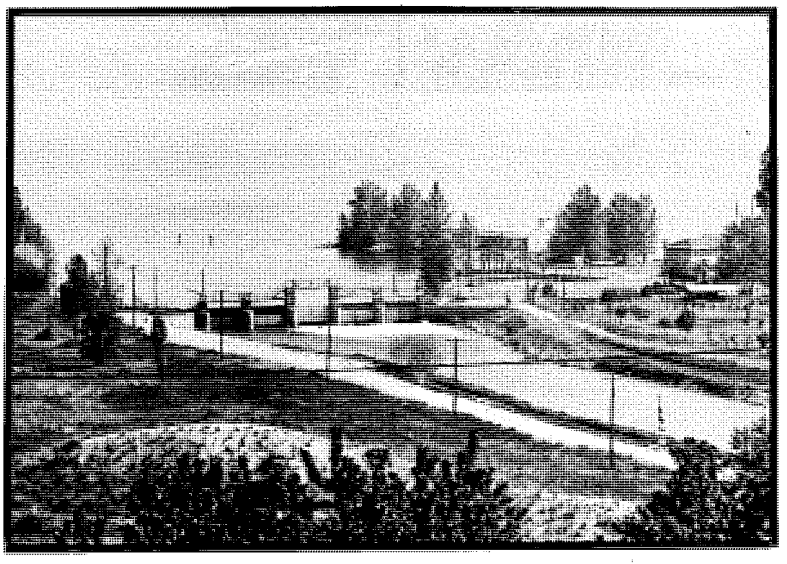
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CANADA-BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT



WATER QUANTITY COMPUTER MODELS

TECHNICAL SUPPLEMENT II



"Sometimes even nature needs help to conserve water...."

MARCH 1974

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CANADA-BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT

TECHNICAL SUPPLEMENT II

TO THE

FINAL REPORT

WATER QUANTITY COMPUTER MODELLING

PUBLISHED BY

OFFICE OF THE STUDY DIRECTOR

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MARCH, 1974

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THE CONTRIBUTION OF THE FOLLOWING PEOPLE IN
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FOREWORD

This Technical Supplement describes and presents the results of water quantity computer model studies as carried out under the Okanagan Basin Agreement. The results of all other studies concerning water quantity in the Okanagan Basin in Canada are covered in Technical Supplements I 'Water Quantity in the Okanagan Basin', and III 'Water Quantity Alternatives and Supporting Water Quantity Data Tables.'

The material presented in this supplement supercedes that of all earlier preliminary reports or publications prepared under the Canada-British Columbia Okanagan Basin Agreement.

A.M. Thomson,
Study Director

SYNOPSIS

A number of computer models were developed as part of the water quantity component of the Okanagan Basin Study. Since the use of computers in hydrology is a rapidly developing field, each study involves a large element of research and the actual models themselves are often of as much interest as are the results obtained from them. This report describes the various models, the assumptions on which they were based and the lessons learned from them.

Operating models were developed for the Okanagan mainstem system terminating just North of Osoyoos Lake, and for the eight most important tributary basins. These models were designed to simulate operation of the present or projected future systems, on the basis of recorded or estimated past flows, to answer "what if?" types of questions. These models, which were conventional and straightforward, both operated on a monthly time period to reduce the data and output to manageable quantities. The mainstem model provided much useful data for assessing the performance of many possible management alternatives. Great care was taken to present the results of the mainstem model so that maximum use could be made of them. Results were given in both a summary form, that could easily be grasped, and in detailed form to facilitate close comparison of the many alternatives investigated. The tributary operating model also provided much useful first estimate data for planning purposes.

Three research type models were developed in an attempt to model the distribution, throughout the valley, of mean annual and mean monthly precipitation, evaporation and runoff by relating these to physiographic variables. The basic hydrologic problem in the Okanagan is that most of the runoff originates from high elevations while most of the measurements are at the lower elevations where the people live. One approach was the grid square method in which the basin was divided into squares and temperature, precipitation, evapotranspiration and runoff were estimated for each square and matched with the recorded runoff. The second approach attempted to relate meteorological data to physiographic variables by regression and regional analyses using the same squares as in the grid square method. The third related runoff data to physiographic variables, this time on a tributary basis but again using regression analysis. These models appeared to be reasonably successful but one of the reasons for their ex-existence--the lack of high elevation data -- also made it difficult to assess them.

