A COMPUTER MODEL FOR FLOW SIMULATION OF MISSION CREEK

by

RORY MARSHALL MONTGOMERY LEITH

B.Sc., University of British Columbia, 1964
M.Sc., University of British Columbia, 1966

A THESIS SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in the

Department
of
Civil Engineering

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

February, 1972

Department of Civil Engineering

The University of British Columbia
Vancouver 8, Canada

Date February 1, 1972

A B S T R A C T

A description is given of the development and application of a computer program to simulate the streamflows in Mission Creek. This program provides a mathematical hydrologic model of the Mission Creek basin and is applied to 16 years of record between 1948 and 1971. The length of record for a year is normally from 31 March to 30 September inclusive.

The model has been utilized to study the mechanisms for generating runoff, particularly rain runoff, the relationship between evapotranspiration and elevation; and the effectiveness of certain areas of the basin in generating runoff.

The sensitivity and range of the parameters used in the model have been examined and techniques for predicting the parameters have been developed.

Hydrologic areas of concern in the model are: snowmelt, evapotranspiration, runoff from rainfall and soil moisture deficiency.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A C K N O W L E D G E M E N T S

The author wishes to take this opportunity to thank his supervisor, Dr. M. C. Quick, for his suggestion of the problem and his encouragement and assistance throughout the course of the development of the model; Mr. A. Pipes for his advice and aid with the programming; and Professor S. O. Russell for his valuable suggestions. Sincere thanks are also due to Mr. Richard Brun for the diagrams.

Funding for the research came from two sources, the B.C. Provincial Water Resources Grant and the B.C. Disaster Relief Fund. The work forms part of a continuing study on flow forecasting and the hydrology of mountain catchments.

CHAPTER I

INTRODUCTION

I.1 Description of the Okanagan Valley

The Okanagan Valley, which contains the Mission Creek basin, is located in the Thompson Plateau of British Columbia. Extending some 100 miles north from the Canada-United States border, this valley contains several lakes, the largest of which is Lake Okanagan. These lakes together with a pleasant semi-arid climate are attracting increasing numbers of both tourists and permanent residents.

As yet, industrial development in the Okanagan is light, but agriculture, primarily fruit farming, requires irrigation and summer tourism relies on the water recreation afforded by the lakes. Water is therefore of great importance to the valley.

I.2 The Water Quantity Problem of the Okanagan

There has been recent concern for the quality of the water in the lakes, but as far as water quantity is concerned the primary problem of the Okanagan is lake level regulation. Lake Okanagan has a surface area of 84,200 acres and is operated through a surface elevation range of 4 feet, providing a live storage of 337,000 acre-feet. The drawdown limit is imposed primarily by esthetic considerations for the tourists and residents around the lake. The annual inflow into the lake can range from 80,000 acre-feet to 600,000 acre-feet with an average of 350,000 acre-feet.

These inflows, which are net of evaporation, together with a limited capacity to discharge water from the lake, provide some indication of why lake level regulation is a problem.

To achieve lake level regulation improved prediction procedures are required. To this end the mechanisms for runoff are being studied. The Mission Creek Flow Simulation has as one of its prime objectives the examination of runoff generation.

I.3 Geological Background of the Okanagan Valley

The present form of the Okanagan Valley is comparatively recent, of the order of 10,000 years. But the history of the Okanagan Valley began in the early Tertiary, Table 1, when extensive swamps and lake deposits formed in the low areas of what is now British Columbia's Thompson Plateau. During the middle Tertiary, the area was subjected to uplift and extensive lava flows. Also during this period a line of weakness appeared along the present course of the valley. To the north of Kelowna the main depression became a compound valley while to the south it remained a single trench.

TABLE 1

GEOLOGICAL TIME SCALE

ERA	PERIOD	EPOCH	MILLIONS OF YEARS AGO	DURATION MILLIONS OF YEARS
		RECENT		
	QUATENARY			
		PLEISTOCENE	1	1
		PLIOCENE	1 - 13	13
CENEZOIC		MIOCENE	13 - 25	12
	TERTIARY	OLIGOCENE	25 - 36	11
		EOCENE	36 - 58	22
		PALEOCENE	58 - 63	5

During the Pleistocene, the pressure of a 7,000 foot ice pack carved the valley to its present U shape, with pre-existing soils and other loose materials being moved and mixed in the ice. The till from this glacial period still covers the higher elevations of the valley. The last glacial period was the Wisconsin which occurred approximately 25 to 50 thousand years ago. The glacial retreat took place some 10,000 years ago and at this time the Okanagan appeared in roughly its present form. A more complete description of the surface geology of the Okanagan area may be found in Nasmith [1962].

I.4 Description of Mission Creek Basin

Mission Creek flows into Okanagan Lake just south of Kelowna, Figure 1. The basin covers some 330 square miles, much of which is upland area, Table 2, Section 3.2.

TABLE 2

AREAS AND ELEVATIONS OF THE BANDS USED IN THE MISSION CREEK MODEL

BAND NO.	FROM (ft.)	TO (ft.)	CENTER BAND ELEVATION (ft.)	AREA (sq. mi.)	
1	1000	1500	1250	8	
2	1500	2000	1750	12	First Level
3	2000	2500	2250	8	
4	2500	3000	2750	15	
5	3000	3500	3250	24	Second Level
6	3500	4000	3750	33	
7	4000	4500	4250	66	
8	4500	5000	4750	68	
9	5000	5500	5250	38	Third Level
10	5500	6000	5750	37	
11	6000	6500	6250	26	
12	6500	7000	6750	2	

Roughly speaking, three levels may be distinguished on the basis of soil, climate, and vegetation. The first level, extending from the valley floor to 2,000 feet is marked by grassland with shrub vegetation and scattered pine trees. The second level, from 2,000 feet to 4,000 feet, has more fertile soil with increasingly thick forest cover. Above 4,000

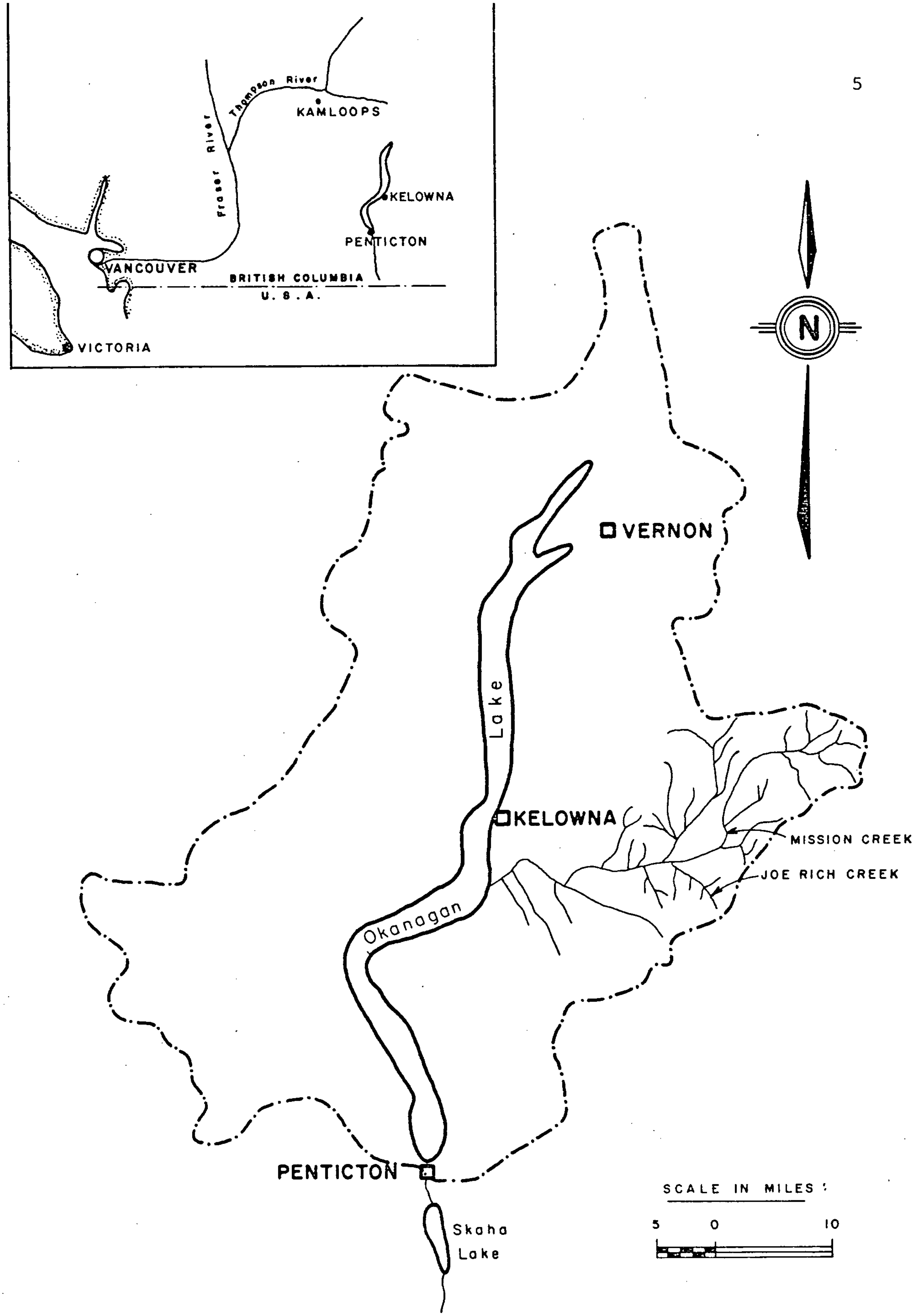


FIG.1 OKANAGAN LAKE AND MISSION CREEK BASIN.

feet, increased precipitation provides winter snow packs of 20 inch water equivalent at 6,000 feet and dense forest occurs except in alpine meadow areas.

Mission Creek provides some 20 to 25 per cent of the yearly inflow to Lake Okaganan [Pipes, 1971] and is the most important single contributor to lake inflow. Thus it is a reasonable candidate for the study of the mechanisms of runoff generation in the Okanagan. The Mission Creek Flow Model described in the following chapters is primarily an attempt to study the generation of runoff.

CHAPTER II

COMPUTER MODELING

II.1 Definition of Terms and Basic Philosophy

As the concepts of system, simulation, and model are now employed in widely divergent disciplines, subtle shades of meaning are attached to these terms. For example, computer programs referred to as simulators by some writers are considered models by others. In the face of this divergence of opinion this thesis has adopted the following definitions from Evans [1967].

(i) a model is defined as a representation both of the parts of a system and of the interactions of the parts. The model may be a symbolic representation or a physical replica of the system;

(ii) a system is defined as a collection of identifiable parts capable of interacting in such a manner that the entire system functions together;

(iii) at any given instant of time the system is in a particular condition or state. The states of a system are usually considered in a chronological succession referred to as a state history.

Two general types of numerical quantities are used in models, parameters and variables. Parameters may be either constants or functionally changing values. For example, in the model described in this thesis, the areas of the bands are constant parameters for each year, while UZ, the unit hydrograph parameter, is a function of flow. Parameters are used as indices of the interactions of the components of a system and as such may be considered as operators on the variables. Variables may be subdivided into input variables, such as daily temperature and variables calculated within the model, such as daily actual evapotranspiration.

The basic philosophy of modeling may be stated in terms of inputs, outputs and transformations. Inputs and outputs are known, with some inputs or outputs known with greater accuracy than others. Now the system is the so-called "black box" which transforms the inputs into outputs. Better simulation, that is closer replication, of the system's state history by the model's state history is assumed to indicate better representation of the system, see Section IV.1. The better representation of the system provides a more reliable quantitative description of the components and of their interactions in the system. With this approach, simulation may be regarded as the indirect investigation of the response or behaviour of the system.

Certain considerations are important in modeling. A suitable type of model should be chosen for the system. The model should have a maximum physical or empirical background while remaining as simple as possible within the limits of the input data. These considerations are elaborated upon in the following sections.

II.2 Types of Simulation

Three types of models are used in simulation: physical models, analog models, and digital models. This thesis is concerned with the most recent development in digital models, digital computer models. In digital computer modeling, the model is translated into a computer program. This program is then a mathematical representation of the model and the state history of the model is generated by the computer.

In any simulation procedure the model is tested and improved by simulating systems with known input and output. In digital computer modelling enormous benefits in speed and cost of computations are realized. Because of the high computation speed, the model parameters may be tested for adequacy, sensitivity, and optimum values.

II.3 Application to Hydrology

The hydrological cycle is fairly easy to describe in qualitative terms. Principal components of the cycle are reasonably easy to identify and the interactions among major components are known at least qualitatively. The application of this qualitative knowledge to obtain quantitative results is impeded by the difficulty in achieving analytical descriptions of the interactions subject to the initial and boundary conditions of the basin.

Digital computer modeling of the hydrologic cycle has as its object the development of a general system of quantitative analysis, in other words, an analytical description of the system. The high computational speed of a digital computer allows this analytical description to take the form of continuous mathematical relations among the elements of the hydrological system.

In modeling the runoff from a basin, the basin is considered to be the system and the series of outflows are the state history. The identifiable parts of the system may include: interception, evapotranspiration, precipitation, soil moisture, infiltration. The interactions include precipitation-infiltration-soil moisture-evapotranspiration, and temperature-snowmelt runoff.

II.4 Hydrologic Model Requirements

Continuous simulation of the major processes and interactions in the system is the prime requirement for a quantitative hydrologic model. But simulation of all the components and interactions of the system cannot be realized because of the prohibitive amounts of data required. The principal components and interactions must be selected to produce a qualitative description with an acceptable level of simplicity within the limits imposed by the available data. In short, the scope of the model is restricted by the available data, and the amount known about the components and interactions of the system.

Additional criteria for a hydrologic model include:

1. The model should represent the hydrologic regimes of a wide variety of streams with a high level of accuracy.

2. The model should be easily applied to different watersheds with existing hydrologic data.

3. The model should be physically relevant so that estimates of other useful quantities such as actual evapotranspiration and overland flow may be obtained.

II.5 Examples of Hydrologic Modeling

II.5.1 Nash and Sutcliffe. Nash and Sutcliffe [1970] discuss the problem of determining the river flows from rainfall, evaporation, and other factors by means of conceptual models. By conceptual models they refer to a mathematical model which is translated to a computer program. Their contention is that the processes linking rainfall, snowmelt and river flow are deterministic and are governed by reasonably well known physical laws. The difficulties are essentially those outlined in Section II.3 involving interactions and boundary conditions. Simplifying assumptions are justified, they claim, because the basin is a geomorphological system whose components are related to each other by long common history. They also hold out the interesting thought that if the relation between the operation of the basin in converting precipitation to runoff can be recognized, then the operation of even an ungauged catchment might be forecast from, for example, aerial photographs.

Traditional methods of forecasting discharge from rainfall tend to divide the problem into (a) forecasting volumes of runoff; and (b) forecasting the time distribution of the runoff. This procedure for forecasting is distinct from forecasts based on routing hydrographs observed upstream. Co-axial graphical correlation was developed by Linsley, Kohler, and others to forecast folumes [Linsley, 1949]. This method relies upon establishing empirical relations between the volumes of runoff in single floods and corresponding volumes and durations of rainfall, indices of previous rainfall, and time of year. The distribution of the runoff in time is usually estimated by the application of a unit hydrograph.

Nash and Sutcliffe claim that due to inherent impossibility of separating the two components, storm runoff and base flow, the co-axial graphical technique and the unit hydrograph technique appear incapable of further evolution.

If flow were the only variable of interest for a basin, then the only model requirements would be specification of the model's form and parametric values such that the computed output or state history of the model was a close reproduction of the measured output or state history of the system.

But if the model is also to examine the process of converting rainfall to discharge, then additional requirements must be met. First, some guide to the relative significance of model parts and the accuracy and stability of parametric values is required. Second, the model should reflect the physics of the system as closely as possible. Third, the model parameters should be as independent as possible. In short, the model should be as versatile as possible, while being as simple as possible.

Optimization of the model should be achieved by automatic means, that is, by the use of computer optimization programs. The index of agreement between observed and computed values is suggested to be a sum of squares of the differences, F^2, analogous to the residual variance of regression analysis.

The shape of the F^2 surface in the vicinity of the optimum point may be taken as an indication of the stability of the optimum value of the parameters.

Additional details in applying this philosophy to modeling flow from basins is given in O'Connel [1970] and Mandeville [1970].

II.5.2 Rockwood and Nelson. Rockwood and Nelson [1966] describe a computer program for simulating natural streamflow and the effects of reservoir regulation for the Columbia River Basin. This program is claimed to be general enough to be applied to any basin configuration. Streamflows are synthesized by evaluating the entire hydrologic process of snowmelt and rainfall runoff for all important locations along the river system.

The data necessary for the program is primarily physical and meteorological together with time and runoff coefficients representing the hydrologic character of the individual sub-basins, channel reaches and reservoirs. Some of these coefficients are derived empirically, others from physical data. But the empirical coefficients can be derived from repetitive trial and error approximations through the use of historical hydrometeorological data.

Four requirements for developing this hydrologic model were: (1) a time increment sufficiently small to allow representation of fluctuations of streamflow that occur in a given drainage basin; (2) time from receipt of basic meteorological data to derivation of forecasted flows should be less than four hours; (3) the program should allow for adjustment to the computed streamflow values in accordance with observed streamflow conditions; and (4) the method of applying forecast values of input water supply should be flexible, and allow for applying more than one forecast condition.

The program combines evaluation of various hydrometeorological functions to represent the entire process of streamflow simulation, from computation of the following: (1) daily snowmelt over a sub-basin for a period of study or forecast; (2) the rainfall observed or forecast to fall; (3) the relative contributing area of snowmelt or rainfall effective in producing runoff; (4) the division of rainfall or snowmelt excesses into surface or subsurface flow components; (5) the routing of water input through basin storage and addition of appropriate base flow values to derive streamflow from headwater or intermediate drainages; (6) the routing of outflows derived from basin storage through successive reaches of channel storage; (7) the amount of intermediate tributaries inflows, and summing the total routed flows at river junctions; (8) the routing of total lake or reservoir inflows through reservoir storage; (9) the sum of total streamflow at downstream control points.

The program is designed to synthesize streamflow for periods of one month at a time for each basin, channel reach, lake or reservoir. The hydrometeorological information required for determining input to basins, channels, or reservoirs is specified for each computation period at a time. The information includes: (a) daily temperature index data and daily snowmelt rates for computing snowmelt excesses; (2) daily rainfall amounts by basins; (3) specified snowcover or contributing area values; (4) input period distribution values for breaking down daily water excesses to period amounts [3 hours, 6 hours, etc.]; (5) specified daily streamflow values for areas for which basin routing is not required; (6) specified daily outflows for storage reservoirs with controlled outflow; and (7) specified daily storage values for those reservoirs operated with prescribed storage increments.

