINC
      PAV=PINC
C IMPERVIOUS RUNOFF MODIFIED FOR CHANGE IN IMPERVIOUS AND WATER-COVERED
C AREA PERCENT.
      RATIO=(ADIMC-UZTWC)/LZTWM
      ADDRO=PINC*RATIO*RATIO
C COMPUTE BASEFLOW FROM LOWER ZONE.
      BF=LZFPC*DLZP
      FLOBF=FLOBF+BF
      LZFPC=LZFPC-BF
      BF=LZFSC*DLZS
      LZFSC=LZFSC-BF
      FLOBF=FLOBF+BF
C COMPUTE PERCOLATION, BUT NO CALCULATIONS IF NO WATER TO PERCOLATE.
      IF(PINC+UZFWC-.01)380.380.250
C COMPUTE PERCOLATION FROM UPPER ZONE TO LOWER. PERC=PBASE IN LITERATURE.
  250 PERCM=LZPK*LZFPM+LZSK*LZFSM
      PERC=PERCM*DINC
      PERC=PERC*UZFWC/UZFWM
C MODIFICATION FOR FASTER PERCOLATION INTO MOISTURE-DEFICIENT SOIL
C IN LOWER LAYER.
      PERC=PERC*(1.+(ZPERC*(1.-(LZFPC+LZFSC+LZTWC)/(LZFPM+LZFSM+LZTWM))
     $**REXP))
      IF(PERC-UZFWC)270,270,260
  260 PERC=UZFWC
      UZFWC=0
      GO TO 300
  270 UZFWC=UZFWC-PERC
      CHECK=LZFPC+LZFSC+LZTWC+PERC-LZFPM-LZFSM-LZTWM
      IF(CHECK)290.290.280
  280 PERC=PERC-CHECK
      UZFWC=UZFWC+CHECK
C COMPUTE INTERFLOW
  290 DEL=DUZ*UZFWC
      FLOIN=FLOIN+DEL
      UZFWC=UZFWC-DEL
C DISTRIBUTE PERCOLATED WATER,CHECK IF COMPUTED PERCOLATION EXCEEDS
C AVAILABLE TENSION CAPACITY IN LOWER LEVEL. REPLACE TENSION WATER FIRST.
  300 CONTINUE
C SAVE PERCOLATED VOLUME FOR PFREE AREA
      SPERC=PERC
      PERC=PERC*(1.-PFREE)
      IF(PERC-LZTWM+LZTWC)310.310.320
  310 LZTWC=LZTWC+PERC
      PERC=0.
      GO TO 321
```

```
  320 PERC=PERC-LZTWM+LZTWC
      LZTWC=LZTWM
C DISTRIBUTE PERIOD PERCOLATION IN EXCESS OF LOWER ZONE TENSION REQUIREMENT.
  321 PERC=PERC+SPERC*PFREE
      IF(PERC)340,340,323
  323 CONTINUE
      HPL=LZFPM/(LZFPM+LZFSM)
      RATL=LZFPC/LZFPM
      PERCS=PERC-PERC*(HPL*2.*(1.-RATLP)/((1.-RATLP)+(1.-LZFSC/LZFSM)))
      LZFSC=LZFSC+PERCS
      IF(LZFSC-LZFSM)330,330,322
  322 PERCS=PERCS-LZFSC+LZFSM
      LZFSC=LZFSM
  330 CONTINUE
      LZFPC=LZFPC+(PERC-PERCS)
  340 IF(PAV)380,380,350
  350 CONTINUE
C DISTRIBUTE PERIOD RAIN IN EXCESS OF UPPER ZONE TENSION REQUIREMENTS
C TO UPPER ZONE FREEWATER AND SURFACE RUNOFF.
C CHECK WHETHER RESIDUAL RAIN EXCEEDS AVAILABLE UPPER LEVEL FREE WATER MAX.
      IF(PAV-UZFWM+UZFWC)360,360,370
  360 UZFWC=UZFWC+PAV
      GO TO 380
  370 PAV=PAV-UZFWM+UZFWC
      UZFWC=UZFWM
      FLOSF=FLOSF+PAV
      ADDRO=ADDRO+PAV*(1.-ADDRO/PINC)
  380 CONTINUE
      ADIMC=ADIMC+PINC-ADDRO
      ROIMP=ROIMP+ADDRO*ADIMP
C RECYCLE POINT FOR THE TIME INCREMENT ANALYSIS.
  385 CONTINUE
      ADJ=1.-ADJ
      PAV=0.
  390 CONTINUE