An elaborate hydrologic simulation model was developed in an attempt to model runoff throughout the basin on a year round basis to provide data for planning purposes and to serve as a base for forecasting runoff for operating purposes. In developing the model a semi-automatic optimization method EVOP (evolutionary operation) adapted from chemical plant technology was used. With this method it was possible to identify interactions between variables, optimize the parameters in any particular model and assess the adequacy of the model at its current state of development. More than 300 trial runs were made before it was reluctantly concluded that the available knowledge and data are inadequate to support such a complex model. Although this result was disappointing there were several gains from the attempt-the EVOP technique proved a valuable addition to the model builder's "tool kit", useful insights into hydrologic processes were obtained and weak areas needing further research were pinpointed.

A model developed for simulating and forecasting the Fraser River flows during the freshet was adapted to the Okanagan valley. This model works well once it has been "tuned" by adjusting the soil moisture deficit each year.

In another study to determine how forecasts should best be used and how good they need to be, a decision model was developed. This model uses an extension to conventional decision theory concepts to provide guidance about operating policy for Okanagan Lake in the light of inflow forecasts. Although it will require validation in practice the model seems promising and it could have many applications.

Finally in the course of the studies two main bottlenecks to future advance and ways of overcoming them were identified; these were the need for some further measurements in the Okanagan Basin and the need for a conceptual framework on which to "hang" all the different approaches and co-ordinate all the agencies involved. Hydrologic modelling is a field which is not standing still and it is hoped that the Okanagan modelling studies have opened up opportunities for further advances.

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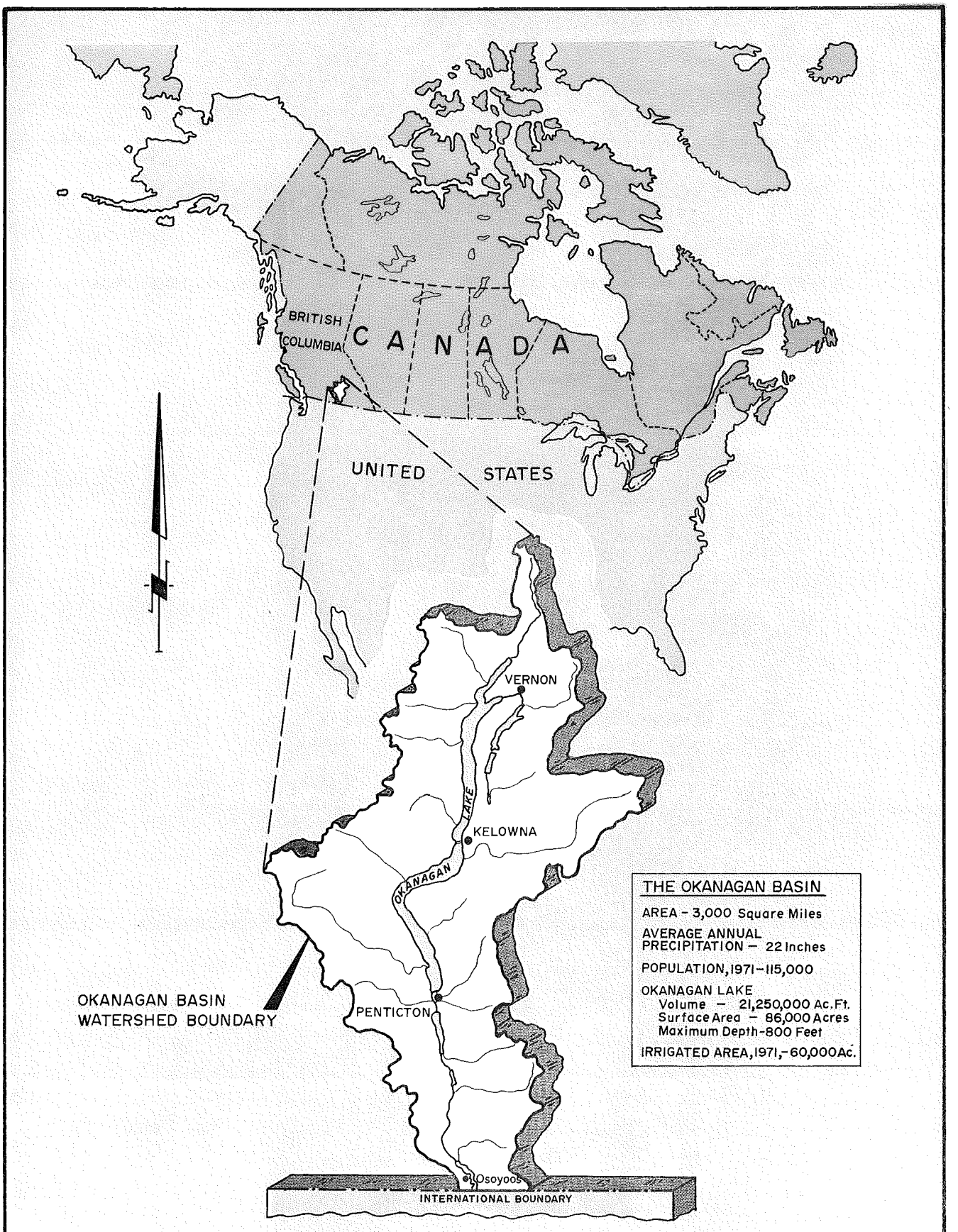
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Figure A