Snowmelt is computed on a maximum daily temperature index, with a base temperature and a melt rate characteristic of the basin. The base temperature and melt rate are determined experimentally: they are variable and may be specified for each day.

Snowcover depletion is one of the prime variables in computing daily snowmelt runoff. In this program, snowcover depletion during active snowmelt is expressed as a cubic function of accumulated generated runoff, that is,

$$Y = A + BX + CX^2 + DX^3$$

where Y is the snow-covered area in per cent of basin total, X is the accumulated generated runoff, in per cent of season total, and A, B, C and D are coefficients derived from experimental data by use of curve fitting procedures.

Each day's computed snowmelt and rainfall are combined to provide the total daily water excesses. As the routing time through basin storage is generally less than one day, the daily water excesses are normally subdivided into period values.

Water input to natural drainages are separated into three components: (1) surface; (2) subsurface; (3) base flow. These components are arranged in order of time delay between inflow and outflow. Base flow represents flow derived from deep percolation through subterranean channels and may be delayed by several months. The subsurface flow takes place within the first few feet but below the first few inches of the surface. The time delay for subsurface flow is of the order of a few days. The surface flow occurs on the surface or within the first few inches of soil, and its time delay may range from a few hours to a few days for a large basin.

The total water input is divided between surface and subsurface flow on a variable percentage basis. For high rates of input, a larger percentage of water is assigned to surface runoff.

Base flows are not routed but are specified from knowledge of runoff characteristics of a particular basin. Base flow values are specified for the beginning and end of the computation period, and the program interpolates intermediate values for each time period.

Basin storage routing (incremental storage routing): the computed period water excesses are converted to basin inflow amounts (in cfs.). Water excesses in each period are routed through surface and sub-surface flow separately . The number of increments, up to 5, of storage and time of storage per increment are specified in the basin characteristics for each basin. By varying the number of increments of storage, the time of storage and the coefficients used in separating surface and subsurface runoff, any shape of time distribution of runoff may be generated.

If the lag and peak characteristics have been found from a previously derived unit hydrograph, the basin storage routing coefficients required to synthesize the unit hydrograph by incremental storage routing method may be found.

The paper continues with details of channel routing, lake or reservoir routing, specifying basin or channel outflows, and adjustments of streamflow routing values to observed conditions. These are not of immediate interest to this thesis.

II.5.3 <u>Stanford IV</u>. Research in digital models of the hydrologic cycle began at Stanford in 1959. The object of this research is the development of a general system of quantitative analysis for hydrologic regimes. The most recent development in this analysis is the Stanford IV model, described by Crawford [1966]. After explaining certain elements of the hydrologic cycle, Crawford goes on to describe the representations of these elements in the model.

The model for infiltration considers the moisture supply, that is the volume of precipitation or snowmelt plus the surface detention carryover available for infiltration. Infiltration is made up of two components, direct and delayed. Delayed infiltration occurs from water which flows into temporary storages. When heavy rainfall occurs, the temporary storages fill and overland flow begins to occur. As areal and temporal variations in infiltration capacity in the watershed will strongly influence watershed behaviour, a cummulative distribution of infiltration capacity is considered, as shown in Figure 2.

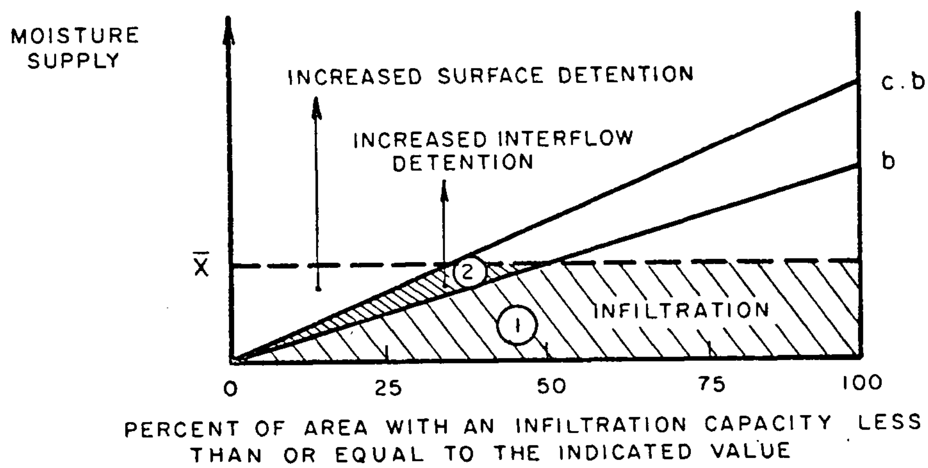


FIG.2

Figure 2

Cummulative Distribution of Infiltration Capacity
Reaction of a Watershed to a Moisture Supply of $\bar{x}$

In area 1 all infiltrated water is assumed to move into the lower zone and groundwater storages. In area 2, the infiltrated water contributes to interflow. Functional relationships for land surface response in terms of $\bar{x}$, c and b can be obtained. These relations lead to functions which provide smooth variation in the components of land surface response as the moisture supply is varied. The quantity of net and lower zone or groundwater infiltration is determined by the current value of b. The value of c alters outflow hydrograph shape by controlling the surface detention.

Delayed infiltration is estimated from the upper zone storage (UZS) and the upper zone nominal capacity (UZSN). UZSN is an input parameter. Evapotranspiration and percolation remove water from the upper zone storage.

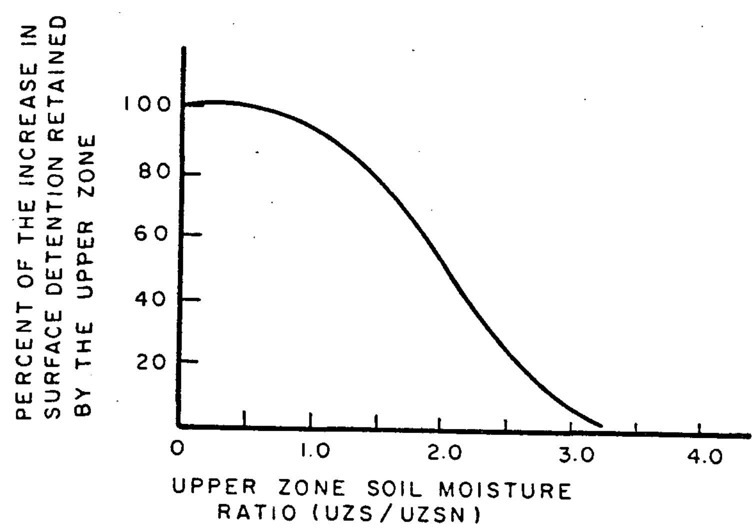


FIG. 3

Figure 3

Percentage of the Increase in Surface Detention Retained
by the Upper Zone as a Function of the Upper Zone Soil Moisture Ratio

Overland flow, the discharge into a stream channel during a given time interval, is a function of the moisture supply rate and of the average detention storage during that time interval.

A requirement for this calculation is that the time interval of calculation is sufficiently small so that the value of discharge in any time interval remains a small fraction of the volume surface detention. The length, slope, and estimated roughness of an overland flow plane are used as input in the watershed model.

Interflow is calculated from interflow detention storage and requires as an input parameter a daily recession or depletion constant.

The inflow to groundwater storage is a portion of the net infiltration and a portion of the delayed infiltration from upper zone storage.

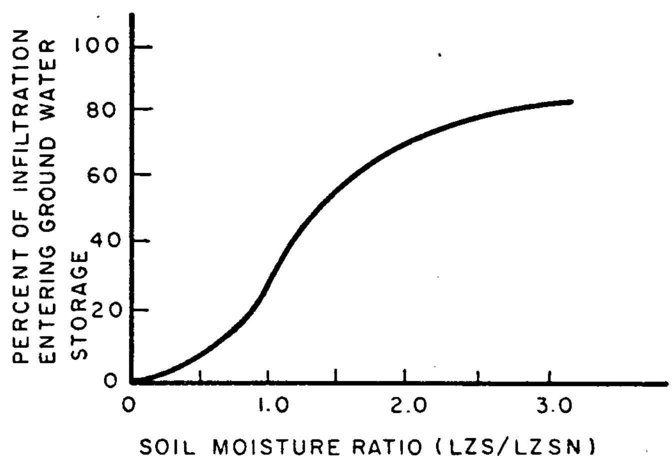


FIG. 4

Figure 4

Assignment of Infiltrated Water to Groundwater

The outflow from groundwater storage is modeled by assuming a representative cross-sectional area of flow and by estimating the energy gradient as a base gradient plus a variable gradient which depends on groundwater accretion.

This paper claims the main contributors to snowmelt are convection, condensation, and rainfall. In one subroutine in the program, snowmelt is calculated from radiation, wind velocity, dewpoint temperature and temperature. This calculation can be used only in well instrumented watersheds. An alternate subroutine using only air temperature data was developed for sparse data situations. From comparison of these two snowmelt calculations, wind velocity and dewpoint temperature data would provide for more accurate snowmelt calculations.

For the first routine, calculations are made hourly and incoming precipitation is added to the snow pack or to liquid water storage. Temperature and radiation data are used to find the net heat exchange in the hour. If the net heat exchange is negative then heat is being lost from the snow pack and there is an addition to the negative heat storage.

When the net heat exchange becomes positive, the negative heat storage is reduced, and when this storage is zero, snowmelt begins. The melt enters liquid water storage until a limiting value is reached after which additional melt or rainfall is discharged from the snow pack.

Snow albedo varies between 0.75 and 0.65, with the high volume used after new snowfall.

Hourly temperatures are calculated for each watershed segment from maximum and minimum temperatures at base stations. Lapse rates are altered to allow for diurnal variation and typical dry weather or storm conditions.

Snow evaporation is calculated from estimated potential snow evaporation if the air temperature is below 32°F.

Storage of liquid water in the snowpack is limited by an input parameter WC that assigns the maximum or limiting liquid water storage as a fraction of storage in the snowpack.

Daily lake evaporation or potential evapotranspiration data are used as inputs. Following the assumption made for infiltration capacity the cummulative frequency distribution of evapotranspiration opportunity is assumed to be linear.

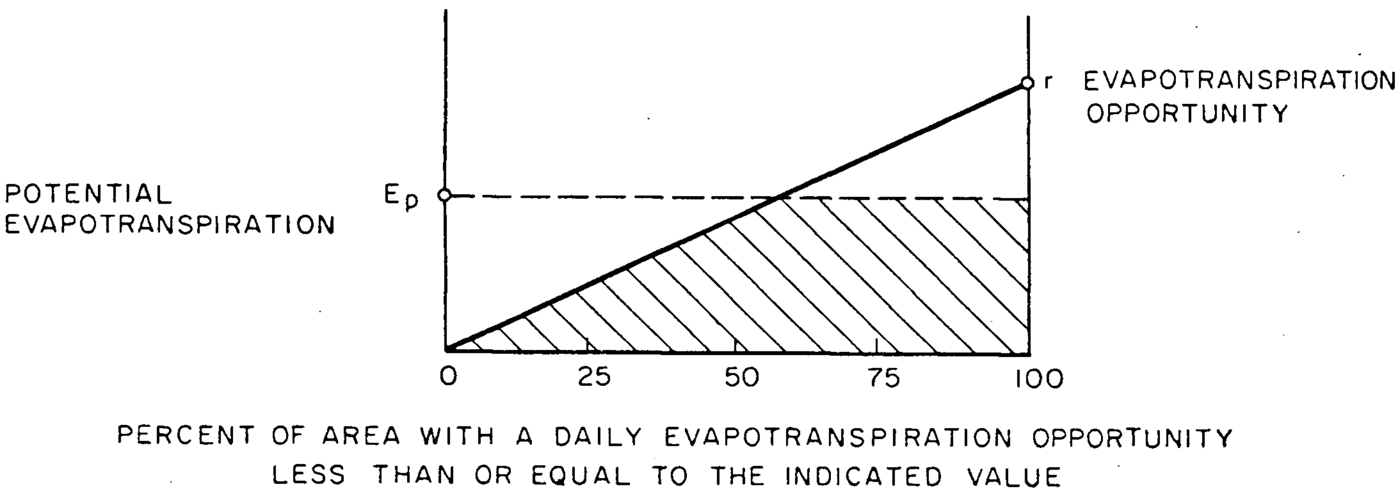


FIG. 5

Figure 5

Cummulative Distribution of Potential Evapotranspiration

The quantity of water lost by evapotranspiration from the lower zone when E_p is less than r is $E = E_p - \frac{E_p^2}{2r}$ where E is the actual E-T. r is computed from K3, an input parameter, and the ratio of storage in the lower zone,LZS,and the nominal storage,LZSN.

The paper concludes with some philosophy and predictions concerning digital modeling as applied to hydrology. In this context the authors note that parameter optimization does not necessarily imply optimum mathematical representation.

CHAPTER III

MISSION CREEK FLOW MODEL

III.1 Input Data Sources

As was noted in Section II.4, a model is limited by the amount and inaccuracy of the input data. For the Mission Creek basin the input data are sparse, but still more numerous than for other creeks flowing into Lake Okanagan.

Daily maximum and minimum temperatures and precipitations are available from three stations, Kelowna Bowes Street (1160 ft.), Joe Rich Creek (2870 ft.), and McCulloch (4100 ft.). This means that no data is available for elevations above 4100 ft., or about 2/3 of the basin area. The locations of these meteorological stations are shown in Figure 6 and the data are listed in *Monthly Record of Meteorological Observations, Canada*.

Monthly snow depths and water equivalents of the snowpack are available at McCulloch (4200 ft.), Aberdeen (4300 ft.), Postill (4500 ft.) and Mission Creek (6000 ft.). The data from these stations are provided in *British Columbia Snow Survey Bulletin*.

The monthly storage from April through June for the lakes and reservoirs Greystoke, Haynes, Hydraulic, Ideal, James and Postill are also available in *British Columbia Snow Survey Bulletin*.

Evaporation data when available are taken from Summerland and are listed in *Monthly Record Meteorological Observations, Canada*. Although Summerland is not in the Mission Creek basin, it is on Okanagan Lake so

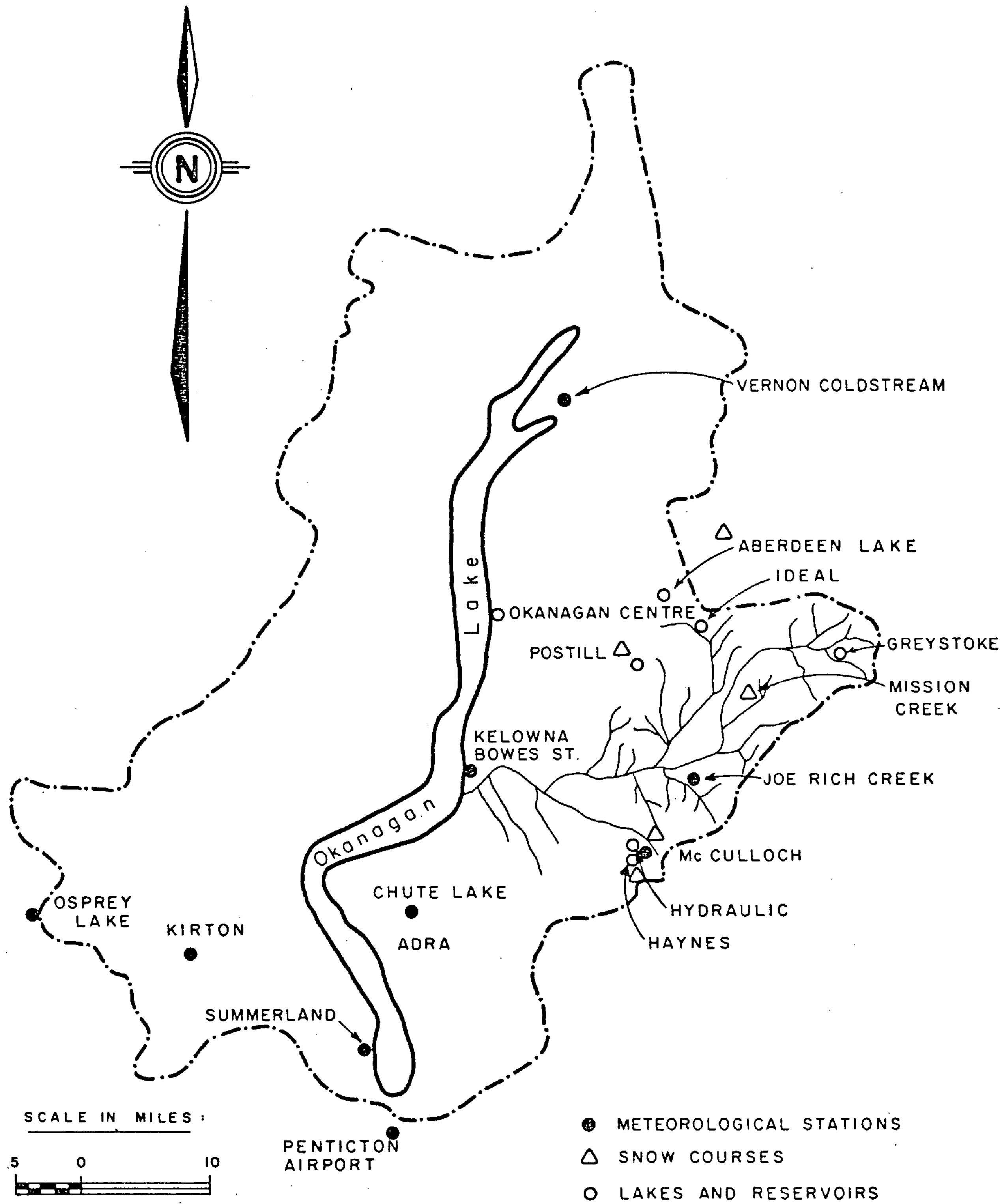


FIG. 6 LOCATIONS OF INPUT DATA STATIONS.

TABLE 3

INPUT DATA STATIONS FOR THE MISSION CREEK BASIN

STATION NAME	ELEVATION	DATA
Kelowna Bowes Street	1160	Daily Maximum and Minimum Temperature Daily Precipitation
Joe Rich Creek	2870	Daily Maximum and Minimum Temperature Daily Precipitation
Ideal	∿ 4000	Monthly Storage (acre ft.)
McCulloch	4100	Daily Maximum and Minimum Temperature Daily Precipitation Water Equivalent (inches of water)
Haynes	∿ 4200	Monthly Storage (acre ft.)
Hydraulic	∿ 4200	Monthly Storage (acre ft.)
Aberdeen	4300	Water Equivalent (inches)
James	4500	Monthly Storage (acre ft.)
Posthill	4500	Water Equivalent (inches) Monthly Storage (acre ft.)
Greystoke	6000	Monthly Storage (acre ft.)
Mission Creek	6000	Water Equivalent (inches)

the evaporation data are assumed to be representative of the evaporation at the first level of the Mission Creek basin.