C SECTIONAL RECYCLE POINT (1ST PASS=WET,2ND PASS=DRY)
      IF(ITIME-1)400,400,410
  410 EUSED=E1+E2+E3
      FLOSF=FLOSF*(1.-PCTIM-ADIMP)
      FLOIN=FLOIN*(1.-PCTIM-ADIMP)
      FLOBF=FLOBF*(1.-PCTIM-ADIMP)
C OUTPUT COMPUTED,WRITTEN TO FILE AND SCREEN,THEN RE-RUN OPTION EXECUTED.
      Q(I)=FLOSF+FLOIN+FLOBF+ROIMP
      SOILWATER=UZTWC+UZFWC+LZTWC+LZFSC+LZFPC
C CUT OFF VERY LOW FLOWS TO AVOID OVER-LONG RECESSIONS****************
      IF(Q(I).LE.0.00014)Q(I)=0.
C     WRITE(1,443)I,TEMP(I),PPT(I),Q(I),SOILWATER,EUSED
C 443 FORMAT(F3.0,1X,F3.0,1X,F5.2,3X,F7.5,1X,F5.2,1X,F5.2)
C     TOTALP=TOTALP+PPT(I)
      TOTALQ=TOTALQ+Q(1)
      TOTALET=TOTALET+EUSED
  999 CONTINUE
C***END OF DAILY LOOP ***********************************************
C     CLOSE(99)
C     WRITE(1,*)'REMEMBER TO PURGE @STREM BEFORE
C    $RE-RUNNING PROGRAM.'
 1000 RETURN
      END
```

APPENDIX B

SUMMARIZED RESULTS OF TRIAL STOCK POND SIMULATIONS FOR WHITESPAR CONDITIONS: POND RETENTION AND DRY DAYS

PERCENT RETENTION STATISTICS

(PERCENT OF ANNUAL RUNOFF)

POND: TRIANGULAR SEEPAGE: 0.00 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	24.481	15.818	9.828	7.327	5.910	2.880
.5	32.579	21.694	13.781	10.389	8.444	4.211
.75	38.266	25.943	16.736	12.698	10.369	5.242
1	42.687	29.332	19.166	14.625	11.977	6.115
2	54.840	39.040	26.334	20.425	16.887	8.822
3	62.808	45.735	31.452	24.689	20.558	10.914
4	68.425	51.040	35.602	28.138	23.574	12.678
5	73.007	55.401	39.057	31.083	26.161	14.233
10	86.509	69.677	51.692	41.866	35.765	20.301
	Mean Annual Runoff (AC-FT)**					
	11.274	22.548	45.095	67.643	90.190	225.475

* Percentage not retained is spilled, e.g., if percent retention = 15.534, percent spilled = 84.466.

** Percent retention (or spillage)* Mean Annual Runoff = Mean Annual Retention (AC-FT Volume).

PERCENT RETENTION STATISTICS

(PERCENT OF ANNUAL RUNOFF)

POND: TRIANGULAR SEEPAGE: 0.02 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	28.866	17.431	10.844	8.089	6.526	3.182
.5	35.533	23.819	15.176	11.448	9.310	4.648
.75	41.533	28.366	18.391	13.976	11.417	5.781
1	46.137	31.982	21.026	16.077	13.175	6.738
2	58.505	42.219	28.701	22.348	18.506	9.700
3	66.351	49.187	34.130	26.901	22.461	11.975
4	71.785	54.576	38.480	30.551	25.675	13.890
5	76.132	58.953	42.091	33.666	28.418	15.571
10	88.648	72.881	55.057	44.932	38.479	22.077
	Mean Annual Runoff (AC-FT)**					
	11.274	22.548	45.095	67.643	90.190	225.475

* Percentage not retained is spilled, e.g., if percent retention = 15.534, percent spilled = 84.466.

** Percent retention (or spillage)* Mean Annual Runoff = Mean Annual Retention (AC-FT Volume).

PERCENT RETENTION STATISTICS

(PERCENT OF ANNUAL RUNOFF)

POND: TRIANGULAR SEEPAGE: 0.05 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	30.095	19.692	12.297	9.185	7.416	5.623
.5	39.454	26.730	17.150	12.962	10.552	5.282
.75	45.732	31.652	20.710	15.788	12.914	6.560
1	50.508	35.560	23.616	18.122	14.879	7.636
2	62.958	46.389	31.922	25.012	20.781	10.956
3	70.390	53.570	37.754	29.926	25.095	13.486
4	75.579	58.944	42.342	33.843	28.564	15.609
5	79.690	63.318	46.142	37.169	31.499	17.464
10	91.050	76.570	59.319	49.002	42.166	24.541
	Mean Annual Runoff (AC-FT)**					
	11.274	22.548	45.095	67.643	90.190	225.475

* Percentage not retained is spilled, e.g., if percent retention = 15.534, percent spilled = 84.466.

** Percent retention (or spillage)* Mean Annual Runoff = Mean Annual Retention (AC-FT Volume).

PERCENT RETENTION STATISTICS*

(PERCENT OF ANNUAL RUNOFF)

POND: TRAPEZOIDAL SEEPAGE: 0.00 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	20.026	12.586	7.642	5.628	4.500	2.140
.5	27.360	17.661	10.926	8.122	6.543	3.177
.75	32.574	21.433	13.432	10.048	8.121	3.991
1	36.788	24.517	15.534	11.673	9.464	4.691
2	48.606	33.501	21.917	16.696	13.640	6.899
3	56.758	39.840	26.620	20.509	16.859	8.638
4	62.750	44.984	30.467	23.660	19.556	10.138
5	67.509	49.340	33.767	26.375	21.907	11.472
10	82.700	64.192	45.865	36.559	30.872	16.781
	Mean Annual Runoff (AC-FT)**					
	11.274	22.548	45.095	67.643	90.190	225.475

*Percentage not retained is spilled, e.g., if percent retention = 15.534, percent spilled = 84.466.

**Percent retention (or spillage)* Mean Annual Runoff = Mean Annual Retention (AC-FT Volume).

PERCENT RETENTION STATISTICS*

(PERCENT OF ANNUAL RUNOFF)

POND: TRAPEZOIDAL SEEPAGE: 0.05 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	24.681	15.647	9.541	7.038	5.635	2.687
.5	33.171	21.746	13.552	10.106	8.152	3.975
.75	39.114	26.170	16.582	12.447	10.085	4.982
1	43.748	29.716	19.095	14.410	11.714	5.841
2	56.327	39.817	26.529	20.388	16.720	8.532
3	64.382	46.785	31.855	24.796	20.512	10.634
4	69.980	52.260	36.139	28.373	23.624	12.418
5	74.437	56.724	39.732	31.424	26.296	13.997
10	87.528	71.022	52.728	42.553	36.205	20.196
	Mean Annual Runoff (AC-FT)**					
	11.274	22.548	45.095	67.643	90.190	225.475

* Percentage not retained is spilled, e.g., if percent retention = 15.534, percent spilled = 84.466.

** Percent retention (or spillage)* Mean Annual Runoff = Mean Annual Retention (AC-FT Volume).

PERCENT RETENTION STATISTICS*

(PERCENT OF ANNUAL RUNOFF)

POND: TRAPEZOIDAL SEEPAGE: 0.02 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	21.978	13.852	8.422	6.205	4.964	2.362
.5	29.826	19.364	12.009	8.938	7.202	3.502
.75	35.362	23.426	14.736	11.038	8.928	4.396
1	39.773	26.711	17.012	12.801	10.391	5.162
2	52.024	36.188	23.854	18.230	14.915	7.569
3	60.169	42.806	28.827	22.304	18.377	9.460
4	65.988	48.134	32.867	25.642	21.258	11.079
5	70.681	52.565	36.289	28.501	23.748	12.514
10	84.958	67.236	48.819	39.084	33.127	18.201
	Mean Annual Runoff (AC-FT)**					
	11.274	22.548	45.095	67.643	90.190	225.475

*Percentage not retained is spilled, e.g., if percent retention = 15.534, percent spilled = 84.466.

**Percent retention (or spillage)* Mean Annual Runoff = Mean Annual Retention (AC-FT Volume).

ANNUAL DRY DAY STATISTICS

(DAYS/YEAR POND IS EMPTY)

POND: TRIANGULAR SEEPAGE: 0.00 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	171.470	168.675	164.665	161.160	158.105	148.830
10	171.470	168.640	164.460	160.700	157.525	147.015

ANNUAL DRY DAY STATISTICS

(DAYS/YEAR POND IS EMPTY)

POND: TRIANGULAR SEEPAGE: 0.02 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	173.605	170.965	167.880	165.200	162.480	153.985
10	173.605	170.965	167.845	165.040	162.160	152.725

ANNUAL DRY DAY STATISTICS

(DAYS/YEAR POND IS EMPTY)

POND: TRIANGULAR SEEPAGE: 0.05 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	176.465	173.135	170.890	168.900	167.100	159.305
10	176.465	173.135	170.890	168.890	167.055	158.820

ANNUAL DRY DAY STATISTICS

(DAYS/YEAR POND IS EMPTY)

POND: TRAPEZOIDAL SEEPAGE: 0.00 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	166.185	160.495	153.905	149.265	145.540	132.515
10	166.135	160.140	152.73	147.420	143.040	127.700

ANNUAL DRY DAY STATISTICS

(DAYS/YEAR POND IS EMPTY)

POND: TRAPEZOIDAL SEEPAGE: 0.02 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	169.160	164.745	158.155	154.380	150.710	138.845
10	169.155	164.630	157.580	153.190	149.075	135.080

ANNUAL DRY DAY STATISTICS

(DAYS/YEAR POND IS EMPTY)

POND: TRAPEZOIDAL SEEPAGE: 0.05 FT/DAY

Pond Size	Watershed Size (acres)					
AC-FT	50	100	200	300	400	1000
.25	171.710	168.665	163.080	159.665	156.985	145.890
10	171.710	168.650	162.935	159.275	156.295	143.635

APPENDIX C

SAMPLE OUTPUT OF POND3 MODEL