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CHAPTER 1

Introduction

1.1 GENERAL

This Technical Supplement describes the mathematical models developed in the course of the water quantity part of the Okanagan Basin Study. Hydrologic information is basic to any study of water management, and in turn, mathematical models and computers are essential to modern hydrology which largely consists of information processing. Since standard hydrological models and computer packages do not exist, the models for the Okanagan studies had to be specially developed for the problems in hand. Hydrology is a developing science and there is a considerable element of research in any major study. Models are built on the basis of existing knowledge but in the course of their development they often contribute new knowledge and new insights which can be incorporated into the next generation of models. These contributions may be as important as the actual immediately useful results.

In the Okanagan water quantity studies, a number of quite different approaches were tried. Not all were an unqualified success, but useful results were obtained; and new insights were gained and new techniques developed which contribute to the fund of knowledge on which future modellers will be able to draw.

This supplement concentrates on the models themselves and the insights gained from them, presenting results only where necessary to illustrate the capability of the models. It thus represents the main contribution of the Okanagan Study to hydrologic practice particularly with reference to the dry interior of British Columbia.

1.2 TYPES OF MODELS

Hydrologic phenomena are extremely complex and hydrologic models are, of necessity, simplified abstractions from reality. Considerable finesse is required in selecting the appropriate level of detail. If it is too coarse, a model may not pass the threshold of reality at which it becomes useful. If it is too fine, computation and data requirements get out of hand. At all times, therefore, the aim is to produce results of acceptable accuracy with models of minimum complexity.

The different types of models can be distinguished by:

(1) Whether or not they deal with time. An example of the former is a model to simulate a runoff hydrograph while a model to compute mean evapotranspiration over a sub-basin would represent an example of the latter.

(2) Whether they are deterministic or stochastic. The former uses series of equations to transform given inputs such as precipitation into outputs such as runoff, while the latter uses statistics to generate a record which is intended to be statistically indistinguishable from the measured record.

(3) Whether they are physical or "black box" models. Physical models consist of sets of equations which attempt to model the actual physics of the hydrologic system. In black box models, on the other hand, the data are simply fitted by the best available mathematical technique regardless of the physical processes. The most widely used example is linear regression.

(4) Whether they simulate natural events only or also include the effects of man-made operations. A model to simulate natural runoff given meteorological data is an example of the former, while a model to simulate the operation of a reservoir given flows of record and sets of operating rules would be an example of the latter.

(5) Whether they simulate past events or predict future ones. A model to simulate runoff given actual recorded meteorological data is an example of the former, while a model to forecast runoff given meteorological forecasts would be an example of the latter. In practice the same model can be used for both purposes and in fact forecasting models are developed and calibrated with recorded data.

The various distinctions above are not pure and many of the models developed in the Study involved several of the above components. A table of the various models developed and the categories to which they belong is given in Section 1.4 below.

THE WATER QUANTITY MODELLING PROGRAM

The water quantity modelling part of the Okanagan Basin Study program was shaped by a number of special circumstances as follows:

(1) Although a considerable amount of hydrologic and meteorological data for the Okanagan Basin existed, the records were fragmented and there was little overlap, which made it difficult to establish correlations and meaningful relationships.

(2) Information on water availability was needed at an early stage as a base for many of the component tasks of the comprehensive study.

(3) Several agencies were involved, all located in different places and operating with different emphasis and procedures. Despite good will and sincere attempts at co-operation, this made co-ordination difficult.

(4) Hydrology is a rapidly developing science with few standard methods and procedures. Hydrologic studies involve considerable elements of research; ingenuity and intuition are needed to extract the most from available data. This unstructured state of the art compounds the problems of co-ordination.

