A SIMULATION MODEL TO ASSESS THE HYDROLOGIC PERFORMANCE OF THE TINAU WATERSHED, NEPAL

by

Rabin Bogati

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Signed: Rabin Bogab

APPROVAL BY THESIS COMMITTEE

This thesis has been approved on the date shown below:

John L Thames
Dr. John L. Thames, Thesis Advisor
Professor of Watershed Management

5/22/86
Date

Mart M. Fogel
Dr. Martin M. Fogel
Professor of Watershed Management

5/23/86
Date

Dr. Peter F. Ffolliott
Professor of Watershed Management

5/22/86
Date

DEDICATION

TO MY DEAR MOTHER, SHOBHA

WHO HAS NEVER STOPPED INSPIRING ME THROUGHOUT MY LIFE.

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ABSTRACT

A physical event-based computer methodology is presented for evaluating the hydrologic performance of the Tinau watershed in Nepal.

A stochastic model of the seasonal precipitation was developed and used to generate long-term daily synthetic rainfall data. Storm systems in the monsoon months of JUNE through SEPTEMBER are treated as frontal systems, and the storms of the remaining months of the year as independent thunderstorm events. A fitted-parameter conceptual model, called a generalized streamflow simulation system (GSSS), is used to simulate long baseflow recessions. The GSSS model transforms the synthetic rainfall data into daily streamflow using a soil moisture accounting process in a physically consistent manner.

The computer output from the model consists of statistics and cumulative density functions for monthly, seasonal and annual discharges, maximum daily high and low flows, and consecutive days of low baseflow. The model output can be used by decision makers to meet the objectives of proper land use and development.

CHAPTER ONE

INTRODUCTION

The Himalayan mountain range is considered to be largest, highest and youngest in the world. The annual south estern monsoon produces heavy rainfall on the southern aspect of the range, which results in the washing off of productive fertile soil from the hill slopes. Nepal lies on this ecological range. Over 90 percent of the poputation of Nepal are engaged in agriculture, mainly subsistence agriculture. Over 350,000 people are added to the population of farmers each year. Unfortunately agricultural production has not been able to keep pace with population growth. Cultivation and animal husbandry have been expanded to unsuitable terrain and steeper slopes to meet the growing needs. The human activities place extreme pressure on forests and hill slopes already in delicate balance with the natural environment. In addition to accelerated soil loss, landslides commonly occur every year which destroy human lives, kill livestock and destroy crops. The depletion of soil from the hill lands produces sediment choked streams and river in the valleys and flood plains, causes floods during the rainy season, and droughts during the dry season.

It is estimated that on the average over 240 million cubic meters of soil is lost every year from Nepalese hills. The principal areas of this erosion are on public lands; e.g. forest, shrub and brush, and pasture lands. Land management is an urgent need in those areas, but decision makers and planners have difficulties due to the lack of accurate and up to date assessment of the water resources in that region.

Land use management and environmental protection are key issues of development strategies for the Tinau watershed. An accurate and comprehensive assessment of the present natural resource base, and its potential for development would help to optimize the benefits from agricultural land-use as well as reduce the damage to the natural environment. Because an adequate data base for making decisions in water resources development is not available, a land use management plan and policy has not yet been developed for the Tinau watershed.

Fleming (1978) found that the Tinau watershed was in the poorest hydrologic condition of any watershed in western Nepal. Winter cropping is not practised, and the valley floors remain dry and unirrigated during winter and spring. The small town, Butwal, in the plain is threated by frequent floods. Rieger et at. (1976) proposed a land management strategy for the development of water resources to increase the productivity of the valley and for flood control downstream of the watershed.

In planning for the water resource, there is a need for a methodology that takes account the variability of rainfall, runoff and erosion from the watershed with time.

Objective

The primary objective of this study was to develop a method for evaluating the hydrologic performance of the Tinau watershed that can be used as a hydrologic tool for land management and policy making decisions.

The special objectives of the study were to develop a computer model, TINAU, that:

1) is simple to use and calibrate, and requires only a small amount of readily available data;

2) can be used as a physical event-based sediment yield model to assess the soil erosion losses from the watershed, and sedimentation on the downstream;

3) can be used as a hydrologic tool to estimate the probabilities of high flows and low flows in the river;

4) can be used as a water yield model to plan and implement a land use policy; and

5) is able to reflect the natural variation in the climate.

Approach

The approach of the TINAU model was to: (1) simulate a time series of daily rainfall using stochastic methods, (2) route the rainfall into a series of cascading soil moisture storage compartments, (3) drain the soil water to generate interflow and baseflow, and (4) evaluate the statistics of hydrologic performance in terms of monthly, seasonal, and annual streamflows, maximum and minimum daily discharges, and consecutive days of low flows. A simulation technique was used because of the short historical flows record available for the Tinau river, and because the most severe drought period and the greatest flow of the historical records are unlikely to be the maximum possible.

The following steps were made in determining the TINAU watershed model:

(1) Develop a physical event-based stochastic precipitation model to simulate a long-term series of daily rainfall data;

(2) Develop a fitted parameter, soil moisture accounting hydrologic model to transform the synthetic rainfall data into sequence of daily streamflow events;

(3) Produce statistical summaries and plot cumulative frequencies on monthly, seasonal and annual flows, daily maximum discharge and daily minimum discharge, and consecutive days of low baseflow recessions; and

4) Evaluate the results.

A seperate submodel was developed and operateed for each of steps 1 to 2 described above and are linked into the overall TINAU model. The development , calibration, and testing of each submodel is discussed in chapters three through five.

CHAPTER TWO

THE STUDY AREA

The Tinau Watershed is located in western Nepal. This study was made for the catchment of the Tinau River that lies in Palpa district. The catchment covers an area of 550 square kilometers. The area is roughly oval shaped, elongated east-west and lies between 27° 42' N to 27° 52' N latitude and 83° 18' E - 83° 42' E longitude (Fig. 1).

The Tinau River originates in the mid-hill Mahabharat range, drains the Madi valley and flows through the narrow gorge in the lower foot-hill Churia range. The main tributaries are the Jhumsa and Dovan Rivers. The Tinau River in the plain at Butwal creates flood hazzards and deposits sediment on the fertile flood plains.

Topography

The topography of the watershed is characterized by its situation in the southern range of the Himalayas. The mountain range which runs east to west restricts the river course and largely determines the land-use patterns in the watershed. The watershed is in the foot-hills; the Churia hills are to the south and the middle Mahabharat range is in the north. The foot-hills rise gently from the plain (180m) to about 600m and converge abruptly into steep, almost

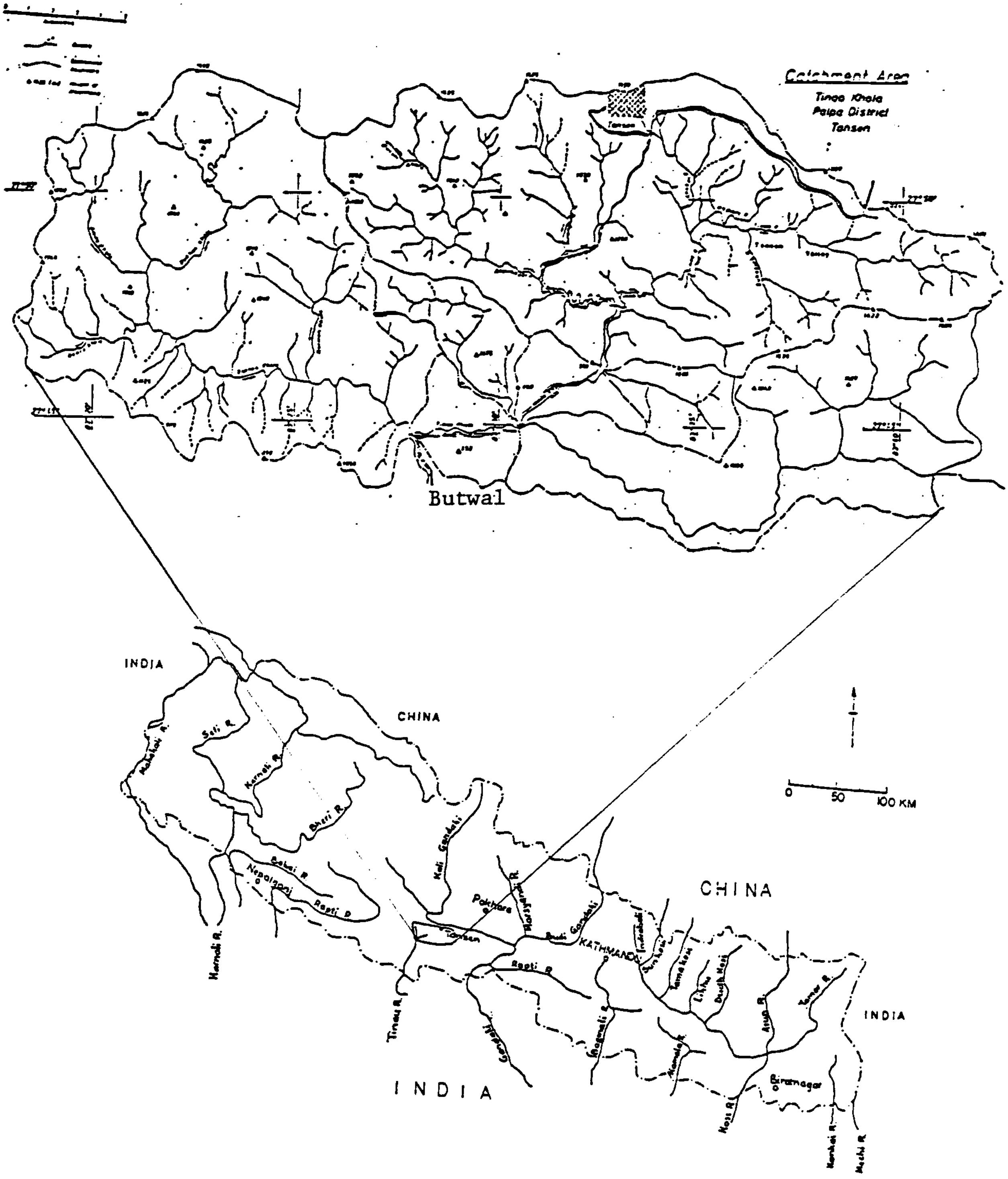


Figure 1. Map of NEPAL Showing Location of the Tinau Watershed, Palpa.

perpendicular escarpments (Churia hills). The mid-hill Mahabharat and inner Himalayan ranges comprise a rough terrain with steep slopes at altitudes of about 1800m.

Geology and Soils

The foot-hills consist of a thick detrital rocks, such as coarsely bedded sandstones, clays, conglomerates and sandy limestones. In the deep canyon, just north of Butwal, where the Tinau River cuts through the foot-hills, thick layers of sandstones vary with green-greyish to reddish clays, giving way in the north to breccious and conglomeratic layers and finally to dolomite or sandy limestones on the north boundry of the foot-hills. The mid-hills range consists mainly of quartzites, phyllites and sandstones with intermediate layers of schists. On the southern border of the Madi valley basin, a small strip of soft, pinkish schists extends from east to west.

However, the soils of the study area, developed from different parent materials, have some common characteristics. The soils vary from alluvial in the plains, foot-hills and mountain valleys; to laterite and lateritic soils in the hills, mountain terraces, hilltops and forested hills; and podzols under pine forest vegetation specially in the north-western sector. Hill soils are poorly developed (Pradhan et al. 1967), do not hold water well, and most of top soil has been washed downhill, especially on southern slopes.

Dominent soil texture is moderately to well drained sandy loam, underlaid by sandy loam, sandy clay loam or clay loam. Soil reaction is slightly alkaline to strongly acidic, and with low to high organic matter content.

The soil types of the north-eastern part, specially south facing slopes, the Madi plain and the upper Tinau valley are sandy clay loam to clay loam, slightly to strongly acidic in reaction. Those in the bottom lands are deep, stonefree loams. In the Dovan valley, lower Tinau valley sandy loam dominates. These soils are strongly acidic to moderately alkaline, medium to high in organic matter content, moderately well to well drained sandy loam.

Climate and Vegetation

Two major climatic regions are recognized in the study area: the hot and humid area of the plains and foot-hills; and the cooler or microthermal region of the Mahabharat range. The plains and foot-hills area below 900 m is a land of humid sub-tropical monsoon climate. The intricate seasonal monsoon rainfall associated with southwest winds of the summer monsoon and practically rainless winters extend into the mountain valleys. In the northern region, the climate changes markedly with elevation. The Mahabharat range and the inner Hamalayan chains have micro-thermal climate. Here, the winters range from moderately cool to severe, with warm and wet summers.

The rainfall of the area varies from 1400 mm to 2000 mm per year. Most of the rainfall is associated with the south west monsoon which breaks about mid June and spreads over the entire watershed within a few days. The south west monsoon usually lasts from June to September, and within this period the watershed area receives approximately 80 percent of the rainfall. Long-term annual rainfall distribution shows the following pattern: 6 months (November to April) are either very dry or have a rainfall below 50mm per month; 2 months (May and October) normally recorded below 75mm of rain; and 4 months (June to September) receive 200mm or more per month.

The physiographic range of the study area, which varies from 250 m to nearly 2000 m above sea level, creates a variation in temperature. The summers are hot with temperatures exceeding 38°C, and winters are cool and pleasant with a mean temperature of 12°C. The subtropical type climate prevails above 900 m where summers are cool and pleasant with a maximum temperature of about 32°C and winters are cold with a mean temperature at 10°C with occasional frost. Fairly dense moist deciduous forest occurs in the southern part of the foot-hills and Churia hills which lies in the tropical climatic region.

The main forest associated with this climatic region is the Shorea/Terminalia type. The tree species in this forest are Shorea robusta, Terminalia spp., Acacia catechu, Salmalia malabarcia, Dalbergia sisoo, Bauhinia vahlii, Mallotus philippinensis. Chirpine grows in the driest part of the Churia hills. Grass cover associated with this forest type is called Saccharum/Phragmites/Imperata (Dutt,1979). The main grass species are Saccharum spontaneum, Phragmatis karka, Imperata cylindrica, Cynadon dactylon, Heteropogon contortus, Eulaliopsri binata.

In the subtropical Mahabharat range two associations, the Shorea/Schima type, and the remnant of Schima/Castanopis type are dominant. Dutt(1979) identified these two types in the Tansen area. The first type concentrates in an elevation range of 600 - 1200 m where Shorea robusta is the dominant species with Schima wallichii a companion species. This dominance of Shorea is related to edaphic factors, as the soil in this area is shallow and the floor composed of mainly rocky outcrops.

The Schima/Castanopsis type occurs at elevations of 1100 - 1500 m. Usually northern and north-eastern slopes are clad in dense forest and the southern slopes are bare, being too steep to maintain a soil cap for the growth of the forest or to allow the winter snow to accumulate. Main tree species in this forest type are Schima wallichii, Castanopsis indica, Fraxinus floribunda, Myrica nagii, Rhododendron arboreum, Englehardititia spicata, Lyonia ovalifolia, Prunus cerasoides, Morus spp., Brassicaopsis hainl, Ficus *religiosa*, *F. bengalensis*,*F. lacor*, *F. semicordata*, *F. glabberimma*, *F. clavata*, *Bauhinia variegata*, *Pyrus paschia*. Pine (*Pinus exelesa*, *P. longifolia*) predominates in the north-western area. Shrubs that are dominant in this area are *Maesia shista*, *Berberis aristada*, *Rubusellipticus*, *Ziziphus* spp. This area is rich in herbs and spices. The main spices and herbs are *Osbeckia stellata*, *Artemisia vulgaris*, *Urtica dioca*. Grammineae play an important role in soil conservation in this forest type. Two main species found are *Dendrocalamus hamiltonii*, *Arundinaria* spp. The grass cover associated with this forest type is called Themeda/Arundinella cover. The grass species in this association are *Themeda anthera*, *Arundinella bengalensis*, *A. nepalensis*, *Chrysopogon fulvus*, *C. gryllus*, *Bothriochloa intermeia*, *B. pertusa*, *Heteropogon contortus*, *Dimeria fuscescens*.

Agriculture and Land-use

The southern part of the watershed Churia hills is forested hilly land, where a little agriculture is practiced. The rest of the area is in the central hill farming system. The Tinau Watershed Project (TWP, 1980) has prepared a land-use map of the study area. The map indicates two predominant land-use types: south and central portion: forest-covered and erosion scared, no intensive agriculture; and northern section: more intensively cultivated, forest cover reduced, shrubs and bushes dominate. In 1980 TWP had estimated the watershed area at 522.4 sq. km, which includes 197.2 sq. km of forest land, 127.4 sq. km of grass land, 168.17 sq. km of agricultural land with mainly rain-fed cultivation, and 12.78 sq. km of erosion, landslides, rivers and ponds.

Agriculture is the basis of life in the study area. Most of the population is engaged in agriculture, so almost every household has a piece of land. The main crops are rice, wheat, pulses, etc, in the lower valley bottom, and corn, millet, barley, sorgum, dry land rice, black gram, soyabean, mustard, pea, sunhemp, potato, ginger etc on the hill slopes and terraces. Most of the cultivation is rain-fed, except for a few irrigated areas in the Madi plain, Jhumsa, and Dovan valleys.

Livestock-keeping is an important farming system next to crop production. Cattle are raised mainly for ploughing and farm manures. Water buffaloes and bullocks are mostly stall-fed. During the wet season, animals are fed mainly fodder from trees, and grasses from private lands. In the dry season animals have to live on straw from different crops, and from grazing on pastures. TWP(1980) had estimated 6000 head of cattle and 2500 goats in the watershed, Grazing is uncontrolled and year round. The resulting overgrazing produces severe erosion during the monsoon season.

The human population of the watershed was 71,000 in 1980, and the rate of population growth was 2 percent. It was estimated that there were 11,141 households in 1978 (TWP, 1980), and 6.1 persons per family. In 1971, about 6500 people lived in and around one small hill town, Tansen, alone. Seasonal migration of the people prevails due to ecological and economic conditions. Seasonal movements take place twice a year, from July to September in the monsoon, and from December to February in the winter.

Data and information for this study area were collected from different agencies in Nepal. Daily rainfall, maximum-minimum temperatures for Tansen and Butwal were obtained from the Nepal Meteorological Service, and stream flow records of the Tinau river at Jhumsa and Butwal from the Hydrology Section, Ministry of Water Resources. Soil Sciences and Agricultural Chemistry, Department of Agriculture provided the soil survey report of Palpa district.

CHAPTER THREE

THE PRECIPITATION MODEL

Precipitation is a key process in most hydrologic models. Because of its variable nature in both time and space, it is a complex process. The stochastic model used in this study is an event-based daily precipitation simulation model. The model takes account of two seasonal precipitation patterns that occur in much of Nepal.

Duckstein, Fogel, and Kisiel (1972) and Duckstein, Fogel, and Davis (1975) developed stochastic models for rainfall patterns prevalent in the south western United States: convective type summer thunderstorms, and frontal type winter storms. These models were adapted to the two major rainfall patterns in south western Nepal: Dry Weather Precipitation and Monsoon Precipitation. Two assumptions were made: hot summer and cold winter thunderstorms occur as independent events; and wet warm storms occur in groups or sequences.

Initial Data Analysis

Daily precipitation records were available for the periods 1978 through 1985 in the Tansen area and 1972 through 1982 in the Butwal area. Similar daily precipitation records were available from two main valleys, the Jhumsa and the Madi plains for 1984 and 1985. A comparison of precipitation amounts at Tansen was made with the other three areas, and it was observed that a correction was needed for spatial distribution of rain storms. The annual rainfall measured at Butwal was greater than that measured at Tansen by a factor of 1.504. It was calculated that the gauge catch at Butwal represented about 15 percent of the study area. Therefore, the daily rainfall measured at Tansen (T) was corrected by

$$\text{Rainfall} = 0.85*T + (1.504)*(0.15)*T \tag{1}$$

For the calibration of the model parameters, daily precipitation data were analyzed by using computer programs &TN1 and &TN2. These two programs, originally written by Jones (1981), were modified for this study. Computer program &TN1 was written to determine the actual precipitation event interarrival day probability density function (PDF) and cumulative density function (CDF) of precipitation events on a monthly basis. Computer program &TN2 was written to determine the actual precipitation amount per event PDF and CDF. These programs also list a sequence of statistical parameters and 't' values, and a corresponding degree of freedom for all possible pairing of months. A student's t-test was conducted at the 0.05 level of significance for grouping of statistically like months to separate seasonal precipitation types, hot and cold dry and wet monsoon.

After completing the t-tests and grouping months, JAN-FEB-MAR, APR-MAY, OCT, and NOV-DEC groups were found to be characterized by the hot and cold dry type seasonal precipitation. Computer programs &TN3 and &TN4 were developed to analyze these groups for estimating the parameters needed to fit the data to theoretical distributions. The months of JUNE through SEPTEMBER were treated separately as a wet monsoon precipitation type. A computer program &MONSOON was used to analyze and describe the parameters used in the wet monsoon seasonal model.

Dry Weather Model

An event-based stochastic model of convective storms (Fogel et al. 1971, and Duckstein et al. 1972) was used as the basis for simulating the hot and cold dry weather precipitation storms model. Two basic assumptions are made in this model:

(1) storms occur independently of each other, and

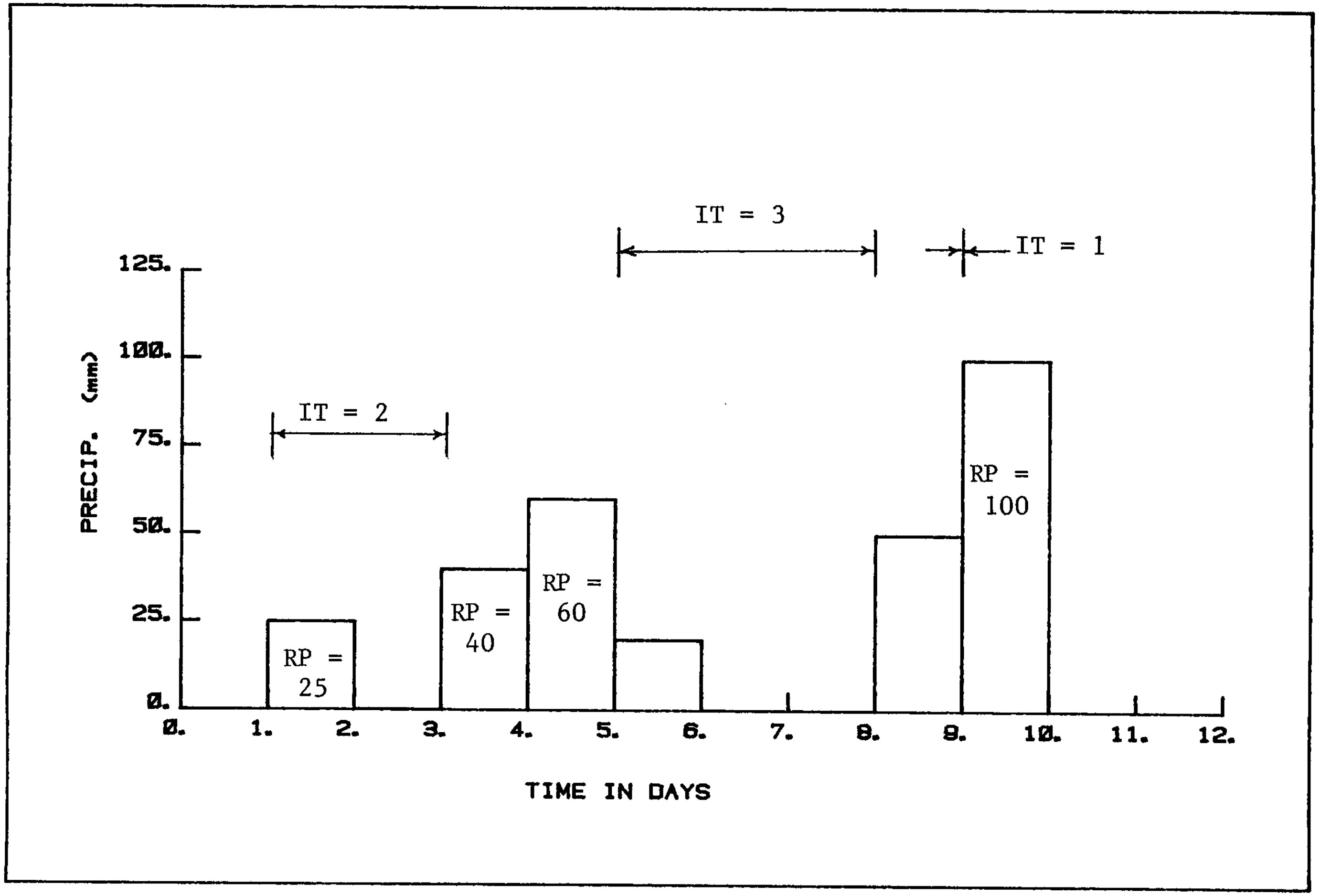
(2) only one precipitation event occurs in a day.

The two random variables used in simulating a sequence of dry weather precipitation events were the amount of precipitation per event (RP) and the interarrival time between rain events (IT). An event is defined to be a rainy day having a total precipitation of at least 0.1 mm. Two consecutive precipitation events were defined to have one day interarrival time, and two precipitation events separated by two dry days to have a three day interarrival time.

A graphical representation of these variables is shown in Figure 2. Empirical frequency distributions were developed for these two variables, and each of the variables was fitted to a theoretical probability distribution. The Kolmogorov-Smirnov (K-S) test was used to indicate the best-fit between the frequency distribution of actual data and theoretical distributions (Benjamin and Cornell, 1970) at the 0.05 significance level.

Interarrival distribution groups 1 and 2 for the months of JAN-FEB-MAR and APR-MAY indicated a significant difference at the 0.05 level in the K-S test from the general theoretical distributions, and thus did not fit the theoretical distributions. In these situations, the actual distributions were shifted by assigning the first interarrival day PDF in the actual distribution to the first interarrival day (Jones, 1981). The shifted PDF, CDF were evaluated for all days beyound the first day. The new set of statistical parameters developed were used to generate new theoretical distributions which were tested against actual distribution using the K-S test as before.

The two parameter gamma distribution was found to fit actual distributions of precipitation amount and



IT = INTERARRIVAL TIME BETWEEN EVENTS (DAYS), RP = PRECIP. AMOUNT PER EVENT (MM). AN "EVENT" IS DEFINED TO BE A DAILY RAINFALL AMOUNT GREATER THAN 0.1 MM.

Figure 2. Hot and Cold Dry Weather Precipitation Model Components.

precipitation event interarrival time for three groups. The PDF for the gamma distribution is:

$$f_x(x) = \frac{\lambda^k \; x^{k-1} \; e^{-\lambda x}}{\Gamma(k)} \tag{2}$$

where, $\lambda = \bar{x}/s^2$ and $k = \bar{x}^2/s^2$.

In this distribution function, x is either precipitation amount per event or interarrival time, k is the shape parameter, lamda (λ) is the scale parameter, $\Gamma(k)$ is the gamma function, $\bar{x}$ is the actual distribution mean, and s^2 is the variance of the actual distribution.

For the monthly grouping, the best-fit theoretical distributions are listed in Table 1. The best-fit theoretical distribution of group precipitation and interarrival time, and their actual frequency distributions are shown in Figures 3 and 4 respectively.