```
                    STOCKPOND SIMULATION FOR 200 YEARS
                        WATERSHED  SIZES,(<1000 ACRES)=  1
                         STOCK POND SIZES,(<10 ACRE-FEET)=  9
                          SEEPAGE RATE=.020 FT/DAY
                        CATTLE*DAYS=      0.0

                        POND TYPE=  TRAPEZOIDAL

*******************************************************************************
*******************************************************************************




*******************************************************************************
       CLIMATOLOGICAL SIMULATION SUMMARY:     50  ACRE WATERSHED
*******************************************************************************


          200 YEAR MEAN YEARLY PRECIPITATION = 25.46 INCHES  STANDARD DEVIATION =  6.722 INCHES
         MEAN RUNOFF =  2.71 INCHES        11.274 ACRE FEET     STANDARD DEVIATION =  3.150 INCHES
          200 YEAR MEAN MAXIMUM TEMPERATURE =  67.03
*******************************************************************************

*******************************************************************************
         STOCKPOND SIZE=   .25 ACRE-FEET          WATERSHED SIZE=   50. ACRES

          MEAN ANNUAL SPILL =  2.1110 INCHES       383152.5 CUBIC FEET       8.796 ACRE FEET
          STANDARD DEVIATION OF SPILL =   2.877 INCHES       11.986 ACRE FEET

          MEAN ANNUAL RETENTION =    .5947 INCHES        107932.4 CUBIC FEET       2.478 ACRE FEET
          STANDARD DEVIATION OF RETENTION =    .3632 INCHES       1.513 ACRE FEET
          MEDIAN OF RETENTION =    .5624 INCHES        2.343ACRE FEET

          MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  21.978
          FILL FACTOR =     9.91

          MEAN ANNUAL NUMBER OF DRY DAYS = 169.160          STANDARD DEVIATION =  83.141


                              MONTHLY DRY DAYS DISTRIBUTIONS
         MONTH        DRY DAY                   NUMBER OF YEARS IN EACH DRY DAY CLASS
                        MEAN      0     1-3    4-6   7-9   10-12 13-15 16-18 19-21 22-24 25-27 28-30   31
        OCTOBER   21.455      42      2      3      7      3      2      3      0      1     17     40     80
         NOVEMBER  18.230      54      7      3      4      1      3      4      1     11     42     70      0
        DECEMBER  15.345      59      7      6      8      7      7      7     12     18     20      5     44
         JANUARY  10.365     102      6      9      4      5      6      5      7      8      8      2     38
        FEBRUARY   6.535     139      2      1      2      6      4      5      3      5      6     27      0
         MARCH      5.305    155      2      0      4      2      2      4      0      1      4     10     16
        APRIL      5.185     160      0      1      1      2      1      1      1      0      6     27      0
         MAY        8.015    135      5      0      4      1      2      1      6      2      2      6     36
        JUNE      12.965      93      3      6      6      1      2      8      4      1     10     66      0
         JULY     19.765      32      8      9     10      5      5      5      7      6     13     66     34
        AUGUST    23.665       8      5      4      5      9      8      9      9      3     22     96     22
         SEPTEMBER 22.125     35      2      3      4      2      1      3      0      5     20    125      0
```

DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL	OCCURENCES	PDF	CDF
.0- 4.2	105.	.525000	.525000
4.2- 8.3	31.	.155000	.680000
8.3- 12.5	15.	.075000	.755000
12.5- 16.7	10.	.050000	.805000
16.7- 20.8	9.	.045000	.850000
20.8- 25.0	9.	.045000	.895000
25.0- 29.2	3.	.015000	.910000
29.2- 33.3	4.	.020000	.930000
33.3- 37.5	7.	.035000	.965000
37.5- 41.7	3.	.015000	.980000
41.7- 45.8	2.	.010000	.990000
45.8- 50.0	0.	0.000000	.990000
50.0- 54.2	0.	0.000000	.990000
54.2- 58.3	1.	.005000	.995000
58.3- 62.5	1.	.005000	1.000000
62.5- 66.7	0.	0.000000	1.000000
66.7- 70.8	0.	0.000000	1.000000
70.8- 75.0	0.	0.000000	1.000000
75.0- 79.2	0.	0.000000	1.000000
79.2- 83.3	0.	0.000000	1.000000

DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL	OCCURENCES	PDF	CDF
.0- 4.2	169.	.845000	.845000
4.2- 8.3	31.	.155000	1.000000
8.3- 12.5	0.	0.000000	1.000000
12.5- 16.7	0.	0.000000	1.000000
16.7- 20.8	0.	0.000000	1.000000
20.8- 25.0	0.	0.000000	1.000000
25.0- 29.2	0.	0.000000	1.000000
29.2- 33.3	0.	0.000000	1.000000
33.3- 37.5	0.	0.000000	1.000000
37.5- 41.7	0.	0.000000	1.000000
41.7- 45.8	0.	0.000000	1.000000
45.8- 50.0	0.	0.000000	1.000000
50.0- 54.2	0.	0.000000	1.000000
54.2- 58.3	0.	0.000000	1.000000
58.3- 62.5	0.	0.000000	1.000000
62.5- 66.7	0.	0.000000	1.000000
66.7- 70.8	0.	0.000000	1.000000
70.8- 75.0	0.	0.000000	1.000000
75.0- 79.2	0.	0.000000	1.000000
79.2- 83.3	0.	0.000000	1.000000

DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL	OCCURENCES	PDF	CDF
1- 18	2.	.010000	.010000
19- 36	6.	.030000	.040000
37- 54	7.	.035000	.075000
55- 73	11.	.055000	.130000
74- 91	13.	.065000	.195000
92-109	11.	.055000	.250000
110-128	15.	.075000	.325000
129-146	20.	.100000	.425000
147-164	14.	.070000	.495000
165-183	17.	.085000	.580000
184-201	20.	.100000	.680000
202-219	13.	.065000	.745000
220-237	15.	.075000	.820000
238-256	8.	.040000	.860000
257-274	6.	.030000	.890000
275-292	4.	.020000	.910000
293-311	3.	.015000	.925000
312-329	2.	.010000	.935000
330-347	3.	.015000	.950000
348-366	10.	.050000	1.000000