(5) Water quantity management in the Okanagan Basin is a matter of continuing concern. The B.C. Water Resources Service has and will continue to have a competent team of hydrologists available to advise on the hydrology of the basin. As a result any improvement made possible by the hydrologic and modelling studies will be picked up and used. Thus any advances in basic knowledge or techniques or new insights represent a gain even if it is not possible to report complete solutions to hydrologic problems in the Okanagan Study report.

To meet the data needs, an extensive program of hydrologic and meteorological measurements was instituted at the beginning of the Study. This program was intended to provide data to help define key relationships, particularly those involving areal variation within the Okanagan. It was also intended that some of the stations be kept on after the Study to provide data for management purposes.

The need for water quantity information for use in other tasks of the Study was met by a flexible series of models of increasing accuracy as time went on. First estimates of streamflow were rough for first cut studies, identification of problem areas, etc. More detailed studies were made as required.

The various agencies involved all began work at approximately the same time and all used different approaches. Attempts were made to keep in close contact, a common information base was established and there were full interchanges of information and output data as the studies progressed.

The various approaches are summarized in the following section and described in more detail in Chapters 3 to 11 of this supplement. In the final chapter an attempt is made to summarize the state of the art or "where we are at now" and outline promising lines for future inquiry.

1.4 SUMMARY OF WATER QUANTITY MODELS

The various models used are listed in Table 1.1 in a form which allows them to be identified with the categories outlined in Section 1.2 above.

The tributary flow model described in Chapter 3 was an early first-cut model to estimate the distribution of flows of record among the tributaries

TABLE 1.1

CHARACTERISTICS OF WATER QUANTITY MODELS

MODEL	CHARACTERISTICS				
	SIMULATE EFFECT OF TIME?	DETERMINISTIC (YES) OR STOCHASTIC (NO)?	PHYSICAL (YES) OR BLACK BOX (NO)?	SIMULATES OPERATIONS ?	CAN BE USED FOR FORECASTING?
Tributary Flow at Mouth (Chapter 3)	Partly	Yes	Yes	No	No
Selected Tributary Flow (Chapter 4)	No	Yes	Yes	No	No
Tributary Operation (Chapter 4)	Yes	Yes	Yes	Yes	No
Mainstem Operation (Chapter 8)	Yes	Yes[1]	Yes	Yes	No
Grid Square (Chapter 5)	No	Yes	-[2]	No	No
AES Precipitation (Chapter 6)	No	Yes	No	No	No
AES Evaporation (Chapter 6)	No	Yes	No[3]	No	No
Basin Characteristic (Chapter 7)	No	Yes	No	No	No
Budgeting (Chapter 9)	Yes	Yes	Yes[4]	No	Yes
Forecasting Budget (Chapter 10)[5]	Yes	Yes	Yes	No	Yes
Decision Analysis (Chapter 11)	Yes[6]	No[6]	No[6]	Yes[6]	No[6]

[1] Forecasts generated stochastically.

[2] Parts of the model are empirically based - parts involve regression.

[3] There is a physical base to part of the model.

[4] Regression is used in parts of the model.

[5] Not developed as part of the Okanagan Basin Study.

[6] In different ways from the usual sense.

of the Okanagan Basin. Output in the form of a table of natural monthly flows in each of the 35 tributaries at their mouths for the period 1921-1970 was used as preliminary water quantity data for other component tasks of the Okanagan Basin Study. The most important feature of this model was the procedure used in its development, where an optimization technique "EVOP" adapated from chemical plant technology was used to find best values of the parameters in the model. It proved to be a versatile and extremely useful tool for hydrologic studies.

Next, as described in Chapter 4, the estimates of flow in eight of the most important tributary basins were refined for high, medium and low years in the light of new data, for purposes of a detailed study of water management in these tributaries. For the management studies an operating model was developed to model natural flows, withdrawals and residual flows at selected points in the tributary basins and also reservoir storages and storage changes. Since the natural flow estimates were on a one year basis the model simulated the effects of time on a within year basis but not on an overyear basis.

The mainstem operating model, Chapter 8, is the basic tool for providing information for studying alternative plans for managing the Okanagan mainstem system. The model operates on a monthly basis simulating flows for the 50 year period of record 1921-1970. The model is set up to accept different operating rules, such as restriction on lake levels, restrictions on discharge at various points in the river, response to flow forecasts, etc. and to provide detailed information so that alternative management plans can be assessed. The model is deterministic with the exception that flow forecasts are generated stochastically to make the simulation realistic since, in practice, forecasts are always made and the lake operated accordingly. Great care was taken with the arrangement of the output of the model since it is important to the acceptance of a computer study to satisfy both those who "want to see the big picture" and also those who "like to read the fine print". Results were provided in a summary form arranged such that their significance could be easily grasped and also in a detailed form to provide data for assessing the implications of any proposed management alternative on any particular aspect of the Okanagan basin.