Monsoon Model

The monsoon period of JUN-JUL-AUG-SEP was modeled differently from the rest of the year. This model was based on the assumption that rainfall events occur from the fronts or waves of large storm systems. Duckstein, Fogel, and Davis (1975) presented a mixed-event winter precipitation model that considered independently arriving storm sequences

Table 1. Probability Distribution Functions and Associated Parameter Values Used in Simutlating Hot and Dry Seasonal Precipitation Model.

Group	Months	Distribution Type	Parameters Values
		Variable: Interarrival Days	
1	1, 2, 3	Gamma	1-day fix: 0.4103 $\lambda = 0.1593$, $k = 1.849$
2	4, 5	Geometric	1-day fix: 0.4766 $x = 4.625$
3	10	Gamma	$\lambda = 0.0621$, $k = 0.2832$
4	11, 12	Gamma	$\lambda = 0.0283$, $k = 0.4841$
		Variable: Precipitation Per Event	
1	1, 2, 3, 4, 5	Gamma	$\lambda = 0.1103$, $k = 0.8873$
2	10, 11	Gamma	$\lambda = 0.0490$, $k = 0.0523$
3	12	Gamma	$\lambda = 0.1504$, $k = 2.6304$

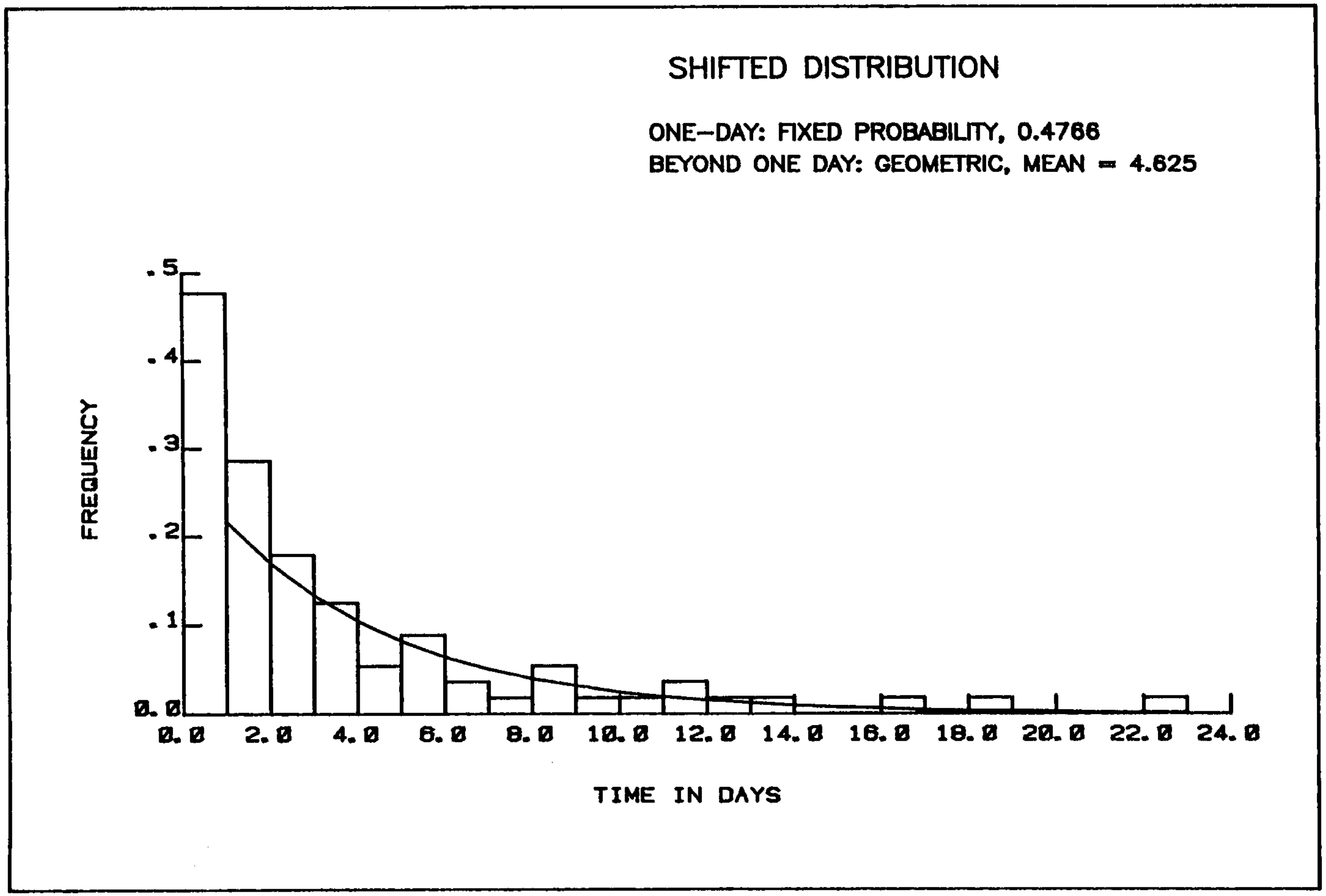


Figure 3. Comparison of Actual Data and Fitted Probability Distribution Function for Storm Interarrival Time in April and May.

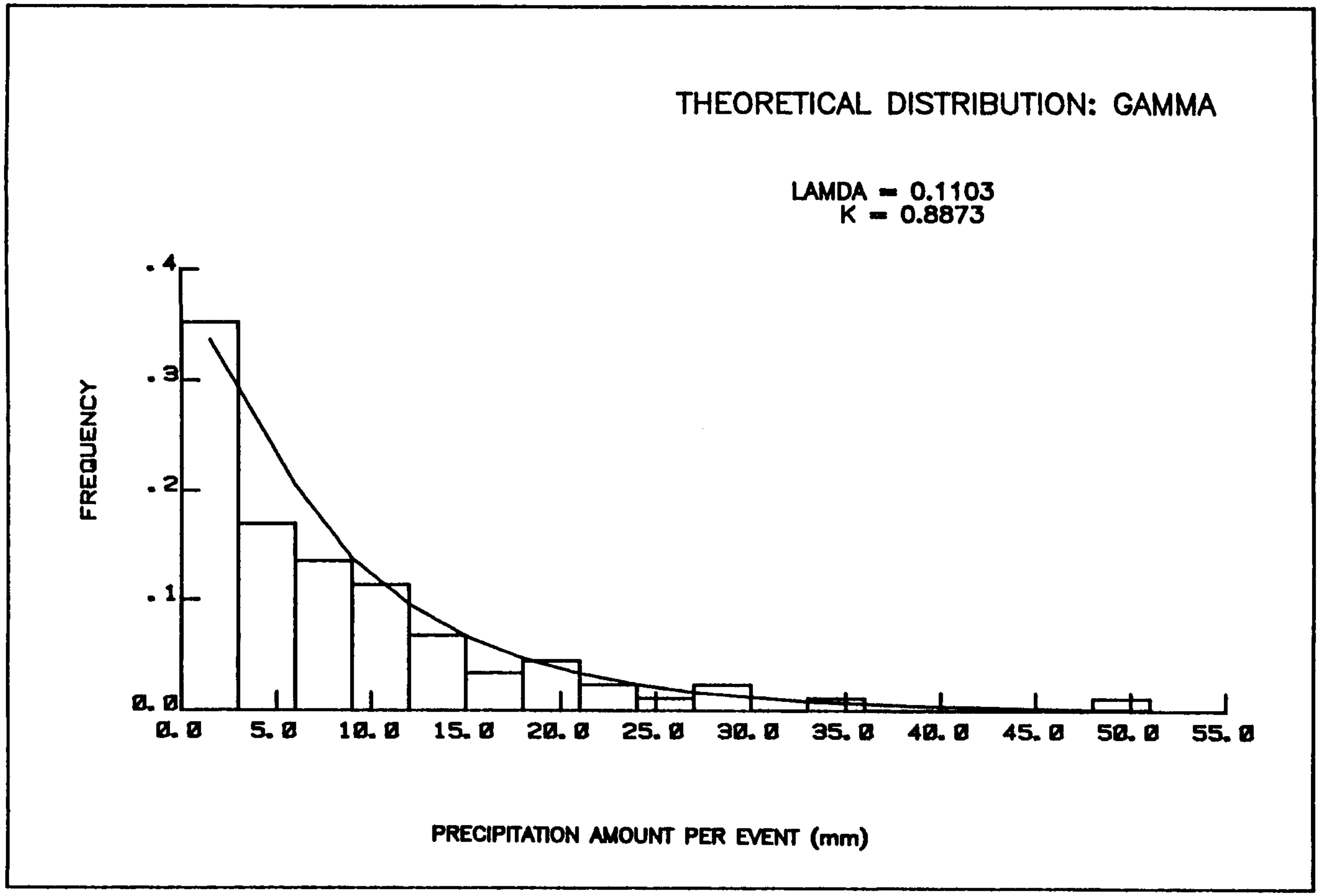


Figure 4. Comparison of Actual Data and Fitted Probability Distribution Function for Precipitation Amount per Event in January, February, March, April and November.

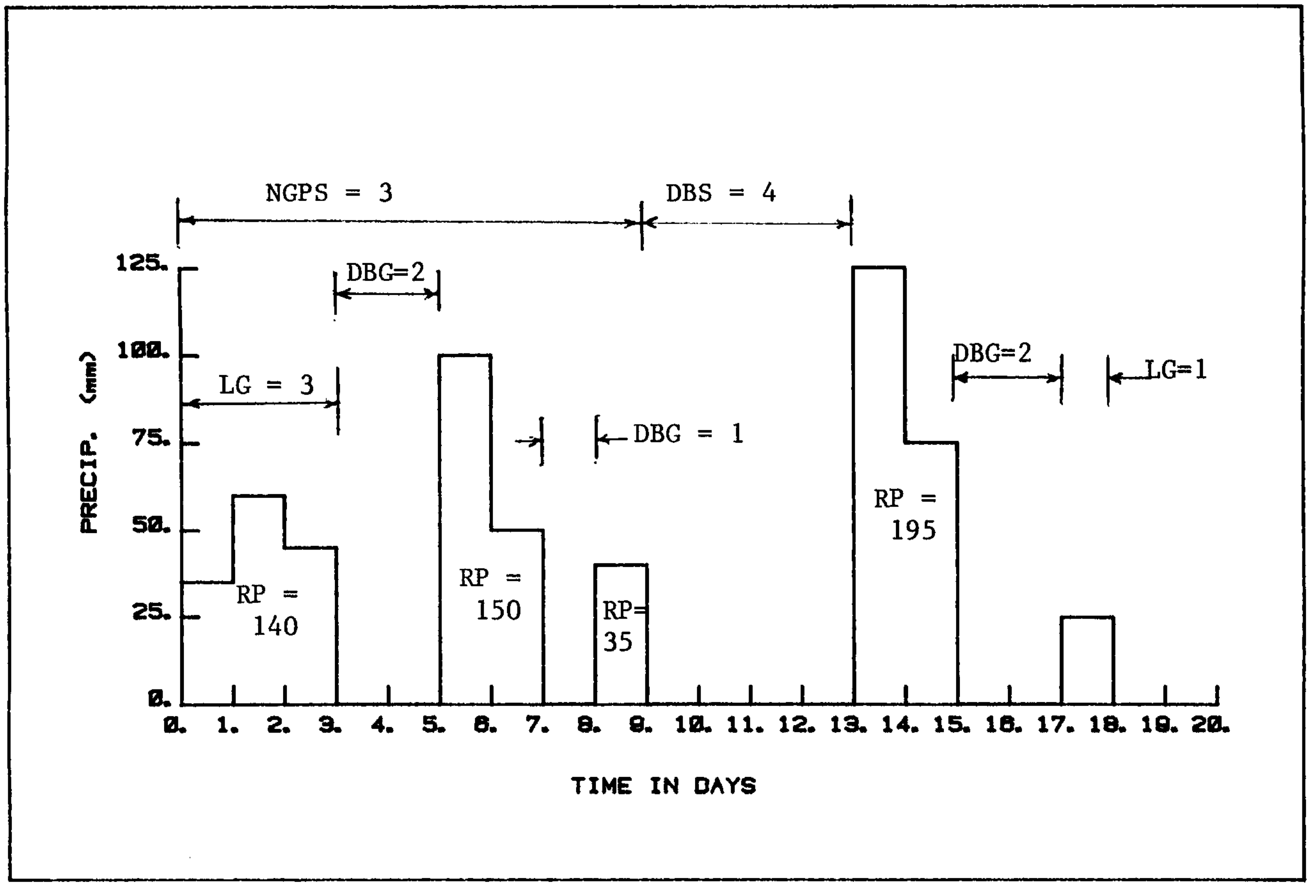
consisting of dependent groups. Monsoon storms often come in sequences in which one storm follows another within a short time interval, while at other times a storm appears to arrive in an independent manner. The element of precipitation unit in this model was precipitation group, defined as consecececutive days of rainfall during which daily precipitation amounts exceeded a minimum of 0.1 mm. Consecutive groups separated by no more than a specified number of dry days consituted a sequence. Hekman (1977) estimated this maximum number to be three in mountainous areas of Arizona, U. S. In this study, rainfall events after five dry days were empirically considered to be in another sequence.

The random variables used in this model are schematically shown in Fig. 5, and defined as follows:

(1) DBS, interarrival time between sequences (days)
(2) DBG, interarrival time between groups (days)
(3) LG, group duration (days)
(4) NGPS, number of groups per sequence, and
(5) RP, total precipitation amount per group (mm).

In this model, events correspond to groups of consecutive rainy days. Two assumptions made concerning the operation of the model are:

(1) precipitation amount per group is uniformally distributed over group length, and



DBS = Dry Days Between Sequences
NGPS = Number of Groups Per Sequence
RP = Precipitation Amount Per Group (MM)
DBG = Dry Days Between Groups
LG = Length of Group

Figure 5. Wet Monsoon Type Precipitation Model Components.

(2) group precipitation is also independent of group duration.

Frequency distributions were developed for the five variables, and hypothetical or theoretical distributions were fitted to each of the actual distribution groups. Goodness of fit tests were conducted to compare actual and hypothetical distributions. The K-S test at a significance level of 0.05 was used to determine best-fit between the actual distribution and the theoretical.

Geometric distributions were used to describe the variables (DBG) number of dry days between groups and (LG) length of group. Dry days between sequences (DBS) were fit to the exponential distribution and number of groups per sequences (NGPS) were fit the gamma distribution. The cumulative density function (CDF) of geometric and exponential distributions are as follows:

Geometric distribution (CDF)

$$F_x(x) = 1 - (1-p)^x, \text{ where } p = 1/\text{Mean} \qquad (3)$$

Exponential distribution (CDF)

$$F_x(x) = 1 - e^{-\lambda x}, \text{ where } \lambda = 1/\text{Mean} \qquad (4)$$

In these distribution, x is one of the random variables DBG, DBS, NGPS, LG, and Mean is the actual distribution mean.

Precipitation amount per group did not fit any of the theoretical distributions, so this variable was grouped into different classes having intervals of 10 mm rainfall. These Class groups fit the gamma CDF's, so a mathematical relation was established to estimate precipitation amount in mm.

$$PPT = (10\ x - 5) \tag{5}$$

where, PPT = precipitation amount in mm

x = grouped precipitation amount class, and

10 and 5 = the class interval and the interval mean, respectively.

A summary of model parameters used in simulation is listed in Table 2, and best-fit theoretical distributions for all variables are schematically presented in Figure 6, 7, 8, 9 and 10.

Operation of the Model

The precipitation model subroutine PANI (See Appendix A) used in this study combined two submodels for dry and wet type rain storms, and operated as an event-based stochastic model of daily rainfall in the Tinau watershed. This model PANI generates a one year time series of the Julian calendar (Jan-Dec). The model operates by a series of Monte Carlo simulation (Benjamin and Cornell, 1970), using random numbers generated by the computer to sample the

Table 2. Probability Distribution Functions and Associated Parameter Values Used in Simulating Monsoon Precipitation Model.

Variable	Distribution Type	Parameter Values
1. Days Between Sequences (DBS)	Exponential	$x = 8.722$
2. Days Between Groups (DBG)	Geometric	$x = 1.813$
3. Days in a Group (LG)	Geometric	$x = 3.730$
4. Groups per Sequence (NGPS)	Gamma	$\lambda = 0.1388$ $k = 0.7609$
5. Precipitation Amount per Group (RP) (grouped class)	Gamma	$\lambda = 0.0672$ $k = 0.5648$

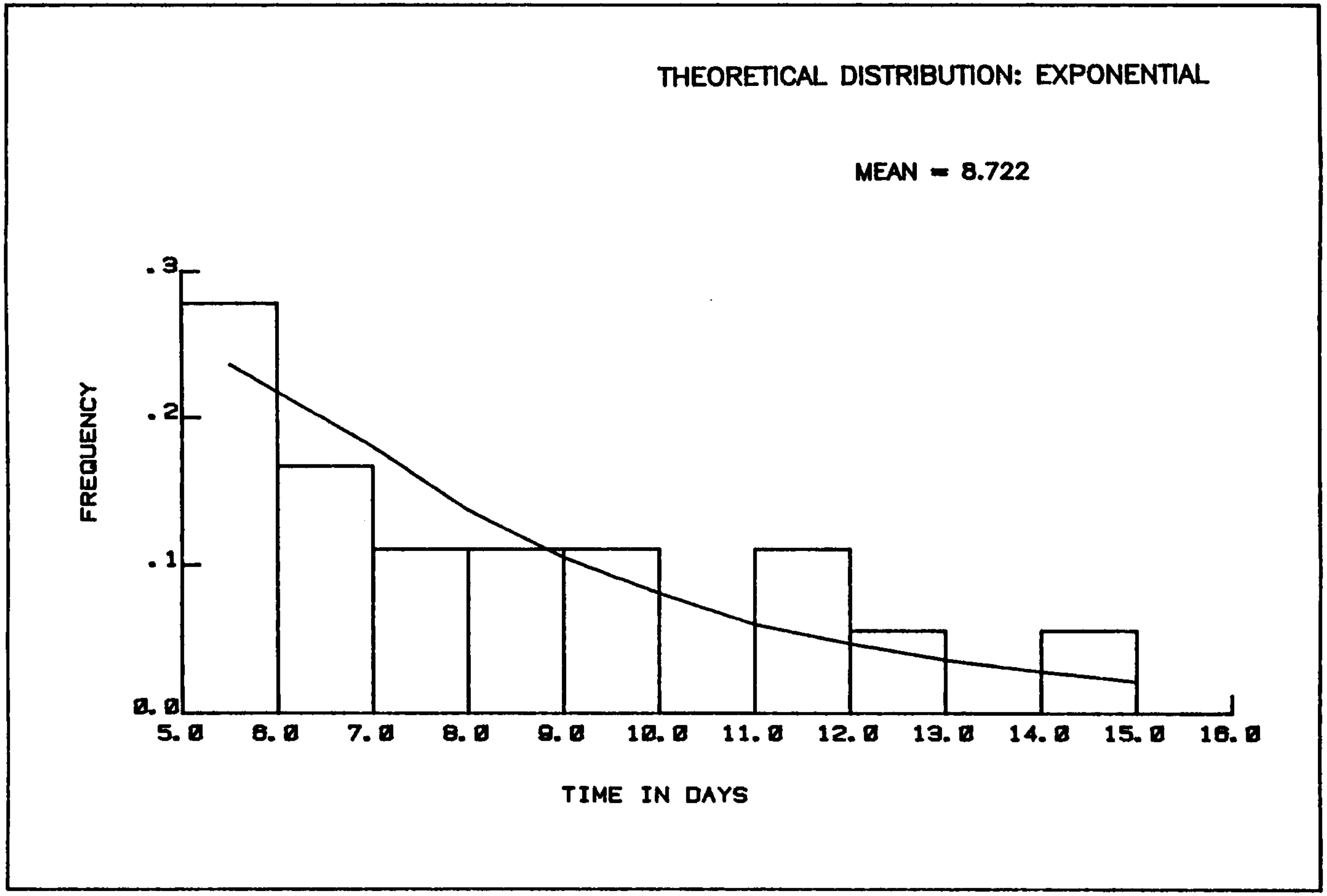


Figure 6. Comparison of Actual Data and Fitted Probability Distribution Function for Dry Days Between Sequences (DBS).

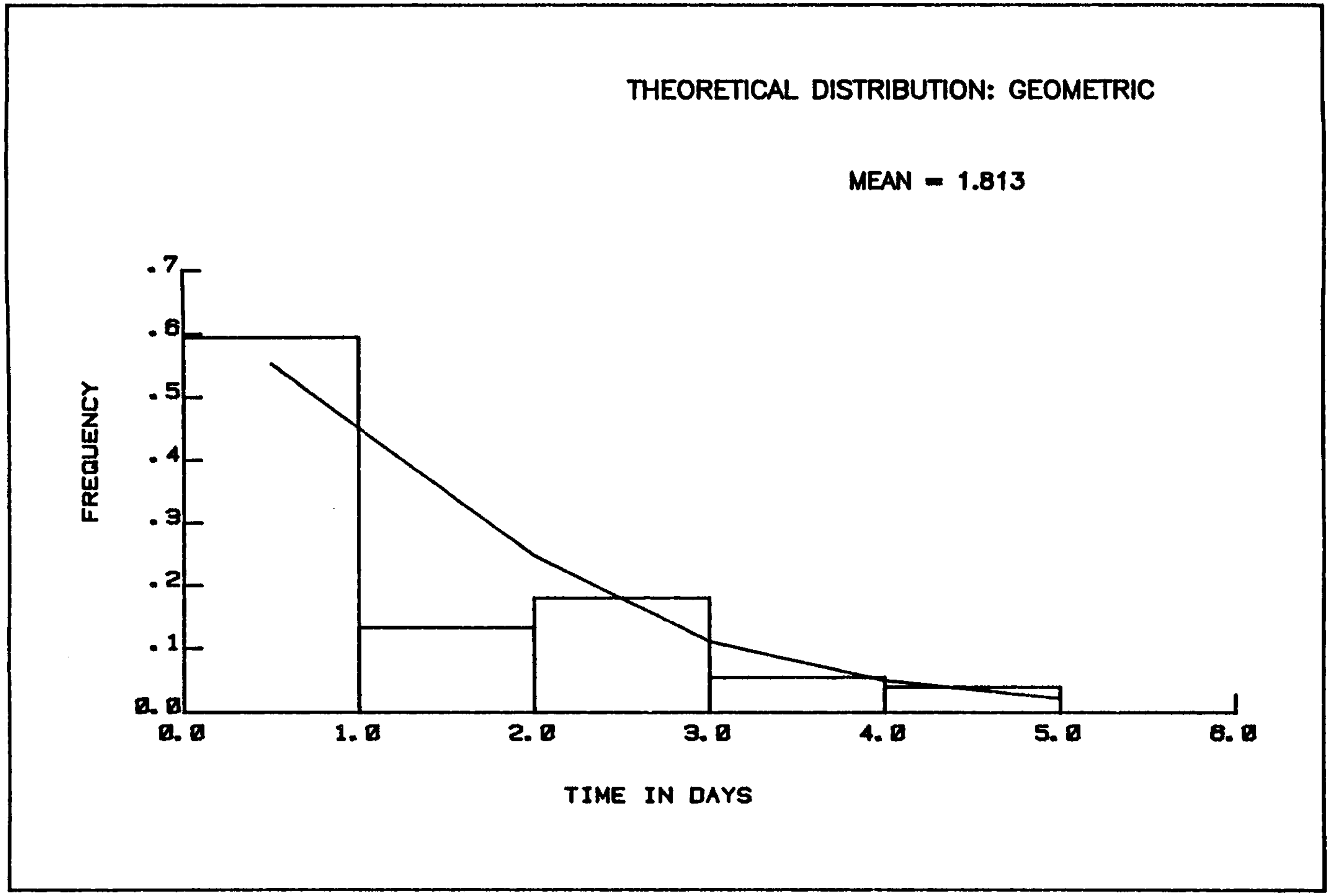


Figure 7. Comparison of Actual Data and Fitted Probability Distribution Function for Dry Days Between Groups (DBG).

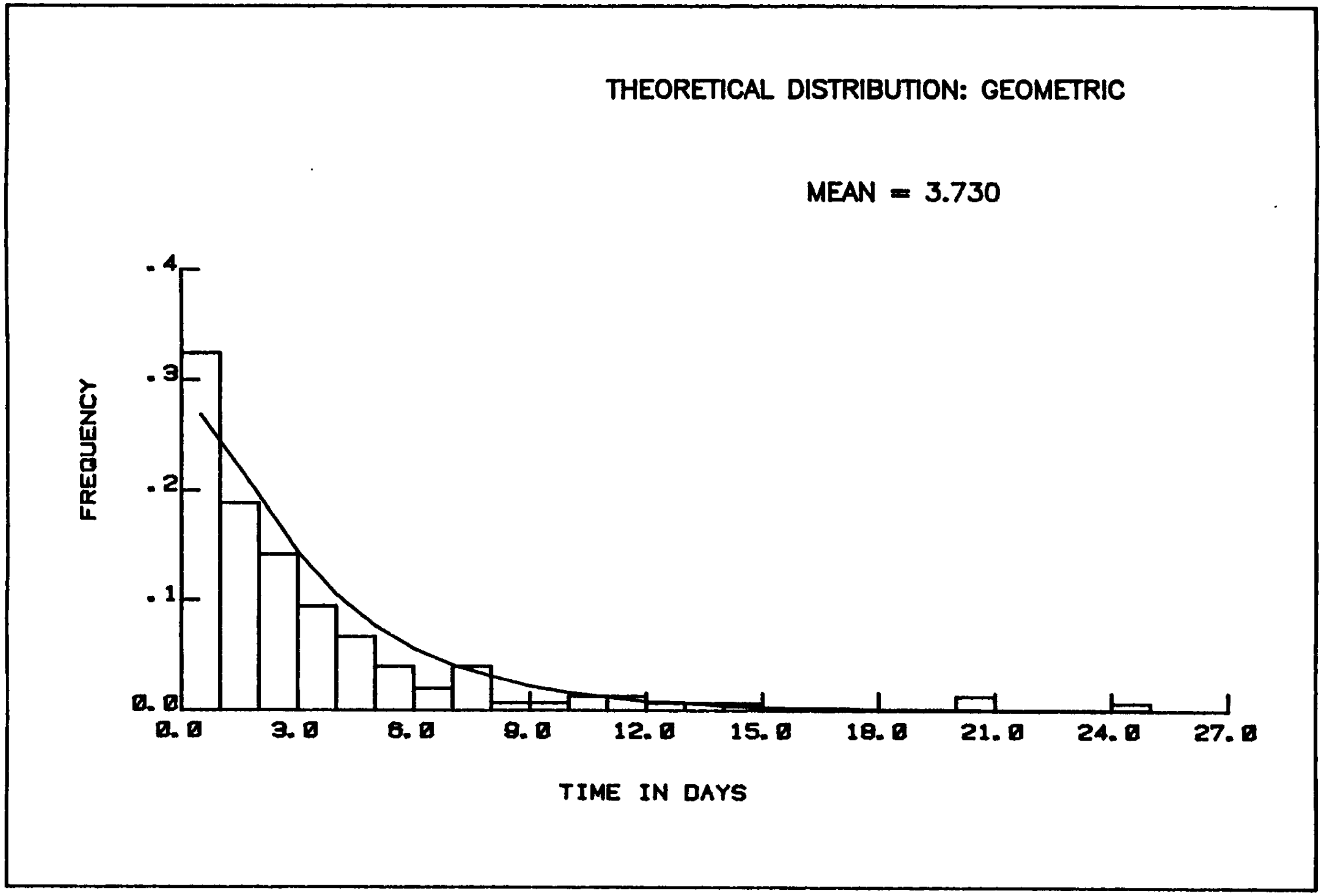


Figure 8. Comparison of Actual Data and Fitted Probability Distribution Function for Group Duration (LG).