Mission Creek flows are gauged by a recording gauge (8nm116) at Taylor Road, 1-1/2 miles southwest of Rutland. The gauge was moved 1-3/4 miles downstream in 1968. The flows used in the model are the daily mean flows in cubic feet per second.

III.2 Basin Subdivision

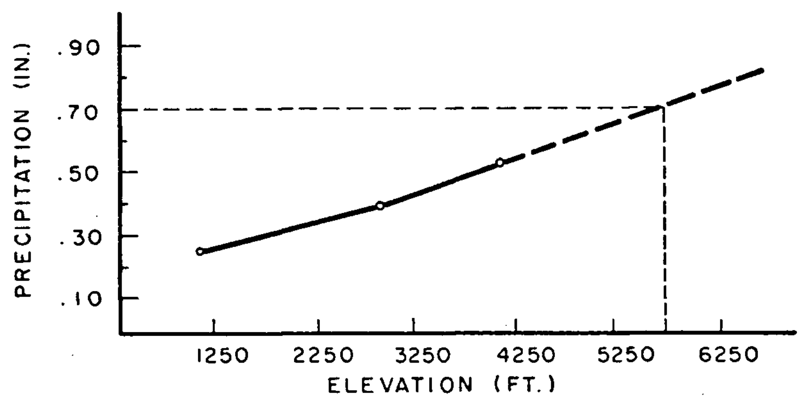
For analytical purposes the Mission Creek basin was divided into 12 elevation bands or levels. For example, the first band extends from an elevation of 1,000 ft. above sea level to 1,500 ft. with a center band elevation of 1,250 ft. and an area of 8 sq. mi., Table 2. The height of the elevation bands was arrived at arbitrarily while the areas were determined from a topographical map of the region. With the relocation of the Mission Creek gauge in 1968, the drainage area of the basin was apparently increased from 322 to 338 square miles. In the model the 338 square mile value was used for all the years.

III.3 Treatment of the Input Data

III.3.1 <u>Temperature</u>. The daily maximum and minimum temperatures are averaged at each station. This average station temperature is lapsed over all the elevation bands of the basin using the lapse rate, TLAPS, usually 3.5 F^{o}/1000 ft. This provides three temperatures for each band, which are averaged to provide the average daily temperature in a band, T(J, L). The daily maximum temperatures were handled in a similar manner to provide a maximum daily temperature for each band, TXL (J, L).

The value of 3.5F°/1000 ft. was chosen from consideration of the International Standard Atmosphere. Later results indicated that this value is low for some years, but does appear a reasonable starting value.

III.3.2 <u>Precipitation</u>. An example of the method for finding the daily precipitation in each band is shown in Figure 7. For bands 1 to 4 precipitation values are found from a straight line connecting precipitations at Kelowna Bowes Street and Joe Rich Creek. For higher bands a straight line connecting precipitation values at Joe Rich Creek and McCulloch is extrapolated. If the precipitation should become negative it is set equal to zero. If the daily average temperature in a band was less than or equal to 35°F., then any precipitation falling into that band was considered to be snow.



Day 52	Year 1970	
Kelowna Bowes Street		.25 inches
Joe Rich Creek		.39
McCulloch		.52

Precipitation on Day 52 Band 10 is .7 inches

Figure 7

Example of Lapsing the Precipitation

There are arguments for using relations other than linear in the precipitation-elevation relation. For this model, lack of information regarding orientation, exposure and slope dictated the use of the simple linear segments.

III.3.3 Evaporation. Evaporation is a general term for the complex processes involved in the net transfer of liquid water from soil and plants to water vapour in the air. In particular, all water losses by both transpiration and evaporation, where transpiration is the process by which plans transfer water to the atmosphere, are known as total evaporation or evapotranspiration (E-T). The maximum rate at which water can be transferred to the air is called the potential evapotranspiration rate.

In crop-oriented studies, the term consumptive use is frequently applied to the total amount of water taken up by vegetation for transpiration and building of plant tissue plus evaporation of soil moisture, evaporation from snow, and intercepted precipitation. Consumptive use is highly dependent upon environmental factors such as weather, soil moisture, and groundwater. In this thesis the actual evapotranspiration is taken to be equal to consumptive use.

Evaporation is dependent upon vapour pressure difference between the water surface and the air above the water surface, the temperatures in the air and water, wind, atmospheric pressure, the quality of the water, and the nature of the evaporating surface. In this model, because of the limited available data, the parameter of major concern is temperature. As the temperature of a body of water increases, the kinetic energy of the molecules in the body of water increases and the rate of escape of molecules and hence evaporation increases.

Of special interest in the model is the behaviour of evaporation with elevation [Blaney, 1956]. The reduction in pressure with increasing elevation should increase evaporation, but temperature will decrease with elevation. Additional features such as the orientation of the slope further complicate the relation.

Lake evaporation was assumed to be the potential evapotranspiration for the first level of the Mission Creek basin. If lake evaporation data were not available, the pan evaporation was corrected to lake evaporation using the average pan coefficients listed in Table 4. These coefficients were calculated from months when both pan and lake evaporation data were provided. Here pan coefficients are defined as the ratio of evaporation from a large body of water and evaporation from a pan.

TABLE 4

AVERAGE MONTHLY PAN COEFFICIENTS FOR SUMMERLAND

MONTH	PAN COEFFICIENT	NUMBER OF YEARS	STANDARD DEVIATION
April	0.75	6	0.02
May	0.74	7	
June	0.72	6	0.01
July	0.70	6	
August	0.68	6	
September	0.69	6	

If neither pan nor lake evaporation were available the monthly evaporation was estimated from the monthly degree days, Figure 8. The monthly degree days, STEX(M), is the sum over the number of days of the month of the daily average temperatures minus 40. This 40 base was chosen as the STEX(M) fitted the lake evaporation data better than STEX(M) with a base 32. The comparison was made when lake evaporation data were available. As can be seen from Figure 8 there is considerable scatter, evidence that wind and other facotrs must be considered in evaporation. The regression equation was found to be LKEVP = $4.6 \times 10^{-3} \times$ STEX(M) + 2.5.

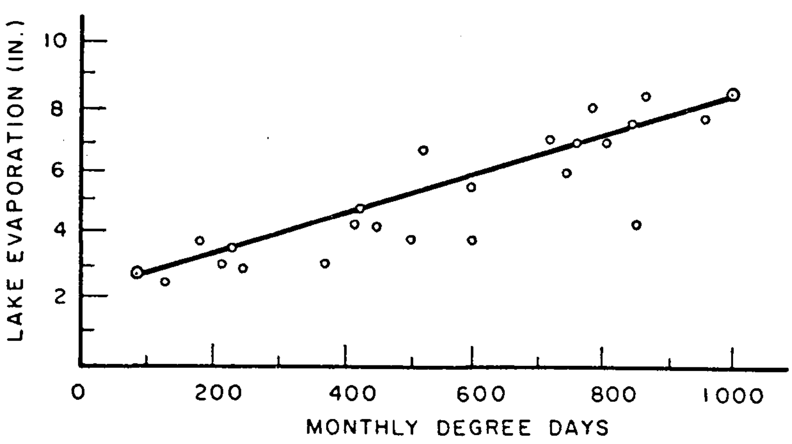


FIG. 8

Figure 8

Lake Evaporation as a Function of Degree Days

The daily potential evapotranspiration for the first level was found from a ratio of the daily excess temperature, TEX(J,1), and the monthly degree days, STEX(M), multiplied by the monthly evaporation. That is,

$$\mathrm{DPEVP}\ (J,1) = \frac{\mathrm{TEX}(J,1)}{\mathrm{STEX}(M)} \times \mathrm{LKEVP}(M)$$

To lapse the potential evapotranspiration to the higher bands, the maximum daily temperature, TXL(J,L), of each band was employed as follows:

$$\mathrm{DPEVP}\ (J,L) = \frac{\mathrm{TXL}(J,L)}{\mathrm{TXL}(J,1)} \times \mathrm{DPEVP}(J,1)$$

where the subscript J refers to the day, L to the level, and M to the month.

Evaporation from the snowpack was assumed to be zero. This was due to lack of data on wind speed, vapour pressure, and orientation of the slopes or sheltering of trees. Nelson [1962] indicates that from a hydrological point of view, evaporation losses from a large watershed area are likely to be less than the errors in obtaining the total water content of the snowpack.

III.4 Snowmelt

The physics of snowmelt are complicated. The thermal conductivity of snow appears to be a function of density and crystal structure but always has a relatively small value and so heat transmission through snow is not large.

Heat may be transferred to the snowpack from the surrounding air, the ground below, rain falling into the snow and direct solar radiation. According to Linsley []949], the heat transferred by conduction from still air is small and convective transfer is more efficient. Heat flow to the snowpack from the underlying soil probably does not contribute to the snowmelt after the pack has been on the ground for several weeks, but it may melt sufficient snow to fill the soil moisture deficit. This priming of the soil may be an important antecedent condition. Heat from rainfall is by itself not important in melting snow [Linsley, 1949].

Direct solar radiation is an important and under some conditions may be the most important factor in melting snow. Solar radiation penetrates only some 18 inches of pack. If the pack is thin enough for radiation to reach the ground then a greater portion of the radiation is absorbed and the snowpack is warmed from beneath. The amount of incoming radiation is a function of time of year and cloud cover. The amount of radiation producing snowmelt is determined by the snow's albedo, that is, reflection coefficient, which is dependent on the snow's condition. Dry freshly fallen snow may have an albedo of 0.90 while an old wet snow surface may have an albedo of 0.40.

The water equivalent of the snow, that is, the depth of water which would result from melting is dependent on snow density as well as depth. Water content refers to the liquid water in the snow, with snow being able to hold large volumes of water which can be released suddenly. In this model, rain falling into snow contributed to runoff through snowmelt by the quantity BMRF(J, L).

As no other data were available, snowmelt in this model was estimated from the number of degrees the daily band temperature was above 32°F. and a point melt factor PTM. The point melt factor was 0.55 cubic feet per second per square mile per Fahrenheit degree per day, in all years but 1969.

III.5 Snow Line Recession

Snow line recession was established through a band switch parameter LSW(L). The band switch time for a band is the day on which the snow line passes the upper boundary of that band. The rationale for using band switch times for snow line recession is provided in Geiger [1965], Section 46. Even if the snow melts at different times in different years, the melting pattern is the same. The actual manner in which snow melts in upland areas is closely related to topography with steep southern facing slopes melting first, followed by the more gentle slopes and northern slopes.

For 1960, 1963, 1964, 1965, 1967, 1968 and 1969 the band switch days (LSW) were obtained by finding the best fit simulation of the daily flows. Here, best fit was established on the basis of minimizing the residual variance. From these best fit values, a routine was established by which a certain percentage of the water equivalent in each band was melted. The water equivalent was found by constructing a linear relation, on a semi-log graph, between the water equivalents, on a logarithmic scale, and the elevations on a linear scale, at McCulloch (4200 ft.), Aberdeen (4300 ft.), Postill (4500 ft.) and Mission Creek (6000 ft.).

The rate at which the snow melted was found from the daily average band temperatures, T(J,L) and the point melt factor, PTM. The number of days required to melt the determined percentage of snow in a band provided the band switch day for that band.

As the computer predicted band switch days and the best fit band switch days for the various years did now show complete correlation, Figure 9, an equation relating the fitted LSW's and the predicted LSW's was developed.

$$LSW(L)_{FITTED} = 6.1 + 0.95 \times LSW(L)_{PREDICTED}$$

III.6 Interception

Interception is the effect of vegetal cover in reducing the amount of precipitation reaching the ground. Interception is most effective on the early precipitation from a storm. As most storms yield small amounts of precipitation, interception by dense cover or forests may amount to 25 per cent of the annual precipitation.

Wind effects interception in two opposed ways, on one hand reducing the maximum storage by shaking the branches and leaves and on the other increasing the evaporation from storage.

Formulae for interception have been developed [Linsley, 1949] but these require knowledge of parameters not measured or known in the Mission Creek basin.

Interception of precipitation was modeled simply by assuming that the interception was a fraction of the rainfall, the fraction increasing with elevation. The fraction varied from 10 for the lowest bands to 20 per cent for the highest bands.

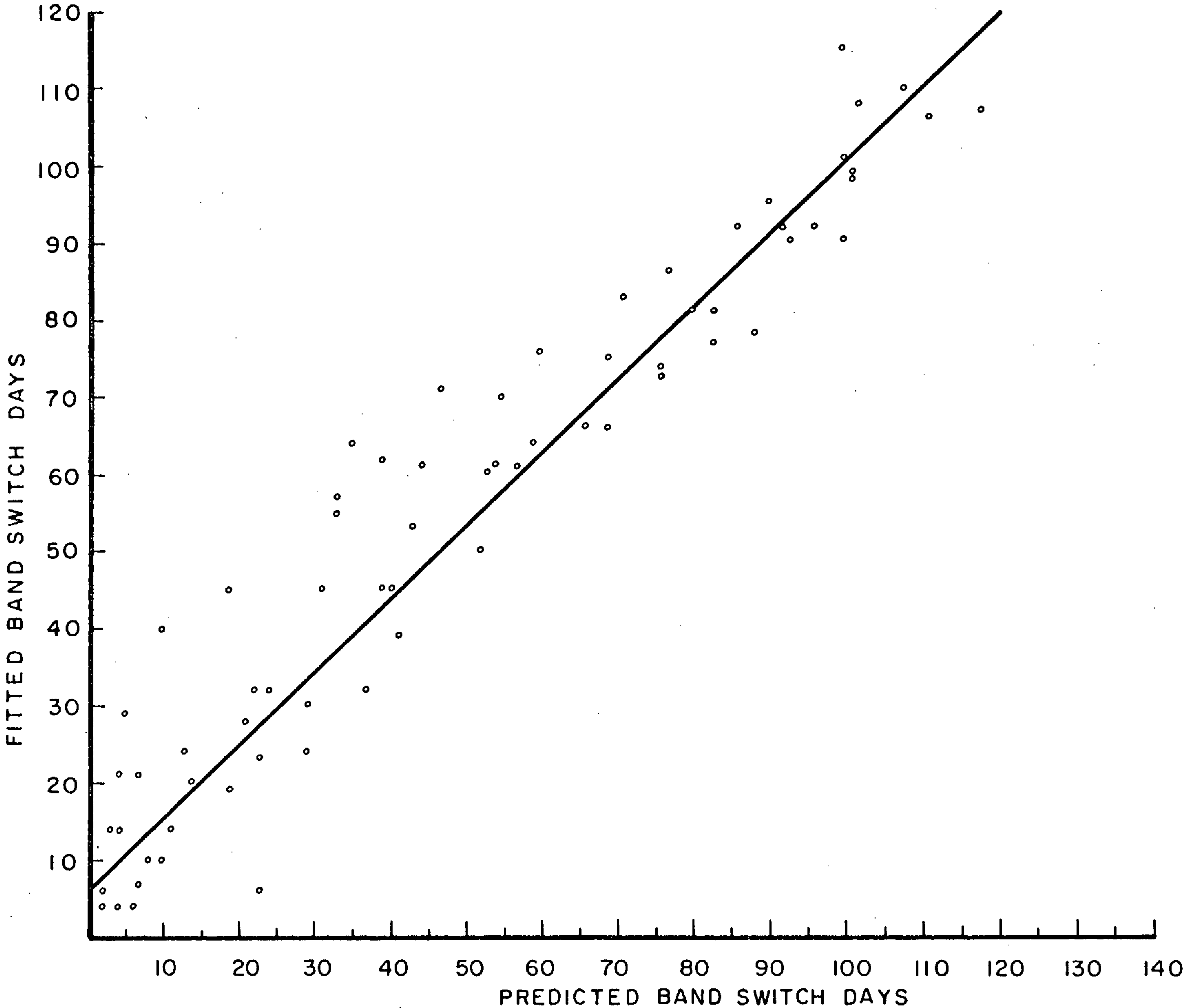


FIG. 9 THE REGRESSION OF FITTED BAND SWITCH TIMES (LSW) ON PREDICTED BAND SWITCH TIMES.

III.7 Early Season Storage

The early season storage is estimated in two parts, the first for April, the second for May. After June 1st the assumption of no basin storage is made. April storage is found by consideration of the change in total storage of the reservoirs, Haynes, Hydraulic, James, Greystoke. Ideal and Postill between April 1st and May 1st. May storage is the change in these reservoirs between May 1st and June 1st.

Thirty per cent of the daily flow from each of the bands 7 through 12 is subtracted for storage, until either the storage requirement for the month has been filled or the month is over.

III.8 Infiltration

Infiltration is defined as the passage of water through the soil surface into the soil. Infiltration capacity is the maximum rate at which a given soil in a given condition can absorb rain as it falls.

Infiltration capacity varies with the porosity of the soil, the initial moisture content of the soil, the rainfall intensity, and the season. For fine dry sandy soils, the infiltration capacity may be low when the soil is dry and increase as the soil is wetted. The rate of infiltration usually varies directly with rainfall intensity provided intensity is less than infiltration capacity. But when the intensity exceeds the infiltration capacity then intensity has little effect on the rate of infiltration. Finally, the infiltration rate is a function of season [Horton, 1940], with infiltration capacity increasing in May and decreasing in September.

Infiltration is not directly modelled; instead a feedback loop involving soil moisture deficit, actual evapotranspiration, precipitation, and runoff is employed.

The actual daily evapotranspiration [DEVP(J,L)] equals the potential daily E.T. [DPEVP (J,L)] times a factor [FACTOR (J,L)]. This factor is dependent of the soil moisture deficit [MDEF (J,L)] and a decay parameter C2.

$$FACTOR\ (J,L) = EXP[-1 \times C2 \times MDEF(J,L)]$$

The soil moisture deficit is set to 0. on the day the snow line passes out of a band. This is a reasonable assumption for the upper bands, although the lower bands may have a permanent deficiency. Thereafter the soil moisture deficit is determined by the gain of moisture, precipitation, and the loss of moisture, actual evapo-transpiration, and runoff. An assumption is made that if the precipitation is greater than or equal to .25 of an inch of rain in a day, the E-T would take place at the potential rate.

Next additional assumptions in the form of a network of IF-statements involving the precipitation and soil moisture deficit were fitted for several years. These should approximate the infiltration capacities of the soils in the basin. As only daily records are available, intensities are over a 24-hour period and this makes modelling difficult. Also rain amounts on the bands above 4,000 feet are quite uncertain. Details of the network are given in Appendix 2.

III.9 Runoff

Runoff is provided through snowmelt and rainfall. The snow is melted in daily amounts from a band using PTM and the daily temperature above 32°F., up to that band's band switch time on which day the snow is assumed to have gone from that band. The band melts above each band are summed for each day and then this sum of band melts is routed by the previously derived unit hydrograph to provide an estimated band runoff EBRO(J,L) for a given band on a given day.

A similar procedure is followed for rainfall which is effective in producing runoff,PRO(J,L), that is rainfall over and above that needed to supply soil moisture deficit and evapotranspiration requirements. The estimated band runoff for level L on day J is EBRORF(J,L).