```
********************************************************************************
          STOCKPOND SIZE=    .50 ACRE-FEET           WATERSHED SIZE=    50. ACRES

           MEAN ANNUAL SPILL =  1.8987 INCHES       344614.5 CUBIC FEET        7.911 ACRE FEET
            STANDARD DEVIATION OF SPILL =    2.753 INCHES       11.469 ACRE FEET

           MEAN ANNUAL RETENTION =    .8070 INCHES       146470.4 CUBIC FEET        3.362 ACRE FEET
            STANDARD DEVIATION OF RETENTION =    .5169 INCHES       2.154 ACRE FEET
           MEDIAN OF RETENTION =    .7626 INCHES        3.178ACRE FEET

            MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  29.826
           FILL FACTOR =     6.72

           MEAN ANNUAL NUMBER OF DRY DAYS = 169.160          STANDARD DEVIATION =  83.141


              DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL       OCCURENCES      PDF          CDF

   .0-  4.2     117.        .585000       .585000
  4.2-  8.3      24.        .120000       .705000
  8.3- 12.5      12.        .060000       .765000
 12.5- 16.7       8.        .040000       .805000
 16.7- 20.8      12.        .060000       .865000
 20.8- 25.0       7.        .035000       .900000
 25.0- 29.2       2.        .010000       .910000
 29.2- 33.3       6.        .030000       .940000
 33.3- 37.5       6.        .030000       .970000
 37.5- 41.7       4.        .020000       .990000
 41.7- 45.8       0.       0.000000       .990000
 45.8- 50.0       0.       0.000000       .990000
 50.0- 54.2       1.        .005000       .995000
 54.2- 58.3       0.       0.000000       .995000
 58.3- 62.5       1.        .005000      1.000000
 62.5- 66.7       0.       0.000000      1.000000
 66.7- 70.8       0.       0.000000      1.000000
 70.8- 75.0       0.       0.000000      1.000000
 75.0- 79.2       0.       0.000000      1.000000
 79.2- 83.3       0.       0.000000      1.000000

           DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL       OCCURENCES      PDF          CDF

   .0-  4.2     129.        .645000       .645000
  4.2-  8.3      69.        .345000       .990000
  8.3- 12.5       2.        .010000      1.000000
 12.5- 16.7       0.       0.000000      1.000000
 16.7- 20.8       0.       0.000000      1.000000
 20.8- 25.0       0.       0.000000      1.000000
 25.0- 29.2       0.       0.000000      1.000000
 29.2- 33.3       0.       0.000000      1.000000
 33.3- 37.5       0.       0.000000      1.000000
 37.5- 41.7       0.       0.000000      1.000000
 41.7- 45.8       0.       0.000000      1.000000
 45.8- 50.0       0.       0.000000      1.000000
 50.0- 54.2       0.       0.000000      1.000000
 54.2- 58.3       0.       0.000000      1.000000
 58.3- 62.5       0.       0.000000      1.000000
 62.5- 66.7       0.       0.000000      1.000000
 66.7- 70.8       0.       0.000000      1.000000
 70.8- 75.0       0.       0.000000      1.000000
 75.0- 79.2       0.       0.000000      1.000000
 79.2- 83.3       0.       0.000000      1.000000
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                  DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL     OCCURENCES      PDF         CDF

   1- 18          2.       .010000      .010000
  19- 36          6.       .030000      .040000
  37- 54          7.       .035000      .075000
  55- 73         11.       .055000      .130000
  74- 91         13.       .065000      .195000
  92-109         11.       .055000      .250000
 110-128         15.       .075000      .325000
 129-146         20.       .100000      .425000
 147-164         14.       .070000      .495000
 165-183         17.       .085000      .580000
 184-201         20.       .100000      .680000
 202-219         13.       .065000      .745000
 220-237         15.       .075000      .820000
 238-256          8.       .040000      .860000
 257-274          6.       .030000      .890000
 275-292          4.       .020000      .910000
 293-311          3.       .015000      .925000
 312-329          2.       .010000      .935000
 330-347          3.       .015000      .950000
 348-366         10.       .050000     1.000000

********************************************************************************

         STOCKPOND SIZE=   .75 ACRE-FEET          WATERSHED SIZE=   50. ACRES

          MEAN ANNUAL SPILL =  1.7489 INCHES       317427.6 CUBIC FEET       7.287 ACRE FEET
          STANDARD DEVIATION OF SPILL =   2.655 INCHES       11.061 ACRE FEET

          MEAN ANNUAL RETENTION =    .9568 INCHES       173657.2 CUBIC FEET       3.987 ACRE FEET
          STANDARD DEVIATION OF RETENTION =    .6338 INCHES       2.641 ACRE FEET
          MEDIAN OF RETENTION =    .8693 INCHES       3.622ACRE FEET

          MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  35.362
          FILL FACTOR =     5.32

          MEAN ANNUAL NUMBER OF DRY DAYS = 169.155         STANDARD DEVIATION =  83.139


               DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL     OCCURENCES      PDF         CDF

   .0-  4.2     122.       .610000      .610000
  4.2-  8.3      24.       .120000      .730000
  8.3- 12.5      11.       .055000      .785000
 12.5- 16.7       8.       .040000      .825000
 16.7- 20.8      12.       .060000      .885000
 20.8- 25.0       3.       .015000      .900000
 25.0- 29.2       6.       .030000      .930000
 29.2- 33.3       5.       .025000      .955000
 33.3- 37.5       4.       .020000      .975000
 37.5- 41.7       3.       .015000      .990000
 41.7- 45.8       0.      0.000000      .990000
 45.8- 50.0       0.      0.000000      .990000
 50.0- 54.2       1.       .005000      .995000
 54.2- 58.3       1.       .005000     1.000000
 58.3- 62.5       0.      0.000000     1.000000
 62.5- 66.7       0.      0.000000     1.000000
 66.7- 70.8       0.      0.000000     1.000000
 70.8- 75.0       0.      0.000000     1.000000
 75.0- 79.2       0.      0.000000     1.000000
 79.2- 83.3       0.      0.000000     1.000000
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                DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL       OCCURENCES      PDF           CDF