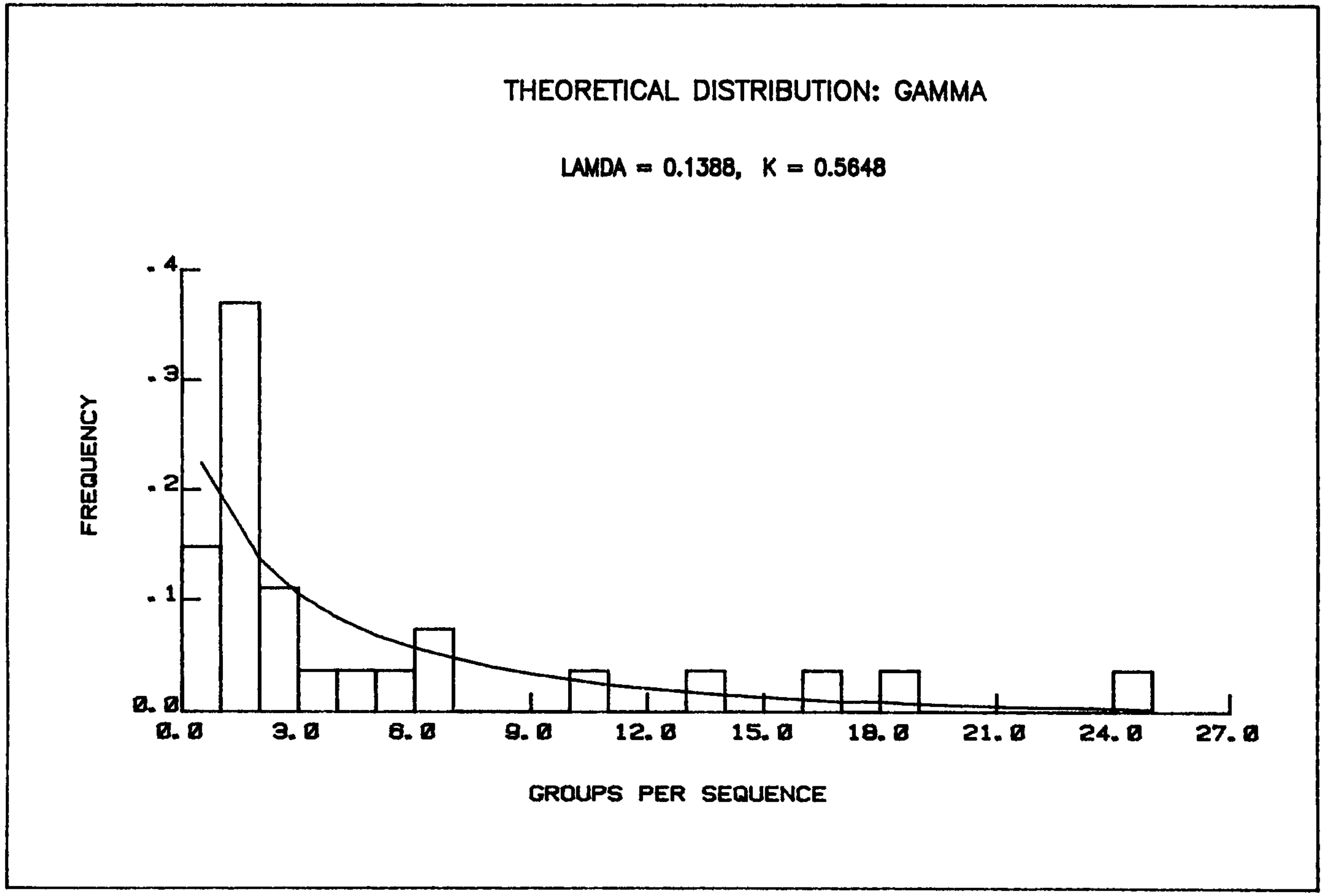


Figure 9. Comparison of Actual Data and Fitted Probability Distribution Function for Number of Groups per Sequence (NGPD).

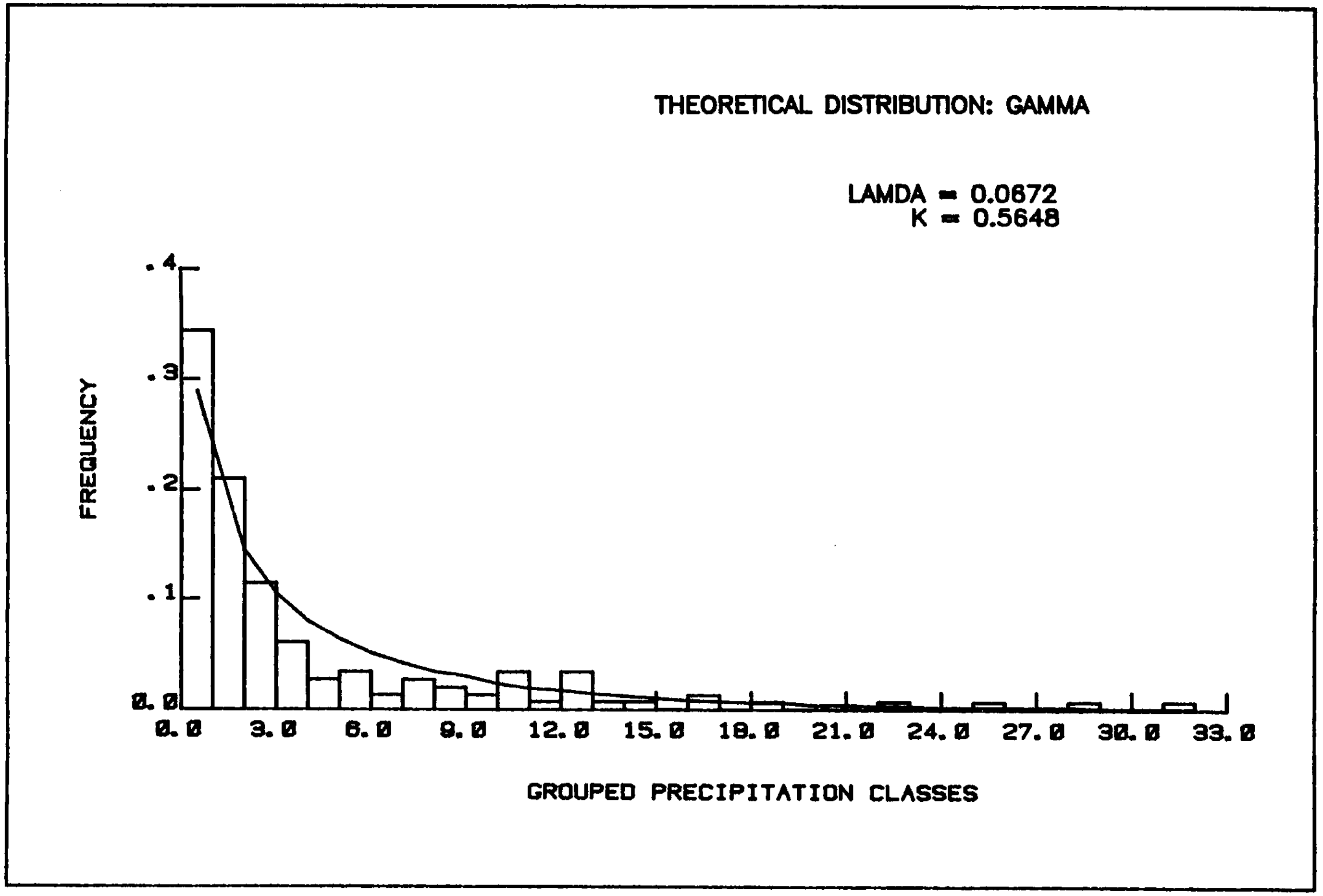


Figure 10. Comparison of Actual Data and Fitted Probability Distribution Function for Precipitation amount per Group (RP).

appropriate theoretical cumulative distribution function for each month and model parameters.

The cumulative probability function for any random variable is uniformally distributed over the interval 0 to 1, and random variables are generated from this probability distribution (Haan, 1982). These variables are generated by: generating a random number uniformly distributed between 0 and 1; setting that random number to CDF of the random variable distribution; and equating the distribution equation for the random variable occurence. An example of the geometric distribution is as follows:

$$CDF = F_X(x) = 1 - (1-p)^x \tag{6}$$

where, x = Occurence

p = 1/Mean

and $CDF = F_X(x)$ = a random number.

In this equation, the occurence x is determined by substituting values of CDF and p. Occasionaly this inverse transformation could not be matched for a certain distribution as in the case of gamma. In these cases a gamma random variable generating function was used to describe interarrival time and precipitation amount per event.

The model was operated, starting from the first day of the Julian Calendar (Jan 1), in the following sequences.

(1) A random rumber is generated and that number is set to evaluate interarrival day CDF. The CDF equation is solved to determine interarrival day. The Julian calendar day is advanced keeping tract of each seasonal group.

(2) On the day indicated for rainfall event, another random number is generated and CDF for precipitation per event is evaluated to give rainfall amount for that day.

As the calendar advanced, a check was made to determine if it entered the monsoon season. When the entrance was noticed, the following steps were operated.

(3) Generate a random number and enter it into the dry days between sequences distribution function. The calender is advanced and counts the days of a year, accordingly.

(4) For the sequence indicated for rainfall groups, generate and enter another random number into the number of groups in a sequence function to evaluate number of groups.

(5) Generate and enter another random number into the group duration distribution function, and evaluate group length.

(6) Generate a random number and enter it into the distribution function for precipitation amount per group.

(7) Evaluate the precipitation amount on each day of the group by dividing total precipitation amount per group by number of days in a group.

(8) When more than one group was observed in a sequence then step 5 was repeated. And when there was only one group

in a sequence then another sequence was determined repeating step 3.

The calender is still in progress, so a check is made whether the date has the monsoon season or not. If it is the hot and cold dry season repeat steps 1 and 2 till the are repeated untill day of the calendar.

The calibrated model was verified to test its ability to estimate long-term seasonal precipitation patterns. The test was conducted by simulating 100 years of precipitation events. Mean number of precipitation events per seasonal group and mean precipitation amount per event or group were calculated and compared with actual data. A summary of the comparisons are presented in Table 3.

Table 3. Comparison of Precipitation Characteristics Between the Historical 8 Year Record and the Simulated 100 Year Record for the Tinau Watershed.

Month	Mean Monthly Precipitation		Mean Precip. per Event		Mean Number of Events per Month	
	Actual	Simulated	Actual	Simulated	Actual	Simulated
	(mm)		(mm)		(Number)	
JAN	21.2	15.6	9.9	7.5	2.1	2.1
FEB	11.0	21.3	9.7	8.2	1.2	2.5
MAR	18.1	26.6	6.9	7.6	2.7	3.4
APR	33.4	46.5	8.0	7.9	4.3	5.9
MAY	95.5	105.1	9.7	12.3	9.9	8.5
OCT	48.8	58.8	13.4	11.4	2.7	5.1
NOV	4.5	10.8	5.2	7.5	0.9	1.4
DEC	21.9	33.6	17.5	18.1	1.3	1.8
Sub-Total	254.4	317.3			25.1	30.7
Monsoon seasonal precipitation and groups (JUN,JUL,AUG,SEP)	1482.8	1486.7	80.2	82.6	18.5	18.0

Total
Annual rainfall (mm); Actual = 1737.2, Simulated = 1805.0
Annual rainevents (days); Actual = 94.1, Simulated = 97.8

CHAPTER FOUR

THE STREAMFLOW GENERATION MODEL

The U.S.D.A., SCS runoff equation has been successfully used to transform basin precipitation into daily streamflow in a semi-arid areas. This formula evaluates direct runoff, but is unable to simulate baseflow. So in humid and sub-humid watersheds with perennial streams, a soil moisture accounting model is needed to simulate long recession flows in dry season after the wet monsoon. The Tinau watershed lies the in sub-humid zone with an average annual rainfall of 1700 mm. The monsoon and post-monsoon storms contribute perennial flows in the Tinau river. One of the objectives of this study was to develop a methodology which required only readily obtainable information, so it was necessary that the model be able to transform synthesized long-term daily climatic data into a corresponding record of daily streamflow volumes.

The transformation of rainfall to streamflow was accomplished by the use of a determistic hydrologic model. The criteria used in selecting a hydrologic model for this study were: the input requirement for the calibration and operation of the model must be limited to daily precipitation, daily temperature, and daily runoff volumes;

calculated parameters must be minimized; the model must be capable of accurately modeling baseflow recessions; and if possible there should be a precedent for its use.

The Generalized Hydrologic Model (GHM) contained in the Generalized Streamflow Simulation System (GSSS) developed by the Joint Federal-State River Forecast Center in Sacramento, California (Burnash et al. 1973) met the above criteria, and was selected for this study. The GHM is a fitted parameters, conceptual model which uses a system of soil moisture storage and drainage components to simulate perennial streamflow. The conceptual logic of the GHM was designed to approximate the physical processess which occur on a watershed. Burnash et al. (1973, pp.11) describe this hydrologic model in the following manner:

> It (model) is based on a system of percolation, soil-moisture storage, drainage, and evapotranspiration characteristics which are intended to represent the significant hydrologic processes in a rational manner. Each variable included in the model is intended to represent a discrete and understandable characteristic required for effective hydrologic analysis. The definition of model parameters is achieved by establishing a soil-moisture computation which allows the determination of basin streamflow from basin precipitation. Effective moisture storage capacities in the soil profile are estimated not by sampling of the soil profile, but by inference from the rainfall and discharge records.

The structure and basic components of the GSSS runoff model are presented in Figures 11 and 12. The model operates by routing basin precipitation into a series of cascading soil

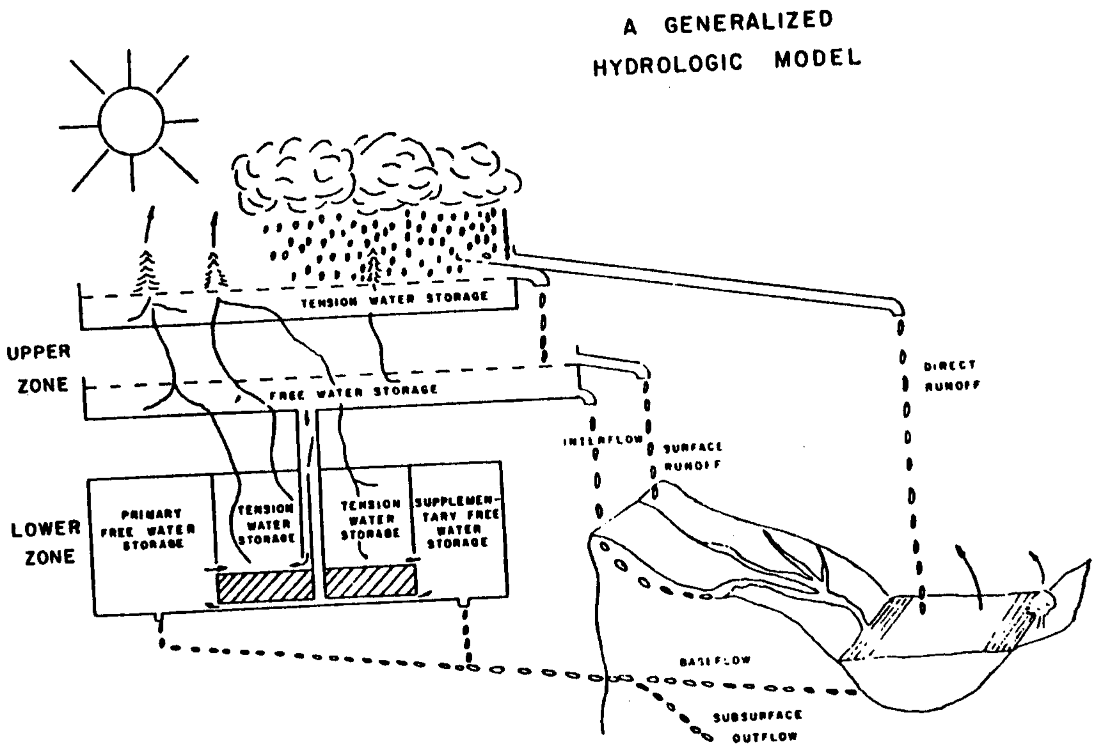


Figure 11. Conceptual Structure of the Hydrologic Cycle Used in the Generalized Streamflow Simulation System (From Burnash et al., 1973).

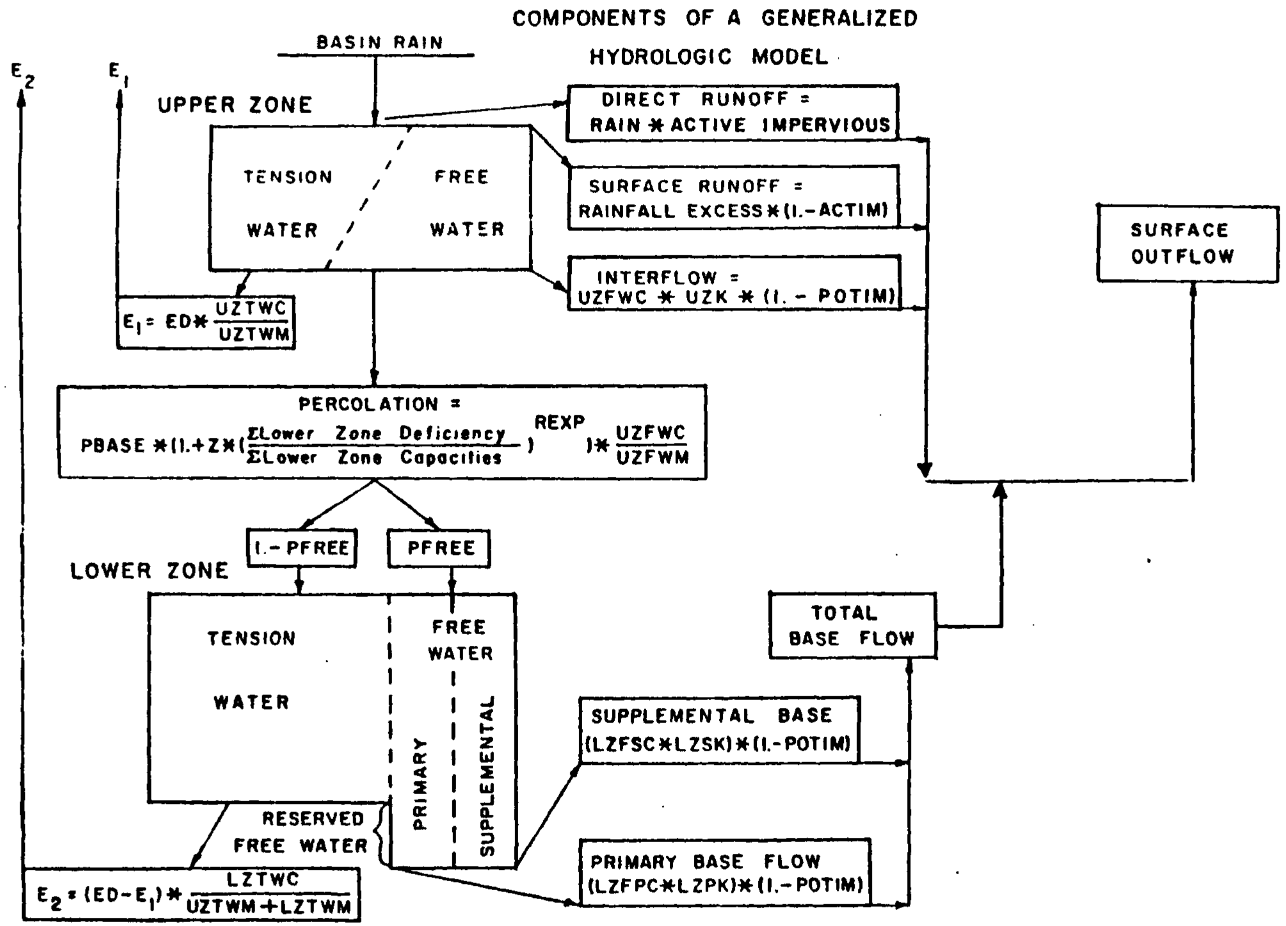


Figure 12. Principal Components of the Generalized Streamflow Simulation System (From Burnash et al., 1973).

moisture compartments, and slowly drains the soil water to form interflow and baseflow. The drainage depends upon the maximum soil water storage capacity of these compartments and the soil water content at present at them.

Rainfall encounters both permeable and impermeable surface areas. Impermeable areas, such as lakes and streams, transform all rainfall into runoff, while permeable areas transform direct runoff only when rainfall exceeds infiltration capacities. The GSSS allocates permeable areas into two layers upper and lower zone. Each zone is composed of tension water and free water storages. Upper zone tension represents the precipitation volume required under dry conditions to satisfy interception requirements and to provide sufficient moisture to the upper soil mantle for horizontal drainage and to begin deep percolation. When the upper zone tension volume is filled to its capacity, the excess precipitation is routed into upper zone free water storage. In this storage, horizontal interflow and vertical percolation to the lower zone originate. Percolation rate is controlled by the upper zone free water contents and capacities of lower zone moisture volumes. Interflow occurs only when the precipitation exceeds the maximum percolation rate. When the maximum rates of both interflow and percolation are exceeded and upper zone storage are full, surface runoff results.

Water percolated from upper zone reaches to the lower zone, where it is divided among three storages: tension, primary free, and supplementary free. Lower zone tension water capacities associated with suction forces absorb most of the percolating water. The percolated water that is not absorbed as lower zone tension water is distributed to primary and supplementary free water storages in response to their relative capacities. The horizontal output from the lower zone free water storages constitutes the baseflow. The differential release rate of the free water zones enable the modeling of a wide variety of streamflow recession curves.

The GSSS model expresses the watershed as a set of storages of determinable capacities, which hold water temporarily and which gradually recede as their contents are diminished by vertical percolation, evapotranspiration and/or lateral drainage. The important parameters in the model are evaluated by analyzing historical precipitation and simultaneous streamflow records. Burnash et al.(1973) utilized twenty four parameters in operating this model, and presented initial parameters estimation method. The critical parameters of the model are defined as follows:

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

Soil Moisture Drainage Rates

UZK, Lateral drainage rate from the upper zone expressed as a fraction of the contents per day

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, Exponant which controls change in the percolation rate

There are forteen other parameters in the GSSS model; they are all less sensitive as compared to parameters mentioned above or self-adjusting. A list of all these parameters are presented on subroutine DOVAN (see Appendix A).

Initial Parameter Estimation

The critical parameters, such as drainage rates and water storage capacities, were estimated for the GSSS runoff model operation. Examples of the procedures of estimation of soil moisture drainage rates LZPK and LZSK, and upper zone tension water content UZTWC are explained below.

The lower limits of soil moisture drainage parameters LZSK and LZPK were estimated from historical hydrographs analysis. These parameters were used to calibrate the simulated streamflow recession curves. The assumption made in calibration was that long-term recession curves can be modeled as the sum of drainage from two lower zone soil moisture, such that:

$$\text{Baseflow} = LZPK*LZFPC + LZSK*LZFSC \qquad (1)$$

where LZFPC and LZFSC are the current soil moisture contents of the soil moisture storage compartments, and LZPK and LZSK are as defined above. The moisture contents of the soil moisture storage compartments are updated daily.

The primary baseflow recession charactertics were estimated by a simple exponential dacay function:

$$QP_t = QP_o * K^t \qquad (2)$$

where, K is the recession coefficient of primary baseflow for time unit used, usually daily.

t is the number of time units in days.

QP_o is a discharge when recession is occuring at primary rate.

QP_o is the discharge t time units later.

Solving for decay factor K,

$$K = (QP_t/QP_o)^{1/t} \qquad (3)$$

The lower zone primary moisture drainage rate is simply estimated as follows:

$$LZPK=(1-K) \tag{4}$$

$$\text{and, } LZFPM = QP_{max}/LZPK \tag{5}$$

where LZPK and LZFPM are lower zone primary soil moisture drainage rate and capacity, and QP_{max} is the maximum primary baseflow that can inferred from hydrograph analysis.

An initial estimate of these parameters was derived by substituting actual runoff data for QP_t and QP_o in the equation (3) and then using the equation (4) and (5). These drainage rate parameters represent maximum baseflow capacity for the watershed, thus, the historical recession curves chosen for this analysis are those from the largest monsoon flow events.

In estimating these parameters, five monsoon rainstorm flow recessions (1978-1982) were selected. Each was plotted on separate log-normal paper and fit with three straight lines representing early, middle, and late streamflow responses. These linear recessions were combined to form composite recession curves. The composite recessions are presented in Figure 13. The early recession represents streamflow from the upper zone soil moisture storage and that from lower zone compartments, the middle section represents streamflow from two lower zone compartments, and

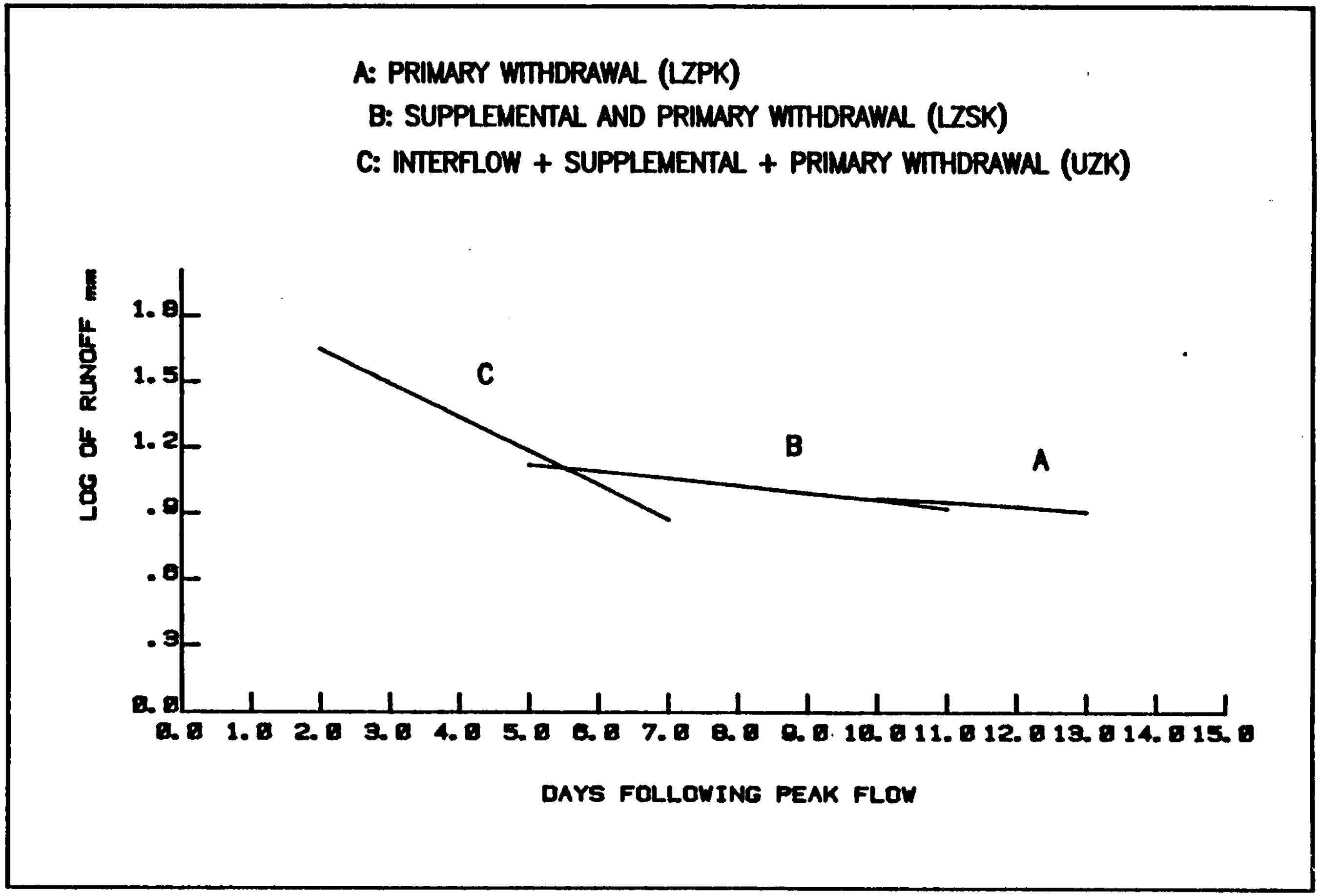


Figure 13. Composite Recession Curves Developed from Five Monsoon Rainstorm Recessions at the Tinau River, Butwal.

late recession curve represents streamflow from the lower zone primary storage.