III.10 Routing

The runoff from both snow and rain is routed by means of a unit hydrograph. Two parameters control the unit hydrograph, NUH, the number of days covered by the unit hydrograph, and UZ, which controls the shape of the unit hydrograph.

The value of the unit hydrograph on day K is UH(K) = (K/UZ) * EXP(-K/UZ). The sum of the UH(K)'s over NUH is normalized.

The general shape of the unit hydrographs for UZ = 1.0, 2.0 and 3.0 is shown in Figure 10.

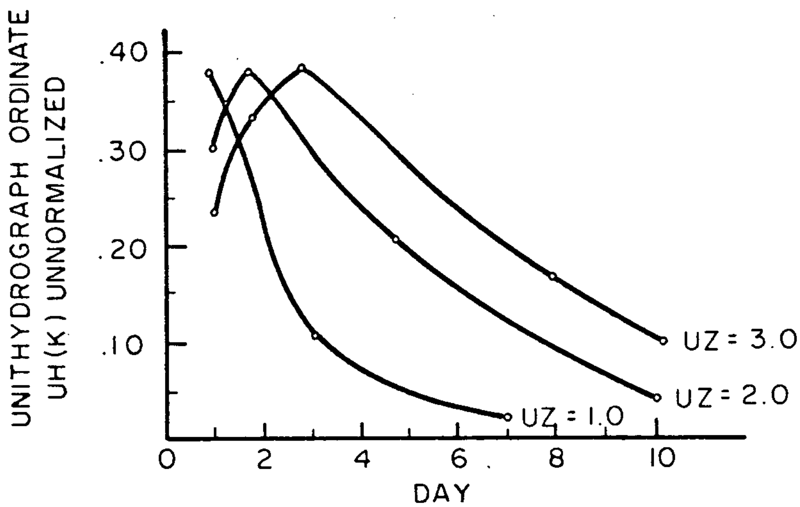


FIG. 10

Figure 10

Shape of Unit Hydrograph

III.11 Operation of the Computer Program

The program, MICKFLMO, written in Fortran IV was run on the IBM 360 computer at the University of British Columbia. A flow chart of the model, a list of parameters and a list of variables are provided in Appendices 1 to 3 respectively. The input data for a year of record was stored in a file, the form of which is shown in Appendix 4. The average CPU time to execute the program for a year of record was approximately 16 seconds, the time depending upon the amount of information required about the basin. The average compile time was 30 seconds, 10 for the main program, and 20 for the runoff generation subroutine, ROGEN.

CHAPTER IV

RESULTS AND CONCLUSIONS

IV.1 Objectives of the Model

The Mission Creek Flow Model (MICKFLMO) was not primarily intended to be predictive, but as was noted in the Introduction, was designed to study certain hydrologic processes. These processes include: variation of evapotranspiration with elevation; how much rainfall and snowmelt runs off; and the areas of the basin which produce the most runoff.

In order to obtain a model which best explained the above mentioned processes, the simulated flow from the basin was made to fit the measured flow as closely as possible by varying the model parameters. At first the best fit was judged by inspection then later by use of the residual variance between synthesized and measured flows. As was pointed out in section II.5.3, care must be exercised with the assumption that the best fit model is indeed the best model for explanation.

The residual variance is computed by

$$\sum_{J=1}^{ND} [BRO(J) - FT(J)]^2$$

where BRO(J) is the measured flow on day J, FT(J) Is the synthezied flow on day J, and ND is the number of days of record. The residual variance provides a measure of the spread of the synthesized and measured flows with large differences given large weighting. The square root of the residual variance divided by the number of days of record provides an estimate of the average daily discrepancy between the measured and synthetic flows.

Some predictive work was also attempted with the model. As flow records are entirely missing for Mission Creek in 1948 and 1966 and only partial flow records are available in 1961 and 1962, the model was employed to simulate the missing data. Existing records in 1961 and 1962 provided partial checks on the simulated data but in 1948 and 1966 the only check on the simulation was the estimated total flow for Mission Creek, Section IV.4.

IV.2 Model Behaviour

IV.2.1 Best Fit Parameters. The best fit parameters year by year are shown in Table 5, but not all parameters were fitted in every year. There is indication that the lapse rate of 3.5 F°/1000 ft. is too low in some years, but still appears a reasonable starting value. The lapse rate would normally be expected to range between 3.0 and 5.0 F°/1000 ft.

C2, the evaporation decay constant, was puzzling as no simple relationship appears to exist between C2 and flow or any other variable. This may be due to the complicated nature of the hydrologic interactions modelled by relations involving C2. Both evaporation and transpiration are considered in the decay of actual evapotranspiration. Soil evaporation should, most experts agree, decrease quasi-exponentially with soil moisture, but transpiration may, according to some writers, be independent of available soil moisture until the wilting point is reached. This independence of soil moisture may be the reason for C2's apparently complicated behaviour.

TABLE 5

BEST FIT PARAMETERS AND FLOWS FOR THE MISSION CREEK MODEL[1]

YEAR	VOLUME MEAS.	VOLUME SIM.	RESIDUAL VARIANCE	C1	C2	UZ	TLAPS	LSW											
				BEST FIT PARAMETERS															
1948		6.70			0.9*	3.0*	3.5*	1	2	3	17	22	26	39	59	69	85	98	121
1954	6.26	6.73	$1.09 \times 10^{7+}$	1.0	0.7	3.0*	3.5*	1	2	3	10	14	23	39	61	74	98	115	140
1958	3.88	4.47	$5.40 \times 10^{6+}$	1.0	1.2	3.0*	3.5*	1	2	3	4	7	12	19	45	52	66	73	95
1959	7.54	8.50	1.13×10^{7}	1.0	1.1	3.5	3.5	1	2	3	14	20	32	57	71	86	99	106	124
1960	4.30	3.95	$7.40 \times 10^{6+}$	1.0	0.2	2.0	3.5*	1	2	3	6	14	21	29	40	61	83	92	108
1961		7.20	+2	1.0	0.6	3.0*	3.5*	1	2	3	4	5	12	30	51	62	70	81	97
1962		5.75	+2	1.0	0.7	3.0*	3.5*	1	2	3	10	14	18	27	63	69	88	95	105
1963	4.10	3.88	$5.97 \times 10^{6+}$	1.0	0.8	3.0*	3.5*	1	2	3	4	6	14	21	28	45	53	70	100
1964	7.55	7.80	2.45×10^{7}	1.0	0.3	3.0*	3.5*	1	2	3	4	5	6	30	62	67	77	92	110
1965	6.35	7.30	6.71×10^{7}	1.0	0.5	3.0*	3.5*	1	2	3	4	5	6	32	64	76	81	90	105
1966		4.80	2	1.0	0.7*	3.0*	3.5*	1	2	3	9	11	14	22	43	60	81	95	112
1967	4.08	4.85	4.68×10^{6}	1.0	0.7*	3.0*	3.5*	1	2	3	4	5	6	32	61	75	78	90	107
1968	6.45	5.68	6.02×10^{6}	1.0	0.7	3.0*	3.5*	1	2	3	4	5	6	24	45	64	81	92	110
1969	7.10	6.70	1.07×10^{7}	1.0	0.3	3.0*	3.5*	1	2	3	4	10	24	45	55	60	66	72	115
1970	2.82	3.78	4.06×10^{6}	1.0	0.9	3.0	3.8	1	2	3	8	12	21	32	53	63	77	86	97

[1]Best fit on the basis of lowest residual variance; 1948, 1961, 1962, 1966 have non-existing data or incomplete flow data.

*No trials with other values.

+No early season storage in model.

[2]Incomplete flow data, year cannot be fitted.

NUM = 10 for all tests.
The areas and number of bands were kept constant.
Volumes in the units of 10^9 cubic feet.

The band switch times, LSW(L), are very sensitive. In years when a substantial rain event occurs near a band switch day a change of one day in switch times will change the flows for several days by hundreds of cubic feet per second. The prediction of band switch time fron snowpack and temperature data is good only to a few days, as evident from the scatter of data points in Figure 9.

Figures 11, 12, and 13 show indications that UZ, the unit hydrograph parameter is higher in high flow years, 1959, than in low flow years, 1960. If true, this is a surprising result meaning that the basin tends to smooth the flow. In 1960 the largest single contribution to the flow comes from band 10, in 1959 the largest single contribution is from band 8. Band 8 is larger and flatter than band 10 so the flow may take longer to develop in band 8.

In low flow years the values of C2, TLAPS and UZ are not as critical as in high flow years. This result can be seen by comparing the sharp minimum in Figure 11 with the broad minima in Figures 12 and 13. This result is in agreement with the indication in Figure 14, where the residual variance of the model is shown to be directly proportional to the total yearly flow. So the model fits low flow or non-critical years more closely than high flow years when the values of the parameters are more sensitive.

IV.2.2 Effect of Lake Evaporation Data. In order to ascertain if the Summerland lake evaporation data provided a significant improvement in the model's performance over pan evaporation and estimated evaporation data, a t-test was oncudcted with the null hypothesis that the average

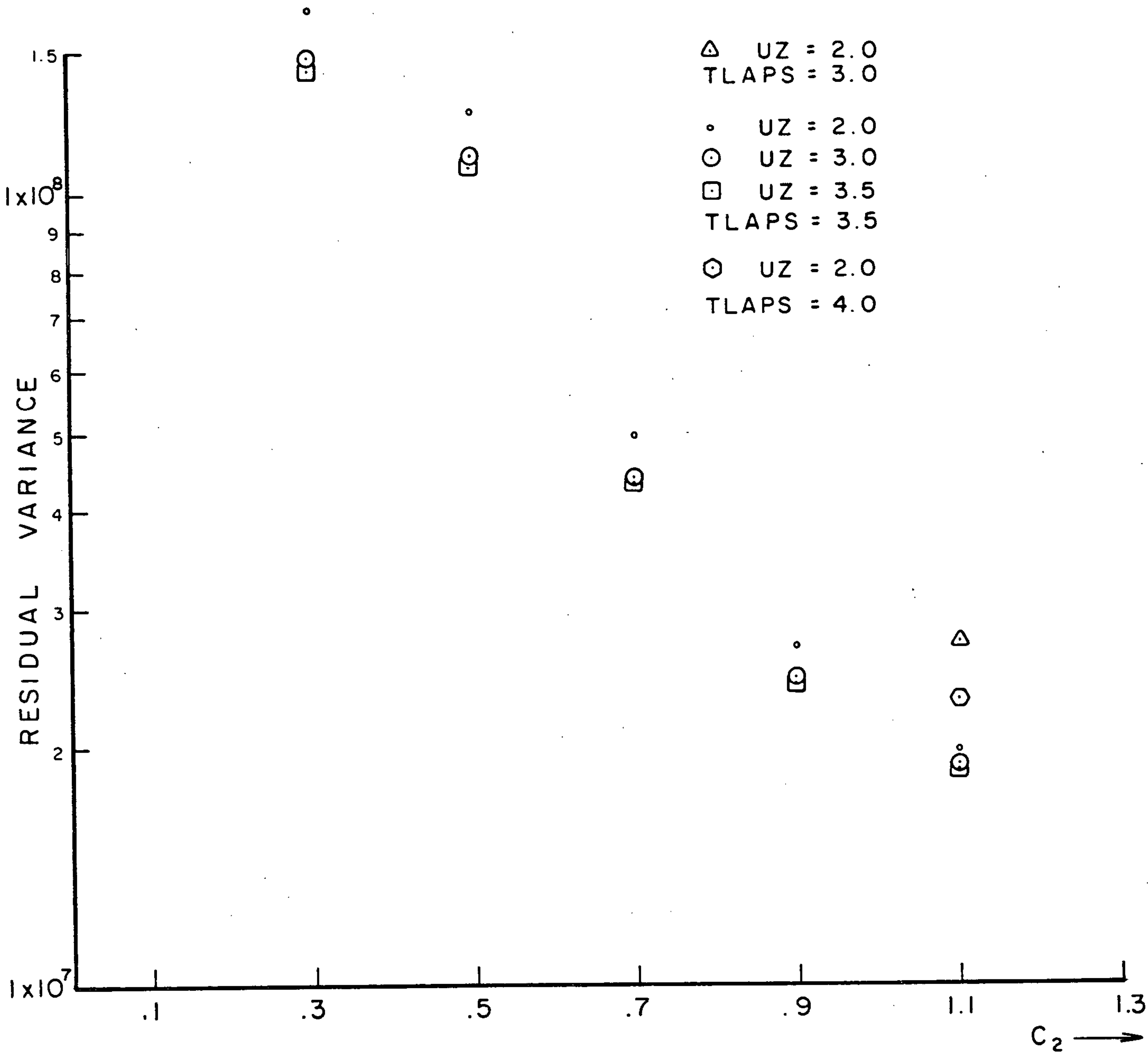


FIG. 11 RESIDUAL VARIANCE AS A FUNCTION OF C_2 FOR 1959

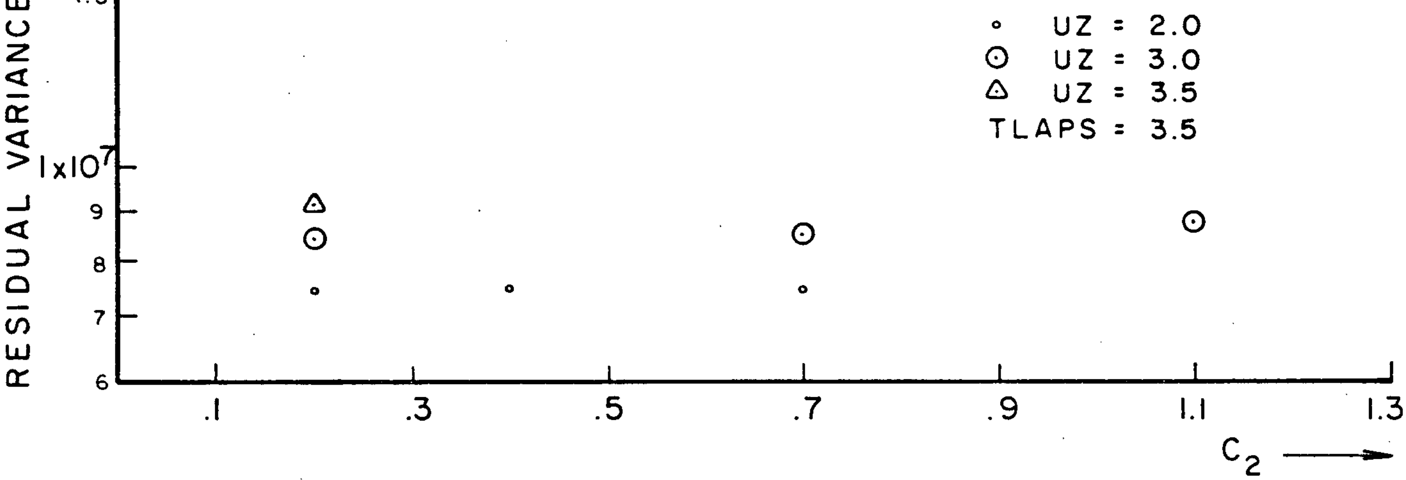


FIG.12 RESIDUAL VARIANCE AS A FUNCTION OF C_2 FOR 1960.

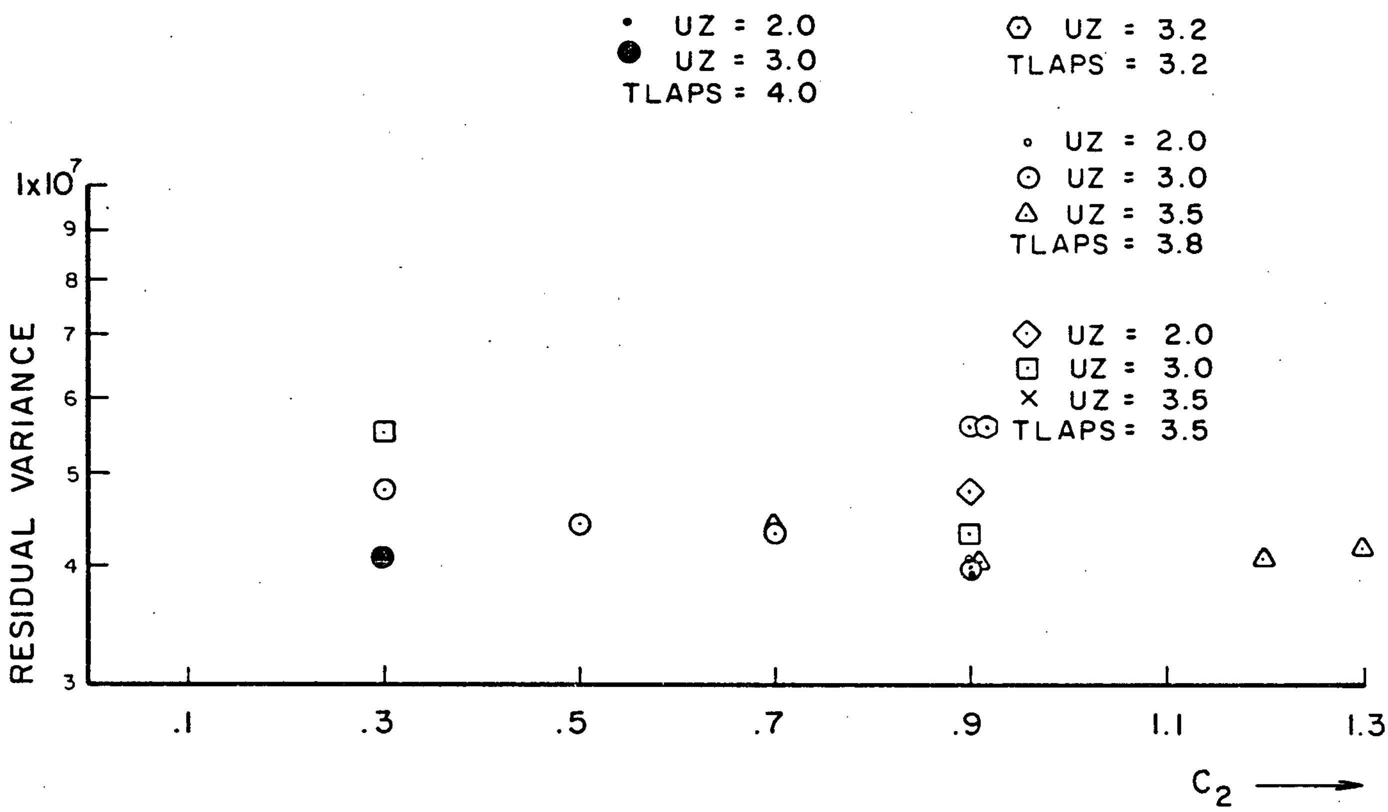


FIG.13 RESIDUAL VARIANCE AS A FUNCTION OF C_2 FOR 1970.