Quite different from the above models, which might be characterised as being oriented towards immediate use, are the models described in Chapters 5, 6 and 7 which can be categorized as exploratory models designed to enhance the understanding of hydrologic processes in the Okanagan basin by relating the main components of precipitation, evaporation and runoff to physiographic variables. The grid square model, Chapter 5, is an extension of a technique originally developed by Solomon (1)[1] and adapted to British Columbia by Obedkoff (2) for the estimation of mean monthly values of temperature, precipitation, evapotranspiration and runoff from each of

[1]Numbers in parentheses refer to references.

the five kilometer squares into which the Okanagan basin is divided. The Atmospheric Environment Service models, Chapter 6, provide estimates of mean monthly precipitation and evapotranspiration on the same squares. These used regression analyses to derive relationships between precipitation and physiographic variables using meteorological (but not snow course) data and generalized estimates of the relation between evaporation and elevation derived from analysis of data in Western Canada. The basin characteristic modelling described in Chapter 7 attempts to relate runoff to basin characteristics.

Hydrologic simulation models attempt to model the main hydrologic processes over time and compute runoff from meteorological data. With meteorological forecasts they can be used for forecasting runoff but since long range weather forecasts are not accurate it is usual to compute high,medium and low runoff forecasts using as input meteorological data recorded during high, average and low runoff years. In simulation it is possible to adjust the parameters to match computed and recorded hydrographs even though the underlying processes are not completely understood. When using a model for forecasting, however, it is necessary to have a simple adjustment procedure so that the model parameters can be quickly tuned to match computed with recorded flow as the latter reveal themselves. In the case of the Okanagan model the model should ideally be tuned at or before the beginning of the freshet season in April since important operating decisions have to be taken at that time or earlier when extreme hydrologic conditions are anticipated.

The budgeting model described in Chapter 9 is set up to model runoff from each of the squares (the same as those used in the Grid Square and AES modelling studies) on a year round basis and to aggregate the flows by tributaries or entire basins as desired by the user. The primary aims were to model runoff throughout the basin for several years of record, to provide data for planning purposes, and to model soil moisture at the beginning of the freshet season either for input to a separate forecasting model or for using the budgeting model itself for forecasting purposes. The EVOP procedure was used in the development process and again great care was taken to arrange the model and the output so that they could be of maximum help to the hydrologist.

The results were disappointing in that the model could not be successfully operated year round and thus could not be used for forecasting purposes. However, the model can be used for simulating runoff for planning purposes and, in the course of its development, new knowledge was discovered and weak areas, where additional data must be obtained if any solid advances are to be made, were identified. If these data are obtained the model can provide a good basis for future work.

A simulation and forecasting model for the Fraser River Basin was adapted to the Okanagan and this model is described in Cahpter 10. It simulates runoff into Okanagan Lake on a daily basis during the freshet season. Adjustments to match computed and recorded flows are made by changing the intial soil moisture deficit

but some time has to elapse before the necessary comparisons can be made to guide the "tuning". This model represents a very useful part of the water management "tool kit".

Chapter 11 desribes a decision making model - an application of decision theory to the problem of operating Okanagan Lake. This model is completely different from the other models in that it deals with values and probabilities and provides guidance on the best action in the light of available flow forecasts. The model seems to be promising, but may need to be tuned in the light of actual operating experience.

Chapter 12 summarizes the present state of the art of modelling in the light of experience gained in the Okanagan Basin Study andoutlines the main conclusions drawn from this experience.

CHAPTER 2

Data Sources

Many of the chapters of this Technical Supplement have a section on data sources used in the modelling they describe. The purpose of this chapter is to identify some of the major sources of data which were extensively used by several models.

2.1 HYDROMETRIC DATA

All streamflow and lake level data were obtained through the Water Survey of Canada. The data were abstracted from the "Surface Water Data Books," published annually, from computer tapes and from unpublished data and other information made available to the study personnel.

Much of this raw data had to be transferred into a more useable form. For example, several of the models such as the tributary flow distribution, the tributary operation, the grid square model and the mainstem operating model required that historic flows should be adjusted to give the best estimate of what the natural flows would have been had man not stored, diverted and used water. The majority of this work on naturalization of monthly flows in the Okanagan which involves allowances for water usage and evaporation losses was done by the B.C. Water Resources Service, Water Investigations Branch (B.C.W.I.B), both prior to and during the study. Their published (3,4) and unpublished data were extensively used. Details of the derivation of these data can be found in Technical Supplements I and III.