An initial value of 0.03 per day was estimated for LZPK, and 363.33 mm for LZFPM. These values were later adjusted in the final model calibration.

The supplemental baseflow characteristics were evaluated as follows (Burnash et al.,1973):

$$Ks = (Qs_1/QS_{max})^{1/t} \tag{6}$$

where, Ks is rate of change of supplemental flow

Qs_1 is lower zone supplemental discharge arbitrarily used at 2/3 time from peak to QP_o, and

QS_{max} is lower zone supplemental discharge at time zero

These supplemental rates were estimated by extending the late recessoion curve backward underneath the middle curve Figure 14. Drainage rates were calculated as:

$$LZSK = (1-Ks) \tag{7}$$

$$\text{and, } LZFSM = QS_{max}/LZSK \tag{8}$$

where, LZSK is rate of change of supplemental storage, and

LZFSM is maximum apparent supplemental storage.

Values of QS_1 and QS_{max} from the middle recession curve were substituted in the equations (6) and (7) to evaluate an initial estimate of LZSK = 0.158 and LZFSM = 49.37 mm, which were later adjusted in the final calibration.

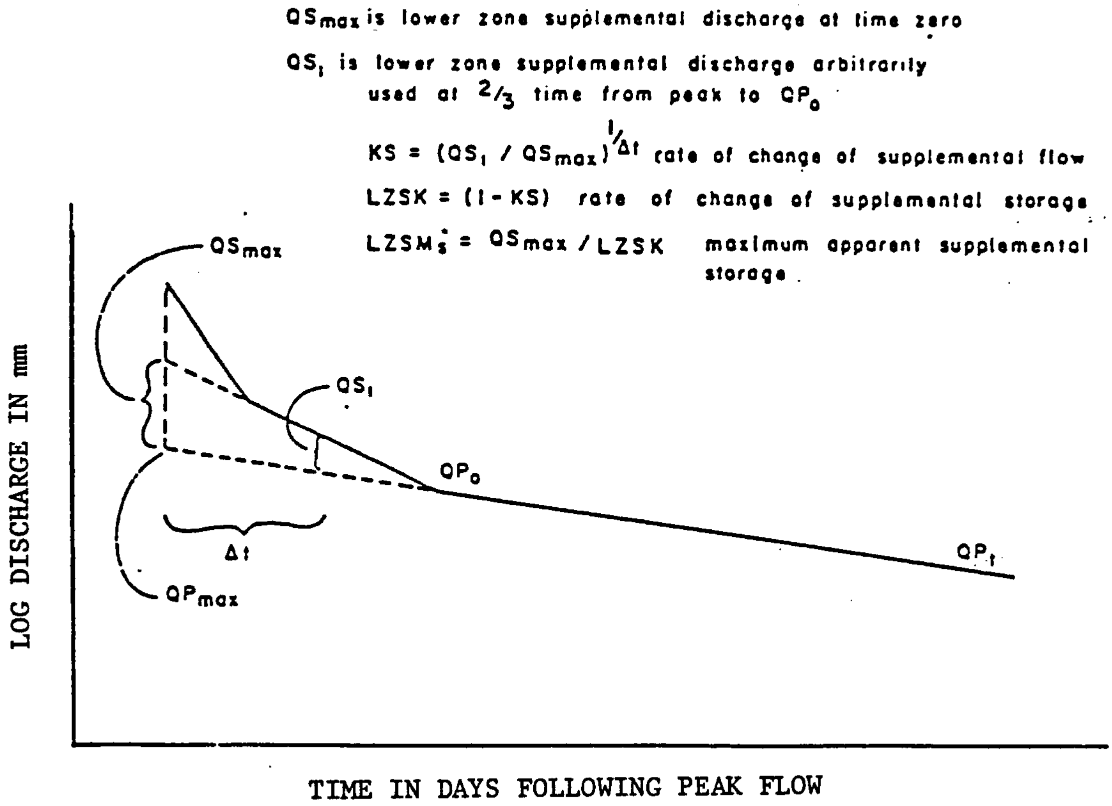


Figure 14. Initial Approximate of Lower Zone Supplemental Water Storage and Depletion Coefficient (From Burnash et al., 1973).

The upper zone soil moisture storage capacity parameter UZTWM is critical for determining both the timing of initial monsoon runoff and the volume of peak one-day flows. The UZTWM simulates upper soil layer which absorbs rainfall until its moisture storage capacity is filled, then spills the excess as surface runoff. Every day, a certain amount of this moisture storage volume is lost to evapotranspiration, percolation, and interflow.

Burnash et al. (1973) have described the initial estimation of UZTWM. For this study a portion of the historical record, following a dry period when evapotranspiration had depleted the upper soil moisture was used to estimate UZTWM. The UZTWM is that volume of rainfall which is retained before the runoff includes any increase beyond that which can be produced by rain on the impervious fraction. Three sequences of extended dry periods followed by several consecutive days of heavy rain were analyzed, one is as follows:

Day	Basin rain (mm)	Observed Discharge (mm)
Jun 4, 1982	0.0	0.99
Jun 5, 1982	34.9	1.04 *
Jun 6, 1982	24.9	1.04 *
Jun 7, 1982	7.0	1.04 *
Jun 8, 1982	0.0	3.87 **

* Direct runoff ** Surface runoff

The sudden flow on June 8, 1982; indicates that soil moisture storage was full and surface runoff exceeded the direct runoff. The UZTWM was estimated as the amount of rainfall before surface runoff begins.

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

0.00 + 34.9 + 24.9 + 7.0 = 66.8 mm

This value of UZTWM was an initial approximation. In another sequence, it was 76.00 mm which was the minimum estimate, because it was not known what rainfall amount on the day after direct runoff should be added to the minimum estimate.

The remaining soil moisture parameters in the GSSS runoff model are estimated by trial and error optimization during successive calibration runs of the model. Burnas et al. (1973) gave starting values and ranges for trial and error parameters estimation. An optimization process was used for prelimilary fitting to historical record in this study.

Evapotranspiration Estimates

The GSSS runoff model requires a daily estimate of potential evapotranspiration (PET) as an input. Evapotranspiration can be the dominant use of the moisture supplied by precipitation , and since it is one of the most difficult process to evaluate in hydrologic analysis, evapotranspiration is frequently a principal source of error in streamflow simulation. Two year (1984-1985) of incomplete pan evaporation data were available. Because of incompleteness and the difficulty in transforming data from the pan site to the the study site the data could not be used. Therefore the Blaney-Criddle method was used to estimate monthly evapotranspiration demand.

Daily maximum and minimum temperature at Tansen were available from year 1980-1984, and monthly maximum and minimum temperature at Butwal from 1978-1984. A consumptive use estimation equation used in this study required these data. The Blaney-Criddle equation was developed to estimate consumptive use in South-Western United States. It estimates mean monthly PET from mean monthly temperatures, the latitude of the site, and a crop factor (Dunne and Leopold, 1978):

$$PET = (0.142\ T_a + 1.095) * (T_a + 17.8) * K * D \qquad (9)$$

where, T_a is mean air temperature for the month

PET is mean monthly potential evapotranspiration

D is monthly fraction of annual hours of daylight

K is a crop fractor chosen from a table of suggested values.

In equation (9), D was evaluated from a table for the latitude of Tansen, and a weighted K was evaluated for each month with respect to land-use and ground cover in the watershed. Mean temperatures were calculated from the temperature data from Tansen and Butwal. Yearly pan evaporation recorded at Tansen is 775 mm, and that at Butwal is 1708 mm. These values were used to verify the Blaney-Criddle method. The results of the comparison are presented in Table 4.

The GSSS model suggests that a weighting factor for monthly PET rates be employed to account for seasonal plant growth characteristics. The monthly weighing factors chosen for this study were based on the crop rotation pattern and the vegatative cover in the watershed. The GSSS model uses the daily fraction of adjusted monthly PET, and daily loss calculated as the product of the adjusted PET values and a soil moisture volume to soil moisture capacity ratio.

Hydrologic Model Calibration and Testing

The GSSS model was calibrated by a series of trial simulation runs, in which the model parameters were adjusted until the simulated daily runoff sequence approached the actual daily runoff record (McDowell, 1985). The actual daily precipitation data were needed as input for each simulation. Simultaneous daily runoff data were used to validate the model calibration.

A year sequence of climatological and runoff data were used for model calibration. Six years (1977-1982) of daily streamflows from the Tinau river at Butwal were used for calibration. The actual and simulated streamflow records

Table 4. Summary of Potential Evapotranspiration Estimates for the Tinau Watershed, Palpa.

Month	Blaney-Criddle Estimate (mm)	Adjusted factor for GSSS	Adjusted monthly PET (mm)	Adjusted Daily PET fraction (mm)
January	55.8	0.60	33.5	1.1
February	70.0	0.60	42.0	1.5
March	125.0	0.70	87.5	2.8
April	135.7	0.70	95.0	3.2
May	139.6	0.80	111.7	3.6
June	96.0	0.85	81.6	2.7
July	93.0	0.85	79.1	2.6
August	83.7	0.85	71.1	2.3
September	75.0	0.75	56.3	1.9
October	71.3	0.70	49.9	1.6
November	60.0	0.70	42.0	1.4
December	49.6	0.60	29.8	1.0
Total	1054.7 mm		779.5 mm	

displays on a HP-1000 computer and HP-7221B graphic 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.

The water years selected for the final model calibration were 1980-1981 and 1981-1982. Two criteria used in calibration of the model were: model results should match recorded data; and the estimates of parameter values should be consistent with watershed characteristics. For the calibration years, rainfall was found to be uniformally distributed over the watershed as indicated by a close correlation between total rainfall recorded in Butwal and in Tansen.

An interactive version of the GSSS runoff model was written and modified to facilitate rapid parameter adjustment. Critical parameters were adjusted by trial and error, using the initial parameter values described in the preceeding sections as a first trial. Parameters were adjusted using the conceptual structure and function of the GSSS model. For example, if the simulated streamflow was high, the soil moisture storage parameters were increased, and if it was low the storage parameters were reduced. If a simulated streamflow sequence gave low peak flows and exagerated base flows, percolation and/or lower zone soil moisture storage the 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 base flow. Burnash et al. (1973) described the parameter calibration and its effect on simulated streamflow. Definations and the final estimated values for the major parameters of runoff model are presented in Appendix B.

The calibrated runoff simulation model was tested on a continuous and simultaneous six year sequence (1977-1982). It was considered important to test the model on a continuous multi-year data sequence to check for long-term trending errors. But, due to unavilability of streamflow and precipitation data, a long-term calibration could not be made. The performance of the calibrated runoff model is illustrated by the comparison made in Figure 15.

The calibrated streamflow simulation model was used in the main watershed model TINAU. The listing of the interactive version of the GSSS runoff model, used for calibration of the model with a one year data set (starting from June to May) is presented in Appendix A, as a subroutine DOVAN.

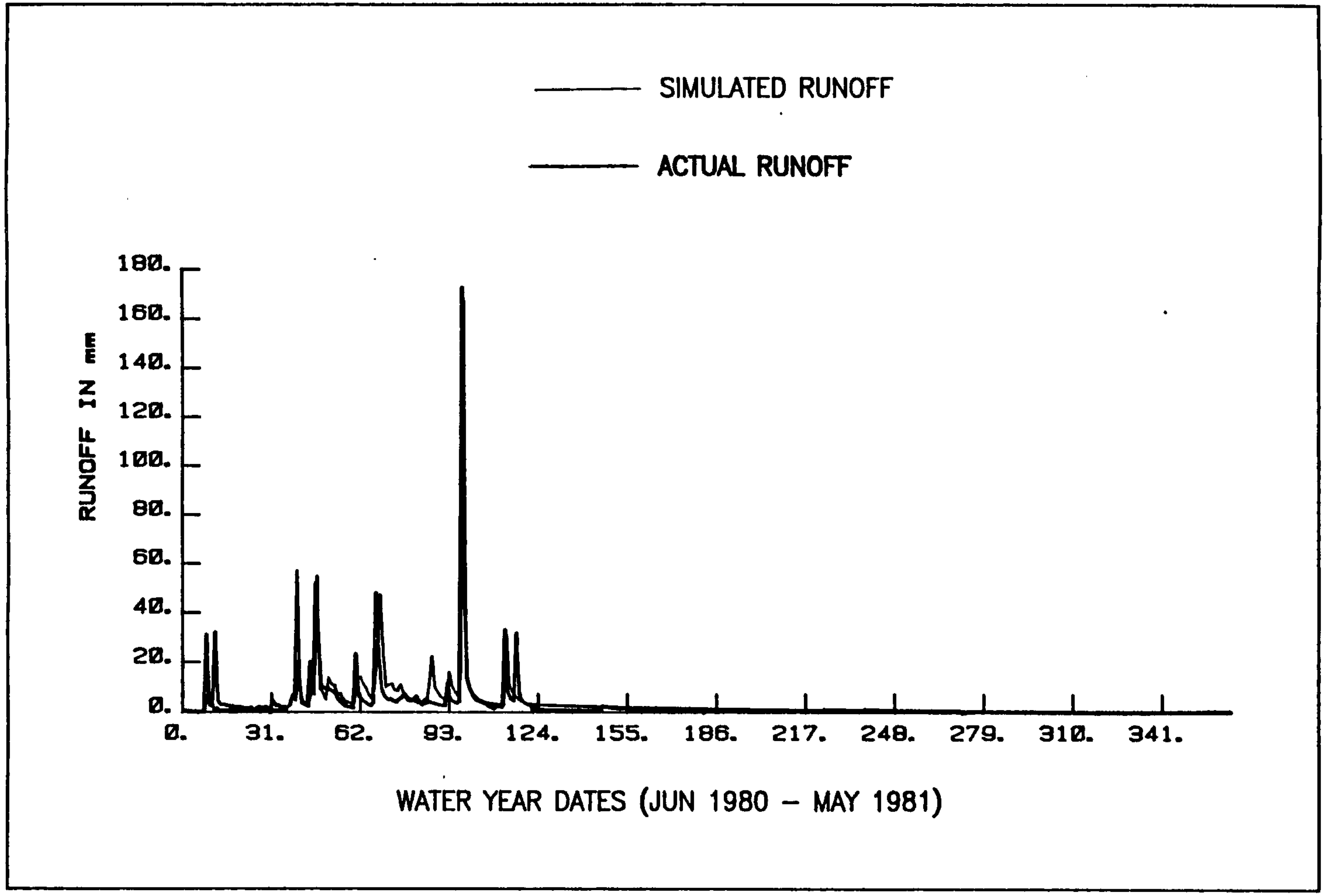


Figure 15. Comparison of Simulated and Actual Runoff at the Tinau River, Butwal for the Water Year 1980-1981.

CHAPTER FIVE

THE WATERSHED MODEL

All the component models of precipitation, streamflow genaration described previously were linked to form a watershed model TINAU. TINAU is driven by the component model for stochastic precipitation simulation. The deterministic runoff model transformed this simulated rainfall data into daily streamflow. The TINAU performs a daily water budget and calculates the monthly and yearly runoff output statistics. It also computes consecutive days of low flow. A complete listing of the FORTRAN IV program for the TINAU is given in Appendix A. The TINAU was run for 100 years. Sample output of the monthly runoff frequencies, yearly and seasonal runoff frequencies, storm daily high and low discharge frequencies, and frequencies of consecutive days of low flow are given in Appendix C.

A flow chart of the TINAU program is illustrated in Figure 16. The model program is set up in discrete steps. The stochastic components of the precipitation model are independent of each other, but each step in the deterministic streamflow generation model is dependent upon the previous step. Each step in the deterministic model is driven by the stochastic model.

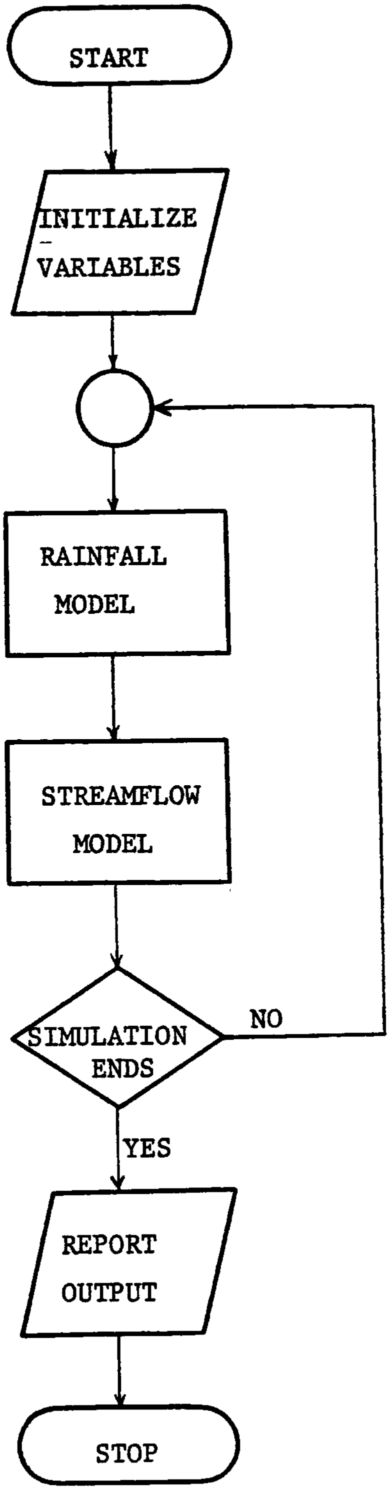


Figure 16. Flow Chart of the Watershed Model TINAU.

The TINAU program operates by simulating one year at a time, then storing each year's results for subsequent statistical analysis. The stochastic precipitation sub-model PANI is operated begining with the first day of the Julian calendar (Jan 1). PANI was calibrated, run, and verified using Julian dates. PANI generates input variables, dry days between rainfall events and rainfall amount for the event according to a random process, which is guided by the statistics and the distributions derived from the actual data. PANI has capability to simulate a time series of rainfall data, and assign zero rain for each rainless dry day. Since, the deterministic streamflow generation model operates on the water year (June-May), the synthetic rainfall data was rearranged accordingly.

The deterministic streamflow genaration model DOVAN uses mathematical equations to transform the daily synthetic rainfall data in runoff values. DOVAN accounts for soil moisture and evaporation, using daily evapotranspiration demand and soil water parameter values in a physically consistent processes. A statistical update is made for each day to determine the frequency of runoff amounts. The mean and standard deviation were calculated from the these frequencies on a monthly, seasonal and annual bases. The frequency of maximum and minimum flows were used to evaluate annual daily maximum and minimum events.

CHAPTER SIX

RESULT AND DISCUSSION

To evaluate the hydrologic performance of the Tinau river at Butwal, the watershed model TINAU was run for a 100 year similation period. The results presented here are concerned with total annual, monthly and seasonal discharge, maximum daily high and low discharges, and consecutive days of low flow. These quantities were selected for evaluation because of their relevence to watershed management and water utilization in the valleys upstream, and to water yield and storm flows downstream.

Monthly Discharge

The monthly discharge of the Tinau river is influenced by the monsoon season. The probabilities of amount and timing of high and low discharge determine the reliability of water supplies during the non-monsoon season and the flood risks that may involved during the monsoon months. A knowledge of the probabilities can help in the planning of watershed management activities, conserving water when it is plentiful and that release water when it is in short supply.

The simulated Monthly discharge of the Tinau river at Butwal for the non-monsoon season is presented in Table 5. The values in the table are the occurrence probability of monthly flow events equal to or less than the particular values. The distribution curves developed indicate that minimums flow of 0.15 mm or less could occur in January, April and May and that the probability of flows less than 1.5 mm is low in the post monsoon month of October. The simulation also indicated that 50 percent of the time the stream flow expected is less than 1.7 mm for all non-monsoon months, except October. A cumulative probability frequency plot for March, presented in Figure 17, and indicates that 90 percent of the time the stream flow in March is equal to or less than 0.71 mm. Results of simulated monthly discharge frequencies, means, and standard deviations are listed in Appendix C.

Annual and Seasonal Discharge

The simulated monsoon and annual discharges at Butwal varied over a wide range. The total monsoon discharge for the driest year of simulation was 120 mm, and for the wettest year it was 2,150 mm. The probability frequency analysis indicated that 90 percent of the time during the monsoon season the flow was equal to or less than 1,350 mm and 50 percent of the time equal to or less than 740 mm. The occurrence of flows equal to or less than 190 mm was only 5

Table 5. Monthly Discharge Probability of the Tinau River, Butwal

	Monthly Flow Frequency Probability - percent -									
Month	10	20	30	40	50	60	70	80	90	99
JANUARY	0.52	0.63	0.70	0.78	0.85	0.92	0.99	1.08	1.20	1.65
FEBRUARY	0.42	0.46	0.51	0.56	0.61	0.68	0.75	0.80	0.97	1.60
MARCH	0.25	0.30	0.37	0.42	0.46	0.50	0.55	0.59	0.71	1.00
APRIL	0.21	0.25	0.27	0.30	0.33	0.36	0.39	0.44	0.49	0.70
MAY	0.15	0.17	0.21	0.23	0.25	0.27	0.33	0.43	0.53	2.50
OCTOBER	1.50	1.78	2.03	2.25	2.50	2.75	3.00	3.70	5.00	22.00
NOVEMBER	1.08	1.32	1.44	1.58	1.71	1.84	1.96	2.13	2.34	3.25
DECEMBER	0.77	0.90	1.01	1.11	1.20	1.30	1.39	1.51	1.67	3.00

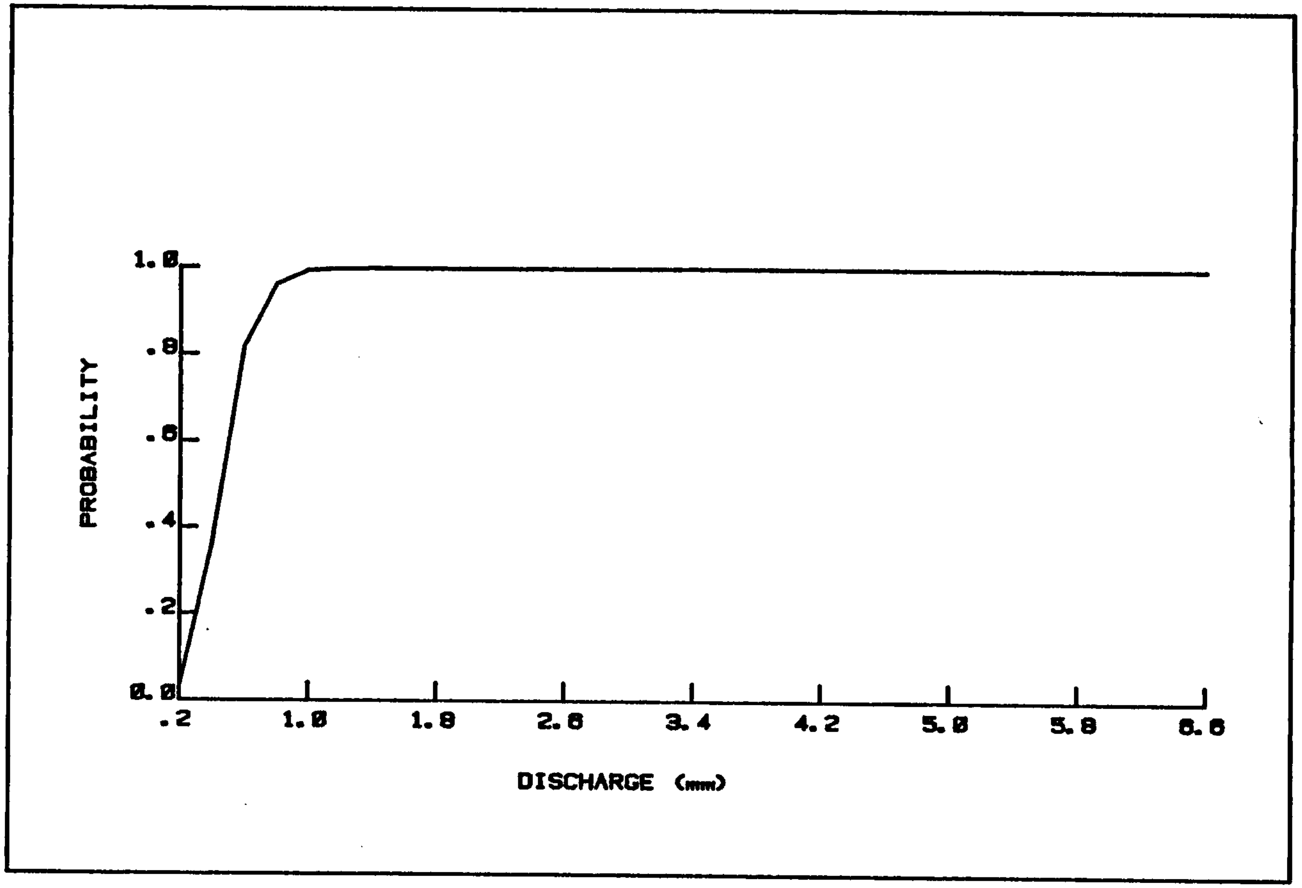


Figure 17. Probability of Total Discharge of the Tinau River for March.

percent. The simulated total annual discharge was 165 mm for the driest year and for the wettest year 2,375 mm. The annual flows were equal to or less than 1,660 mm 90 percent of the time and 50 percent of the time equal to or less than 1,040 mm. The probability of an annual discharge of 360 mm or less was only 5 percent. A summary of total seasonal and annual discharge occurance probability is presented in Table 6, and the cumulative probability frequencies are illustrated in Figure 18 and 19.