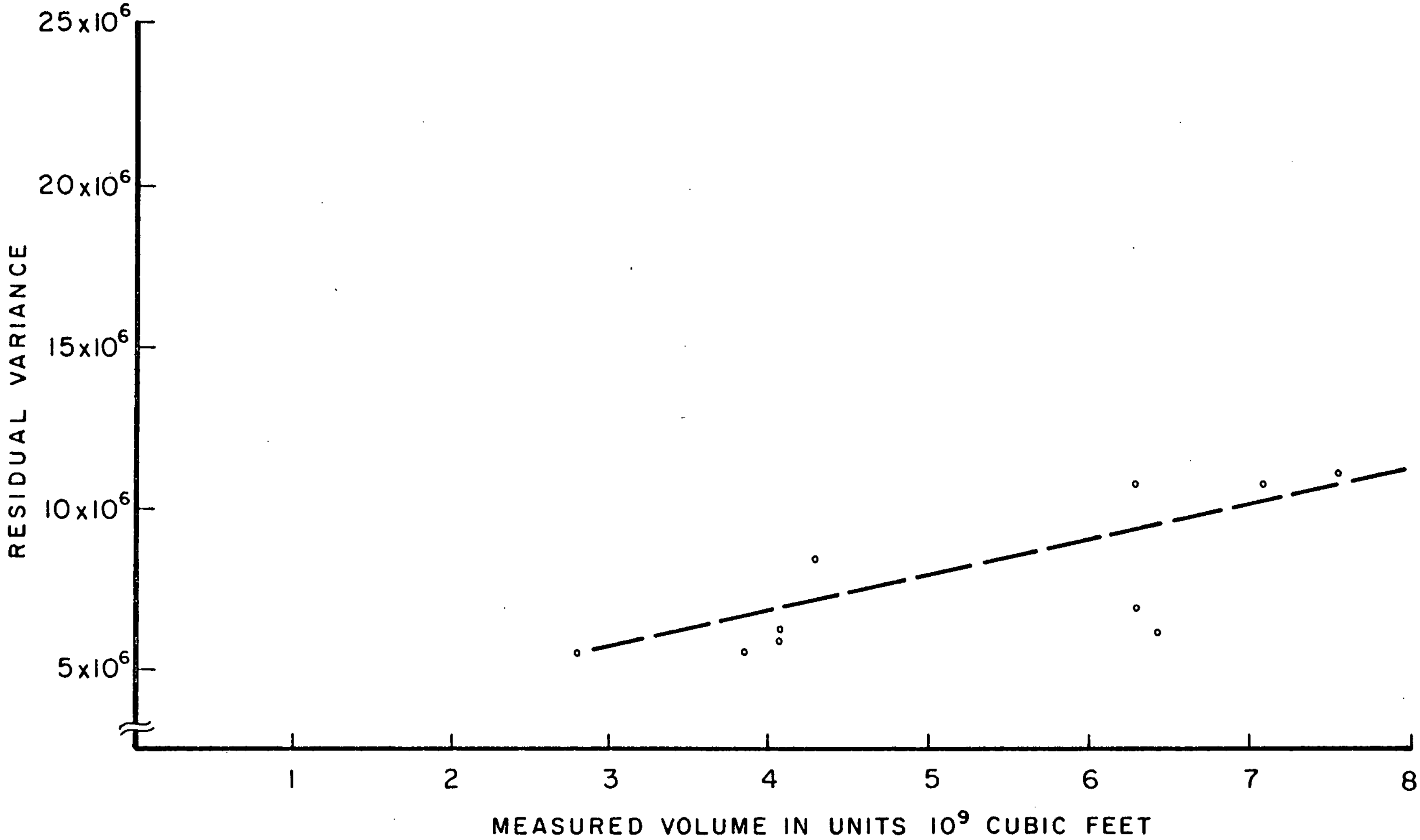


FIG. 14 RESIDUAL VARIANCE AS A FUNCTION OF MEASURED FLOW.

residual variance for years with lake evaporation data was equal to the residual variance for years without lake evaporation data. Unfortunately there are only three years with complete sets of lake evaporation data, 1967, 1968 and 1969. Table 6 presents the results of the t-test which indicate that lake evaporation data does not significantly improve the model.

TABLE 6

t-TEST DATA

	NUMBER	AVG. RES. VAR.	STAND. DEV.
Years with lake evaporation data	3	$A_1 = 7.17 \times 10^6$	2.28
Years without lake evaporation data	8	$A_2 = 9.57 \times 10^6$	2.50

Value of t statistic with 9 degrees of freedom: 0.23

At a 1% level of significance $t_{0.01}(9) = 2.821$

Null hypothesis $A_1 = A_2$ is accepted as t tabulated > t calculated

IV.2.3 Effect of Adding Early Season Storage. The effect on the residual variance including early season storage in the model is indicated in Table 7. The procedure for estimating the effect of early season storage on flow is described in Section III.7. In general the fit was improved, that is, the residual variance decreased, except in 1969 where the increase in residual variance was small. Apparently early season storage is a significant element in the system.

TABLE 7

EFFECT OF ADDING EARLY SEASON STORAGE TO THE MODEL

YEAR	MES. FLOW	SIM FLOW WITHOUT E.S.S.	SIM FLOW WITH E.S.S.	RES. VAR. WITHOUT E.S.S.	RES. VAR. WITH E.S.S
1964	7.55×10^9	7.80×10^9	7.71×10^9	2.56×10^7	2.45×10^7
1965	6.35×10^9	7.30×10^9	7.20×10^9	6.85×10^6	6.71×10^7
1967	4.06×10^9	4.85×10^9	4.67×10^9	6.18×10^6	4.68×10^6
1968	6.47×10^9	5.88×10^9	5.69×10^9	6.74×10^6	6.02×10^6
1969	7.10×10^9	6.77×10^9	6.70×10^9	1.03×10^7	1.08×10^7
1970	2.82×10^9	3.92×10^9	3.76×10^9	6.96×10^6	5.40×10^6

IV.3 Analytical Results

IV.3.1 Precipitation Elevation Relationships. To a rough approximation, the precipitation elevation relations generated by the model appear linear, Figure 15, with the deviations from linearity due to high rainfall at Joe Rich Creek. However, if the curves are taken as linear then an interesting result unfolds, namely, the rate of change of rainfall

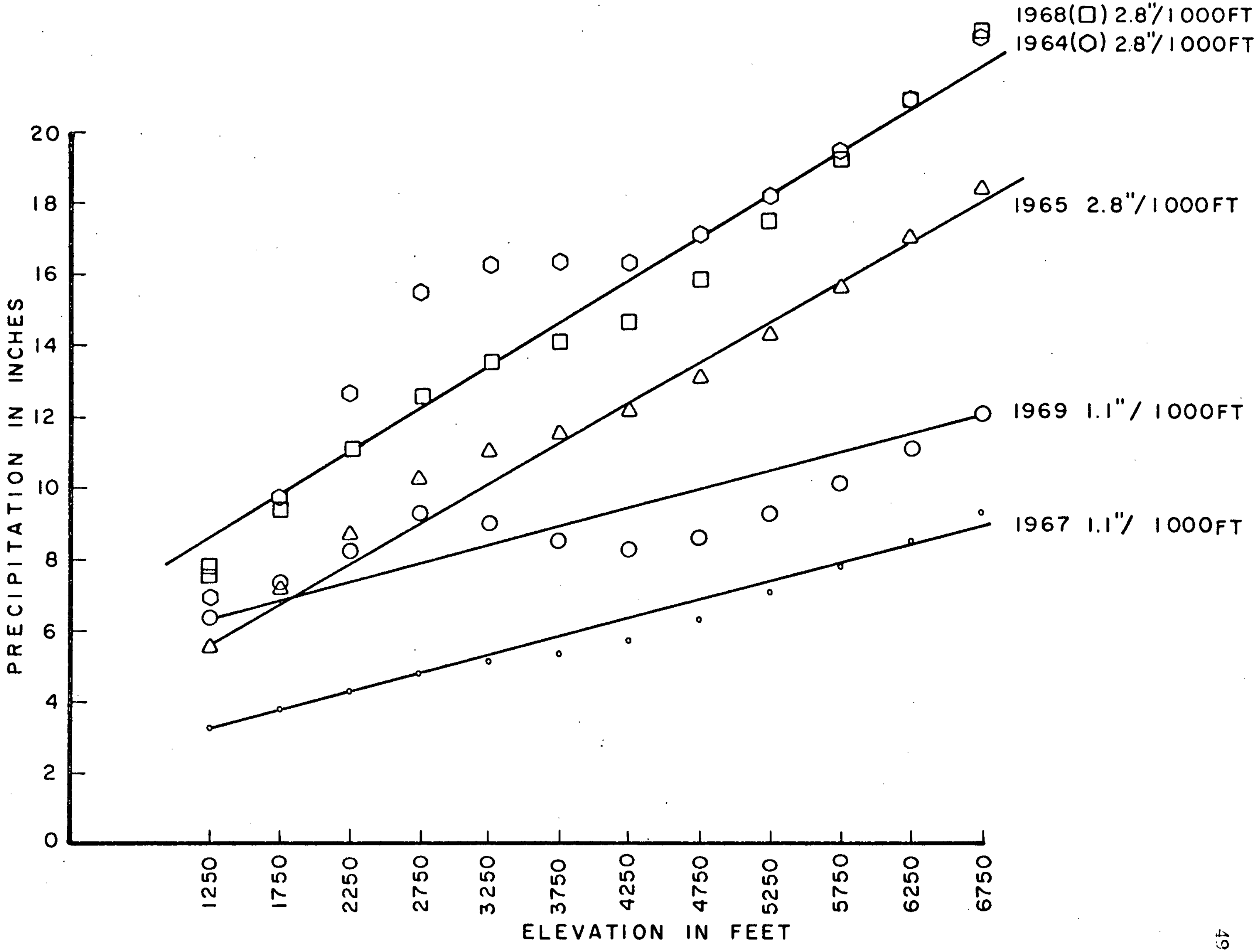


FIG. 15 PRECIPITATION - ELEVATION RELATIONSHIPS FOR 1964, 65, 67, 68 AND 69.

with elevation is proportional to the rainfall in the first level. Apparently in warm years, i.e., years with high STEX, the rainfall is low and consequently the rainfall gradient is low, which has definite repercussions in evaporation considerations. These results are, of course, a consequence of the model chosen for lapsing the daily precipitation. Had a model such that the daily average precipitation been applied throughout the basin been adopted, then the precipitation elevation relation would have been a horizontal straight line.

IV.3.2 Evapotranspiration Lapsing. According to the results of the model, the total seasonal potential evapotranspiration declines linearly with increasing elevation. The slope of this relationship bears no apparent correlation with evapotranspiration at the first level, the sum of the degree days, or the slope of the rainfall curve. Unfortunately there are too few lapse rate values to attempt a correlation study.

TABLE 8

POTENTIAL EVAPOTRANSPIRATION AND SLOPE OF POTENTIAL EVAPOTRANSPIRATION

YEAR	SLOPE OF POT E-T	POT E-T 1st LEVEL	ACTUAL E-T 1st LEVEL	STEX	AMOUNT OF RAIN 1st LEVEL	SLOPE OF RAIN
1948	1.67"/1000 Ft.	28.77	11.67	--	12.8	4.45
1954	1.40"/1000 Ft.	28.13	9.05	2867	7.9	4.85
1958	1.25"/1000 Ft.	27.95	5.60	3779	4.4	2.8
1959	1.62"/1000 Ft.	24.14	5.82	3105	6.0	3.6
1960	1.68"/1000 Ft.	24.95	11.1	3366	4.3	0.98
1961	1.46"/1000 Ft.	32.05	4.25	3691	11.8	2.9
1962	1.43"/1000 Ft.	30.30	7.32	3157	4.8	1.7
1963	1.11"/1000 Ft.	28.90	7.12	--	5.4	1.5
1964	0.00"/1000 Ft.	26.23	9.27	2942	7.8	2.8
1965	1.30"/1000 Ft.	27.65	7.18	3348	5.5	2.8
1966	1.40"/1000 Ft.	29.49	7.66	--	5.2	0.80
1967	1.53"/1000 Ft.	34.23	6.82	3752	3.3	1.1
1968	1.43"/1000 Ft.	30.11	9.05	3255	7.8	2.8
1969	1.46"/1000 Ft.	32.05	11.24	3536	6.1	1.1
1970	2.00"/1000 Ft.	35.01	6.25	3404	4.0	1.1"/1000

The total seasonal actual evapotranspiration behaves in a much more complicated fashion. In the first elevation band the actual E-T is from 20 to 40 per cent of the potential E-T, with the percentage directly proportional to the amount of rain, Figure 16. In other words, as pointed out in Section IV.3.1, in hot dry years the ratio of actual evapotranspiration to potential evapotranspiration is low, which is a common sense result. The shape of the actual E-T elevation curve changes from year to year with the maximum apparently proportional to rainfall. Figures 17 and 18 show that usually as the maximum value of the E-T increases there is a tendency for the maximum to occur in higher bands. In warm years, the tail of the curve tends to flatten, as the upper levels are warmer and tend to lose more water.

The total actual E-T for the basin is inversely proportional to the excess temperature, that is, the sum of the degree days, Figure 19. Or as the sum of the degree days and the rainfall gradient are inversely related, the total actual E-T for the basin is directly proportional to the rainfall gradient for the basin, Figure 20.

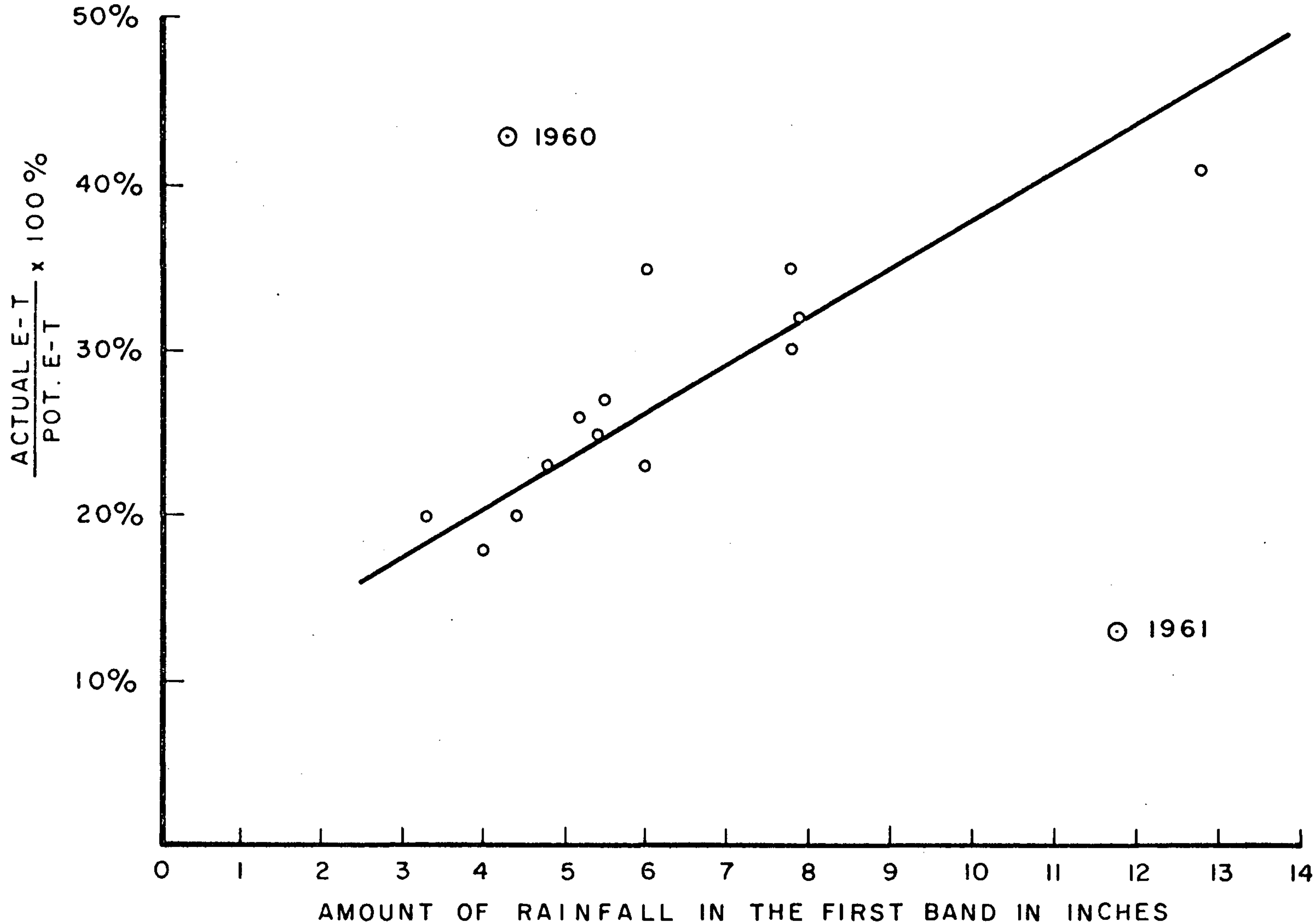


FIG. 16 RATIO OF ACTUAL EVAPOTRANSPIRATION TO POTENTIAL EVAPOTRANSPIRATION IN THE FIRST ELEVATION BAND AS A FUNCTION OF RAINFALL IN THE FIRST ELEVATION BAND.