Some data sets were not complete for the 50 year period of the study and for modelling purposes it was desirable that they be completed by correlation techniques. Examples include the flows in the Shuswap at Enderby and the local inflows to the Okanagan River south of Penticton. This work was undertaken by the B.C.W.I.B. and made available to the study participants.

2.2 METEOROLOGICAL DATA

Temperature, precipitation and some evaporation data were obtained from the Atmospheric Environment Services (A.E.S) of Environment Canada. Most of the data were published in the "Monthly Record of Meteorological Observations in Canada" published by the A.E.S. but use was also made of unpublished data made available to the Study personnel.

Data derived by the A.E.S. during the course of the study such as the mean annual and monthly precipitation in the Okanagan valley on a grid square basis (described in detail in Chapter 6 of this Technical Supplement) were made

available to all study participants as soon as they were calculated.

Extensive use was made of the snow survey information contained in the B.C. Water Resources Service "Snow Survey Bulletins" published six times a year during the runoff season. This information on high level accretion and depletion of the snowpacks complemented the information gathered at the standard meteorological stations, the majority of which are at the lower elevations in the valley. The models making most use of these data were the grid square hydrologic model and the budgeting hydrologic model.

As the potential evaporation in the Okanagan was not measured prior to 1962, it was necessary to estimate monthly lake evaporation figures for the period 1921-1961. This was undertaken by the B.C.W.I.B. (4) by correlating temperature and evaporation for the period 1962-1970 and using the equation thus derived to give estimates of the monthly lake evaporation for the period of the study.

2.3 GRID SQUARE DATA

Several of the models described in this Technical Supplement such as the grid square hydrologic model, the Atmospheric Environment Service models and the budgeting hydrologic model used physiographic and other parameters on a five or ten kilometer grid system. All of the models used the same grid system which is generally coincident with the military grid in the area. The only exception was that where there is a discontinuity in the military grid system at longitude 120°W, the grid system adopted for the study continued on the west side of this line as an extension of the grid defined to the east of the line. This entailed the abstraction of several parameters for up to 500 squares and the majority of this work was undertaken by the B.C.W.I.B. and made available to all study personnel. Additional data were abstracted in the Department of Civil Engineering at UBC to define tributary sub-basins by grid square. A meteorological parameter suggested by Danard (5) was abstracted on the 5 kilometer grid system by the B.C.W.I.B.

2.4 MISCELLANEOUS

In the early models requiring population, irrigated areas and industrial use of water, figures estimated by the B.C.W.I.B. (6) were used. These were later replaced by figures for both present and various projected future conditions supplied by the socio-economic task force of the Study. These figures are fully explained in Technical Supplement No. 7.

Estimates of monthly lake evaporation, tributary storage changes, diversion duty of water, monthly diversion and return flow figures were all obtained from data published by the B.C.W.I.B. (4). These data are detailed in Technical Supplement No. I.

CHAPTER 3

Tributary Flow Distribution Model

3.1 INTRODUCTION

Estimates of natural flows in the 35 Okanagan tributary basins were required at an early stage in the study. These were needed for input to other component tasks involving water quality, fisheries, recreation, etc. and for a preliminary matching of water supply and demand on a tributary basis.

Although a considerable amount of data existed, it was fragmentary and most of the streamflow data had not been corrected for diversions and irrigation withdrawals. Estimates of the total inflow to Okanagan Lake were available for the 50 year period of record 1921-70 and it was also possible to make estimates of the total annual flows in 7 tributaries for an average of 19 years each.

In the light of this information, it was decided that estimates of natural monthly flows in the tributaries for the 50 years 1921-70 were the best that could be expected and that this would be adequate for first stage studies. The first problem was thus to fill in the gaps in the table of annual flows for the 7 tributaries which had some records and also for the remaining 28 sub-basins for which virtually no records existed, and then to break down the annual totals into monthly flows.

A very simple model was used to distribute the flows among the tributaries. The model parameters were optimized by a special technique - evolutionary operation (EVOP) adapted from chemical plant technology.

This particular study was begun in January 1971; preliminary results were made available in March 1971 and the study was completed by May 1971. Apart from the results themselves two important innovations came from the study. One was the adaptation of EVOP to this type of study where data are poor and scattered - an innovation which was used to good effect in later hydrologic studies. The other was the computation procedure described in Section 3.4 which made quite complex calculations feasible.