Maximum and Minimum Discharge

The amount and timing of peak discharge are affected by the flow during the monsoon season. The probability of peak flow can be used to determine the design and stability of flood control structures in the plains, the safety of water supply for human and agriculture use, and in problem of power generation. A knowledge of low flow probabilities aids in optimizing the operation of power plant, water supply and irrigation.

Annual maximum discharge and minimum discharge were evaluated for the 100 simulation period. The maximum discharge noted was 4,440 m^3/s. The actual highest flows recorded at Butwal were 3,300 m^3/s in 1970, and 3,500 m^3/s in 1981. Simulated results indicated that 50 percent of the time maximum flows should be equal to or less than 840 m^3/s. The probability of exceeding 2040 m^3/s was found to be only 10

Table 6. Discharge and Low Flow Days Probability of the Tinau River, Butwal.

	Probability of Occurrence - percent -									
	10	20	30	40	50	60	70	80	90	99
	Total Discharge Equal to or Less Than - mm -									
Monsoon (JUN-SEP)	300	440	560	670	740	890	1020	1170	1350	1940
Total Annual	475	710	830	950	1040	1180	1305	1490	1660	2310
	Daily Storm Flow Equal to or Less Than - cubic meter per sec -									
Annual Maximum Flow	145	360	510	645	840	1080	1270	1560	2040	4200
Annual Minimum Flow	0.91	1.07	1.18	1.30	1.38	1.50	1.64	1.78	1.88	2.31
	Consecutive Days of Flows Less Than 1.5 cu. m. per sec.									
	2.6	4.0	8.3	11.5	16.5	22.0	25.7	33.7	51.5	120

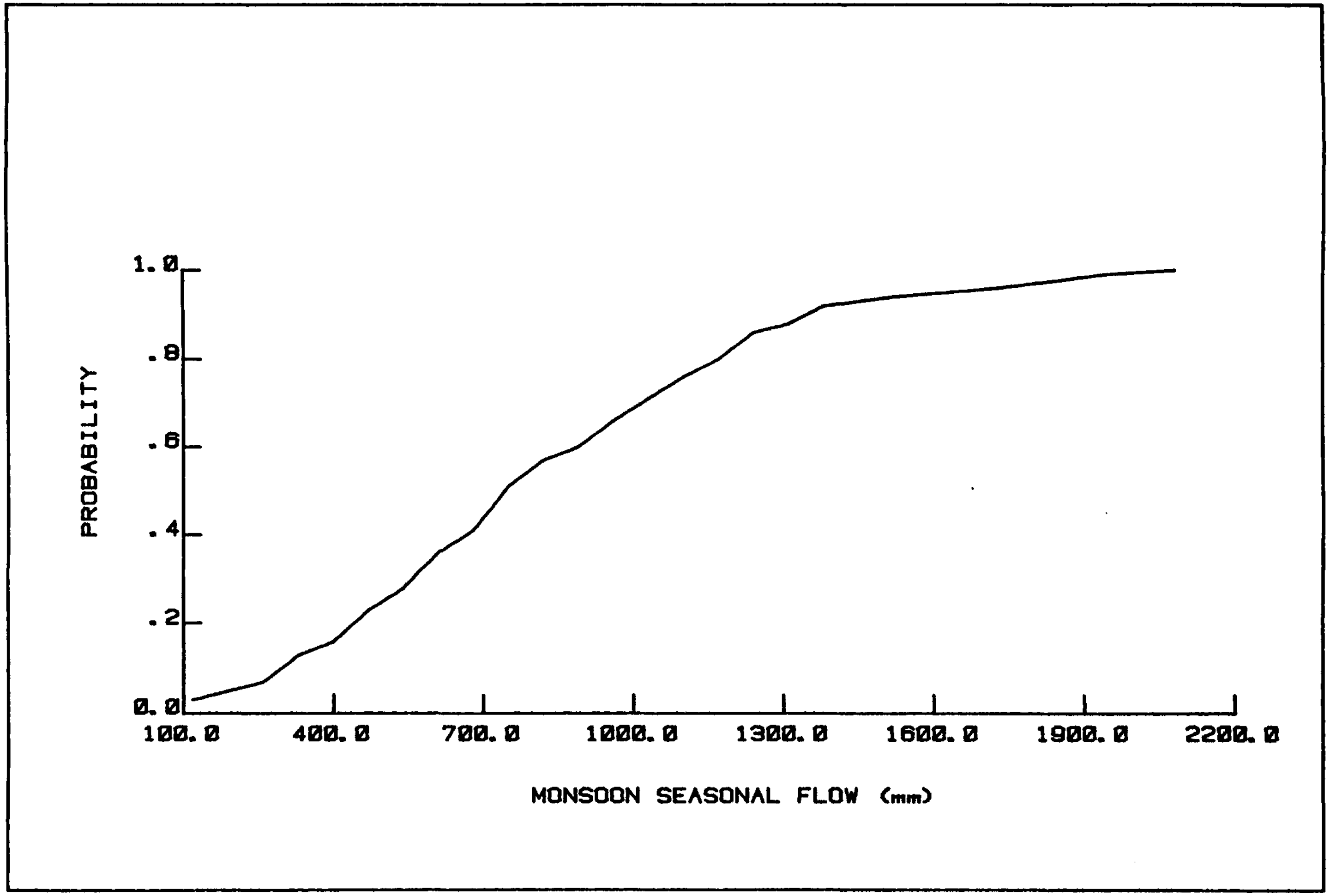


Figure 18. Probability of Monsoon Seasonal Discharge from the Tinau Watershed, Palpa.

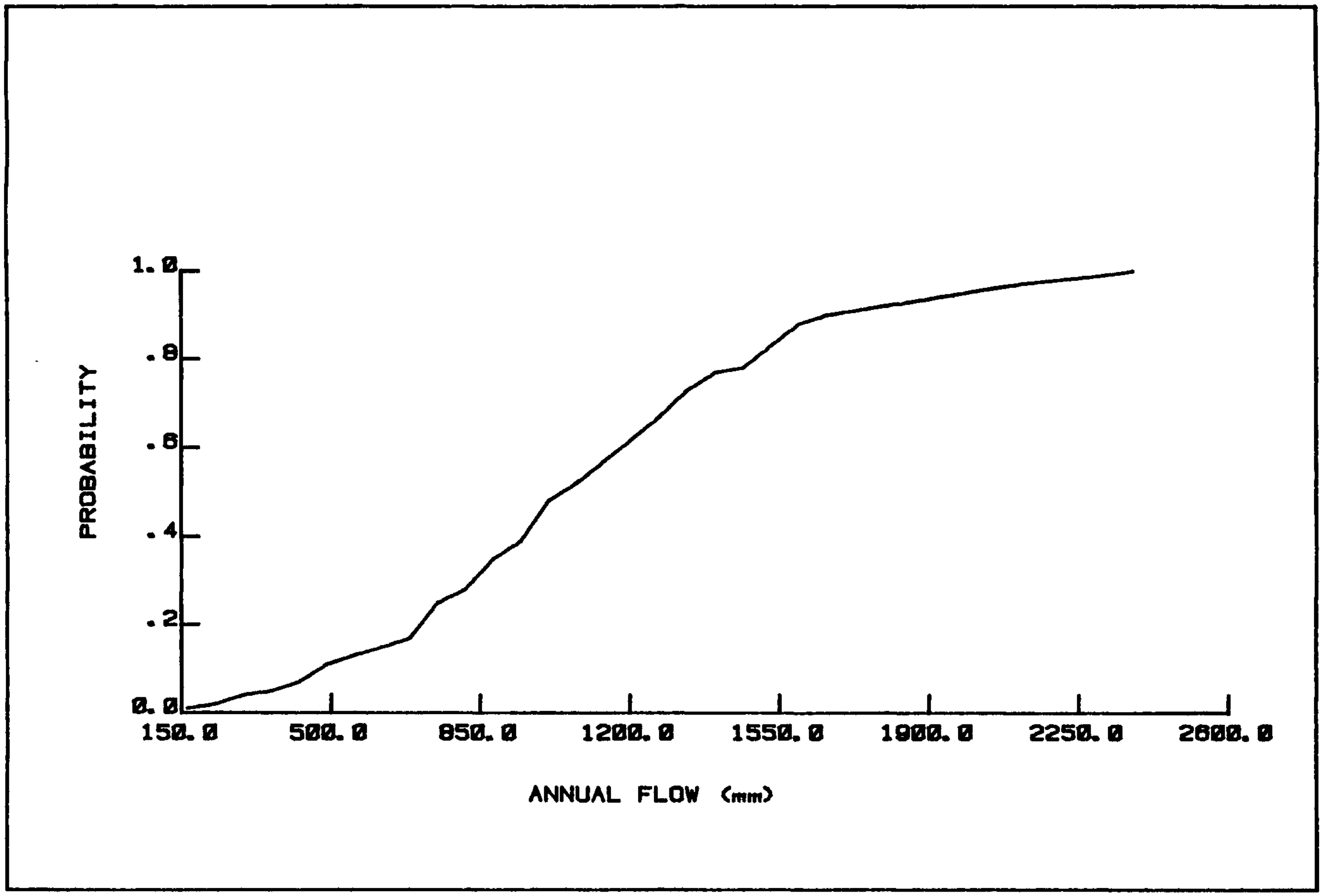


Figure 19. Probability of Annual Discharge from the Tinau Watershed, Palpa.

percent. A probable maximum discharge of only 120 m^3/s occurred in the driest year of the simulation. Cumulative frequency curves of annual maximum discharge are given in Figure 20. Discharges equal to or less than 2.5 m^3/s were considered to be low flows. Low flow occurred mainly in late March, April, May, and early June. The probable minimum flow noted for the simulation period was 0.253 m^3/sec, the actual low flow of the historical record was 0.94 m^3/s in 1981.

The simulation indicated that 90 percent of the time the annual minimum flow is less than 1.88 m^3/s. A cumulative probability frequency of the annual low flows is illustrated in Figure 21. The probabilities of occurrence of annual maximum and mimimum flows equal to or less than a given amount are presented in Table 6. A summary of simulation results of high and low discharges are listed in Appendix C.

The peak of a storm flow could be much higher than the maximum daily flow as analyzed here. Thus, flood control devices and other water utilization structures should be designed and constructed accordingly. An alternative safe water supply scheme may be designed to share low flow with power plant and irrigation in the dry period.

Consecutive Days of Low Flow

Consecutive days of low flow are assumed to be those periods when the daily stream discharge is less than 1.5 m^3/s. Although a constant flow of 1.5 m^3/s is satisfactory

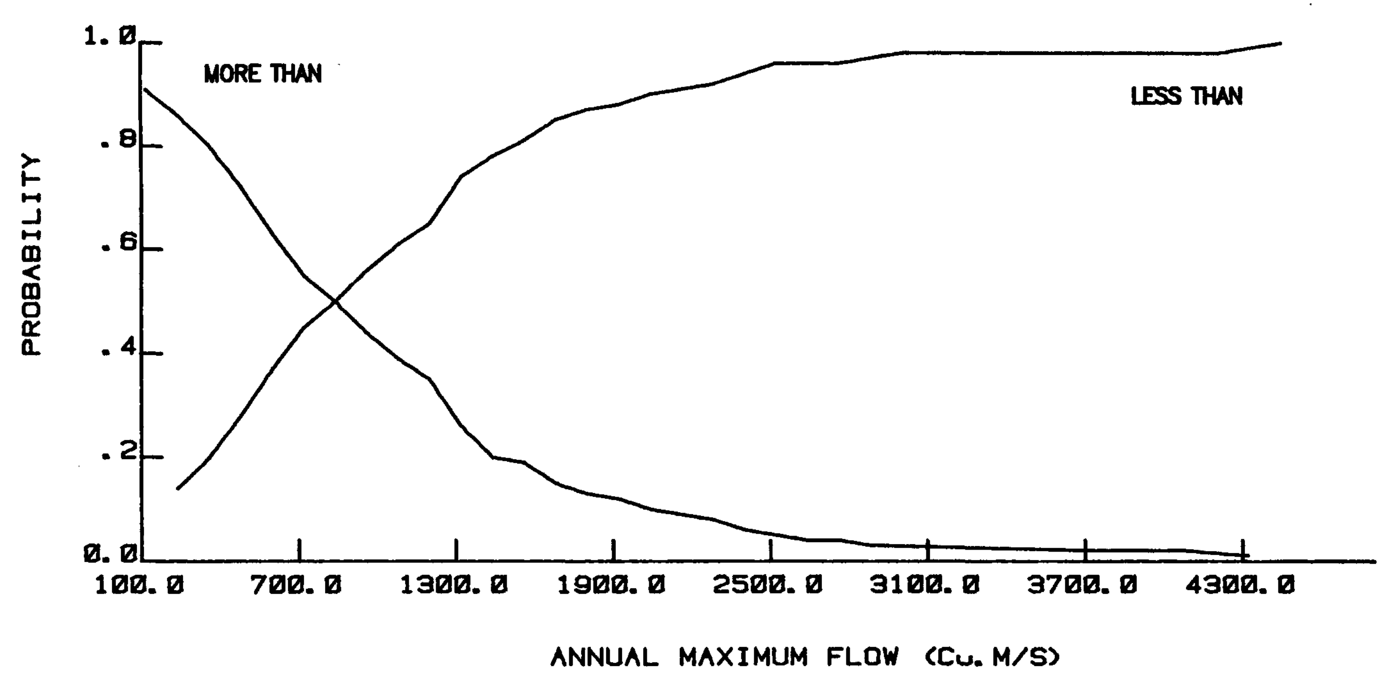


Figure 20. Probability of Annual Maximum Flows of the Tinau River, Butwal

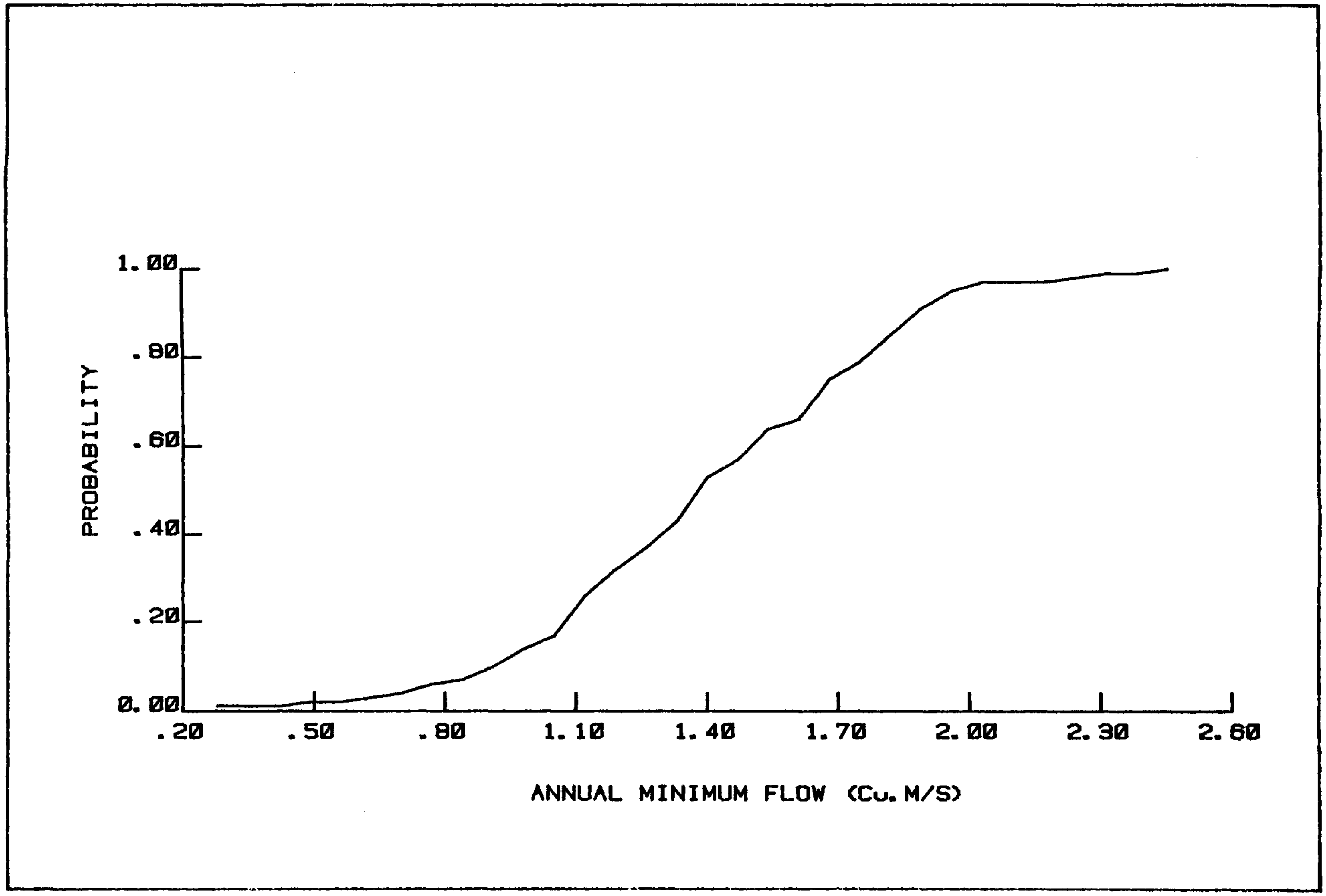


Figure 21. Probability of Annual Minimum Flows of the Tinau River, Butwal.

to maintain power production downstream at Butwal, flows less than this could affect the operation of the hydropower station, irrigation schedules and water supplies in the plains. A summary of probable consecutive days of low flow is given in Table 6 and the cumulative probability frequency is illustrated in Figure 22.

Simulation results showed that in 100 years, 1930 days have streamflow less than 1.5 m^3/s, 5.3 percent of the time. The mean consecutive days of low flow was 24.42 with a maximum of 157 days for the 100 year simulation. It was noted that 90 percent of the time the duration of low flows was 51 days or less. Most of the low flow occured in late March, April, May and in early June. However, in relatively dry simulation year low flow began in mid January and February, and in years when monsoon started late, low flows began in May and extended untill July. The actual flow data showed that if rainfall were high in the post-monsoon months flows below 2.5 m^3/s were produced only from late May untill late summer when the monsoon came early and low flow began in early December.

Application of the Model

The watershed model TINAU can be applied to a variety of problems in managing the Tinau watershed, Palpa. The event-based approach presented in the model is a hydrologic tool to assess storm discharge and sediment yield from the

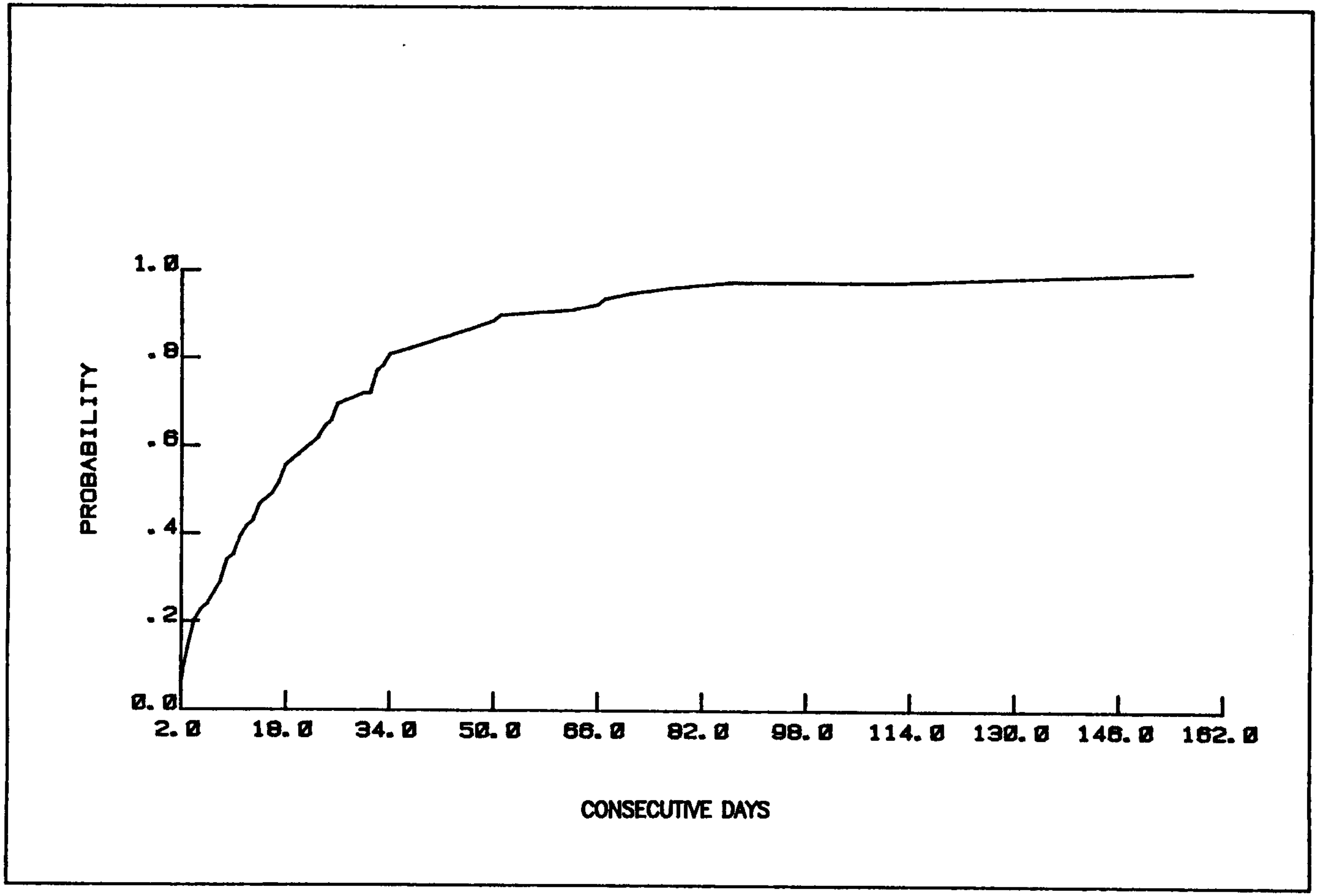


Figure 22. Probability of Consecutive Days of Low Flows of the Tinau River, Butwal.

watershed. Watershed management and water utilization activities in the three main sub-catchments Jhumsa, Dovan and Madi are critical questions. The TINAU model can be operated in these three subcatchments separetely to evaluate water and sediment yield, extreme events, and consecutive days of low flow. The model was designed to operate in snow free area and may be used in the various activities listed below:

a) Flood control activities: The Tinau river creates flood damages in the Butwal area. The maximum daily discharge from the model output can be used to design flood control structures. The model can also be used as a tool to determine risks in flood forecasting and damage assessment process.

b) Sediment yield: The model generates daily runoff from the watershed. Due to unavailability of rainfall duration information, the model was not designed to evaluate instantaneous peak discharge. If adequate rainfall data were available, the modified universal soil loss equation (Williams, 1975), which uses storm discharge and peak flow variables to estimates storm sediment yield, could be applied. Information on rainfall duration could be used to evaluate peak flows, and watershed characteristics applied to evaluate other parameters required for sediment yiel estimation. It is possible to link a sediment yield sub-model with the TINAU to assess sediment yield from the watershed. This information could be used to give land management practices recommendations toward minimizing soil loss from the watershed.

c) Water yield: The annual, seasonal, and monthly water yield under present land use practices are discussed above. A monthly assessment of water yield can be applied in planning, design, and operation of land treatment, vegetation management, and water utilization practices. The precipitation model could also be coupled with an irrigation model to obtain optimum scheduling of irrigation water for long-term scheduling. Coupled with a drainage model an economic and efficient drainage system could be designed for operation in the Madi plain.

d) Extreme events: The model permits estimates of extreme events and extreme sequences which are not yet recorded in the actual streamflow data. The model provides sequences of extremely low flows, which would help in designing, and planning surface irrigation system in the Butwal area, as well as operation of the hydropower plant in Butwal.

e) Small water impounding structures: One application of the model could in designing regional stock ponds. The model can be regionalized for any part of the watershed. Pond and spillway could be designed to utilize maximum flows and conserve water for dry periods.

CHAPTER SEVEN

SUMMARY AND CONCLUSION

This study presents a methodology for evaluating the hydrologic performance of small watersheds in Nepal. The methodology was intended to be used by decision makers for watershed management practices for both upstream and downstream benefits. The most practical use of the methodology could be in estimating erosion lossess, water management and utilization. The model developed has particular application to the Madi, Jhumsa and Dovan valleys, and flood control measures in the Butwal area.

The methodology is in the form of a coupled stochastic and deterministic computer simulation model called TINAU. The procedure followed in the model envolves:

(1) the use of the stochastic precipitation model to simulate synthetic time series of rainfall data;

(2) the use of the deterministic hydrologic model to transform the synthetic rainfall record to a long-term streamflow records; and

(3) the use of a watershed model to evaluate the hydrologic performance.

A coupled stochastic and deterministic model was utilized in this study, because stochastic simulation creates a time series of synthetic rain fall data and allows one to view an ensemble of possible regionalization of precipitationrunoff regimes at a given site. A model that utilizes only historical data provides an unique and limited set of results. The stochastically generated time series of rainfall record include a wide spectrum of amounts and sequential patterns resulting in the probabilistic distribution range of streamflow responses.

In this study, the objective was to develop a methodology that is generally applicable, uses readily available data and operates in a simple but physically consistent manner. The TINAU model only requires daily precipitation, temperature, evaporation, and streamflow data. Data used to calibrate the parameters required by the model were obtained from the Tansen and Butwal stations.

The stochastic precipitation sub-model, which drives the watershed model, involved two main assumptions: that rainfall patterns in the monsoon season (JUN-SEP) occur in sequences; and independent thunderstorms occur in the winter and summer months. The random variables used in the model were rainfall events (groups in the monsoon season) and rainfall amount per event. The model synthesizes a time series record of daily rainfall.

The event-based, deterministic hydrologic sub-model transfores the synthetic rainfall data into daily streamflow. The hydrologic sub-model DOVAN was a generalized, fitted parameter model. Parameters for the DOVAN model were calibrated with the daily streamflow records in the Tinau river at Butwal, and with evaporation and temperature data from Tansen and Butwal.

The watershed model TINAU was run for 100 years. The simulated mean annual runoff was 1090.6 mm with a and a mean maximum daily discharge of 1010.4 m^3/s. High pre-monsoon rainfall produced an early commencement of baseflow in some year. Late monsoon rainfall caused long baseflow recessions throughout the summer months, March April and May. The mean consecutive days of low flow during this period was 24.42. Periods of low flow days extended as long as 157 days. April and May were the driest months with low flows falling as low as 0.10 mm. Winter flows were satisfactory with mean flow of 0.9 mm. August and September were the wettest months with an average flow of 11.6 mm.

Some limitations were observed in the watershed model. In the stochastic precipitation model, daily rainfall amount was evaluated by distributing total rainfall amount per group among the number of days in a group. So, extreme rainfall events could not be considered for the assessment of peak flows. However, the actual highest daily flow recorded was 3500 m^3/s in 1981. The simulated result showed a highest daily flow of 4440 m^3/s. Another limitation of the model was low baseflow production. The actual baseflow was

0.95 m^3/s in 1981, but the simulated baseflow was as low as 0.253 m^3/s.