   .0-  4.2     115.       .575000       .575000
  4.2-  8.3      72.       .360000       .935000
  8.3- 12.5      13.       .065000      1.000000
 12.5- 16.7       0.      0.000000      1.000000
 16.7- 20.8       0.      0.000000      1.000000
 20.8- 25.0       0.      0.000000      1.000000
 25.0- 29.2       0.      0.000000      1.000000
 29.2- 33.3       0.      0.000000      1.000000
 33.3- 37.5       0.      0.000000      1.000000
 37.5- 41.7       0.      0.000000      1.000000
 41.7- 45.8       0.      0.000000      1.000000
 45.8- 50.0       0.      0.000000      1.000000
 50.0- 54.2       0.      0.000000      1.000000
 54.2- 58.3       0.      0.000000      1.000000
 58.3- 62.5       0.      0.000000      1.000000
 62.5- 66.7       0.      0.000000      1.000000
 66.7- 70.8       0.      0.000000      1.000000
 70.8- 75.0       0.      0.000000      1.000000
 75.0- 79.2       0.      0.000000      1.000000
 79.2- 83.3       0.      0.000000      1.000000

                         DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL       OCCURENCES      PDF           CDF

   1- 18           2.       .010000       .010000
  19- 36           6.       .030000       .040000
  37- 54           7.       .035000       .075000
  55- 73          11.       .055000       .130000
  74- 91          13.       .065000       .195000
  92-109          11.       .055000       .250000
 110-128          15.       .075000       .325000
 129-146          20.       .100000       .425000
 147-164          14.       .070000       .495000
 165-183          17.       .085000       .580000
 184-201          20.       .100000       .680000
 202-219          13.       .065000       .745000
 220-237          15.       .075000       .820000
 238-256           8.       .040000       .860000
 257-274           6.       .030000       .890000
 275-292           4.       .020000       .910000
 293-311           3.       .015000       .925000
 312-329           2.       .010000       .935000
 330-347           3.       .015000       .950000
 348-366          10.       .050000      1.000000

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         STOCKPOND SIZE=  1.00 ACRE-FEET          WATERSHED SIZE=   50. ACRES

          MEAN ANNUAL SPILL =  1.6296 INCHES       295763.9 CUBIC FEET       6.790 ACRE FEET
          STANDARD DEVIATION OF SPILL =   2.570 INCHES      10.709 ACRE FEET

          MEAN ANNUAL RETENTION =  1.0761 INCHES       195321.0 CUBIC FEET       4.484 ACRE FEET
          STANDARD DEVIATION OF RETENTION =   .7340 INCHES       3.058 ACRE FEET
          MEDIAN OF RETENTION =   .9681 INCHES        4.034ACRE FEET

          MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  39.773
          FILL FACTOR =     4.48

          MEAN ANNUAL NUMBER OF DRY DAYS = 169.155         STANDARD DEVIATION =  83.139
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              DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL       OCCURENCES      PDF           CDF

   .0-  4.2     127.        .635000       .635000
  4.2-  8.3      23.        .115000       .750000
  8.3- 12.5      10.        .050000       .800000
 12.5- 16.7       6.        .030000       .830000
 16.7- 20.8      13.        .065000       .895000
 20.8- 25.0       2.        .010000       .905000
 25.0- 29.2       5.        .025000       .930000
 29.2- 33.3       6.        .030000       .960000
 33.3- 37.5       4.        .020000       .980000
 37.5- 41.7       2.        .010000       .990000
 41.7- 45.8       0.       0.000000       .990000
 45.8- 50.0       0.       0.000000       .990000
 50.0- 54.2       1.        .005000       .995000
 54.2- 58.3       1.        .005000      1.000000
 58.3- 62.5       0.       0.000000      1.000000
 62.5- 66.7       0.       0.000000      1.000000
 66.7- 70.8       0.       0.000000      1.000000
 70.8- 75.0       0.       0.000000      1.000000
 75.0- 79.2       0.       0.000000      1.000000
 79.2- 83.3       0.       0.000000      1.000000

            DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL       OCCURENCES      PDF           CDF

   .0-  4.2     104.        .520000       .520000
  4.2-  8.3      69.        .345000       .865000
  8.3- 12.5      27.        .135000      1.000000
 12.5- 16.7       0.       0.000000      1.000000
 16.7- 20.8       0.       0.000000      1.000000
 20.8- 25.0       0.       0.000000      1.000000
 25.0- 29.2       0.       0.000000      1.000000
 29.2- 33.3       0.       0.000000      1.000000
 33.3- 37.5       0.       0.000000      1.000000
 37.5- 41.7       0.       0.000000      1.000000
 41.7- 45.8       0.       0.000000      1.000000
 45.8- 50.0       0.       0.000000      1.000000
 50.0- 54.2       0.       0.000000      1.000000
 54.2- 58.3       0.       0.000000      1.000000
 58.3- 62.5       0.       0.000000      1.000000
 62.5- 66.7       0.       0.000000      1.000000
 66.7- 70.8       0.       0.000000      1.000000
 70.8- 75.0       0.       0.000000      1.000000
 75.0- 79.2       0.       0.000000      1.000000
 79.2- 83.3       0.       0.000000      1.000000

                DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL       OCCURENCES      PDF           CDF

   1- 18          2.        .010000       .010000
  19- 36          6.        .030000       .040000
  37- 54          7.        .035000       .075000
  55- 73         11.        .055000       .130000
  74- 91         13.        .065000       .195000
  92-109         11.        .055000       .250000
 110-128         15.        .075000       .325000
 129-146         20.        .100000       .425000
 147-164         14.        .070000       .495000
 165-183         17.        .085000       .580000
 184-201         20.        .100000       .680000
 202-219         13.        .065000       .745000
 220-237         15.        .075000       .820000
 238-256          8.        .040000       .860000
 257-274          6.        .030000       .890000
 275-292          4.        .020000       .910000
 293-311          3.        .015000       .925000
 312-329          2.        .010000       .935000
 330-347          3.        .015000       .950000
 348-366         10.        .050000      1.000000
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        STOCKPOND SIZE=  2.00 ACRE-FEET          WATERSHED SIZE=   50. ACRES

         MEAN ANNUAL SPILL =  1.2981 INCHES       235604.1 CUBIC FEET       5.409 ACRE FEET
        STANDARD DEVIATION OF SPILL =   2.301 INCHES       9.589 ACRE FEET