3.2 DATA

The only data recorded continuously over the 50 year period were the Okanagan Lake Levels, the discharges to the Okanagan River at Penticton and some meteorological records at a few valley bottom stations. All other basic data were either discontinuous or unavailable and it was therefore necessary to derive

and estimate much of the data. The following were the principal data used:

(1) Estimates for each month of the 50-year period of the study of the natural inflow to both the Okanagan Lake basin and to the whole Okanagan basin in Canada (1,2).

(2) Estimates of the monthly flows in 7 creeks tributary to the mainstem system. These figures were abstracted from data published by the Water Survey of Canada. The creeks used were: Whiteman, Deep, BX, Mission, Trepanier, Vaseux and Trout. Where necessary seasonal flows were converted to annual flows by assuming that the same ratio applied to the sub-basin as applied to the whole basin.

(3) Precipitation and temperature data recorded at those stations having reasonably continuous records over some period of the study. These data were abstracted from data published by the Meteorological Service of the Department of Transport (now the Atmospheric Environment Service). The stations used were: Oliver, Penticton, Summerland, Adra, Kirton, Chute Lake, Osprey Lake, McCulloch, Joe Rich Creek, Kelowna, Okanagan Centre and Vernon Coldstream.

(4) Area elevation data for the valley and for each of the sub-basins. These were abstracted from 1:50,000 maps of the area.

3.3 MODEL DEVELOPMENT

3.3.1 General

The basic model was set up in such a way that the results could be displayed in graphic form and their accuracy assessed. Then either the parameters in the model or the model itself could be readily changed to improve the results. EVOP provided the necessary framework for systematically improving the model. This procedure for changing and improving the model was thus more important than the actual model itself.

EVOP was developed by statisticians Box and Draper (7) as a practical method for improving the operation of full-scale chemical plants. Factorial experiments are run on the plant and the results displayed in a special format which is readily comprehensible to the operator and allows him to improve the operation of his plant step by step while keeping in full control at all times. The procedure has the same advantages when applied to hydrologic models. It allowed any particular model to be pushed quickly to its limit. If still inadequate the model was changed and the new one optimized. The process was repeated until satisfactory results were obtained.

In the course of the study several basic models were tried - but only the final one is described in detail. The model is a physical one. Meteorological data from a few long-term stations at different elevations were used to derive

general relationships between precipitation, potential evaporation and actual evaporation. Simple assumptions were made about the variation in precipitation with elevation and latitude.

With these, estimates were made of the annual precipitation actual evapotranspiration and, by subtraction, runoff from each of the elevation bands of each of the sub-basins for each of the years of record. The comparison between computed and recorded values of the runoff from those sub-basins with records provided the necessary criteria for adjusting the parameter or the model. The main assumptions and components of the basis model are given in the following sections.

3.3.2 Precipitation Variation

It was assumed that precipitation over the valley was consistent in that if x% of the long-term average annual rainfall occurred in any particular year at one point in the valley, then x% of the long-term average would fall at all other points in that year. On a seasonal basis this assumption is believed to be reasonable, although wide variations can be found over shorter time periods. It was also assumed that a simple relationship existed between precipitation and elevation and between precipitation and latitude.

With few meteorological stations located other than in the valley bottom it was not possible to establish a relationship between precipitation and elevation from meteorological data. In these circumstances two simple relationships were modelled, one assuming a linear variation with elevation and one exponential. Eventually the linear one was adopted. The equation has the form:

$$P_{xy} = P_y \ (1 + K1(E_X - E_L)) \qquad (3.3.1)$$

where

P_{xy} = precipitation at point x, at distance y from the base line;

P_y = precipitation at lake level at distance y from the base line;

E_X = elevation of X;

E_L = elevation of lake; and

K_1 is a constant - to be found by trial with the model.

It was apparent from the meteorological records that precipitation increases from south to north but again the data were insufficient to define the relationship. Initially it was assumed that precipitation varied linearly with latitude. Later, better results were obtained by assuming that precipitation varied linearly with distance from a line drawn in an approximately NW-SE direction through the center of the valley. An equation of the following form was used;

$$P_y = P_c(1 + D_y/K2) \qquad (3.3.2)$$

where

P_y = the lake level precipitation at distance D_y from the base line (NE is positive);

P_c = the mean precipitation for the valley at lake level - the "base" precipitation;

K2 is a constant to be found by trial with the model.

These two equations (3.3.1 and 3.3.2) can be combined to give

$$P_{xy} = P_c(1 + D_y/K2)\ (1 + K1\ (E_X - E_L) \qquad (3.3.3)$$

3.3.3 Evapotranspiration

Evapotranspiration is a complex phenomenon. To estimate it on an annual basis the following assumptions were made.