The TINAU model was calibrated with only 8 years of historical data. The model could be recalibrated, tested, and validated with additional rainfall and runoff data when it becomes available. Even so, the output of the precipitation model developed closely matched the quantity and variability of the actual rainfall measured in the critical period of the monsoon season. A more realiable output would be expected if a longer historical record were available. The use of the output of the model will depend upon the objective of the user. The model may be used as a part of a comprehensive watershed model in decision making process. The model has the advantage of allowing decisions to be made based upon the risks the user is willing to take.

APPENDIX A

COMPUTER PROGRAM LISTING OF TINAU SIMULATION MODEL, INCLUDING SUBROUTINES

```
FTN7X,L
$FILES?,9

      PROGRAM TINAU

**********************************************************************
*    THIS IS A WATERSHED HYDROLOGIC MODEL DEVELOPED FROM A COUPLE    *
*    OF STOCHASTIC  PRECIPITATION MODEL AND A DETERMINISTIC          *
*    STREAMFLOW MODEL. THIS MODEL IS CALIBRATED FROM CLIMATOLOGICAL  *
*    AND HYDROLOGICAL DATA FROM TANSEN AND BUTWAL.                   *
*                                                                    *
*         STATIONS : TANSEN, and BUTWAL                              *
*         DATA YEAR: CLIMATOLOGICAL (1972-1985)                      *
*                    HYDROLOGIC (1977-1982)                          *
*         PROGRAM DEVELOPED BY: RABIN BOGATI                         *
*                               SCHOOL OF RENEWABLE NATURAL RESOURCES *
*                               THE UNIVERSITY OF ARIZONA            *
*                               TUCSON, ARIZONA 85721                *
*                               1985-1986                            *
**********************************************************************
*
*-------------------------------------- DECLARATION OF VARIABLES

*     REAL    FQJUN(40),FQJUL(40),FQAUG(40),FQSEP(40)
*     REAL    FQOCT(40),FQNOV(40),FQDEC(40),FQJAN(40)
*     REAL    FQFEB(40),FQMAR(40),FQAPR(40),FQMAY(40)
*     REAL    FQMSUN(40),FQYRSUM(40),FQYRMX(75),FQYRMIN(40)
      REAL    MSOONQ,YRSUMQ,YRMXFLO,YRMINFLO
      CHARACTER  CALENDAR(12)*10

      COMMON /A/ III,ILEAP,PPT(366),FLOWTOT(366),RUNOFF(366),LU

      COMMON /B/FQJUN(40),FQJUL(40),FQAUG(40),FQSEP(40),FQOCT(40),
     &FQNOV(40),FQDEC(40),FQJAN(40),FQFEB(40),FQMAR(40),FQAPR(40),
     &FQMAY(40),FQMSUN(40),FQYRSUM(40),FQYRMX(40),FQYRMIN(40)

      COMMON /C/MSOONQ, YRSUMQ,YRMXFLO,YRMINFLO

      DATA CALENDAR/'JUNE','JULY','AUGUST','SEPTEMBER','OCTOBER',
     &'NOVEMBER','DECEMBER','JANUARY','FEBRUARY','MARCH',
     &'APRIL','MAY'/
*------------------------- Initialize years of simulation and output

```

```
      WRITE(1,*) 'HOW MANY YEARS YOU WANT TO BE SIMULATED?'
      WRITE(1,*) 'TYPE IN NUMBER AND HIT RETURN.'
      READ(1,*) LBARSA
      WRITE(1,*) 'THIS MODEL IS SIMULATING FOR:',LBARSA,'(YEARS)'
      WRITE(1,*)'WHAT IS THE OUTPUT DEVICE NUMBER 1=? OR 6=?'
      READ(1,*) LU

C     OPEN(123, FILE='BARSA', STATUS = 'NEW')
C     OPEN(234, FILE='BHEL', STATUS='NEW')
C     OPEN(345, FILE='MINBHEL',STATUS='NEW')

      WRITE(1,*)'********* PROGRAM IS RUNNING **********'
*
*------------------          Initialize the RANDOM NUMBER generation
*                                        and the addition variables.
      CALL SSEED(12345)

      DO  15  N = 1, 40
         FQJUN(N) = 0.
         FQJUL(N) = 0.
         FQAUG(N) = 0.
         FQSEP(N) = 0.
         FQOCT(N) = 0.
         FQNOV(N) = 0.
         FQDEC(N) = 0.
         FQJAN(N) = 0.
         FQFEB(N) = 0.
         FQMAR(N) = 0.
         FQAPR(N) = 0.
         FQMAY(N) = 0.
         FQMSUN(N) =0.
         FQYRSUM(N) = 0.
         FQYRMX(N) = 0.
         FQYRMIN(N) = 0.
 15   CONTINUE

*------------------------ THE YEARLY LOOP BEGINS  **************

        DO 9999   III = 1, LBARSA

*                                     !   Check the LEAPYEAR value

          LEAP = MOD(III,4)
          IF(LEAP .EQ. 0) THEN
               ILEAP = 1
          ELSE
               ILEAP = 0
          END IF
```

```

* --------------- Operate the Stochastic PRECIPITATION model
*                 to simulate one year series of rainfall data

       CALL PANI    ! A Stochastic PRECIPITATION model

*---------------- Operate the Streamflow generation model
*                 to transform one year series of rainfall to runoff
*
*--------- Initialize PEAK and TOTAL flows to be computed
       MSOONQ = 0.0
       YRSUMQ = 0.0
       YRMXFLO = 0.0
       YRMINFLO = 2.5   !  Cubic meter per second mean daily flow

       CALL DOVAN       ! The G.S.S.S. Hydrologic Model

 9999 CONTINUE

*---------------------- ! Report the monthly, annual and storm flow
*
     WRITE(LU,20) CALENDAR(1)
     CALL REPORT(FQJUN,0.,14.,LU,40)  ! Report monthly frequency JUNE
     WRITE(LU,20) CALENDAR(2)
        CALL REPORT (FQJUL,0.,13.,LU,40)   !    JULY
     WRITE(LU,20) CALENDAR(3)
        CALL REPORT (FQAUG,0.,17.,LU,40)   !    AUGUST
     WRITE(LU,20) CALENDAR(4)
        CALL REPORT (FQSEP,0.,12.,LU,40)   !    SEPTEMBER
     WRITE(LU,20) CALENDAR(5)
        CALL REPORT (FQOCT,0.,10.,LU,40)   !    OCTOBER
     WRITE(LU,20) CALENDAR(6)
        CALL REPORT (FQNOV,0.,0.3,LU,40)   !    NOVEMBER
     WRITE(LU,20) CALENDAR(7)
        CALL REPORT (FQDEC,0.,0.60,LU,40)  !    DECEMBER
     WRITE(LU,20) CALENDAR(8)
        CALL REPORT (FQJAN,0.,0.3,LU,40)   !    JANUARY
     WRITE(LU,20) CALENDAR(9)
        CALL REPORT (FQFEB,0.,0.25,LU,40)  !    FEBRUARY
     WRITE(LU,20) CALENDAR(10)
        CALL REPORT (FQMAR,0.,0.3,LU,40)   !    MARCH
     WRITE(LU,20) CALENDAR(11)
        CALL REPORT (FQAPR,0.,0.35,LU,40)  !    APRIL
     WRITE(LU,20) CALENDAR(12)
        CALL REPORT (FQMAY,0.,1.5,LU,40)   !    MAY

```

```
 20   FORMAT(/////, 10X, '  MONTHLY SIMULATION RUNOFF FREQUENCY',/
     &,10X,'  SUMMARY RESULT FOR THE MONTH - ',A10,/,
     &10X,'        RUNOFF IN WATERSHED MM',//)
*  -------------------------  Report total annual Monsoon flow
      WRITE(LU,30)
         CALL REPORT (FQMSUN, 50.0,70.,LU,40)
 30   FORMAT(///,12X,'SUMMARY OF TOTAL MONSOON SEASON ',/

*                               ! Report total annual streamflow
     &,12X,'   RUNOFF VOLUME IN MM',//)
      WRITE(LU,40)
         CALL REPORT (FQYRSUM, 100.,65.,LU,40)
 40   FORMAT(///,10X,'SUMMARY OF TOATL YEARLY RUNOFF VOLUME IN MM',//)

*_                ! Report maximum annual stormflow in cubic meter per sec.

      WRITE(LU,50)

 50   FORMAT(///,10X,'SUMMARY OF MAXIMUM DAILY FLOW IN CU. M/SEC',//)
         CALL REPORT (FQYRMX,0.0 ,120.,LU,40)

*-------------             ! Report minimum annual stormflow
      WRITE(LU,60)
         CALL REPORT (FQYRMIN,0.0,.07,LU,40)
 60   FORMAT(///,10X,' SUMMARY OF EXTREMELY LOW FLOWS IN CU.M/SEC',/,
     &10X,' (Flows less than 2.5 cubic meter per sec )',//)
      WRITE(1,*) ' PURGE *BARSA* AND *BHEL* BEFORE RERUNNING PROGRAM'

      STOP
      END
```

```

      SUBROUTINE   PAN1
**********************************************************************
* A PRECIPITATION SIMULATION MODEL                                   *
* THIS SUBPROGRAM SIMULATES DAILY RAINFALL DATA FOR ONE YEAR AT      *
* A TIME STARTING FROM JANUARY 1 AND ENDS IN DECEMBER (JULIAN CACENDAR)
* THE RAINFALL MODEL IS A STOCHASTIC MODEL,BASED ON STATISTICAL PROBA-*
* BILITY , THAT TREATS MONTHS OF JUNE THROUGH SEPTEMBER  AS A SERIES *
* OF A FRONTAL STORM AND OCTOBER THROUGH MAY AS INDEPENDENT THUNDER - *
* STORM RAINFALL PATTERNS. THUNDERSTORM MONTHS ARE FURTHER SUBDIVIDED *
* IN TO STATISTICALLY NON DIFFERENT GROUPS.                          *
*                                                                    *
*       MONSOON = JUNE, JULY, AUGUST, SEPTEMBER                      *
*                                                                    *
*    Rainfall event interarrival time for OCT-MAY (IT)               *
*       GROUP 1 = JANUARY, FEBRUARY, MARCH  (gamma)                  *
*       GROUP 2 = APRIL, MAY                (geometric)              *
*       GROUP 3 = OCTOBER                   (gamma)                  *
*       GROUP 4 = NOVEMBER, DECEMBER        (gamma)                  *
*                                                                    *
*    Rainfall amount per event (PPT/EVENT)                           *
*       GROUP 1 = JANUARY,FEBRUARY, MARCH, APRIL, MAY  (gamma)       *
*       GROUP 2 = OCTOBER, NOVEMBER                   (gamma)        *
*       GROUP 3 = DECEMBER                            (gamma)        *
**********************************************************************

      REAL K(8), LAMDA(8), MEAN(5), PPTMON(5)
      REAL TEVENT(12), DAY(12), CDF(46), DBS(70), NGS(35)
      REAL RAIN, LNGP(25), DAYBC(10),GRAIN,CLASSRAIN
      INTEGER DCOUNT
      REAL JAL(12),MONSOON, TEMP
      REAL XEVENT(5)

      COMMON /A/ III, ILEAP,PPT(366),FLOWTOT(366),RUNOFF(366),LU
* THESE ARE THE STATISTICAL PARAMETER VALUES USED IN SIMULATION.

      DATA LAMDA/.1593,.0621,.0285,.11030,.0490,.1504,.0672,.134/
      DATA K/1.849,.2832,.4841,.8873,.5236,2.6308,.5648,.761/
      DATA MEAN/4.625,3.730,5.481,1.813,3.722/
         DO  JL = 1, 366
              PPT(JL) =0.0
         END DO


       JDAY = 0
       DCOUNT = 0
       RAIN = 0.0

```

```
************************  MODEL FOR JAN,FEB,MAR     *******

       JDAY = 90  + ILEAP
        DO WHILE(DCOUNT .LE. JDAY)
            X =URAN( )                ! a RANDOM NUMBER genaration
            IF(X .LE. 0.4103) THEN    ! shifted distribution
              NINT = 1
            ELSE
              NINT =INT(GAMMA(K(1),1./LAMDA(1))+1.)+1
            END IF

            DCOUNT = DCOUNT + NINT

            IF(DCOUNT .GT. JDAY) GO TO 20
            PPT(DCOUNT) = GAMMA(K(4),1./LAMDA(4))
            IF(PPT(DCOUNT) .LT. .1) PPT(DCOUNT) = .00
            IF(DCOUNT .GE. JDAY) GO TO 20
 20     END DO

****************** MODEL FOR THE MONTH APR-MAY ***********

          JDAY = 151 + ILEAP
        DO WHILE(DCOUNT .LE. JDAY)
             X = URAN( )
             IF(X .LE. 0.4766) THEN      !  a shifted distribution
                 NINT = 1
             ELSE

            X = URAN( )
           P  = 1./MEAN(1)
         NINT = INT((ALOG(1.-X))/(ALOG(1.-P))+1.) + 1
             END IF

        DCOUNT = DCOUNT + NINT
         IF(DCOUNT .GT. JDAY) GO TO 30

           IF(DCOUNT .LE. (120+ILEAP)) THEN
              PPT(DCOUNT) = GAMMA(K(4),1./LAMDA(4))
           ELSE
              PPT(DCOUNT) = GAMMA(K(5),1./LAMDA(5))
           END IF
         IF(PPT(DCOUNT) .LT. .10) PPT(DCOUNT) = .00
         PPTMON(2) = PPTMON(2) + PPT(DCOUNT)
         TEVENT(2) = TEVENT(2) + 1

         IF(DCOUNT .GE. JDAY) GO TO 30
 30     END DO

```

```
******************** MONSOON SEASONAL MODEL  **********

            JDAY = 273 + ILEAP
            ITRANSIT = 1
          DO WHILE (DCOUNT .LE. JDAY)
              IF (ITRANSIT .EQ. 1) CO TO 31
*********** Dry days between sequences (DBS)

              X = URAN( )
            NINT = INT((ALOG(1.-X)*(-MEAN(5)))) + 5
           TNINT = TNINT + 1
        DBS(NINT) = DBS(NINT) + 1

          TOTDBS = TOTDBS + NINT  !  between sequences.

           DCOUNT = DCOUNT + NINT
          IF(DCOUNT .GT. JDAY) GO TO 39
*********** Groups per sequence  (NGPS)
  31    ITRANSIT = 0

           NGRPS=INT(GAMMA(K(8),1./LAMDA(8)) + 1.)

************ A computation within the group

           DO 40  JJ = 1, NGRPS

**                  Groupduration in days (LG) ****

             X = URAN( )
             P = 1./MEAN(2)
            LG = INT((ALOG(1.-X))/(ALOG(1.-P)) + 1.)
          TOTLG = TOTLG + LG  ! count the group duration

**                  Rainfall amount per group (RP) ****

        CLASSRAIN = GAMMA(K(7),1./LAMDA(7))  ! simulate class

            GRAIN = (CLASSRAIN*10.- 5.)  ! Translate the RAINFALL
          MONSOON = MONSOON + GRAIN
          MONEVENT= MONEVENT + 1

          DO 45  I = 1, LG
             DCOUNT = DCOUNT + 1
             PPT(DCOUNT) = GRAIN/LG
             PPTMON(3) = PPTMON(3) + PPT(DCOUNT)
             IF(PPT(DCOUNT) .LT. .1) PPT(DCOUNT) = 0.0
  45      CONTINUE

          IF(DCOUNT .GE. JDAY) GO TO 39

```

```
**       Dry days between groups    (DBG)  ****

 32       X = URAN( )
          P = 1./MEAN(4)
        DBG = INT (ALOG(1.-X)/(ALOG(1.-P))+1.)
        IF (DBG .GT. 6) GO TO 32
        DAYBG(DBG) = DAYBG(DBG) + 1

        TOTDBG = TOTDBG + DBG          ! Count DBG

        DCOUNT = DCOUNT + DBG          ! Added lengh of dry day too.

        IF(DCOUNT .GE. JDAY) GO TO 39

 40     CONTINUE
 39    END DO

*****************    THE MODEL FOR OCTOBER  **********

          JDAY = 304 + ILEAP
        DO WHILE (DCOUNT .LE. JDAY)
            NINT = INT(GAMMA(K(2),1./LAMDA(2))+1)
            DCOUNT = DCOUNT + NINT
            IF(DCOUNT .GT. JDAY) GO TO 50

            PPT(DCOUNT) = GAMMA(K(5),1./LAMDA(5))
            IF(PPT(DCOUNT).LT. .1) PPT(DCOUNT) = .0

            IF(DCOUNT .GE. JDAY) GO TO 50
 50     END DO

*************** THE MODEL FOR NOV-DEC  **********

            JDAY = 365+ILEAP
         DO WHILE (DCOUNT .LE. JDAY)
           NINT = INT(GAMMA(K(3),1./LAMDA(3))+1.)
           DCOUNT = DCOUNT + NINT
           IF(DCOUNT .GT. JDAY) GO TO 60

           IF(DCOUNT .LE.(334+ILEAP))  THEN
             PPT(DCOUNT) = GAMMA(K(4),1./LAMDA(4))
           ELSE
            PPT(DCOUNT) = GAMMA(K(6),1./LAMDA(6))
           END IF
           IF(PPT(DCOUNT) .LT. .1) PPT(DCOUNT) = .0
           IF(DCOUNT .GE. JDAY) GO TO 60

 60      END DO

```

```
*------------------------------   CONVERT THE CALENDAR
*                                 JUNE 1 TO MAY LAST
         DO  I = 1, 151+ILEAP
             TEMP = PPT(1)
             DO J = 2, 365+ILEAP
                PPT(J-1) = PPT(J)
             END DO
             PPT(365) = TEMP
         END DO
*------------------------------   COUNT THE YEARLY RAINFALL
         TOTPPT = 0.
         DO M = 1, 365+ILEAP
            TOTPPT = TOTPPT + PPT(M)
         END DO
C        WRITE(123,*)III, TOTPPT
      RETURN
      END

***************************************************************
*    GAMMA FUNCTION
*    THIS FUNCTION WAS DEVELOPED TO EVALUATE GAMMA CDF
***********************************************************

      FUNCTION GAMMA(ALPHA,BETA)

       IF(ALPHA .GT. 1.) GO TO 222
        B = 1.+ALPHA/2.17828183
 111    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
            ELSE
            END IF
        ELSE
            Y = P**(1./ALPHA)
            IF(U .LE. EXP(-Y)) THEN
                GAMMA = Y*BETA
                RETURN
            ELSE
            END IF
        END IF

```

```
       GO TO 111
222   A = 1./SQRT(2.*ALPHA-1.)
      B = ALPHA-ALOG(4.)
      Q = ALPHA+1./A
      E = 4.5
      D = 1.+ALOG(E)
333   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
       ELSE
       END IF
      GO TO 333
      END
```

```
      SUBROUTINE DOVAN
*************************************************************************
*  THIS IS A MODIFICATION OF THE GENERALIZED STREAMFLOW SIMULATION  *
*  SYSTEM DEVELOPED BY JOINT FEDERAL-STATE RIVER FORECAST CENTER IN *
*  SACRAMENTO, CALIFORNIA (BURNAS, FERRAL, AND MCGUIRE, 1973). THIS *
*  PROGRAM UTILIZES EVAPORATION AND PRECIPITATION DATA, AND OTHER   *
*  WATERSHED PARAMETERS TO GENARATE STREAMFLOW. PARAMETERS DEVELOPED*
*  ARE IN ENGLISH UNIT SO THE MODEL USES THE DATA IN ENGLISH UNIT.  *
*  THE MODEL IS OPERATED FROM THE MONTH OF JUNE TO MAY.             *
*  THE MODEL HAS BEEN CALIBRATED FROM CONSECUTIVE DATA ON RAINFALL  *
*  AND RUNOFF FROM TANSEN AND TINAU RIVER AT BUTWAL RESPECTIVELY.   *
*  THE CALIBRATION YEARS ARE 1977-1982.                             *
*    (NOTE) DAY ONE IS JUNE 1 ST AND LAST DAY OF YEAR IS MAY LAST   *
*                                                                   *
*************************************************************************
      REAL LZTWC, LZFSC, LZFPC, LZTWM, LZFPM, LZFSM,ET(12),LZSK,LZPK,
     &RAINZ(11),TOTALP,TOTALQ,TOTALET,TOTALFLO,DSNOWZ(11),EVAP(366)

*     REAL FQJUN(40),FQJUL(40),FQAUG(40),FQSEP(40),FQOCT(40),
      REAL   MSDONQ,YRSUMQ,YRMXFLO,YRMINFLO
      INTEGER MON(13)

      COMMON /A/III,ILEAP,PPT(366),FLOWTOT(366),RUNOFF(366),LU
      COMMON /B/ FQJUN(40),FQJUL(40),FQAUG(40),FQSEP(40),FQOCT(40),
     &FQNOV(40),FQDEC(40),FQJAN(40),FQFEB(40),FQMAR(40),FQAPR(40),
     &FQMAY(40),FQMSUN(40),FQYRSUM(40),FQYRMX(40),FQYRMIN(40)
      COMMON /C/ MSDONQ,YRSUMQ,YRMXFLO,YRMINFLO

      DATA MON/0,30,61,92,122,153,183,214,245,273,304,334,365/

      DATA ET/2.7,2.6,2.3,1.9,1.6,1.4,1.0,1.1,1.5,2.8,3.2,3.6/


C**********VARIABLE INITIALIZATION ROUTINE*******************


        UZTWM = 5.5          ! Inches
        UZFWM = 2.0          !
        LZTWM = 7.0          !
        LZFSM = 5.5
        LZFPM = 10.0

*----------------   RATE OF DRAINAGE TO INTERFLOW AND BASEFLOW
        UZK   = 0.19
        LZSK  = 0.02
        LZPK  = 0.01

```

```
*---------------      PERCOLATION, FRACT,and PFREE
       ZPERC = 25.
       REXP  = 1.9
       FRACT = 1.0
       PFREE = 0.3

*------------------  INITIAL WATER CONTENT AT DIFFERENT LAYERS
       UZTWC = 4.9
       UZFWC = 0.5
       LZTWC = 0.09
       LZFSC = 0.05
       LZFPC = 1.50

        ADIMP = 0.1
        PCTIM = 0.0005
        SIDE  = 5.
        ADIMC = 0.0
        PBASE = 0.3

      SSOUT=0.
      SARVA=0.
      RSERV=0.4
      IMPRT=0.


C *********VARIABLE*INITIALIZATION*DONE,**READ*DATA*FILES*****************

      TOTALP=0.
      TOTALQ=0.
      TOTALET=0.
      FLOWTOT=0.
      TOTALM =0.
      TOTALPL=0.
      PAV=0.


*------------------  ANNUAL LOOP BEGINS


      DO 999, I = 1, 365+ILEAP

       PLIQ = PPT(I)/25.4   ! Assign todays's precip in English unit
*
* COMPUTE TRANSPIRATION LOSS FROM UPPER ZONE TENSION WATER.
* THE RAINY DAY NORMAL IS ASSUMED TO BE ONE INCH OF RAIN. THIS IS PDNOR.
      PDNOR=1.
      PDN20=PDNOR*.20
      E2=0.
C *************ALTERED GSSS TO USE EVAP ARRAY WITHOUT MULTIPLYING FRACT****

```

```
      CALL CONVERT (1,MAHINA,ILEAP)
      EDMND = ET (MAHINA)/25.4  ! Assign evapotranspiration  data

C****************************************************************************

      E1 = EDMND * UZTWC/UZTWM
      RED = EDMND - E1
      UZTWC = UZTWC - E1
      IF(UZTWC)100,155,155
  100 E1 = EDMND + UZTWC
      UZTWC = 0.
      RED = EDMND - E1

***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

*** If upper zone free water exceeds upper zone tension
*   water content, then 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

****  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.
      FLOWTOT(I)=FLOSF+FLOIN+FLOBF+ROIMP
      SOILWATER=UZTWC+UZFWC+LZTWC+LZFSC+LZFPC

C*******ADJUSTMENT FOR RIDICULOUSLY PROLONGED LOW FLOWS***********
      IF(FLOWTOT.LE.0.00014)FLOWTOT=0.

      FLOWTOT(I) = FLOWTOT(I)*25.4  ! CONVERT TO MATRIC MM
      RUNOFF(I) = FLOWTOT(I)/.152   ! CONVERT DAILY MEAN FLOW C.M/S

***********   STATISTICAL CALULATION OF FLOWS

```

```

       IF( MAHINA .EQ. 1) THEN
          CALL UPDATE(FLOWTOT(I), FQJUN, 0.,17.,40)  ! JUNE
       ELSE IF (MAHINA .EQ. 2) THEN
          CALL UPDATE(FLOWTOT(I), FQJUL, 0.,13.,40)  ! JULY
       ELSE IF (MAHINA .EQ. 3) THEN
          CALL UPDATE(FLOWTOT(I),FQAUG, 0.,17.,40)   ! AUGUST
       ELSE IF (MAHINA .EQ. 4) THEN
          CALL UPDATE(FLOWTOT(I), FQSEP,0.,12.,40)   ! SEPTEMBER
       ELSE IF (MAHINA .EQ. 5) THEN
          CALL UPDATE(FLOWTOT(I),FQOCT,0.,10.,40)    ! OCTOBER
       ELSE IF (MAHINA .EQ. 6) THEN
          CALL UPDATE(FLOWTOT(I),FQNOV,0.,.25,40)    ! NOVEMBER
       ELSE IF (MAHINA .EQ. 7) THEN
          CALL UPDATE(FLOWTOT(I),FQDEC, 0.,0.2,40)   ! DECEMBER
       ELSE IF (MAHINA .EQ. 8) THEN
          CALL UPDATE(FLOWTOT(I), FQJAN, 0.,0.15,40) ! JANUARY
       ELSE IF (MAHINA .EQ. 9) THEN
          CALL UPDATE(FLOWTOT(I), FQFEB, 0.,.20,40)  ! FEBRUARY
       ELSE IF (MAHINA .EQ. 10) THEN
          CALL UPDATE(FLOWTOT(I), FQMAR, 0.,0.2,40)  ! MARCH
       ELSE IF (MAHINA .EQ. 11) THEN
          CALL UPDATE(FLOWTOT(I),FQAPR, 0.,.10,40)   ! APRIL
       ELSE IF (MAHINA .EQ. 12) THEN
          CALL UPDATE(FLOWTOT(I), FQMAY, 0.,0.3,40)  ! MAY
       ELSE
       END IF
****
*     --------- COUNT THE MONSOON SEASONAL AND ANNUAL TOTAL RUNOFF
      IF(MAHINA .EQ. 1 .OR. MAHINA .EQ. 2 .OR. MAHINA .EQ. 3 .OR.
     &MAHINA .EQ. 4) THEN
         MSOONQ = MSOONQ + FLOWTOT(I)
      ELSE
      END IF
***
        YRSUMQ = YRSUMQ + FLOWTOT(I) ! ANNUAL TOTAL FLOW

*** Sorting the peak discharge and minimum flow of a year.

      IF(RUNOFF(I) .GT. YRMXFLO) YRMXFLO = RUNOFF(I)
      IF(RUNOFF(I) .LT. YRMINFLO) YRMINFLO = RUNOFF(I)

** A count for the consecutive days of low baseflow.
** A baseflow less than or equal to 1.5 Cu. M /S is considered.
*        IF (RUNOFF(I) .LE. 1.5) THEN
*          WRITE(345,*) III, I, RUNOFF(I)
*        ELSE
*        END IF
  999 CONTINUE
```

```
************************ END OF DAILY LOOP
* COUNT YEARLY FREQUENCIES.
         CALL UPDATE (MSOONQ, FQMSUN, 50.0,70.,40)
         CALL UPDATE (YRSUMQ, FQYRSUM.100.,65.,40)
         CALL UPDATE (YRMXFLO,FQYRMX,0.0 ,120.,40)
         CALL UPDATE (YRMINFLO, FQYRMIN, 0.0,0.07,40)
***************************      END OF ANNUAL LOOP

C     WRITE(234,*) III, YRSUMQ

      RETURN
 1000 STOP
      END


      SUBROUTINE CONVERT (I, MAHINA, ILEAP)
***********************************************************************
* A SUBPROGRAM TO CONVERT THE DAILY DATA TO MONTHLY SET
      INTEGER I, J, MAHINA, NDAY, LAST(12)


      LAST(1) = 30
      LAST(2) = 61
      LAST(3) = 92
      LAST(4) =122
      LAST(5) =153
      LAST(6) =183
      LAST(7) =214
      LAST(8) =245
      LAST(9) =273+ILEAP
      LAST(10)=304+ILEAP
      LAST(11)=334+ILEAP
      LAST(12)=365+ILEAP


      DO  600 J = 1, 12

         IF( I .LE. LAST(J)) THEN
           MAHINA = J
           RETURN
         ELSE
         END IF

 600  CONTINUE

      RETURN
      END