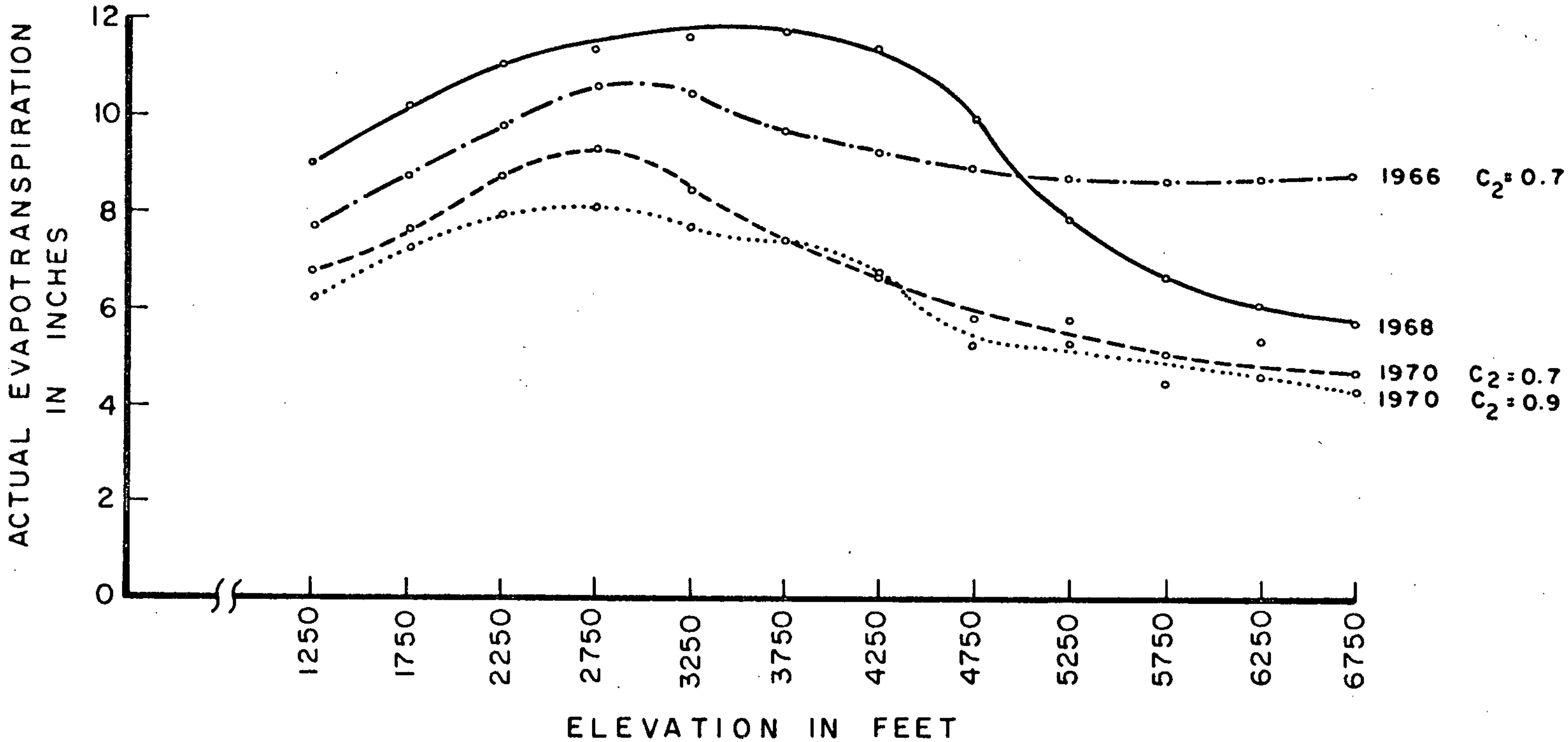


FIG. 17 EVAPOTRANSPIRATION ELEVATION RELATIONSHIPS FOR 1966, 1968, 1970.

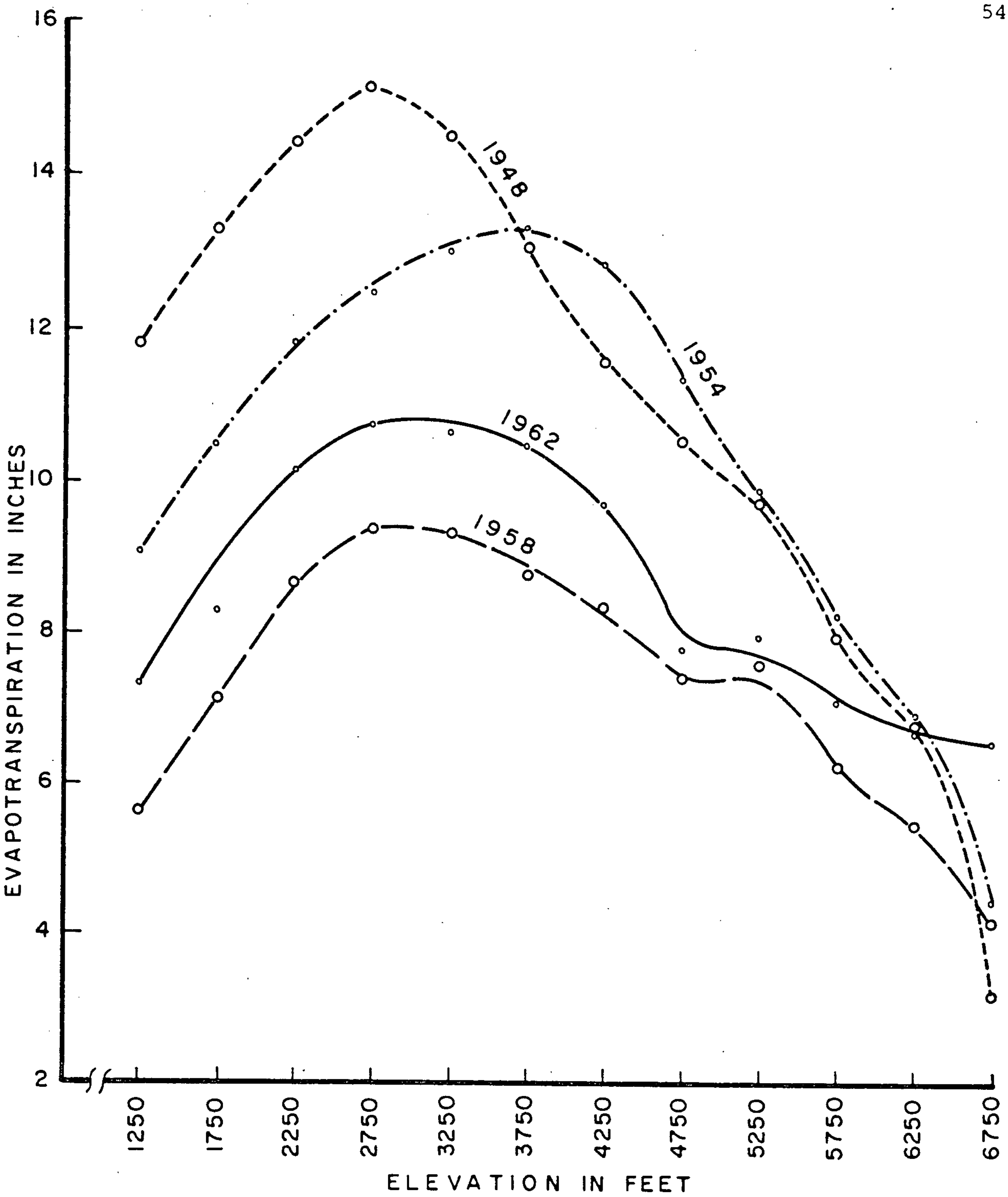


FIG. 18 EVAPOTRANSPIRATION ELEVATION RELATIONSHIPS.

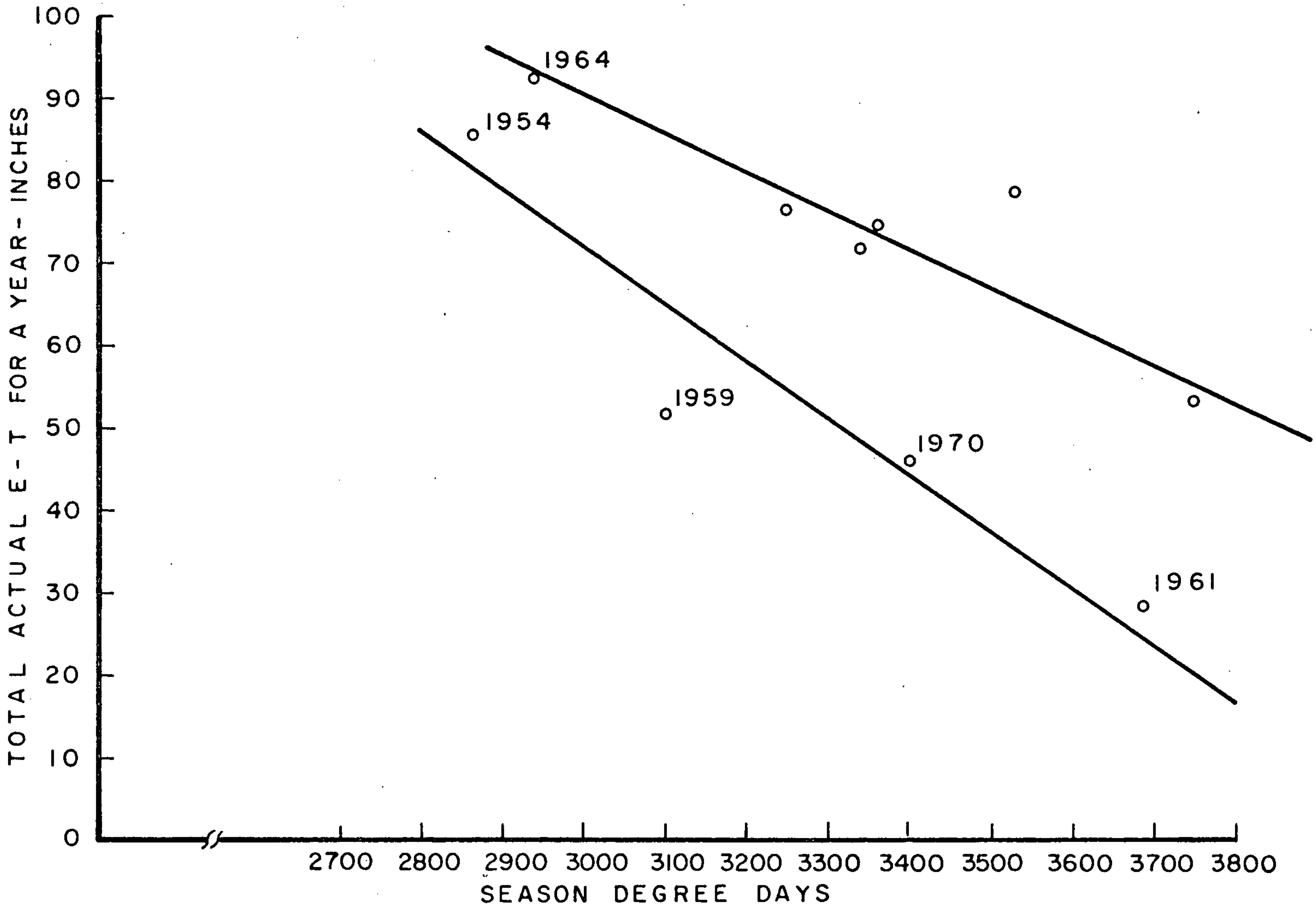


FIG. 19 TOTAL ACTUAL EVAPOTRANSPIRATION FOR THE MISSION CREEK BASIN AS A FUNCTION OF THE SEASON DEGREE DAYS.

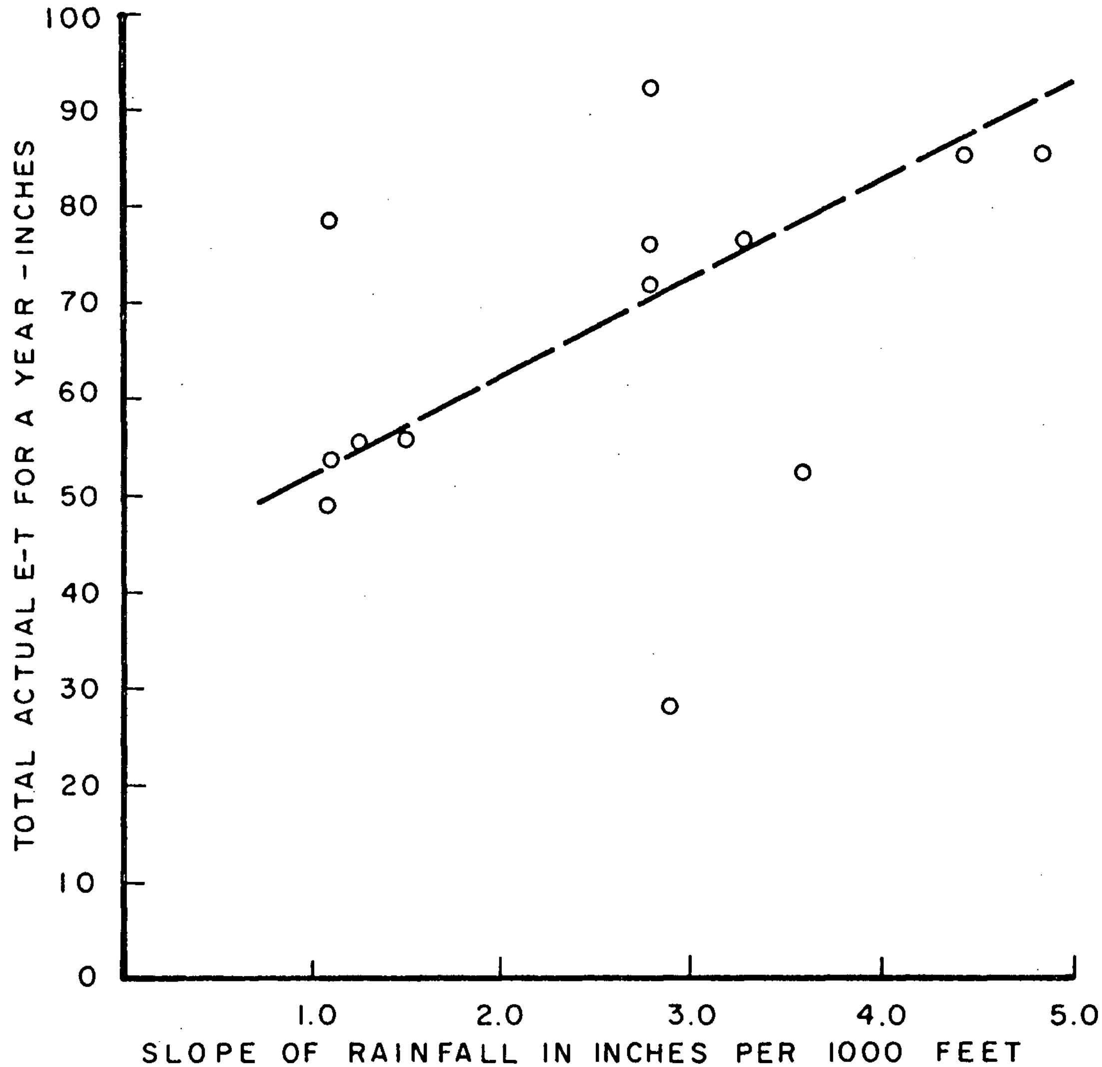


FIG. 20 TOTAL ACTUAL EVAPOTRANSPIRATION FOR A SEASON AS A FUNCTION OF THE SLOPE OF THE RAINFALL IN THE MISSION CREEK BASIN.

IV.3.3 Water Budget in the Basin. Table 9 contains a summary of results from a water budget analysis on a band by band basis for the Mission Creek Basin. By way of explanation of terms in the table, the snow efficiency is the percentage of the total snowpack that produces runoff, the rain efficiency is the percentage of rain that produces runoff, where the rain is the total precipitation but the rain runoff is measured from the date of snow line recession, the overall efficiency is the percentage of the total water input to basin that produces runoff. As there are possible errors in the estimation of both the snowpack and rainfall, the efficiencies must be regarded only as rough indicators. Obviously the rain falling into snow contributes to runoff and hence the total rain efficiency would be higher and the total snow efficiency lower. The volume of rain runoff from each band is very strongly influenced by the values of C2, LSW's.

Tables 10 through 19 provide details for the various years. In these tables, volumes are stated in 10^8 cubic feet, snowpack is based on the water equivalents for 1 April, rainfall is measured for 31 March on, and the rainfall runoff is the runoff after the snow line has receeded.

1960, Table 18, was interesting as the volume of water leaving the basin was greater than the volume of water entering the basin. But this was a year when E-T exceeded the rainfall and so rainfall may have been underestimated. In general there is a net water surplus of between 10 and 70 x 10^8 cubic feet of water. This probably goes to groundwater and slow runoff. The slow runoff, or base flow for Mission Creek appears to range from 20 to 60 CFS per day or some 10^8 cubic feet over the season. This would indicate considerable and varying amounts of water going to groundwater.

TABLE 9

SUMMARY OF WATER BUDGET RESULTS

YEAR	BASIN SNOW EFFICIENCY	BASIN RAIN EFFICIENCY	OVERALL BASIN EFFICIENCY	LARGEST RAIN RUNOFF BAND	LARGEST RAIN RUNOFF VOLUME	LARGEST RAIN RUNOFF EFF	LARGEST SNOW RUNOFF BAND	LARGEST SNOW RUNOFF VOLUME	LARGEST SNOW RUNOFF EFF
1959	75%	1.7%	40%	11	0.47	3 %	8	18.0	90%
1960	69	0.6	38	4	0.08	2.5	10	8.07	73
1963	73	0.5	31	5	0.04	1	10	6.77	67
1964	73	1.5	36	6	0.44	4	8	18.0	105
1965	73	2	40	5	0.41	7	8	16.1	103
1967	52	0.5	36	6	0.11	2	8	12.0	73
1968	63	2	30	9	0.85	6	10	11.9	81
1969	67	0.6	40	6	0.36	5	8	15.4	92
1970	62	1.7	34	6	0.19	4	10	9.0	80

The overall basin efficiency is relatively constant compared with basin snow efficiency indicating why it is difficult to estimate the runoff from snow data alone. There is an indication that rainfall after the snow line recession is an order of magnitude less effective than snowmelt in producing runoff. Bands 8 and 10 are the most efficient and also the largest contributors to snowmelt runoff, while the most efficient band for rainfall runoff is much more variable.

TABLE 10

1970 MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT		
	SNOWPACK	PRECIP.	E-T	STORAGE	RAIN	SNOW AND RAIN IN SNOW	SNOW ONLY
1	0.00	0.74	1.18	0.00	0.13	0.03	0.03
2	0.48	1.34	1.97	0.00	0.13	0.09	0.09
3	0.41	1.04	1.42	0.00	0.01	0.07	0.06
4	0.98	2.24	2.74	0.00	0.17	0.55	0.47
5	2.02	3.62	4.17	0.00	0.25	0.78	0.67
6	3.55	4.82	5.57	0.00	0.23	1.31	1.00
7	9.08	9.60	9.72	1.96	0.00	4.55	4.14
8	12.00	10.90	7.96	1.14	0.00	8.71	7.87
9	8.55	6.84	4.47	0.50	0.00	6.35	5.97
10	10.60	7.40	3.69	0.23	0.00	9.00	8.42
11	9.56	5.72	2.74	0.07	0.00	7.04	6.80
12	0.94	0.48	0.19	0.00	0.00	0.61	0.57
	58.42	54.74	45.82	3.90	0.92	37.09	34.89

Volumes in 10^8 cubic feet.