         MEAN ANNUAL RETENTION =  1.4076 INCHES       255480.8 CUBIC FEET       5.865 ACRE FEET
        STANDARD DEVIATION OF RETENTION =  1.0515 INCHES       4.381 ACRE FEET
         MEDIAN OF RETENTION =  1.2909 INCHES       5.379ACRE FEET

        MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  52.024
         FILL FACTOR =    2.93

        MEAN ANNUAL NUMBER OF DRY DAYS = 169.155          STANDARD DEVIATION =  83.139


             DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL      OCCURENCES      PDF          CDF

     .0-  4.2     138.       .690000       .690000
   4.2-  8.3      16.       .080000       .770000
   8.3- 12.5      10.       .050000       .820000
  12.5- 16.7      14.       .070000       .890000
  16.7- 20.8       2.       .010000       .900000
  20.8- 25.0       6.       .030000       .930000
  25.0- 29.2       6..      .030000       .960000
  29.2- 33.3       3.       .015000       .975000
  33.3- 37.5       3.       .015000       .990000
  37.5- 41.7       0.      0.000000       .990000
  41.7- 45.8       0.      0.000000       .990000
  45.8- 50.0       1.       .005000       .995000
  50.0- 54.2       1.       .005000      1.000000
  54.2- 58.3       0.      0.000000      1.000000
  58.3- 62.5       0.      0.000000      1.000000
  62.5- 66.7       0.      0.000000      1.000000
  66.7- 70.8       0.      0.000000      1.000000
  70.8- 75.0       0.      0.000000      1.000000
  75.0- 79.2       0.      0.000000      1.000000
  79.2- 83.3       0.      0.000000      1.000000

          DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL      OCCURENCES      PDF          CDF

     .0-  4.2      83.       .415000       .415000
   4.2-  8.3      60.       .300000       .715000
   8.3- 12.5      39.       .195000       .910000
  12.5- 16.7      17.       .085000       .995000
  16.7- 20.8       1.       .005000      1.000000
  20.8- 25.0       0.      0.000000      1.000000
  25.0- 29.2       0.      0.000000      1.000000
  29.2- 33.3       0.      0.000000      1.000000
  33.3- 37.5       0.      0.000000      1.000000
  37.5- 41.7       0.      0.000000      1.000000
  41.7- 45.8       0.      0.000000      1.000000
  45.8- 50.0       0.      0.000000      1.000000
  50.0- 54.2       0.      0.000000      1.000000
  54.2- 58.3       0.      0.000000      1.000000
  58.3- 62.5       0.      0.000000      1.000000
  62.5- 66.7       0.      0.000000      1.000000
  66.7- 70.8       0.      0.000000      1.000000
  70.8- 75.0       0.      0.000000      1.000000
  75.0- 79.2       0.      0.000000      1.000000
  79.2- 83.3       0.      0.000000      1.000000
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                      DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL      OCCURENCES     PDF        CDF

  1- 18           2.       .010000     .010000
 19- 36           6.       .030000     .040000
 37- 54           7.       .035000     .075000
 55- 73          11.       .055000     .130000
 74- 91          13.       .065000     .195000
 92-109          11.       .055000     .250000
110-128          15.       .075000     .325000
129-146          20.       .100000     .425000
147-164          14.       .070000     .495000
165-183          17.       .085000     .580000
184-201          20.       .100000     .680000
202-219          13.       .065000     .745000
220-237          15.       .075000     .820000
238-256           8.       .040000     .860000
257-274           6.       .030000     .890000
275-292           4.       .020000     .910000
293-311           3.       .015000     .925000
312-329           2.       .010000     .935000
330-347           3.       .015000     .950000
348-366          10.       .050000    1.000000

********************************************************************************
         STOCKPOND SIZE=  3.00 ACRE-FEET          WATERSHED SIZE=   50. ACRES

          MEAN ANNUAL SPILL =  1.0777 INCHES       195601.9 CUBIC FEET       4.490 ACRE FEET
          STANDARD DEVIATION OF SPILL =   2.093 INCHES       8.721 ACRE FEET

          MEAN ANNUAL RETENTION =  1.6280 INCHES       295483.0 CUBIC FEET       6.783 ACRE FEET
          STANDARD DEVIATION OF RETENTION =  1.2939 INCHES       5.391 ACRE FEET
          MEDIAN OF RETENTION =  1.4380 INCHES       5.992ACRE FEET

          MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  60.169
          FILL FACTOR =     2.26

          MEAN ANNUAL NUMBER OF DRY DAYS = 169.155          STANDARD DEVIATION =  83.139


                DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL      OCCURENCES     PDF        CDF

   .0-  4.2     150.       .750000     .750000
  4.2-  8.3      12.       .060000     .810000
  8.3- 12.5       8.       .040000     .850000
 12.5- 16.7      10.       .050000     .900000
 16.7- 20.8       2.       .010000     .910000
 20.8- 25.0       9.       .045000     .955000
 25.0- 29.2       4.       .020000     .975000
 29.2- 33.3       3.       .015000     .990000
 33.3- 37.5       0.      0.000000     .990000
 37.5- 41.7       0.      0.000000     .990000
 41.7- 45.8       1.       .005000     .995000
 45.8- 50.0       1.       .005000    1.000000
 50.0- 54.2       0.      0.000000    1.000000
 54.2- 58.3       0.      0.000000    1.000000
 58.3- 62.5       0.      0.000000    1.000000
 62.5- 66.7       0.      0.000000    1.000000
 66.7- 70.8       0.      0.000000    1.000000
 70.8- 75.0       0.      0.000000    1.000000
 75.0- 79.2       0.      0.000000    1.000000
 79.2- 83.3       0.      0.000000    1.000000
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          DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL      OCCURENCES      PDF          CDF

    .0-  4.2     83.        .415000      .415000
   4.2-  8.3     42.        .210000      .625000
   8.3- 12.5     38.        .190000      .815000
  12.5- 16.7     26.        .130000      .945000
  16.7- 20.8     10.        .050000      .995000
  20.8- 25.0      1.        .005000     1.000000
  25.0- 29.2      0.       0.000000     1.000000
  29.2- 33.3      0.       0.000000     1.000000
  33.3- 37.5      0.       0.000000     1.000000
  37.5- 41.7      0.       0.000000     1.000000
  41.7- 45.8      0.       0.000000     1.000000
  45.8- 50.0      0.       0.000000     1.000000
  50.0- 54.2      0.       0.000000     1.000000
  54.2- 58.3      0.       0.000000     1.000000
  58.3- 62.5      0.       0.000000     1.000000
  62.5- 66.7      0.       0.000000     1.000000
  66.7- 70.8      0.       0.000000     1.000000
  70.8- 75.0      0.       0.000000     1.000000
  75.0- 79.2      0.       0.000000     1.000000
  79.2- 83.3      0.       0.000000     1.000000