```

```
      SUBROUTINE UPDATE( FLOW, FREQ, CLS, DELTA, LG)
***********************************************************************
*     A SUBPROGRAM TO COUNT THE FREQUENCY OF THE FLOW

      REAL FREQ(40)

         DO 400 J = 1, LG
            RLOW = FLOAT(J-1)*DELTA + CLS
            RUPR = FLOAT(J)*DELTA + CLS
            IF (FLOW .LE. RLOW .OR. FLOW  .GT. RUPR) GO TO 400
            FREQ(J) = FREQ(J) + 1

            RETURN
  400    CONTINUE

      RETURN
      END
```

```
      SUBROUTINE  REPORT (FREQ, CLS, CLASS, LU,NN)
********************************************************************
* A SUBPROGRAM TO PEPORT THE MONTHLY, SEASONAL AND YEARLY FREQUENCIES

      REAL     CLS, PDF, CDF, CLASS
      REAL     FREQ(40), TOTAL

      WRITE(LU,10)
 10   FORMAT(3X,'      CLASS         FREQUENCY       PDF       CDF',/)

      TOTAL = 0
          X = 0.
         XX = 0.
        DO 100 J = 1, NN
           TOTAL = TOTAL + FREQ(J)
 100    CONTINUE
       IF (TOTAL.LE.0) THEN TOTAL = 1
       CDF = 0.
        DO 200  I = 1, NN
            FREQI = FREQ(I)
              CDF = CDF + FREQI
              PDF = FREQI/TOTAL
             CDF1 = CDF/TOTAL
               XL = CLASS*FLOAT(I-1) + CLS
               XU = CLASS*FLOAT(I) + CLS
                X = FREQI * 0.5*(XL+XU) + X
               XX = XX + FREQI*.25*(XL+XU)*(XL+XU)
         WRITE(LU,20)XL,XU,FREQI,PDF,CDF1

 200    CONTINUE
 20   FORMAT(3X,F7.2,'-',F7.2,4X,F8.1,4X,F9.7,2X,F9.7)

            X = X/TOTAL
          XX  = SQRT(XX/TOTAL - X*X)
          WRITE(LU,30) TOTAL, X, XX
 30   FORMAT(/,10X,'   TOTAL (EVENTS) = ',F10.1,/
     &10X,'      MEAN (FLOW) = ', F10.1,/,
     &10X,'  STD. DEV (FLOW) =',F10.2,/)
      RETURN
      END
```

APPENDIX B

LISTING OF PARAMETER VALUES FOR THE STREAM FLOW GENERATION MODEL

Parameter	Description	Value
UZTWM	Upper zone tension water capacity	147.30
UZFWM	Upper zone free water capacity	53.30
LZTWM	Lower zone tension water capacity	180.30
LZFSM	Lower zone free water supplemental capacity	139.70
LZFPM	Lower zone free water primary capacity	254.00
UZK	Fraction of upper zone free water intering interflow in one day	0.19
LZSK	Fraction of lower zone supplemental free water drained in one day	0.02
LZPK	Fraction of lower zone primary free water drained in one day	0.01
ZPERC	Percolation factor	25.00
REXP	An exponent governing rate of change of percolation rate with changing lower zone water contents	1.90
SIDE	A ratio of non-channel baseflow to channel baseflow	5.00
SSOUT	Surface channel flow required before channel flow becomes visible at the gaging station	0.0

Parameter	Descriptoin	Value
PCTIM	Watershed fraction contributing to the instantaneous runoff	0.0005
SARVA	Watershed fraction covered by streams, lakes, and riparian vegetations	0.0
RSERV	Fraction of lower zone free water not available for lower zone tension water	0.4
UZTWC	Upper zone tension initial water content	124.5
UZFWC	Upper zone initial free water content	12.70
LZTWC	Lower zone initial tension water content	2.30
LZFSC	Lower zone initial free supplemental water content	1.3
LZFPC	Lower zone initial free primary water content	38.1
ADIMP	Additional fraction of impervious area which develops as tension water requirements are met	0.10
PFREE	Fraction of percolated water directly claimed by lower zone free water storages	0.30

APPENDIX C

SAMPLE OUTPUT OF TINAU MODEL

```
          MONTHLY SIMULATION RUNOFF FREQUENCY
         SUMMARY RESULT FOR THE MONTH - JANUARY
               RUNOFF IN WATERSHED MM


   CLASS            FREQUENCY       PDF        CDF

  0.00-    .30          2.0      .0006452   .0006452
   .30-    .60         43.0      .0138710   .0145161
   .60-    .90         99.0      .0319355   .0464516
   .90-   1.20        346.0      .1116129   .1580645
  1.20-   1.50        592.0      .1909677   .3490323
  1.50-   1.80        719.0      .2319355   .5809678
  1.80-   2.10        614.0      .1980645   .7790322
  2.10-   2.40        387.0      .1248387   .9038709
  2.40-   2.70        181.0      .0583871   .9622581
  2.70-   3.00         63.0      .0203226   .9825807
  3.00-   3.30         24.0      .0077419   .9903226
  3.30-   3.60          2.0      .0006452   .9909678
  3.60-   3.90          3.0      .0009677   .9919355
  3.90-   4.20          2.0      .0006452   .9925807
  4.20-   4.50          1.0      .0003226   .9929032
  4.50-   4.80          0.0     0.0000000   .9929032
  4.80-   5.10          4.0      .0012903   .9941936
  5.10-   5.40          2.0      .0006452   .9948387
  5.40-   5.70          4.0      .0012903   .9961290
  5.70-   6.00          2.0      .0006452   .9967742
  6.00-   6.30          1.0      .0003226   .9970968
  6.30-   6.60          3.0      .0009677   .9980645
  6.60-   6.90          1.0      .0003226   .9983871
  6.90-   7.20          1.0      .0003226   .9987097
  7.20-   7.50          1.0      .0003226   .9990323
  7.50-   7.80          1.0      .0003226   .9993548
  7.80-   8.10          0.0     0.0000000   .9993548
  8.10-   8.40          1.0      .0003226   .9996774
  8.40-   8.70          0.0     0.0000000   .9996774
  8.70-   9.00          0.0     0.0000000   .9996774
  9.00-   9.30          0.0     0.0000000   .9996774
  9.30-   9.60          0.0     0.0000000   .9996774
  9.60-   9.90          0.0     0.0000000   .9996774
  9.90-  10.20          1.0      .0003226  1.0000000
 10.20-  10.50          0.0     0.0000000  1.0000000
 10.50-  10.80          0.0     0.0000000  1.0000000
 10.80-  11.10          0.0     0.0000000  1.0000000
 11.10-  11.40          0.0     0.0000000  1.0000000
 11.40-  11.70          0.0     0.0000000  1.0000000
 11.70-  12.00          0.0     0.0000000  1.0000000

          TOTAL (EVENTS) =      3100.0
             MEAN (FLOW) =         1.7
         STD. DEV (FLOW) =         .65
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          MONTHLY SIMULATION RUNOFF FREQUENCY
           SUMMARY RESULT FOR THE MONTH - FEBRUARY
                RUNOFF IN WATERSHED MM


      CLASS            FREQUENCY       PDF        CDF

   0.00-    .25          35.0      .0123894   .0123894
    .25-    .50         240.0      .0849558   .0973451
    .50-    .75        1060.0      .3752213   .4725664
    .75-   1.00         926.0      .3277876   .8003540
   1.00-   1.25         392.0      .1387611   .9391150
   1.25-   1.50         127.0      .0449558   .9840708
   1.50-   1.75          15.0      .0053097   .9893805
   1.75-   2.00           4.0      .0014159   .9907964
   2.00-   2.25           2.0      .0007080   .9915044
   2.25-   2.50           4.0      .0014159   .9929204
   2.50-   2.75           2.0      .0007080   .9936283
   2.75-   3.00           3.0      .0010619   .9946903
   3.00-   3.25           2.0      .0007080   .9953983
   3.25-   3.50           1.0      .0003540   .9957522
   3.50-   3.75           0.0     0.0000000   .9957522
   3.75-   4.00           2.0      .0007080   .9964602
   4.00-   4.25           4.0      .0014159   .9978760
   4.25-   4.50           1.0      .0003540   .9982301
   4.50-   4.75           1.0      .0003540   .9985840
   4.75-   5.00           0.0     0.0000000   .9985840
   5.00-   5.25           1.0      .0003540   .9989381
   5.25-   5.50           0.0     0.0000000   .9989381
   5.50-   5.75           2.0      .0007080   .9996461
   5.75-   6.00           0.0     0.0000000   .9996461
   6.00-   6.25           0.0     0.0000000   .9996461
   6.25-   6.50           0.0     0.0000000   .9996461
   6.50-   6.75           0.0     0.0000000   .9996461
   6.75-   7.00           0.0     0.0000000   .9996461
   7.00-   7.25           0.0     0.0000000   .9996461
   7.25-   7.50           0.0     0.0000000   .9996461
   7.50-   7.75           0.0     0.0000000   .9996461
   7.75-   8.00           0.0     0.0000000   .9996461
   8.00-   8.25           0.0     0.0000000   .9996461
   8.25-   8.50           0.0     0.0000000   .9996461
   8.50-   8.75           0.0     0.0000000   .9996461
   8.75-   9.00           1.0      .0003540  1.0000000
   9.00-   9.25           0.0     0.0000000  1.0000000
   9.25-   9.50           0.0     0.0000000  1.0000000
   9.50-   9.75           0.0     0.0000000  1.0000000
   9.75-  10.00           0.0     0.0000000  1.0000000

            TOTAL (EVENTS) =     2825.0
               MEAN (FLOW) =         .8
           STD. DEV (FLOW) =        .41
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            MONTHLY SIMULATION RUNOFF FREQUENCY
           SUMMARY RESULT FOR THE MONTH - MARCH
                  RUNOFF IN WATERSHED MM


      CLASS            FREQUENCY        PDF          CDF

    0.00-     .30         77.0       .0248387    .0248387
     .30-     .60       1035.0       .3338709    .3587097
     .60-     .90       1421.0       .4583871    .8170968
     .90-    1.20        446.0       .1438710    .9609678
    1.20-    1.50        101.0       .0325806    .9935484
    1.50-    1.80         11.0       .0035484    .9970968
    1.80-    2.10          2.0       .0006452    .9977419
    2.10-    2.40          1.0       .0003226    .9980645
    2.40-    2.70          1.0       .0003226    .9983871
    2.70-    3.00          0.0      0.0000000    .9983871
    3.00-    3.30          0.0      0.0000000    .9983871
    3.30-    3.60          1.0       .0003226    .9987097
    3.60-    3.90          0.0      0.0000000    .9987097
    3.90-    4.20          0.0      0.0000000    .9987097
    4.20-    4.50          0.0      0.0000000    .9987097
    4.50-    4.80          2.0       .0006452    .9993548
    4.80-    5.10          1.0       .0003226    .9996774
    5.10-    5.40          0.0      0.0000000    .9996774
    5.40-    5.70          0.0      0.0000000    .9996774
    5.70-    6.00          0.0      0.0000000    .9996774
    6.00-    6.30          0.0      0.0000000    .9996774
    6.30-    6.60          0.0      0.0000000    .9996774
    6.60-    6.90          0.0      0.0000000    .9996774
    6.90-    7.20          0.0      0.0000000    .9996774
    7.20-    7.50          0.0      0.0000000    .9996774
    7.50-    7.80          0.0      0.0000000    .9996774
    7.80-    8.10          0.0      0.0000000    .9996774
    8.10-    8.40          0.0      0.0000000    .9996774
    8.40-    8.70          0.0      0.0000000    .9996774
    8.70-    9.00          0.0      0.0000000    .9996774
    9.00-    9.30          0.0      0.0000000    .9996774
    9.30-    9.60          0.0      0.0000000    .9996774
    9.60-    9.90          1.0       .0003226   1.0000000
    9.90-   10.20          0.0      0.0000000   1.0000000
   10.20-   10.50          0.0      0.0000000   1.0000000
   10.50-   10.80          0.0      0.0000000   1.0000000
   10.80-   11.10          0.0      0.0000000   1.0000000
   11.10-   11.40          0.0      0.0000000   1.0000000
   11.40-   11.70          0.0      0.0000000   1.0000000
   11.70-   12.00          0.0      0.0000000   1.0000000

            TOTAL (EVENTS) =      3100.0
               MEAN (FLOW) =         .7
           STD. DEV (FLOW) =        .33
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              MONTHLY SIMULATION RUNOFF FREQUENCY
               SUMMARY RESULT FOR THE MONTH - APRIL
                    RUNOFF IN WATERSHED MM

      CLASS            FREQUENCY       PDF         CDF

   0.00-     .35          33.0      .0110000    .0110000
    .35-     .70         210.0      .0700000    .0810000
    .70-    1.05         957.0      .3190000    .4000000
   1.05-    1.40        1035.0      .3450000    .7450000
   1.40-    1.75         509.0      .1696667    .9146667
   1.75-    2.10         178.0      .0593333    .9740000
   2.10-    2.45          52.0      .0173333    .9913334
   2.45-    2.80          16.0      .0053333    .9966667
   2.80-    3.15           0.0     0.0000000    .9966667
   3.15-    3.50           0.0     0.0000000    .9966667
   3.50-    3.85           0.0     0.0000000    .9966667
   3.85-    4.20           1.0      .0003333    .9970000
   4.20-    4.55           0.0     0.0000000    .9970000
   4.55-    4.90           0.0     0.0000000    .9970000
   4.90-    5.25           1.0      .0003333    .9973333
   5.25-    5.60           1.0      .0003333    .9976667
   5.60-    5.95           1.0      .0003333    .9980000
   5.95-    6.30           3.0      .0010000    .9990000
   6.30-    6.65           0.0     0.0000000    .9990000
   6.65-    7.00           0.0     0.0000000    .9990000
   7.00-    7.35           1.0      .0003333    .9993334
   7.35-    7.70           0.0     0.0000000    .9993334
   7.70-    8.05           1.0      .0003333    .9996667
   8.05-    8.40           0.0     0.0000000    .9996667
   8.40-    8.75           0.0     0.0000000    .9996667
   8.75-    9.10           0.0     0.0000000    .9996667
   9.10-    9.45           0.0     0.0000000    .9996667
   9.45-    9.80           0.0     0.0000000    .9996667
   9.80-   10.15           1.0      .0003333   1.0000000
  10.15-   10.50           0.0     0.0000000   1.0000000
  10.50-   10.85           0.0     0.0000000   1.0000000
  10.85-   11.20           0.0     0.0000000   1.0000000
  11.20-   11.55           0.0     0.0000000   1.0000000
  11.55-   11.90           0.0     0.0000000   1.0000000
  11.90-   12.25           0.0     0.0000000   1.0000000
  12.25-   12.60           0.0     0.0000000   1.0000000
  12.60-   12.95           0.0     0.0000000   1.0000000
  12.95-   13.30           0.0     0.0000000   1.0000000
  13.30-   13.65           0.0     0.0000000   1.0000000
  13.65-   14.00           0.0     0.0000000   1.0000000

               TOTAL (EVENTS) =     3000.0
                  MEAN (FLOW) =        1.2
              STD. DEV (FLOW) =        .51
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        MONTHLY SIMULATION RUNOFF FREQUENCY
        SUMMARY RESULT FOR THE MONTH - MAY
              RUNOFF IN WATERSHED MM

   CLASS            FREQUENCY      PDF        CDF

 0.00-   1.50        2087.0     .6732258   .6732258
 1.50-   3.00         888.0     .2864516   .9596775
 3.00-   4.50          37.0     .0119355   .9716129
 4.50-   6.00          24.0     .0077419   .9793549
 6.00-   7.50           5.0     .0016129   .9809678
 7.50-   9.00          11.0     .0035484   .9845161
 9.00-  10.50           9.0     .0029032   .9874194
10.50-  12.00           9.0     .0029032   .9903226
12.00-  13.50           3.0     .0009677   .9912903
13.50-  15.00           4.0     .0012903   .9925807
15.00-  16.50           3.0     .0009677   .9935484
16.50-  18.00           1.0     .0003226   .9938710
18.00-  19.50           5.0     .0016129   .9954839
19.50-  21.00           0.0    0.0000000   .9954839
21.00-  22.50           3.0     .0009677   .9964516
22.50-  24.00           0.0    0.0000000   .9964516
24.00-  25.50           1.0     .0003226   .9967742
25.50-  27.00           0.0    0.0000000   .9967742
27.00-  28.50           0.0    0.0000000   .9967742
28.50-  30.00           1.0     .0003226   .9970968
30.00-  31.50           2.0     .0006452   .9977419
31.50-  33.00           3.0     .0009677   .9987097
33.00-  34.50           1.0     .0003226   .9990323
34.50-  36.00           0.0    0.0000000   .9990323
36.00-  37.50           0.0    0.0000000   .9990323
37.50-  39.00           0.0    0.0000000   .9990323
39.00-  40.50           0.0    0.0000000   .9990323
40.50-  42.00           0.0    0.0000000   .9990323
42.00-  43.50           0.0    0.0000000   .9990323
43.50-  45.00           1.0     .0003226   .9993548
45.00-  46.50           0.0    0.0000000   .9993548
46.50-  48.00           0.0    0.0000000   .9993548
48.00-  49.50           0.0    0.0000000   .9993548
49.50-  51.00           0.0    0.0000000   .9993548
51.00-  52.50           0.0    0.0000000   .9993548
52.50-  54.00           0.0    0.0000000   .9993548
54.00-  55.50           0.0    0.0000000   .9993548
55.50-  57.00           1.0     .0003226   .9996774
57.00-  58.50           1.0     .0003226  1.0000000
58.50-  60.00           0.0    0.0000000  1.0000000

           TOTAL (EVENTS) =      3100.0
              MEAN (FLOW) =         1.6
          STD. DEV (FLOW) =        2.77
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           MONTHLY SIMULATION RUNOFF FREQUENCY
          SUMMARY RESULT FOR THE MONTH - JUNE
                RUNOFF IN WATERSHED MM

      CLASS          FREQUENCY       PDF        CDF

    0.00-  14.00      2928.0     .9760000   .9760000
   14.00-  28.00        27.0     .0090000   .9850000
   28.00-  42.00        16.0     .0053333   .9903333
   42.00-  56.00         4.0     .0013333   .9916667
   56.00-  70.00         6.0     .0020000   .9936666
   70.00-  84.00         5.0     .0016667   .9953333
   84.00-  98.00         5.0     .0016667   .9970000
   98.00- 112.00         4.0     .0013333   .9983333
  112.00- 126.00         0.0    0.0000000   .9983333
  126.00- 140.00         0.0    0.0000000   .9983333
  140.00- 154.00         0.0    0.0000000   .9983333
  154.00- 168.00         2.0     .0006667   .9990000
  168.00- 182.00         1.0     .0003333   .9993334
  182.00- 196.00         0.0    0.0000000   .9993334
  196.00- 210.00         0.0    0.0000000   .9993334
  210.00- 224.00         0.0    0.0000000   .9993334
  224.00- 238.00         0.0    0.0000000   .9993334
  238.00- 252.00         1.0     .0003333   .9996667
  252.00- 266.00         0.0    0.0000000   .9996667
  266.00- 280.00         0.0    0.0000000   .9996667
  280.00- 294.00         0.0    0.0000000   .9996667
  294.00- 308.00         0.0    0.0000000   .9996667
  308.00- 322.00         0.0    0.0000000   .9996667
  322.00- 336.00         0.0    0.0000000   .9996667
  336.00- 350.00         0.0    0.0000000   .9996667
  350.00- 364.00         0.0    0.0000000   .9996667
  364.00- 378.00         0.0    0.0000000   .9996667
  378.00- 392.00         0.0    0.0000000   .9996667
  392.00- 406.00         0.0    0.0000000   .9996667
  406.00- 420.00         0.0    0.0000000   .9996667
  420.00- 434.00         0.0    0.0000000   .9996667
  434.00- 448.00         0.0    0.0000000   .9996667
  448.00- 462.00         0.0    0.0000000   .9996667
  462.00- 476.00         0.0    0.0000000   .9996667
  476.00- 490.00         0.0    0.0000000   .9996667
  490.00- 504.00         0.0    0.0000000   .9996667
  504.00- 518.00         1.0     .0003333  1.0000000
  518.00- 532.00         0.0    0.0000000  1.0000000
  532.00- 546.00         0.0    0.0000000  1.0000000
  546.00- 560.00         0.0    0.0000000  1.0000000

          TOTAL (EVENTS) =     3000.0
             MEAN (FLOW) =        8.2
         STD. DEV (FLOW) =     13.21
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              MONTHLY SIMULATION RUNOFF FREQUENCY
              SUMMARY RESULT FOR THE MONTH - JULY
                   RUNOFF IN WATERSHED MM

       CLASS             FREQUENCY        PDF        CDF

    0.00-   13.00          2928.0      .9445162   .9445162
   13.00-   26.00            40.0      .0129032   .9574194
   26.00-   39.00            28.0      .0090323   .9664516
   39.00-   52.00            30.0      .0096774   .9761291
   52.00-   65.00            14.0      .0045161   .9806452
   65.00-   78.00             9.0      .0029032   .9835484
   78.00-   91.00             9.0      .0029032   .9864516
   91.00-  104.00             9.0      .0029032   .9893548
  104.00-  117.00             5.0      .0016129   .9909678
  117.00-  130.00             3.0      .0009677   .9919355
  130.00-  143.00             3.0      .0009677   .9929032
  143.00-  156.00             3.0      .0009677   .9938710
  156.00-  169.00             4.0      .0012903   .9951613
  169.00-  182.00             2.0      .0006452   .9958065
  182.00-  195.00             3.0      .0009677   .9967742
  195.00-  208.00             0.0     0.0000000   .9967742
  208.00-  221.00             0.0     0.0000000   .9967742
  221.00-  234.00             1.0      .0003226   .9970968
  234.00-  247.00             3.0      .0009677   .9980645
  247.00-  260.00             0.0     0.0000000   .9980645
  260.00-  273.00             0.0     0.0000000   .9980645
  273.00-  286.00             0.0     0.0000000   .9980645
  286.00-  299.00             1.0      .0003226   .9983871
  299.00-  312.00             0.0     0.0000000   .9983871
  312.00-  325.00             2.0      .0006452   .9990323
  325.00-  338.00             0.0     0.0000000   .9990323
  338.00-  351.00             0.0     0.0000000   .9990323
  351.00-  364.00             2.0      .0006452   .9996774
  364.00-  377.00             0.0     0.0000000   .9996774
  377.00-  390.00             0.0     0.0000000   .9996774
  390.00-  403.00             0.0     0.0000000   .9996774
  403.00-  416.00             0.0     0.0000000   .9996774
  416.00-  429.00             1.0      .0003226  1.0000000
  429.00-  442.00             0.0     0.0000000  1.0000000
  442.00-  455.00             0.0     0.0000000  1.0000000
  455.00-  468.00             0.0     0.0000000  1.0000000
  468.00-  481.00             0.0     0.0000000  1.0000000
  481.00-  494.00             0.0     0.0000000  1.0000000
  494.00-  507.00             0.0     0.0000000  1.0000000
  507.00-  520.00             0.0     0.0000000  1.0000000

               TOTAL (EVENTS) =      3100.0
                  MEAN (FLOW) =        10.2
              STD. DEV (FLOW) =       22.75
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             MONTHLY SIMULATION RUNOFF FREQUENCY
              SUMMARY RESULT FOR THE MONTH - AUGUST
                   RUNOFF IN WATERSHED MM


      CLASS           FREQUENCY        PDF        CDF

   0.00-  17.00        2907.0       .9377420   .9377420
  17.00-  34.00          67.0       .0216129   .9593549
  34.00-  51.00          44.0       .0141935   .9735484
  51.00-  68.00          29.0       .0093548   .9829032
  68.00-  85.00          15.0       .0048387   .9877419
  85.00- 102.00          10.0       .0032258   .9909678
 102.00- 119.00           5.0       .0016129   .9925807
 119.00- 136.00           4.0       .0012903   .9938710
 136.00- 153.00           4.0       .0012903   .9951613
 153.00- 170.00           2.0       .0006452   .9958065
 170.00- 187.00           1.0       .0003226   .9961290
 187.00- 204.00           1.0       .0003226   .9964516
 204.00- 221.00           4.0       .0012903   .9977419
 221.00- 238.00           1.0       .0003226   .9980645
 238.00- 255.00           1.0       .0003226   .9983871
 255.00- 272.00           1.0       .0003226   .9987097
 272.00- 289.00           0.0      0.0000000   .9987097
 289.00- 306.00           1.0       .0003226   .9990323
 306.00- 323.00           0.0      0.0000000   .9990323
 323.00- 340.00           0.0      0.0000000   .9990323
 340.00- 357.00           1.0       .0003226   .9993548
 357.00- 374.00           1.0       .0003226   .9996774
 374.00- 391.00           0.0      0.0000000   .9996774
 391.00- 408.00           0.0      0.0000000   .9996774
 408.00- 425.00           0.0      0.0000000   .9996774
 425.00- 442.00           0.0      0.0000000   .9996774
 442.00- 459.00           0.0      0.0000000   .9996774
 459.00- 476.00           0.0      0.0000000   .9996774
 476.00- 493.00           0.0      0.0000000   .9996774
 493.00- 510.00           0.0      0.0000000   .9996774
 510.00- 527.00           0.0      0.0000000   .9996774
 527.00- 544.00           0.0      0.0000000   .9996774
 544.00- 561.00           0.0      0.0000000   .9996774
 561.00- 578.00           0.0      0.0000000   .9996774
 578.00- 595.00           0.0      0.0000000   .9996774
 595.00- 612.00           0.0      0.0000000   .9996774
 612.00- 629.00           0.0      0.0000000   .9996774
 629.00- 646.00           0.0      0.0000000   .9996774
 646.00- 663.00           1.0       .0003226  1.0000000
 663.00- 680.00           0.0      0.0000000  1.0000000

             TOTAL (EVENTS) =      3100.0
                MEAN (FLOW) =        12.2
            STD. DEV (FLOW) =       22.56
```

```
         MONTHLY SIMULATION RUNOFF FREQUENCY
         SUMMARY RESULT FOR THE MONTH - SEPTEMBER
               RUNOFF IN WATERSHED MM

     CLASS            FREQUENCY        PDF          CDF

  0.00-  12.00         2686.0       .8953333     .8953333
 12.00-  24.00          104.0       .0346667     .9299999
 24.00-  36.00           59.0       .0196667     .9496666
 36.00-  48.00           39.0       .0130000     .9626666
 48.00-  60.00           33.0       .0110000     .9736667
 60.00-  72.00           18.0       .0060000     .9796667
 72.00-  84.00           10.0       .0033333     .9830000
 84.00-  96.00            6.0       .0020000     .9850000
 96.00- 108.00            6.0       .0020000     .9870000
108.00- 120.00            5.0       .0016667     .9886667
120.00- 132.00            6.0       .0020000     .9906666
132.00- 144.00            6.0       .0020000     .9926667
144.00- 156.00            5.0       .0016667     .9943334
156.00- 168.00            2.0       .0006667     .9950000
168.00- 180.00            2.0       .0006667     .9956666
180.00- 192.00            7.0       .0023333     .9980000
192.00- 204.00            2.0       .0006667     .9986666
204.00- 216.00            0.0      0.0000000     .9986666
216.00- 228.00            0.0      0.0000000     .9986666
228.00- 240.00            1.0       .0003333     .9990000
240.00- 252.00            0.0      0.0000000     .9990000
252.00- 264.00            0.0      0.0000000     .9990000
264.00- 276.00            1.0       .0003333     .9993334
276.00- 288.00            0.0      0.0000000     .9993334
288.00- 300.00            0.0      0.0000000     .9993334
300.00- 312.00            1.0       .0003333     .9996667
312.00- 324.00            0.0      0.0000000     .9996667
324.00- 336.00            0.0      0.0000000     .9996667
336.00- 348.00            0.0      0.0000000     .9996667
348.00- 360.00            0.0      0.0000000     .9996667
360.00- 372.00            0.0      0.0000000     .9996667
372.00- 384.00            0.0      0.0000000     .9996667
384.00- 396.00            0.0      0.0000000     .9996667
396.00- 408.00            0.0      0.0000000     .9996667
408.00- 420.00            0.0      0.0000000     .9996667
420.00- 432.00            0.0      0.0000000     .9996667
432.00- 444.00            0.0      0.0000000     .9996667
444.00- 456.00            1.0       .0003333    1.0000000
456.00- 468.00            0.0      0.0000000    1.0000000
468.00- 480.00            0.0      0.0000000    1.0000000

           TOTAL (EVENTS) =      3000.0
              MEAN (FLOW) =        10.9
          STD. DEV (FLOW) =       22.24
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                 MONTHLY SIMULATION RUNOFF FREQUENCY
                 SUMMARY RESULT FOR THE MONTH - OCTOBER
                        RUNOFF IN WATERSHED MM


        CLASS            FREQUENCY        PDF          CDF

     0.00-  10.00         3001.0       .9680645     .9680645
    10.00-  20.00           71.0       .0229032     .9909678
    20.00-  30.00           20.0       .0064516     .9974194
    30.00-  40.00            1.0       .0003226     .9977419
    40.00-  50.00            3.0       .0009677     .9987097
    50.00-  60.00            2.0       .0006452     .9993548
    60.00-  70.00            0.0      0.0000000     .9993548
    70.00-  80.00            1.0       .0003226     .9996774
    80.00-  90.00            0.0      0.0000000     .9996774
    90.00- 100.00            0.0      0.0000000     .9996774
   100.00- 110.00            0.0      0.0000000     .9996774
   110.00- 120.00            0.0      0.0000000     .9996774
   120.00- 130.00            0.0      0.0000000     .9996774
   130.00- 140.00            0.0      0.0000000     .9996774
   140.00- 150.00            0.0      0.0000000     .9996774
   150.00- 160.00            0.0      0.0000000     .9996774
   160.00- 170.00            0.0      0.0000000     .9996774
   170.00- 180.00            0.0      0.0000000     .9996774
   180.00- 190.00            0.0      0.0000000     .9996774
   190.00- 200.00            0.0      0.0000000     .9996774
   200.00- 210.00            0.0      0.0000000     .9996774
   210.00- 220.00            0.0      0.0000000     .9996774
   220.00- 230.00            0.0      0.0000000     .9996774
   230.00- 240.00            0.0      0.0000000     .9996774
   240.00- 250.00            0.0      0.0000000     .9996774
   250.00- 260.00            0.0      0.0000000     .9996774
   260.00- 270.00            0.0      0.0000000     .9996774
   270.00- 280.00            0.0      0.0000000     .9996774
   280.00- 290.00            0.0      0.0000000     .9996774
   290.00- 300.00            0.0      0.0000000     .9996774
   300.00- 310.00            0.0      0.0000000     .9996774
   310.00- 320.00            0.0      0.0000000     .9996774
   320.00- 330.00            0.0      0.0000000     .9996774
   330.00- 340.00            0.0      0.0000000     .9996774
   340.00- 350.00            0.0      0.0000000     .9996774
   350.00- 360.00            0.0      0.0000000     .9996774
   360.00- 370.00            1.0       .0003226    1.0000000
   370.00- 380.00            0.0      0.0000000    1.0000000
   380.00- 390.00            0.0      0.0000000    1.0000000
   390.00- 400.00            0.0      0.0000000    1.0000000

                TOTAL (EVENTS) =      3100.0
                   MEAN (FLOW) =         5.6
               STD. DEV (FLOW) =        7.17
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             MONTHLY SIMULATION RUNOFF FREQUENCY
            SUMMARY RESULT FOR THE MONTH - NOVEMBER
                   RUNOFF IN WATERSHED MM


     CLASS              FREQUENCY       PDF         CDF

  0.00-    .30             0.0     0.0000000   0.0000000
   .30-    .60            30.0      .0100000    .0100000
   .60-    .90            40.0      .0133333    .0233333
   .90-   1.20           152.0      .0506667    .0740000
  1.20-   1.50           304.0      .1013333    .1753333
  1.50-   1.80           494.0      .1646667    .3400000
  1.80-   2.10           584.0      .1946667    .5346667
  2.10-   2.40           595.0      .1983333    .7330000
  2.40-   2.70           405.0      .1350000    .8680000
  2.70-   3.00           243.0      .0810000    .9490000
  3.00-   3.30            83.0      .0276667    .9766667
  3.30-   3.60            30.0      .0100000    .9866667
  3.60-   3.90            11.0      .0036667    .9903333
  3.90-   4.20             7.0      .0023333    .9926667
  4.20-   4.50             6.0      .0020000    .9946667
  4.50-   4.80             4.0      .0013333    .9960001
  4.80-   5.10             3.0      .0010000    .9970000
  5.10-   5.40             1.0      .0003333    .9973333
  5.40-   5.70             2.0      .0006667    .9980000
  5.70-   6.00             0.0     0.0000000    .9980000
  6.00-   6.30             2.0      .0006667    .9986666
  6.30-   6.60             1.0      .0003333    .9990000
  6.60-   6.90             0.0     0.0000000    .9990000
  6.90-   7.20             1.0      .0003333    .9993334
  7.20-   7.50             0.0     0.0000000    .9993334
  7.50-   7.80             0.0     0.0000000    .9993334
  7.80-   8.10             1.0      .0003333    .9996667
  8.10-   8.40             0.0     0.0000000    .9996667
  8.40-   8.70             0.0     0.0000000    .9996667
  8.70-   9.00             0.0     0.0000000    .9996667
  9.00-   9.30             0.0     0.0000000    .9996667
  9.30-   9.60             0.0     0.0000000    .9996667
  9.60-   9.90             0.0     0.0000000    .9996667
  9.90-  10.20             0.0     0.0000000    .9996667
 10.20-  10.50             1.0      .0003333   1.0000000
 10.50-  10.80             0.0     0.0000000   1.0000000
 10.80-  11.10             0.0     0.0000000   1.0000000
 11.10-  11.40             0.0     0.0000000   1.0000000
 11.40-  11.70             0.0     0.0000000   1.0000000
 11.70-  12.00             0.0     0.0000000   1.0000000

          TOTAL (EVENTS) =       3000.0
             MEAN (FLOW) =          2.1
         STD. DEV (FLOW) =          .67
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          MONTHLY SIMULATION RUNOFF FREQUENCY
           SUMMARY RESULT FOR THE MONTH - DECEMBER
                RUNOFF IN WATERSHED MM


     CLASS            FREQUENCY       PDF        CDF

  0.00-    .60          0.0       0.0000000  0.0000000
   .60-   1.20         39.0        .0125806   .0125806
  1.20-   1.80         69.0        .0222581   .0348387
  1.80-   2.40        279.0        .0900000   .1248387
  2.40-   3.00        480.0        .1548387   .2796774
  3.00-   3.60        692.0        .2232258   .5029032
  3.60-   4.20        666.0        .2148387   .7177420
  4.20-   4.80        487.0        .1570968   .8748387
  4.80-   5.40        249.0        .0803226   .9551613
  5.40-   6.00         69.0        .0222581   .9774194
  6.00-   6.60         23.0        .0074194   .9848387
  6.60-   7.20          4.0        .0012903   .9861290
  7.20-   7.80          7.0        .0022581   .9883871
  7.80-   8.40          4.0        .0012903   .9896774
  8.40-   9.00          3.0        .0009677   .9906452
  9.00-   9.60          4.0        .0012903   .9919355
  9.60-  10.20          4.0        .0012903   .9932258
 10.20-  10.80          3.0        .0009677   .9941936
 10.80-  11.40          0.0       0.0000000   .9941936
 11.40-  12.00          2.0        .0006452   .9948387
 12.00-  12.60          1.0        .0003226   .9951613
 12.60-  13.20          3.0        .0009677   .9961290
 13.20-  13.80          1.0        .0003226   .9964516
 13.80-  14.40          3.0        .0009677   .9974194
 14.40-  15.00          0.0       0.0000000   .9974194
 15.00-  15.60          1.0        .0003226   .9977419
 15.60-  16.20          2.0        .0006452   .9983871
 16.20-  16.80          0.0       0.0000000   .9983871
 16.80-  17.40          0.0       0.0000000   .9983871
 17.40-  18.00          0.0       0.0000000   .9983871
 18.00-  18.60          1.0        .0003226   .9987097
 18.60-  19.20          1.0        .0003226   .9990323
 19.20-  19.80          3.0        .0009677  1.0000000
 19.80-  20.40          0.0       0.0000000  1.0000000
 20.40-  21.00          0.0       0.0000000  1.0000000
 21.00-  21.60          0.0       0.0000000  1.0000000
 21.60-  22.20          0.0       0.0000000  1.0000000
 22.20-  22.80          0.0       0.0000000  1.0000000
 22.80-  23.40          0.0       0.0000000  1.0000000
 23.40-  24.00          0.0       0.0000000  1.0000000

           TOTAL (EVENTS) =      3100.0
              MEAN (FLOW) =         3.7
          STD. DEV (FLOW) =        1.44
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```
          SUMMARY OF TOTAL MONSOON SEASON
             RUNOFF VOLUME IN MM

      CLASS           FREQUENCY      PDF        CDF

   50.00- 120.00         3.0      .0300000   .0300000
  120.00- 190.00         2.0      .0200000   .0500000
  190.00- 260.00         2.0      .0200000   .0700000
  260.00- 330.00         6.0      .0600000   .1300000
  330.00- 400.00         3.0      .0300000   .1600000
  400.00- 470.00         7.0      .0700000   .2300000
  470.00- 540.00         5.0      .0500000   .2800000
  540.00- 610.00         8.0      .0800000   .3600000
  610.00- 680.00         5.0      .0500000   .4100000
  680.00- 750.00        10.0      .1000000   .5100000
  750.00- 820.00         6.0      .0600000   .5700001
  820.00- 890.00         3.0      .0300000   .6000000
  890.00- 960.00         6.0      .0600000   .6600000
  960.00-1030.00         5.0      .0500000   .7100000
 1030.00-1100.00         5.0      .0500000   .7600000
 1100.00-1170.00         4.0      .0400000   .8000000
 1170.00-1240.00         6.0      .0600000   .8600000
 1240.00-1310.00         2.0      .0200000   .8800000
 1310.00-1380.00         4.0      .0400000   .9200000
 1380.00-1450.00         1.0      .0100000   .9299999
 1450.00-1520.00         1.0      .0100000   .9400001
 1520.00-1590.00         0.0     0.0000000   .9400001
 1590.00-1660.00         0.0     0.0000000   .9400001
 1660.00-1730.00         2.0      .0200000   .9600000
 1730.00-1800.00         1.0      .0100000   .9700000
 1800.00-1870.00         0.0     0.0000000   .9700000
 1870.00-1940.00         2.0      .0200000   .9900000
 1940.00-2010.00         0.0     0.0000000   .9900000
 2010.00-2080.00         0.0     0.0000000   .9900000
 2080.00-2150.00         1.0      .0100000  1.0000000
 2150.00-2220.00         0.0     0.0000000  1.0000000
 2220.00-2290.00         0.0     0.0000000  1.0000000
 2290.00-2360.00         0.0     0.0000000  1.0000000
 2360.00-2430.00         0.0     0.0000000  1.0000000
 2430.00-2500.00         0.0     0.0000000  1.0000000
 2500.00-2570.00         0.0     0.0000000  1.0000000
 2570.00-2640.00         0.0     0.0000000  1.0000000
 2640.00-2710.00         0.0     0.0000000  1.0000000
 2710.00-2780.00         0.0     0.0000000  1.0000000
 2780.00-2850.00         0.0     0.0000000  1.0000000

            TOTAL (EVENTS) =      100.0
               MEAN (FLOW) =      812.3
           STD. DEV (FLOW) =    428.31
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```
                SUMMARY OF TOATL YEARLY RUNOFF VOLUME IN MM

            CLASS            FREQUENCY        PDF        CDF

      100.00- 165.00            1.0       .0100000   .0100000
      165.00- 230.00            1.0       .0100000   .0200000
      230.00- 295.00            2.0       .0200000   .0400000
      295.00- 360.00            1.0       .0100000   .0500000
      360.00- 425.00            2.0       .0200000   .0700000
      425.00- 490.00            4.0       .0400000   .1100000
      490.00- 555.00            2.0       .0200000   .1300000
      555.00- 620.00            2.0       .0200000   .1500000
      620.00- 685.00            2.0       .0200000   .1700000
      685.00- 750.00            8.0       .0800000   .2500000
      750.00- 815.00            3.0       .0300000   .2800000
      815.00- 880.00            7.0       .0700000   .3500000
      880.00- 945.00            4.0       .0400000   .3900000
      945.00-1010.00            9.0       .0900000   .4800000
     1010.00-1075.00            4.0       .0400000   .5200000
     1075.00-1140.00            5.0       .0500000   .5700001
     1140.00-1205.00            5.0       .0500000   .6200000
     1205.00-1270.00            5.0       .0500000   .6700000
     1270.00-1335.00            6.0       .0600000   .7300000
     1335.00-1400.00            4.0       .0400000   .7700000
     1400.00-1465.00            1.0       .0100000   .7800000
     1465.00-1530.00            5.0       .0500000   .8300000
     1530.00-1595.00            5.0       .0500000   .8800000
     1595.00-1660.00            2.0       .0200000   .9000000
     1660.00-1725.00            0.0      0.0000000   .9000000
     1725.00-1790.00            2.0       .0200000   .9200000
     1790.00-1855.00            1.0       .0100000   .9299999
     1855.00-1920.00            0.0      0.0000000   .9299999
     1920.00-1985.00            2.0       .0200000   .9500000
     1985.00-2050.00            1.0       .0100000   .9600000
     2050.00-2115.00            1.0       .0100000   .9700000
     2115.00-2180.00            0.0      0.0000000   .9700000
     2180.00-2245.00            0.0      0.0000000   .9700000
     2245.00-2310.00            2.0       .0200000   .9900000
     2310.00-2375.00            1.0       .0100000  1.0000000
     2375.00-2440.00            0.0      0.0000000  1.0000000
     2440.00-2505.00            0.0      0.0000000  1.0000000
     2505.00-2570.00            0.0      0.0000000  1.0000000
     2570.00-2635.00            0.0      0.0000000  1.0000000
     2635.00-2700.00            0.0      0.0000000  1.0000000

                TOTAL (EVENTS) =       100.0
                   MEAN (FLOW) =      1090.6
               STD. DEV (FLOW) =     472.64
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```
          SUMMARY OF MAXIMUM DAILY FLOW IN CU. M/SEC

    CLASS            FREQUENCY       PDF         CDF

   0.00- 120.00          9.0      .0900000    .0900000
 120.00- 240.00          5.0      .0500000    .1400000
 240.00- 360.00          6.0      .0600000    .2000000
 360.00- 480.00          8.0      .0800000    .2800000
 480.00- 600.00          9.0      .0900000    .3700000
 600.00- 720.00          8.0      .0800000    .4500000
 720.00- 840.00          5.0      .0500000    .5000000
 840.00- 960.00          6.0      .0600000    .5599999
 960.00-1080.00          5.0      .0500000    .6100000
1080.00-1200.00          4.0      .0400000    .6500000
1200.00-1320.00          9.0      .0900000    .7400000
1320.00-1440.00          4.0      .0400000    .7800000
1440.00-1560.00          3.0      .0300000    .8099999
1560.00-1680.00          4.0      .0400000    .8500000
1680.00-1800.00          2.0      .0200000    .8700000
1800.00-1920.00          1.0      .0100000    .8800000
1920.00-2040.00          2.0      .0200000    .9000000
2040.00-2160.00          1.0      .0100000    .9100000
2160.00-2280.00          1.0      .0100000    .9200000
2280.00-2400.00          2.0      .0200000    .9400001
2400.00-2520.00          2.0      .0200000    .9600000
2520.00-2640.00          0.0     0.0000000    .9600000
2640.00-2760.00          0.0     0.0000000    .9600000
2760.00-2880.00          1.0      .0100000    .9700000
2880.00-3000.00          1.0      .0100000    .9800000
3000.00-3120.00          0.0     0.0000000    .9800000
3120.00-3240.00          0.0     0.0000000    .9800000
3240.00-3360.00          0.0     0.0000000    .9800000
3360.00-3480.00          0.0     0.0000000    .9800000
3480.00-3600.00          0.0     0.0000000    .9800000
3600.00-3720.00          0.0     0.0000000    .9800000
3720.00-3840.00          0.0     0.0000000    .9800000
3840.00-3960.00          0.0     0.0000000    .9800000
3960.00-4080.00          0.0     0.0000000    .9800000
4080.00-4200.00          1.0      .0100000    .9900000
4200.00-4320.00          0.0     0.0000000    .9900000
4320.00-4440.00          1.0      .0100000   1.0000000
4440.00-4560.00          0.0     0.0000000   1.0000000
4560.00-4680.00          0.0     0.0000000   1.0000000
4680.00-4800.00          0.0     0.0000000   1.0000000

           TOTAL (EVENTS) =      100.0
              MEAN (FLOW) =     1010.4
          STD. DEV (FLOW) =    814.18
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          SUMMARY OF EXTREMELY LOW FLOWS IN CU.M/SEC
          (Flows less than 2.5 cubic meter per sec )

    CLASS            FREQUENCY       PDF         CDF

 0.00-    .07           0.0      0.0000000  0.0000000
  .07-    .14           0.0      0.0000000  0.0000000
  .14-    .21           0.0      0.0000000  0.0000000
  .21-    .28           1.0       .0100000   .0100000
  .28-    .35           0.0      0.0000000   .0100000
  .35-    .42           0.0      0.0000000   .0100000
  .42-    .49           1.0       .0100000   .0200000
  .49-    .56           0.0      0.0000000   .0200000
  .56-    .63           1.0       .0100000   .0300000
  .63-    .70           1.0       .0100000   .0400000
  .70-    .77           2.0       .0200000   .0600000
  .77-    .84           1.0       .0100000   .0700000
  .84-    .91           3.0       .0300000   .1000000
  .91-    .98           4.0       .0400000   .1400000
  .98-   1.05           3.0       .0300000   .1700000
 1.05-   1.12           9.0       .0900000   .2600000
 1.12-   1.19           6.0       .0600000   .3200000
 1.19-   1.26           5.0       .0500000   .3700000
 1.26-   1.33           6.0       .0600000   .4300000
 1.33-   1.40          10.0       .1000000   .5300000
 1.40-   1.47           4.0       .0400000   .5700001
 1.47-   1.54           7.0       .0700000   .6400000
 1.54-   1.61           2.0       .0200000   .6600000
 1.61-   1.68           9.0       .0900000   .7500000
 1.68-   1.75           4.0       .0400000   .7900000
 1.75-   1.82           6.0       .0600000   .8500000
 1.82-   1.89           6.0       .0600000   .9100000
 1.89-   1.96           4.0       .0400000   .9500000
 1.96-   2.03           2.0       .0200000   .9700000
 2.03-   2.10           0.0      0.0000000   .9700000
 2.10-   2.17           0.0      0.0000000   .9700000
 2.17-   2.24           1.0       .0100000   .9800000
 2.24-   2.31           1.0       .0100000   .9900000
 2.31-   2.38           0.0      0.0000000   .9900000
 2.38-   2.45           1.0       .0100000  1.0000000
 2.45-   2.52           0.0      0.0000000  1.0000000
 2.52-   2.59           0.0      0.0000000  1.0000000
 2.59-   2.66           0.0      0.0000000  1.0000000
 2.66-   2.73           0.0      0.0000000  1.0000000
 2.73-   2.80           0.0      0.0000000  1.0000000

         TOTAL (EVENTS) =       100.0
            MEAN (FLOW) =         1.4
        STD. DEV (FLOW) =         .40
```