TABLE 11

1969 MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT		
BAND	SNOWPACK	PRECIP.	E-T	STORAGE	RUNOFF RAIN	SNOW AND RAIN IN SNOW	SNOW ONLY
1	0.0	1.18	2.10	0.0	0.12	0.08	0.08
2	0.47	2.02	3.24	0.0	0.16	0.20	0.20
3	0.42	1.52	2.27	0.0	0.13	0.15	0.15
4	1.09	3.17	4.32	0.0	0.18	0.32	0.30
5	2.36	5.00	6.89	0.0	0.21	0.95	0.86
6	4.39	6.54	8.46	0.0	0.36	3.10	2.89
7	11.19	12.70	14.90	1.51	0.0	13.00	11.98
8	16.60	13.60	14.80	0.81	0.05	16.37	15.36
9	12.60	8.12	8.14	0.26	0.14	8.37	8.12
10	16.60	8.62	8.01	0.18	0.05	8.60	8.23
11	15.80	6.62	5.29	0.03	0.07	6.94	6.42
12	1.65	0.56	0.24	0.0	0.0	1.14	1.04
	83.17	69.65	78.66	2.79	1.47	59.22	55.63

Overall Basin Snow Eff. $\frac{55.6}{83.2}$ = 67%

Max. band contributing 8 snow eff. $\frac{15.4}{16.6}$ = 92%

overall band eff. $\frac{16.4}{30.2}$ = 54%

Overall basin efficiency $\frac{60.7}{152.8}$ = 40%

TABLE 12

MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT		
BAND	SNOWPACK	PRECIP. RAIN	E-T	STORAGE	RUNOFF RAIN	RAIN IN SNOW	SNOW ONLY
1	0.0	1.45	1.67	0.0	0.04	0.06	0.06
2	0.28	2.62	2.87	0.0	0.06	0.18	0.17
3	0.26	2.04	2.04	0.0	0.04	0.16	0.16
4	0.70	4.39	3.94	0.0	0.10	0.30	0.29
5	1.60	7.48	6.49	0.0	0.23	0.56	0.49
6	3.15	10.70	9.10	0.0	0.00	0.75	0.59
7	8.98	22.50	17.60	3.0	0.29	2.60	2.50
8	13.20	25.00	16.00	1.81	0.63	9.40	8.65
9	10.50	15.40	6.95	0.82	0.85	11.10	9.30
10	14.60	16.40	5.62	0.42	0.60	14.04	11.90
11	14.60	12.60	3.63	0.13	0.0	12.60	8.95
12	1.61	1.05	0.27	0.0	0.0	1.30	0.95
	69.48	121.63	76.18	6.18	2.82	54.00	44.01

Overall basin eff. $\frac{56.8}{191.0}$ = 30%

TABLE 13

1967 MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT		
BAND	SNOWPACK	PRECIP. RAIN	E-T	STORAGE	RAIN	RUNOFF SNOW RAIN IN SNOW	SNOW ONLY
1	0.00	0.61	1.27	0.0	0.01	0.00	0.00
2	0.37	1.06	1.97	0.0	0.00	0.04	0.04
3	0.35	0.80	1.42	0.00	0.01	0.05	0.05
4	0.92	1.66	2.83	0.00	0.07	0.16	0.16
5	2.07	2.84	4.57	0.00	0.07	0.39	0.29
6	4.01	4.09	6.36	0.00	0.11	0.43	0.39
7	11.30	8.71	10.90	2.06	0.00	2.80	2.46
8	16.30	9.97	9.73	1.24	0.00	13.00	12.00
9	12.80	6.18	4.85	0.53	0.00	10.70	9.90
10	17.50	6.67	4.76	0.25	0.00	10.10	9.20
11	17.30	5.14	2.81	0.07	0.00	9.52	8.50
12	1.87	0.43	2.05	0.00	0.00	0.92	0.83
	84.79	48.16	53.52	4.15	0.26	48.20	43.82
	132.95			97.13			

TABLE 14

1965 MISSION CREEK WATER BUDGET

	WATER IN		WATER OUT				
		PRECIP.				RUNOFF SNOW	
BAND	SNOWPACK	RAIN	E-T	STORAGE	RAIN	RAIN IN SNOW	SNOW ONLY
1	0.00	1.03	1.03	0.00	0.04	0.04	0.03
2	0.38	1.98	2.24	0.00	0.22	0.12	0.10
3	0.35	1.61	1.66	0.00	0.09	0.15	0.12
4	0.91	3.57	3.30	0.00	0.20	0.25	0.19
5	2.03	6.13	5.57	0.00	0.41	0.32	0.27
6	3.90	8.82	7.84	0.00	0.26	0.25	0.27
7	10.90	18.60	15.60	2.05	0.17	7.51	6.82
8	15.60	20.70	14.20	1.08	0.00	18.94	16.10
9	12.22	12.60	6.99	0.41	0.14	15.02	14.10
10	16.50	13.40	6.89	0.18	0.14	14.87	12.23
11	16.20	10.20	4.33	0.06	0.28	10.84	8.02
12	1.74	0.85	0.27	0.00	0.04	1.18	0.96
	80.73	99.49	70.19	3.78	2.00	69.70	59.18
	180.2		130.7				

TABLE 15

1964 MISSION CREEK WATER BUDGET

	WATER IN		WATER OUT				
BAND	SNOWPACK	PRECIP. RAIN	E-T	STORAGE	RAIN	SNOW AND RAIN IN SNOW	SNOW ONLY
1	0.00	1.27	1.73	0.00	0.04	0.02	0.02
2	0.5	2.70	3.10	0.00	0.12	0.07	0.07
3	1.19	5.39	4.77	0.00	0.20	0.19	0.17
4	1.19	5.39	4.77	0.00	0.20	0.19	0.17
5	2.55	8.99	7.94	0.00	0.31	0.41	0.36
6	4.69	12.30	11.10	0.00	0.44	0.66	0.56
7	12.60	24.80	21.20	1.16	0.24	6.36	5.40
8	17.30	26.80	17.20	0.87	0.35	21.00	18.00
9	12.90	15.90	8.94	0.54	0.07	13.10	11.60
10	16.90	16.60	8.31	0.34	0.00	16.70	13.60
11	15.90	12.90	5.21	0.15	0.00	15.11	12.60
12	1.63	1.04	0.33	0.01	0.00	1.54	1.28
	86.66	131.03	92.25	3.07	1.90	76.00	63.73

TABLE 16

1963 MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT		
BAND	SNOWPACK	PRECIP. RAIN	E-T	STORAGE	RAIN	RUNOFF SNOW RAIN IN SNOW	SNOW ONLY
1	0.00	1.01	1.32	--	0.00	0.06	0.06
2	0.10	1.73	2.10	--	0.00	0.14	0.14
3	0.10	1.33	1.49	--	0.00	0.14	0.14
4	0.30	2.81	2.77	--	0.00	0.38	0.38
5	0.73	4.70	4.37	--	0.04	0.65	0.65
6	1.56	6.62	5.46	--	0.00	2.27	1.73
7	4.84	13.80	10.60	--	0.00	5.15	3.87
8	7.74	16.20	10.90	--	0.00	6.30	4.79
9	6.71	9.38	6.34	--	0.00	6.75	6.49
10	10.10	9.93	6.01	--	0.00	7.28	6.77
11	11.10	7.59	4.06	--	0.00	6.97	6.69
12	1.38	0.64	0.20	--	0.00	0.86	0.78
	44.66	75.76	55.62		0.04	36.95	32.51

TABLE 17

1961 MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT	
					FLOW	
BAND	SNOWPACK	PRECIP.	E-T	STORAGE	RAIN	SNOW
1	0.00	1.52	0.82	--	0.01	0.07
2	0.30	2.96	1.32	--	0.07	0.19
3	0.28	2.42	0.86	--	0.07	0.18
4	0.73	5.37	1.59	--	0.17	0.38
5	1.64	8.82	2.57	--	0.49	0.55
6	3.16	12.00	3.30	--	0.49	1.11
7	8.85	24.44	5.87	--	1.01	4.03
8	12.80	27.80	5.27	--	0.69	6.55
9	9.97	17.10	2.59	--	0.34	7.24
10	13.60	18.10	2.34	--	0.36	8.81
11	13.40	13.90	1.47	--	0.33	8.01
12	1.44	1.15	0.10	--	0.05	0.75
	66.17	135.58	28.10		4.08	37.87
	201.75			70.05	41.95	

TABLE 18

1960 MISSION CREEK WATER BALANCE

	WATER IN				WATER OUT		
		PRECIP.				RUNOFF SNOW	
BAND	SNOWPACK	RAIN	E-T	STORAGE	RAIN	RAIN IN SNOW	SNOW ONLY
1	0.00	0.81	2.05	--	0.07	0.05	0.05
2	0.14	1.66	3.34	--	0.07	0.16	0.16
3	0.14	1.41	2.35	--	0.02	0.17	0.17
4	0.39	3.20	4.41	--	0.08	0.67	0.67
5	0.93	4.99	6.49	--	0.08	1.69	1.56
6	1.93	6.24	8.41	--	0.04	2.37	2.08
7	5.79	11.50	15.70	--	0.00	4.81	4.27
8	8.96	12.00	14.50	--	0.00	6.74	6.43
9	7.53	6.97	7.26	--	0.00	5.53	4.75
10	11.00	7.24	6.21	--	0.00	9.09	8.07
11	11.60	5.47	3.84	--	0.00	6.97	6.18
12	1.34	0.45	0.26	--	0.00	0.71	0.65
	49.75	61.94	74.82		0.36	38.96	34.64
	101.69			114.14			

TABLE 19

1959 MISSION CREEK WATER BUDGET

	WATER IN				WATER OUT		
BAND	SNOWPACK	PRECIP. RAIN	E-T	STORAGE	RAIN	SNOW PLUS RAIN IN SNOW	SNOW ONLY
1	0.00	1.08	1.08	--	0.00	0.03	0.03
2	0.66	2.16	2.08	--	0.03	0.10	0.10
3	0.58	1.08	1.60	--	0.01	0.09	0.09
4	1.43	4.05	3.15	--	0.11	0.88	0.88
5	3.02	6.74	4.95	--	0.06	1.67	1.57
6	5.50	9.29	6.25	--	0.00	2.68	2.31
7	14.60	19.50	10.07	--	0.10	15.28	13.70
8	19.90	23.70	10.03	--	0.26	19.40	18.00
9	14.70	15.40	4.89	--	0.37	14.68	13.00
10	18.90	17.30	4.09	--	0.34	16.83	13.90
11	17.60	13.80	2.91	--	0.47	11.00	9.70
12	1.79	1.19	0.19	--	0.04	1.10	0.95
	98.68	115.29	51.29		1.79	82.60	75.23
	213.97			136.29			

IV.3.4 Soil Moisture Deficiencies. Soil moisture deficiencies are the most difficult results of the model to summarize and present. The soil moistures varied from band to band from day to day and year to year. They were assigned a zero value on the band switch day for a band and developed on temperature, rainfall, and evapotranspiration from that day on. Usually for wet years, 1965, the soil moisture deficiencies never rose above 3.0 inches even for the first band, seldom above 2.0 inches for the middle bands, and seldom above 1.5 inches for the upper bands. In dry years, 1970, the soil moisture deficiencies rose to 4.0 inches in the lower bands, 3.0 inches in the middle bands, and occasionally 3.0 in the upper bands. A complete list of deficiencies band by band day by day can be generated by the program.

The assignment of zero value to soil moisture deficiency on the band switch day is probably reasonable for the upper bands but there are indications [Pipes, 1971] that in the lower bands there may be a permanent soil moisture deficiency. In 1967 a higher point melt factor had to be used to obtain reasonable fit. This may have been due to the basin's soils being quite fully charged with moisture from early season melt. However 1967 did show a low overall basin efficiency.

IV.4 Predictive Results

The reasonableness of volumes predicted for 1948, 1961, 1962 and 1966 was tested by comparing the total predicted volume to 20 - 25% of the Okanagan Basin Runoff, Table 20. All values except 1961 fall reasonably close to the 20-25% figure, which was established from the results of other

TABLE 20

COMPARISON OF MISSION CREEK FLOWS AND OKANAGAN BASIN RUNOFF

YEAR	OKANAGAN BASIN RUNOFF (Acre Ft. X 1000)+	20% OF BASIN RUNOFF (in cubic ft.)+	MEASURED MISSION CREEK FLOW (cft.)	SIMULATED MISSION CREEK FLOW (cft.)
1948	783	6.96×10^9		6.79×10^9
1954	626	5.56×10^9	6.26×10^9	6.73×10^9
1958	540	4.80×10^9	3.88×10^9	4.47×10^9
1959	713	6.34×10^9	7.54×10^9	8.50×10^9
1960	521	4.64×10^9	4.3×10^9	3.95×10^9
1961	508	4.52×10^9		7.20×10^9
1962	454	4.04×10^9		5.75×10^9
1963	360	3.20×10^9	4.10×10^9	3.88×10^9
1964	594	5.28×10^9	7.55×10^9	7.80×10^9
1965	434	3.86×10^9	6.35×10^9	7.30×10^9
1966	377	3.33×10^9		4.80×10^9
1967	506	4.50×10^9	4.08×10^9	4.85×10^9
1968	563	5.00×10^9	6.45×10^9	5.68×10^9
1969			7.10×10^9	6.70×10^9
1970			2.82×10^9	3.79×10^9

+For April - July season (values from Pipes)

*For April - September season.

years. In higher than average flow years, Mission Creek appears to contribute higher percentage than in lower flow years. However, the Okanagan basin runoff is for a season of April to July, while the flows generated by the model are for April to September.

As snowmelt has been shown to be overwhelmingly important in Mission Creek, flow, Figure 21 could be used to make rough estimates of the yearly volume of flow. The abscissa is the average value of the maximum water equivalents at each of the four snow course stations for 1 April and 1 May. The values used to determine the average water equivalent are listed in Table 21.

In order to check the snowmelt routine, the water equivalents for the levels containing snow course stations were calculated for May 1, May 15 and June 1. These water equivalents were compared with measured values. Agreement at the Mission Creek station was within 4 inches, that is about 20%, for May 1 and May 15, and within 7 inches, or approximately 50% for June 1.

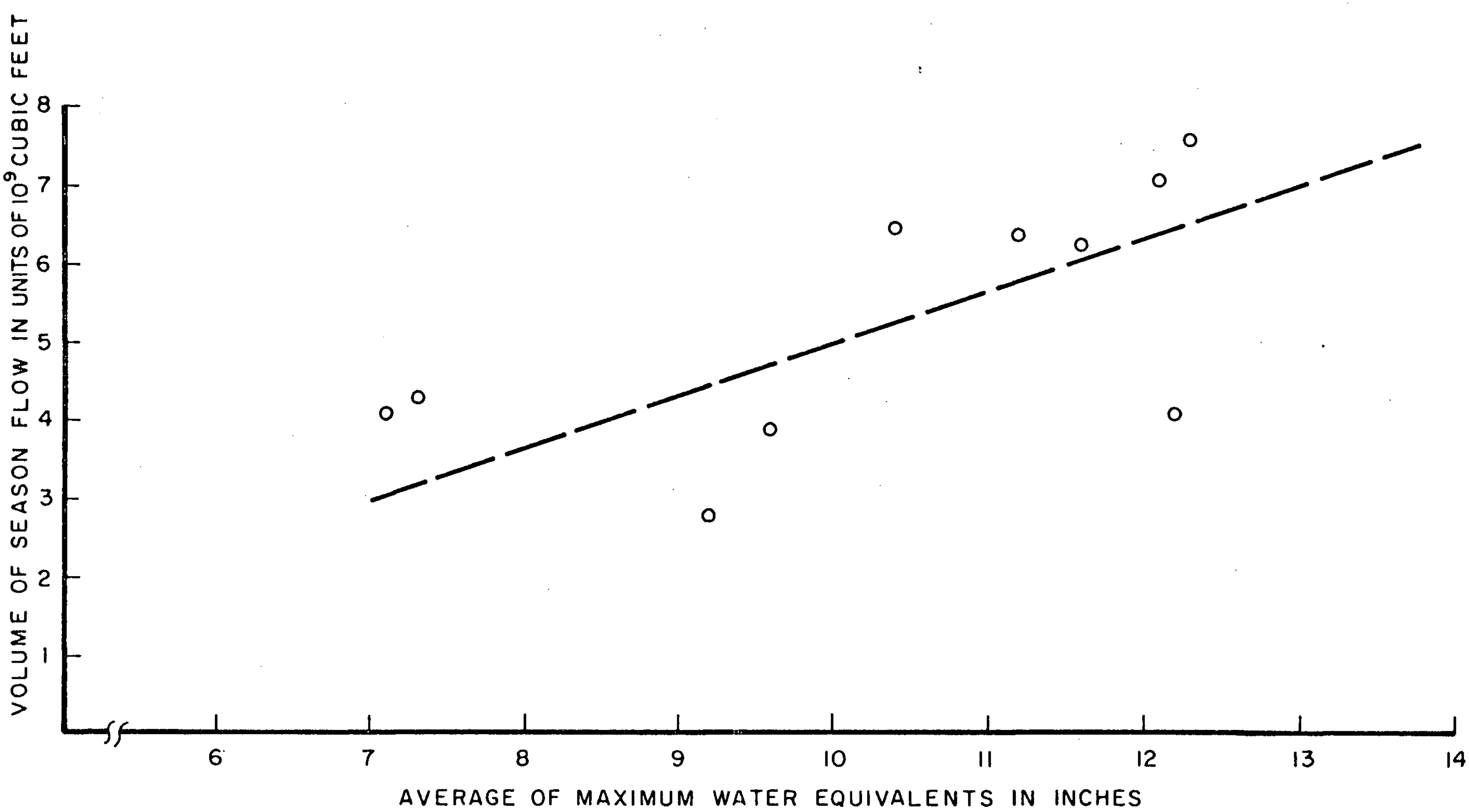


FIG. 21 VOLUME OF SEASON FLOW FROM MISSION CREEK AS A FUNCTION OF AVERAGE OF MAXIMUM WATER EQUIVALENTS.

TABLE 21

WATER EQUIVALENTS FOR THE SNOW COURSES
IN THE MISSION CREEK BASIN
(units are inches of water)

YEAR	ABERDEEN		POSTILL		McCULLOCH		MISSION CREEK		AVG. OF MAXIMUMS	
	A	M	A	M						
1948	5.6	0.0	-	-	6.6	4.5	21.9	-	11.3	-
1954	7.6	1.0	8.1	7.8	6.2	3.9	21.7	24.5	11.6	6.3
1958	4.8	0.0	6.7	7.0	5.2	2.0	18.0	21.2	9.6	3.9
1959	8.8	2.0	11.5	8.9	9.0	4.5	25.3	24.9	13.7	7.5
1960	3.8	0.0	4.9	4.4	3.1	0.0	15.7	17.3	7.3	4.3
1961	5.8	1.0	7.7	6.8	4.4	1.5	18.7	22.3	10.1	-
1962	9.1	0.0	10.2	4.4	9.3	2.8	20.9	17.8	12.4	-
1963	2.2	0.0	4.3	3.4	3.4	0.8	14.7	18.4	7.1	4.1
1964	7.2	4.1	9.2	7.8	8.9	4.7	22.7	23.9	12.3	7.6
1965	5.0	0.0	9.6	4.1	7.4	2.8	22.7	21.1	11.2	6.4
1966	5.0	0.7	7.2	6.1	5.0	0.9	17.5	18.9	9.0	-
1967	5.4	4.8	9.2	8.6	8.2	0.0	24.2	26.1	12.2	4.1
1968	4.8	2.5	8.4	7.8	5.0	1.5	20.3	23.6	10.4	6.5
1969	7.2	0.0	8.6	5.9	8.2	1.1	22.5	21.1	12.1	7.1
1970	4.7	3.7	7.7	7.9	5.8	4.6	14.0	18.2	9.2	2.8

IV.5 Conclusions

A model is no better than the assumptions that go into it. The strengths or weaknesses of a model will follow from the limits imposed by the assumptions. For example, in the Mission Creek Flow Model, the daily precipitation was lapsed in two linear segments. This procedure may have predicted too large precipitations in the higher elevations of the basin, which in turn effects the evaporation and runoff from the basin. Indeed the runoff from the rain in snow was found to be too large so the precipitation had to be decreased by a factor of 1/2 with the assumption that any excess went to soil moisture.