                   DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL      OCCURENCES      PDF          CDF

   1- 18          2.        .010000      .010000
  19- 36          6.        .030000      .040000
  37- 54          7.        .035000      .075000
  55- 73         11.        .055000      .130000
  74- 91         13.        .065000      .195000
  92-109         11.        .055000      .250000
 110-128         15.        .075000      .325000
 129-146         20.        .100000      .425000
 147-164         14.        .070000      .495000
 165-183         17.        .085000      .580000
 184-201         20.        .100000      .680000
 202-219         13.        .065000      .745000
 220-237         15.        .075000      .820000
 238-256          8.        .040000      .860000
 257-274          6.        .030000      .890000
 275-292          4.        .020000      .910000
 293-311          3.        .015000      .925000
 312-329          2.        .010000      .935000
 330-347          3.        .015000      .950000
 348-366         10.        .050000     1.000000

********************************************************************************

        STOCKPOND SIZE=  4.00 ACRE-FEET          WATERSHED SIZE=   50. ACRES

         MEAN ANNUAL SPILL =   .9203 INCHES       167026.5 CUBIC FEET       3.834 ACRE FEET
         STANDARD DEVIATION OF SPILL =   1.918 INCHES       7.990 ACRE FEET

         MEAN ANNUAL RETENTION =  1.7854 INCHES       324058.4 CUBIC FEET       7.439 ACRE FEET
         STANDARD DEVIATION OF RETENTION =  1.4908 INCHES       6.212 ACRE FEET
         MEDIAN OF RETENTION =  1.4380 INCHES       5.992ACRE FEET

         MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  65.988
         FILL FACTOR =    1.86

         MEAN ANNUAL NUMBER OF DRY DAYS = 169.155          STANDARD DEVIATION =  83.139
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             DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL       OCCURENCES      PDF          CDF

    .0-  4.2    153.        .765000       .765000
   4.2-  8.3     11.        .055000       .820000
   8.3- 12.5     14.        .070000       .890000
  12.5- 16.7      2.        .010000       .900000
  16.7- 20.8      8.        .040000       .940000
  20.8- 25.0      5.        .025000       .965000
  25.0- 29.2      4.        .020000       .985000
  29.2- 33.3      1.        .005000       .990000
  33.3- 37.5      0.       0.000000       .990000
  37.5- 41.7      0.       0.000000       .990000
  41.7- 45.8      2.        .010000      1.000000
  45.8- 50.0      0.       0.000000      1.000000
  50.0- 54.2      0.       0.000000      1.000000
  54.2- 58.3      0.       0.000000      1.000000
  58.3- 62.5      0.       0.000000      1.000000
  62.5- 66.7      0.       0.000000      1.000000
  66.7- 70.8      0.       0.000000      1.000000
  70.8- 75.0      0.       0.000000      1.000000
  75.0- 79.2      0.       0.000000      1.000000
  79.2- 83.3      0.       0.000000      1.000000

          DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL       OCCURENCES      PDF          CDF

    .0-  4.2     83.        .415000       .415000
   4.2-  8.3     38.        .190000       .605000
   8.3- 12.5     30.        .150000       .755000
  12.5  16.7     31.        .155000       .910000
  16.7- 20.8     14.        .070000       .980000
  20.8- 25.0      4.        .020000      1.000000
  25.0- 29.2      0.       0.000000      1.000000
  29.2- 33.3      0.       0.000000      1.000000
  33.3- 37.5      0.       0.000000      1.000000
  37.5- 41.7      0.       0.000000      1.000000
  41.7- 45.8      0.       0.000000      1.000000
  45.8- 50.0      0.       0.000000      1.000000
  50.0- 54.2      0.       0.000000      1.000000
  54.2- 58.3      0.       0.000000      1.000000
  58.3- 62.5      0.       0.000000      1.000000
  62.5- 66.7      0.       0.000000      1.000000
  66.7- 70.8      0.       0.000000      1.000000
  70.8- 75.0      0.       0.000000      1.000000
  75.0- 79.2      0.       0.000000      1.000000
  79.2- 83.3      0.       0.000000      1.000000

                   DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL       OCCURENCES      PDF          CDF

   1- 18              2.     .010000       .010000
  19- 36              6.     .030000       .040000
  37- 54              7.     .035000       .075000
  55- 73             11.     .055000       .130000
  74- 91             13.     .065000       .195000
  92-109             11.     .055000       .250000
 110-128             15.     .075000       .325000
 129-146             20.     .100000       .425000
 147-164             14.     .070000       .495000
 165-183             17.     .085000       .580000
 184-201             20.     .100000       .680000
 202-219             13.     .065000       .745000
 220-237             15.     .075000       .820000
 238-256              8.     .040000       .860000
 257-274              6.     .030000       .890000
 275-292              4.     .020000       .910000
 293-311              3.     .015000       .925000
 312-329              2.     .010000       .935000
 330-347              3.     .015000       .950000
 348-366             10.     .050000      1.000000
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         STOCKPOND SIZE=  5.00 ACRE-FEET          WATERSHED SIZE=   50. ACRES

          MEAN ANNUAL SPILL =    .7933 INCHES        143981.5 CUBIC FEET        3.305 ACRE FEET
          STANDARD DEVIATION OF SPILL =   1.766 INCHES        7.356 ACRE FEET

          MEAN ANNUAL RETENTION =  1.9124 INCHES        347103.4 CUBIC FEET        7.968 ACRE FEET
          STANDARD DEVIATION OF RETENTION =  1.6587 INCHES        6.911 ACRE FEET
          MEDIAN OF RETENTION =  1.4380 INCHES       5.992ACRE FEET

          MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  70.681
          FILL FACTOR =    1.59

          MEAN ANNUAL NUMBER OF DRY DAYS = 169.155          STANDARD DEVIATION =  83.139


             DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL      OCCURENCES     PDF         CDF

    .0-  4.2     159.       .795000      .795000
   4.2-  8.3      11.       .055000      .850000
   8.3- 12.5       8.       .040000      .890000
  12.5- 16.7       6.       .030000      .920000
  16.7- 20.8       6.       .030000      .950000
  20.8- 25.0       6.       .030000      .980000
  25.0- 29.2       1.       .005000      .985000
  29.2- 33.3       1.       .005000      .990000
  33.3- 37.5       0.      0.000000      .990000
  37.5- 41.7       2.       .010000     1.000000
  41.7- 45.8       0.      0.000000     1.000000
  45.8- 50.0       0.      0.000000     1.000000
  50.0- 54.2       0.      0.000000     1.000000
  54.2- 58.3       0.      0.000000     1.000000
  58.3- 62.5       0.      0.000000     1.000000
  62.5- 66.7       0.      0.000000     1.000000
  66.7- 70.8       0.      0.000000     1.000000
  70.8- 75.0       0.      0.000000     1.000000
  75.0- 79.2       0.      0.000000     1.000000
  79.2- 83.3       0.      0.000000     1.000000

          DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL      OCCURENCES     PDF         CDF

    .0-  4.2      83.       .415000      .415000
   4.2-  8.3      38.       .190000      .605000
   8.3- 12.5      22.       .110000      .715000
  12.5- 16.7      27.       .135000      .850000
  16.7- 20.8      17.       .085000      .935000
  20.8- 25.0      12.       .060000      .995000
  25.0- 29.2       1.       .005000     1.000000
  29.2- 33.3       0.      0.000000     1.000000
  33.3- 37.5       0.      0.000000     1.000000
  37.5- 41.7       0.      0.000000     1.000000
  41.7- 45.8       0.      0.000000     1.000000
  45.8- 50.0       0.      0.000000     1.000000
  50.0- 54.2       0.      0.000000     1.000000
  54.2- 58.3       0.      0.000000     1.000000
  58.3- 62.5       0.      0.000000     1.000000
  62.5- 66.7       0.      0.000000     1.000000
  66.7- 70.8       0.      0.000000     1.000000
  70.8- 75.0       0.      0.000000     1.000000
  75.0- 79.2       0.      0.000000     1.000000
  79.2- 83.3       0.      0.000000     1.000000
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                    DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL     OCCURENCES     PDF         CDF

  1- 18          2.       .010000     .010000
 19- 36          6.       .030000     .040000
 37- 54          7.       .035000     .075000
 55- 73         11.       .055000     .130000
 74- 91         13.       .065000     .195000
 92-109         11.       .055000     .250000
110-128         15.       .075000     .325000
129-146         20.       .100000     .425000
147-164         14.       .070000     .495000
165-183         17.       .085000     .580000
184-201         20.       .100000     .680000
202-219         13.       .065000     .745000
220-237         15.       .075000     .820000
238-256          8.       .040000     .860000
257-274          6.       .030000     .890000
275-292          4.       .020000     .910000
293-311          3.       .015000     .925000
312-329          2.       .010000     .935000
330-347          3.       .015000     .950000
348-366         10.       .050000    1.000000

*********************************************************************************
          STOCKPOND SIZE= 10.00 ACRE-FEET          WATERSHED SIZE=   50. ACRES

           MEAN ANNUAL SPILL =   .4070 INCHES        73870.2 CUBIC FEET       1.696 ACRE FEET
           STANDARD DEVIATION OF SPILL =   1.187 INCHES        4.946 ACRE FEET

           MEAN ANNUAL RETENTION =  2.2987 INCHES        417214.6 CUBIC FEET       9.578 ACRE FEET
           STANDARD DEVIATION OF RETENTION =  2.2653 INCHES        9.439 ACRE FEET
           MEDIAN OF RETENTION =  1.4380 INCHES       5.992ACRE FEET

           MEAN ANNUAL RETENTION AS A PERCENT OF RUNOFF =  84.958
           FILL FACTOR =       .96

           MEAN ANNUAL NUMBER OF DRY DAYS = 169.155          STANDARD DEVIATION =  83.139


                 DISTRIBUTION OF ANNUAL SPILLS (AC-FT)

INTERVAL      OCCURENCES      PDF         CDF

   .0-  4.2     177.       .885000     .885000
  4.2-  8.3       3.       .015000     .900000
  8.3- 12.5      10.       .050000     .950000
 12.5- 16.7       5.       .025000     .975000
 16.7- 20.8       2.       .010000     .985000
 20.8- 25.0       1.       .005000     .990000
 25.0- 29.2       0.      0.000000     .990000
 29.2- 33.3       2.       .010000    1.000000
 33.3- 37.5       0.      0.000000    1.000000
 37.5- 41.7       0.      0.000000    1.000000
 41.7- 45.8       0.      0.000000    1.000000
 45.8- 50.0       0.      0.000000    1.000000
 50.0- 54.2       0.      0.000000    1.000000
 54.2- 58.3       0.      0.000000    1.000000
 58.3- 62.5       0.      0.000000    1.000000
 62.5- 66.7       0.      0.000000    1.000000
 66.7- 70.8       0.      0.000000    1.000000
 70.8- 75.0       0.      0.000000    1.000000
 75.0- 79.2       0.      0.000000    1.000000
 79.2- 83.3       0.      0.000000    1.000000
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          DISTRIBUTION OF ANNUAL RETENTION (AC-FT)

INTERVAL      OCCURENCES      PDF           CDF

   .0-  4.2      83.        .415000       .415000
  4.2-  8.3      38.        .190000       .605000
  8.3- 12.5      17.        .085000       .690000
 12.5- 16.7      13.        .065000       .755000
 16.7- 20.8      17.        .085000       .840000
 20.8- 25.0      14.        .070000       .910000
 25.0- 29.2       8.        .040000       .950000
 29.2- 33.3       9.        .045000       .995000
 33.3- 37.5       1.        .005000      1.000000
 37.5- 41.7       0.       0.000000      1.000000
 41.7- 45.8       0.       0.000000      1.000000
 45.8- 50.0       0.       0.000000      1.000000
 50.0- 54.2       0.       0.000000      1.000000
 54.2- 58.3       0.       0.000000      1.000000
 58.3- 62.5       0.       0.000000      1.000000
 62.5- 66.7       0.       0.000000      1.000000
 66.7- 70.8       0.       0.000000      1.000000
 70.8- 75.0       0.       0.000000      1.000000
 75.0- 79.2       0.       0.000000      1.000000
 79.2- 83.3       0.       0.000000      1.000000
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                    DISTRIBUTION OF ANNUAL DRY DAYS

INTERVAL      OCCURENCES      PDF           CDF

   1- 18            2.        .010000       .010000
  19- 36            6.        .030000       .040000
  37- 54            7.        .035000       .075000
  55- 73           11.        .055000       .130000
  74- 91           13.        .065000       .195000
  92-109           11.        .055000       .250000
 110-128           15.        .075000       .325000
 129-146           20.        .100000       .425000
 147-164           14.        .070000       .495000
 165-183           17.        .085000       .580000
 184-201           20.        .100000       .680000
 202-219           13.        .065000       .745000
 220-237           15.        .075000       .820000
 238-256            8.        .040000       .860000
 257-274            6.        .030000       .890000
 275-292            4.        .020000       .910000
 293-311            3.        .015000       .925000
 312-329            2.        .010000       .935000
 330-347            3.        .015000       .950000
 348-366           10.        .050000      1.000000
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