SUMMARY OF CONSECUTIVE DAYS OF FLOWS LESS THAN 1.5 C.M/S

CONSECUTIVE DAYS	FREQUENCY	PDF	CDF
2	5	0.06329	0.06329
3	6	0.07595	0.13924
4	5	0.06329	0.20253
5	2	0.02532	0.22785
6	1	0.01266	0.24051
7	2	0.02532	0.26582
8	2	0.02532	0.29114
9	4	0.05406	0.34177
10	1	0.01266	0.35443
11	3	0.03797	0.39241
12	2	0.02532	0.41772
13	1	0.01266	0.43038
14	3	0.03797	0.46835
16	2	0.02532	0.49367
17	2	0.02532	0.51899
18	3	0.03797	0.55696
19	1	0.01266	0.56962
20	1	0.01266	0.58228
21	1	0.01266	0.59494
22	1	0.01266	0.60759
23	1	0.01266	0.62025
24	2	0.02532	0.64557
25	1	0.01266	0.65823
26	3	0.03797	0.69620
30	2	0.02532	0.72152
31	3	0.03797	0.75949
32	1	0.01266	0.77215
33	1	0.01266	0.78481
34	2	0.02532	0.81013
37	1	0.01266	0.82278
43	2	0.02532	0.84810
45	1	0.01266	0.86076
49	1	0.01266	0.87342
50	1	0.01266	0.88608
51	1	0.01266	0.89873
62	1	0.01266	0.91139
66	1	0.01266	0.92405
67	1	0.01266	0.93671
71	1	0.01266	0.94937
77	1	0.01266	0.96203
86	1	0.01266	0.97469
111	1	0.01266	0.98734
157	1	0.01266	1.00000

MEAN CONSECUTIVE DAYS = 24.42
STANDARD DEVIATION (DAYS) = 26.55

REFERENCES CITED

Benjamin, J. R. and C. A. Cornell, 1970. Probability, Statistics, and Decision for Civil Engineers. McGraw Hill Book Company, New York.

Burnash, Robert J. C., R. Larry Ferral, and Richard A. McGuire, 1973. A Generalized Streamflow Simulation System: Conceptual Modeling for Digital Computers. Joint Federal-State River Forecast Center, U.S. Department of Commerce, National Weather Service, and State of California, Department of Water Resources, Sacramento, California.

Duckstein, Lucien, Martin M. Fogel, and C. C. Kisiel, 1972. A Stochastic Model of Runoff-Producing Rainfall for Summer Type Storms. Water Resources Research, Vol. 8, No. 2, pp 410-421.

Duckstein, Lucien, Martin M. Fogel, and Donald D. Davis, 1975. Mountainous Winter Precipitation: a Stochastic Event-Based Approach. Proc. A G U National Symposium on Precipitation Analysis for Hydrologic Modeling, Davis, California.

Dunne, T., and L. B. Leopold, 1978. Water in Environmental Planning. W. H. Freeman and Co., San Francisco, Cal.

Dutt, Prem, 1979. Report on fodder and Pasture Improvement, Report no 3, Tinau Watershed Management Plan, Volume II (Reports), SATA/HMG, Nepal.

Fleming, G., 1975. Computer Simulation Technique in Hydrology. American Elsenier Publishing Co., Inc., New York.

Fleming, William M., 1978. Classification of Catchments in the Western Development Region of Nepal: Erosion Hazzard and Land Management Problems, UNFAO, NEP/74/020 Working Document.

Fogel, Martin M., Lucien Duckstein, and Chester C. Kisiel, 1971. Space-Time Validation of a Thunderstorm Rainfall Model. Water Resources Bulletin, Vol. 7, No. 2, pp 309-316.

Fogel, Martin M., Lucien Duckistein, and Andre Musy, 1976. Event-Based Formulation of Watershed Management. Proceedings of the Specialty Conference on "Environmental Impact of Irrigation & Drainage", Ottawa, Ontario, Canada.

Hann, C. T., 1982. Statistical Method in Hydrology. Iowa State University Press, Ames, Iowa.

Hekman, Louis H., 1977. Simulation and Evaluation of Water Yield Response to Vegetation Management on a Forested Watershed in Arizona, Unpublished Ph. D. Dissertation, The University of Arizona, Tucson

Jones, Allen D., 1981. A methodology of Rainfall Data Analysis and Stochastic Rainfall-Runoff Synthesis. Unpublished Masters Thesis, The University of Arizona, Tucson, Arizona.

Law, A. M. and W. D. Kelton, 1982. Simulation Modeling and Analysis, McGraw-Hill Book Company, New York.

McDowell, William C., 1985. A stock Pond Simulation Model for Chaparral Watershed in Arizona, Unpublished Masters's Thesis, The University of Arizona, Tucson, Arozona.

Pradhan, M. L., P. L. Maharjan, D. B. Tamang, Tej Bahadur K.C.(1966-1967), Soil Survey of Palpa District Lumbini Zone. Soil Science Section, Department of Agricultural Educarion and Research, Ministry of Food and Agriculture HMG/Nepal.

Rieger, Hans C., Fritz Bieri, Helmut Eggers, Willi Goldschall, and Jurgen Steiger, 1976. Himamayan Ecosystem Research Mission Nepal Report, Heidelberg, Federal Republic of Germany.

TWP, 1980. Tinau Watershed Management Plan, Vol I (Maintext) SATA/HMG Nepal.

Williams, J. R., 1975. Sediment Yield Prediction with Universal Equation Using Runoff Energy Factor. In: Present and Prospective Technology for Predicting Sediment Yields and Resources. ARS-S-40, U. S. Department of Agriculture, pp. 244-252.