Also the late season upland storage releases and the diversions for irrigation were assumed to be mutually cancelling. This was a forced assumption as no data is available on the storage releases and diversion.

The assumption of a zero soil moisture deficiency in a band on the day after the snow line recession is probably reasonable for the upper bands of the basin, but the lower bands may have permanent soil moisture deficiencies. The upper bands are those which produce most of the runoff, but if the rain runoff is to be studied the correct initial soil moisture conditions are essential to the model.

On the whole the Mission Creek Flow Model did fit the flows for the years when data was available and the results appear qualitatively reasonable. As checks on the qualitative reliability of the results, the later season water equivalents were checked against measured values and the 1970 year of record was run with no previous fitting and then compared with the measured flows (Figure 22). The results compared closely

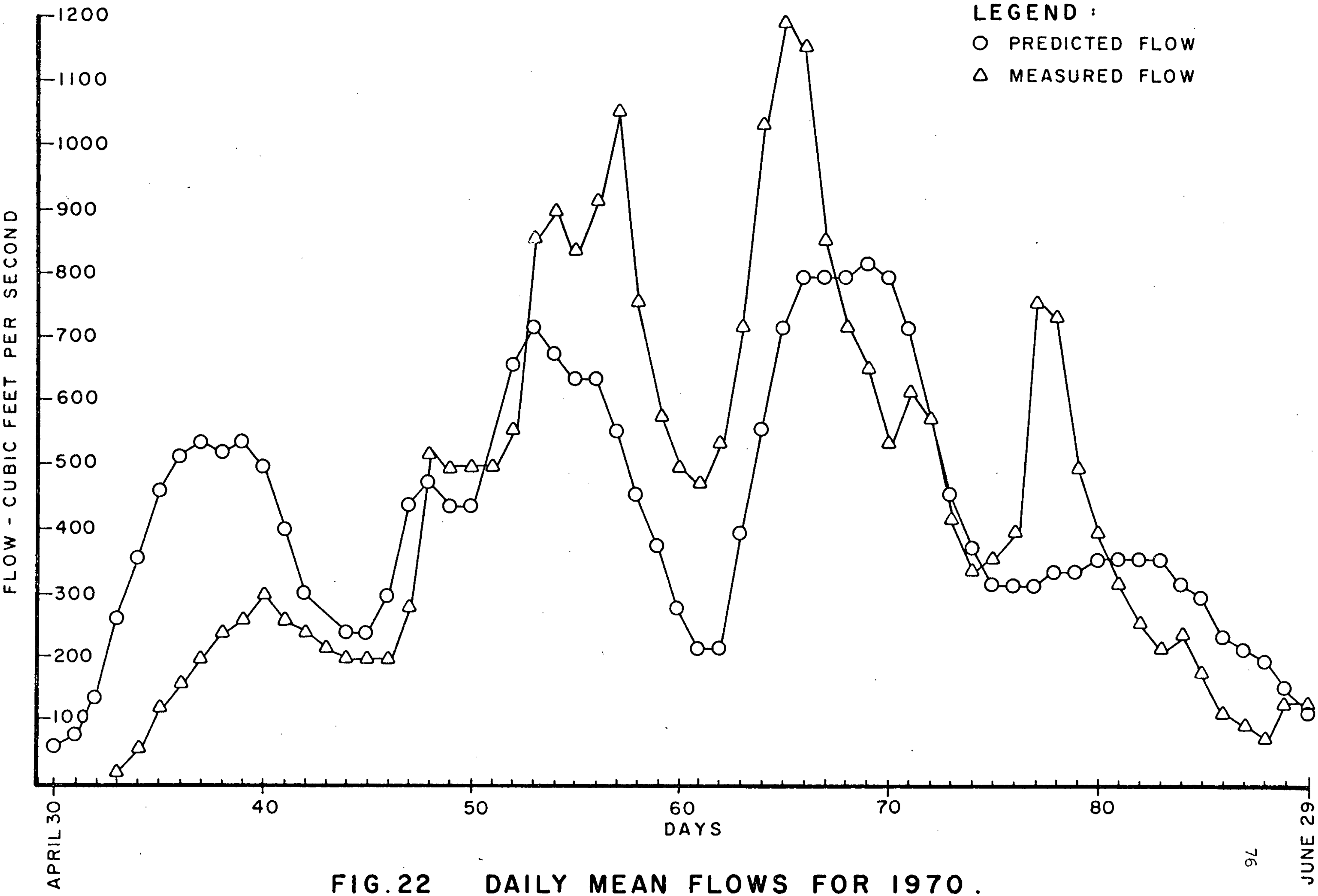


FIG. 22 DAILY MEAN FLOWS FOR 1970.

lending assurance to the representativeness of models. The 1970 simulation is shown from 30 April to 29 June as on other days the flow intake simulated and measured is generally less than 100 cubic feet per second.

In reviewing the objectives of the model, the following conclusions may be drawn. The potential evapotranspiration in the basin declines linearly with an average slope of 1.47 inches/1000 ft., while the actual evapotranspiration shows a hump back behaviour with the maximum and the elevation of the maximum varying from year to year. As to runoff from rainfall and snowmelt, from 50 to 75 per cent of the water equivalent in the snowpack contributes to runoff, while only 1 to 6 per cent of the rainfall after snow contributes to runoff. Bands 8 and 10 produce the largest volume of snow runoff and hence are the major contributors to runoff.

According to the model, snowmelt is the most important factor in runoff and the most important bands are those lying between 4500 and 6000 feet. It is therefore important that if the hydrologic processes of the Mission Creek Basin are to be further studied and better numerical values given for runoff that snow course and meteorological data from these elevations be obtained. So the model has thus provided an indication of the areas of the basin where additional data is required.

Late season rains can provide runoffs of the order of 500 CFS for a short term, so additional information on rainfall in the middle and upper bands would be required for a more detailed investigation of rain runoff. Rainfall does appear to be biased by Joe Rich Creek which receives heavy precipitation compared with McCulloch, Section IV.3.1.

The model has shown that temperature data alone is not adequate to accurately predict the evapotranspiration from the basin, but can be used in estimating evapotranspiration trends. As E-T process are complicated the data required for any improvement in predictions could be prohibitive.

The use in the model of a chain of IF statements involving soil moisture and precipitation values has a built-in bias which limited the model's application to the Mission Creek area for late season rain runoff. Strictly speaking a more general model is required for other creeks in the Okanagan, although Crawford notes that storage and infiltration parameters are quite stable and usually vary only slightly for adjacent watersheds. The bias built into the model against the rain runoff is due to the lack of information on rain at the higher elevations. On the basis of the present model, the middle elevation bands do have some "flashy" response to rain.

In summary, the weaknesses of the model have been discussed but the model does have strengths. These strengths are primarily simplicity, the relatively small amount of data required and the fact that the model does fit the measured flows. Also the model appears capable of growth; the "IF statement chain" may be replaced by an algebraic function; a computer routine for the optimization of variables may be built in; and finally if data does become available from the 4000 to 6000 elevation range the model should be valuable in further study of runoff generation.

REFERENCES

1. Blaney, H. F. Evaporation from Free Water Surfaces at High Elevations. Proceedings ASCE, *J. Irrigation Drainage Division*, Vol. 82, No. IR3, Paper 1104 (1956).

2. British Columbia Snow Survey Bulletin, Water Investigations Branch, Water Resources Service, Department of Lands, Forests and Water Resources, Victoria, B.C.

3. Crawford, N. H. and R. K. Linsley. Digital Simulation in Hydrology: Stanford Watershed Model IV, Technical Report #39, Department of Civil Engineering, Stanford University, July 1966.

4. Evans, G. W. II, G. F. Wallace, G. L. Sutherland. *Simulation Using Digital Computers*. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1967.

5. Geiger, R. *The Climate Near the Ground*. Cambridge, Mass.: Harvard University Press, 1965.

6. Horton, R. E. An Approach Toward A Physical Interpretation of Infiltration Capacity. *Proc. Soil Sci. Soc. Am.*, Vol. 5 (1940), pp. 399-417.

7. Linsley, R. K., M. A. Kohler and J. H. L. Paulus. *Applied Hydrology*. New York: McGraw-Hill, 1949.

8. Mandeville, A. N., P. E. O'Connell, J. V. Sutcliffe and J. E. Nash. River Flow Forecasting Through Conceptual Models, Part III: The Rye Catchment at Grendon Underwood. *Journal of Hydrology*, 11, (1970), pp. 109-128.

9. Monthly Record Meteorological Observations -- Canada.

10. Nash, J. E. and J. V. Sutcliffe. River Flow Forecasting Through Conceptual Models, Part I: A Discussion of Principles. *Journal of Hydrology*, 10, (1970), pp. 282-290.

11. Nasmith, H. Late Glacial History and Surficial Deposits of the Okanagan Valley, British Columbia. Bull. No. 46, Department of Mines and Petroleum Resources, Victoria, B.C. (1962).

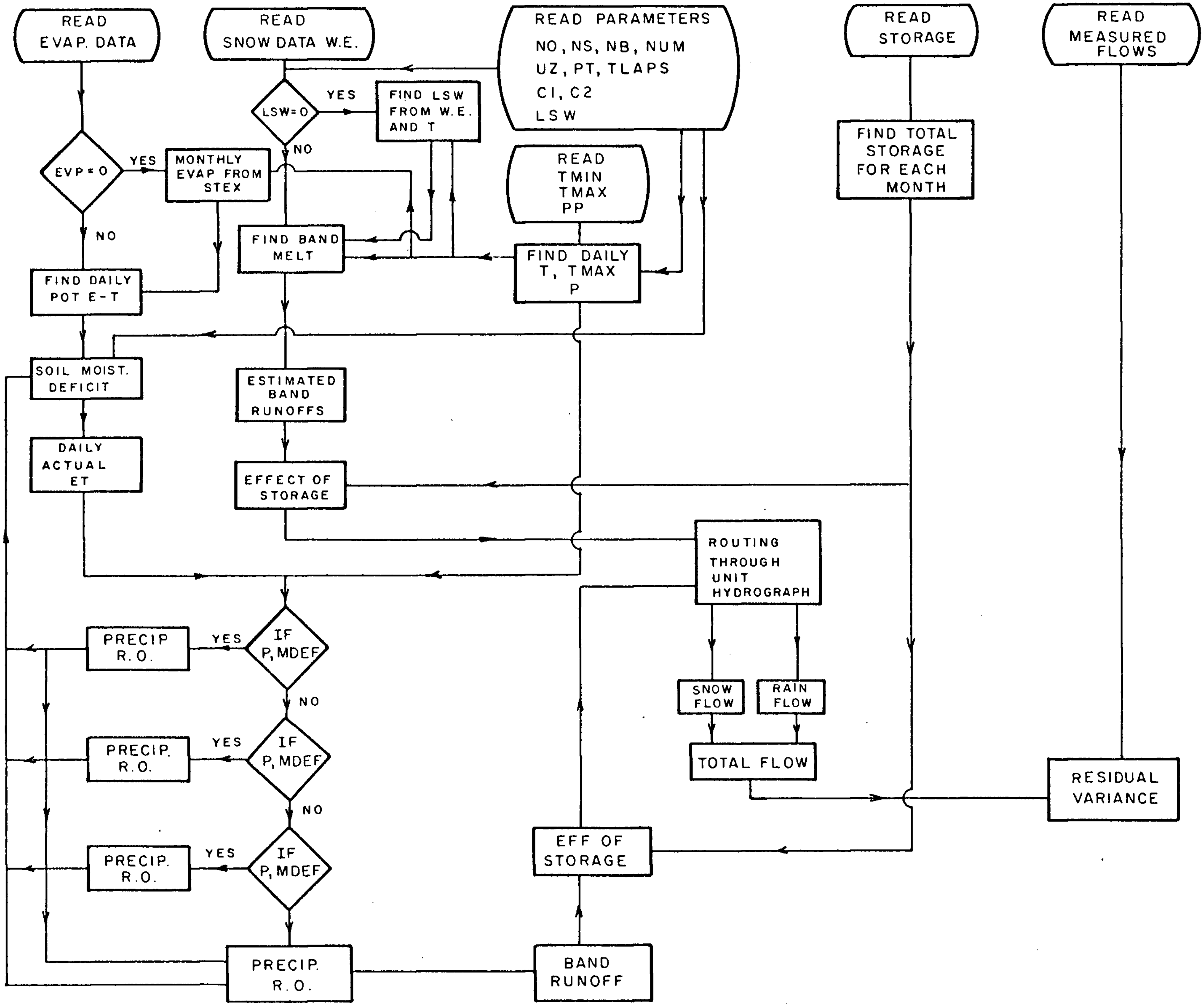
12. Nelson, J. G. and M. J. Chambers. *Weather and Climate*. Methuen, 1962.

13. O'Connell, P. E., J. E. Nash and J. P. Farrell. River Flow Forecasting Through Conceptual Methods, Part II: The Brosna Catchment at Ferbane. *Journal of Hydrology*, 10, (1970), pp. 317-329.

14. Pipes, A. An Analysis of the Carrs Landing Watershed, IHD Project IWB-RB-37 BC8, June 1971, Water Investigations Branch, Water Resources Service, Department of Lands, Forests and Water Resources, Victoria, B.C.

15. Rockwood, P. M. and M. L. Nelson. Computer Application to Streamflow Synthesis and Reservoir Regulation. International Commission on Irrigation and Drainage. Sixth Congress, R. 4, Question 22.

APPENDIX I FLOW CHART OF MISSION CREEK - FLOW MODEL.



APPENDIX 2

PARAMETERS USED IN MISSION CREEK FLOW MODEL

A(L)	-	Area of the bands	square miles
C1	-	Pan evaporation coefficient	dimensionless
C2	-	Evapotranspiration decay factor	$(\text{inches})^{-1}$
EL(I)	-	Elevations of the meteorological stations	feet
ELL(L)	-	Center elevations of the bands	feet
LSW(L)	-	Band switch times	days
NB	-	Number of bands	dimensionless
ND	-	Number of days	dimensionless
NS	-	Number of metecrological stations	dimensionless
NUH	-	Number of days in the unit hydrograph	dimensionless
PTM	-	Point melt factor for snow	CFS/SQ.MI./F°/DAY
TLAPS	-	Lapse rate for temperature	F°/1000 FT.

APPENDIX 3

LIST OF VARIABLES

INPUT

T(J,L)	Temperature in day J band L	°F.
TB(I,J,L)	Temperature from station I data for day J level L	°F.
TX(I,J)	Maximum temp. at station I on day J	°F.
TN(I,J)	Minimum temp. at station I on day J	°F.
TM(I,J)	Average temp. at station I on day J	°F.
P(J,L)	Precipitation on day J band L	inches
PB(I,J,L)	Precipitation from station I, data for day J band L	inch x 10^{-2}
PP(I,J)	Precipitation at station I on day J	inch x 10^{-2}
WE(L)	Water equivalent of snow in band L	inches

OUTPUT

BM(J,L)	Band melt for day J, level L	CFS
BMRF(J,L)	The contribution to runoff of rain on day J in level L	inches
BRO(J)	Measured daily flow	CFS
DPEVP(J,L)	Daily potential evapotranspiration for day J level L	inches
DEVP(J,L)	Actual evapotranspiration for day J level L	inches
EBRO(J,L)	Estimated band runoff	CFS
EBRORF(J,L)	Estimated band runoff from rainfall	CFS

ET(L)	is the total actual evapotranspiration for band L for the season	inches
EVP(M,L)	is the monthly evapotranspiration for month M and level L	inches
F(J)	Flow due to snowmelt	CFS
FLST(L)	Flow into early season storage for band L	CFS
FRF(J)	Daily flow to rainfall runoff	CFS
FT(J)	Daily total synthesized flow	CFS
MDEFF(J,L)	is the soil moisture deficit on day J and level L	inches
PANEVP(M)	A misnomer, really the lake evaporation	inches
PI(L)	Total precipitation into band L over the season	CFS
PRO(J,L)	Precipitation runoff	CFS
SI(L)	Total water equivalent of snow band L at beginning of season	inches
STA(R)	Storage in reservoir/lake R at beginning of April	Acre-ft.
STM(R)	Storage in reservoir/lake R at beginning of May	Acre-ft.
STJ(R)	Storage in reservoir/lake R at beginning of June	Acre-ft.
STEX(M,L)	The sum of the excess temperatures for one month for band L	F°.
TEX(J,L)	The daily excess temperature for band L (above 40°F)	F°.
TPEVP(L)	Total potential E-T for band L for season	inches
WL(L)	Total winter lost through E-T for season for band L	ft.

APPENDIX 4

DATA INPUT FOR MISSION CREEK FLOW MODEL

CARD NO.	QUANTITIES	FORMAT
1	ND NS NB NUH	10I7
2	6 EVAPS FOR APRIL-SEPT	10F7.0
3	C1 C2	10F7.0
4	UZ PTM TLAPS	10F7.0
5	ELEVATIONS OF MET STATIONS	10F7.0
6	CENTER BAND ELEVATIONS OF THE LEVELS	10F7.0
7	CENTER BAND ELEVATIONS OF THE LEVELS	10F7.0
8	AREAS OF THE LEVELS	10F7.0
9	AREAS OF THE LEVELS	10F7.0
10	LSW'S BAND SWITCH TIMES FOR THE LEVELS	10F7.0
11	LSW'S BAND SWITCH TIMES FOR THE LEVELS	10F7.0
12	WATER EQUIVALENTS APRIL 1	10F7.0
13	WATER EQUIVALENTS MAY 1	10F7.0
14	TMAX STATION 1 FOR ALL ND	10F7.0
	.	
	.	
	TMIN STATION 1 FOR ALL ND	10F7.0
	.	
	.	
	.	
	PP STATION 1 FOR ALL ND	10F7.0
	.	
	.	
	.	
	TMAX STATION 2 FOR ALL ND	10F7.0
	.	
	.	
	.	
	TMIN STATION 2 FOR ALL ND	10F7.0
	.	
	.	
	.	
	PP STATION 3 FOR ALL ND	10F7.0