(1) Potential evaporation was consistent over the valley in that if x% of the long-term average potential evaporation occurred in any particular year at one point, then x% of the long-term average value would occur at all points in that year. "x" was obtained from the lake evaporation estimates (1).

(2) Potential evaporation varied with elevation but not with location or latitude.

(3) Actual evaporation in any year depended on the precipitation and potential evaporation in that year.

Estimates were made of the long-term average potential and actual evaporation at different elevations, using a computerized version of Thornthwaite's method. The precipitation and temperatures were then varied both above and below the average for each station and several runs were made for each combination of precipitation and temperature. (Different assumptions about the soil moisture capacity of the soil were also tried but these made little difference). It was then necessary to generalize this data - to interpolate and extrapolate to find the potential evapotranspiration (PE) and actual evapotranspiration (AE) for a range of conditions in each elevation band. Computed values of PE were plotted against AE for each elevation band for a range of precipitation, and it was found that the relationship between AE and PE over the likely range of values was essentially linear and could be expressed by the equation:

$$AE = C_1 + C_2 * PE + W(C_3 - C_4W) \qquad (3.3.4)$$

where

C_1 through C_4 are constants for each band determined from the above analysis;

and

$$W = \frac{\text{Annual Precip.} - \text{Av. Annual Precip.}}{\text{Av. Annual Precip.}} \qquad (3.3.5)$$

Constraints that AE could not exceed either the PE or the precipitation in any year were applied to the equation.

For any particular year and elevation band it was assumed that

$$PE = PE_{av*} \left(\frac{\text{Lake evap. for that year}}{\text{Av. lake evap.}}\right) \qquad (3.3.6)$$

Combining equations (3.3.4) and 3.3.6) the actual evapotranspiration (AE) was calculated from:

$$AE = C_1 + C_2 * PE_{av}\left(\frac{\text{Lake evap.}}{\text{Av. lake evap.}}\right) + W(C_3 - C_4 W) \qquad (3.3.7)$$

3.4 MODEL TESTING AND PARAMETER OPTIMIZATION

3.4.1 General

Equation (3.3.3) contains two parameters K1 and K2 which have to be evaluated. The procedure for optimizing their values was built into the model. The time-sharing computing facilities at UBC Computing Centre were used and the results of the modelling were displayed on cathode ray tube display terminals. This display enabled the operator to assess the results, make changes in K1 and/or K2 and repeat the process for almost instant new results. This rapid turn around allowed the EVOP procedure for step by step optimization to be used to full advantage.

3.4.2 Operation of the Model

The steps in the operation of the model were as follows:

(1) Basic data for the whole basin was fed in. This included area/elevation data, the natural inflow and the lake evaporation for each year of the period of record, the average annual PE for each elevation band, values for the constants C1 to C4 and upper and lower limits of the possible annual "base" precipitation at the valley bottom.

(2) Two trial values for each of the constants K1 and K2 are read in.

(3) Annual precipitation and AE are computed for each 500 ft. elevation band for a range of 5 values each of base precipitation, P_c and PE (given by lake evaporation) using the trial values of K1 and K2. The annual runoff from each band is then calculated from the band area and the difference between precipitation and AE. Total runoff from the basin is obtained by summing the runoff from the bands and the result is stored in a table.

(4) For each year in turn, values of the total basin runoff and the lake evaporation are entered in the table of runoff values described in (3) above and the corresponding value of the base precipitation P_c is obtained by double interpolation.

(5) Basic data for each sub-basin are read in. This includes area elevation data, the location of the sub-basin (to allow computation of D_y) and recorded runoff where this is available.

(6) For each year, compute the precipitation, the AE and, by subtraction, the runoff from each band of each sub-basin, for which records are available, using the values of K1 and K2 in (2) and the value of P_c from (4). Multiply the runoff from each band by its area and sum to obtain the total runoff from the sub-basin.

(7) Compute the following error indicators for a measure of the adequacy of the model and parameters.

(a) the difference between the computed and recorded runoff from each sub-basin for each year;

(b) a sub-basin error indicator EF_i by the equation

$$EF_i = 100 \frac{\Sigma(Qc_i - Pr_i)^2}{nQa_i^2}$$

where

Qc_i = computed flow from model;
Qr_i = recorded flow;
Qa_i = average flow;
n_i = number of years of record

ALL FOR SUB-BASIN i

(c) an overall error indicator E.F given by $E.F. = (\sum_i (EF_i)^2/b)^{1/2}$

where

b = number of sub-basins.

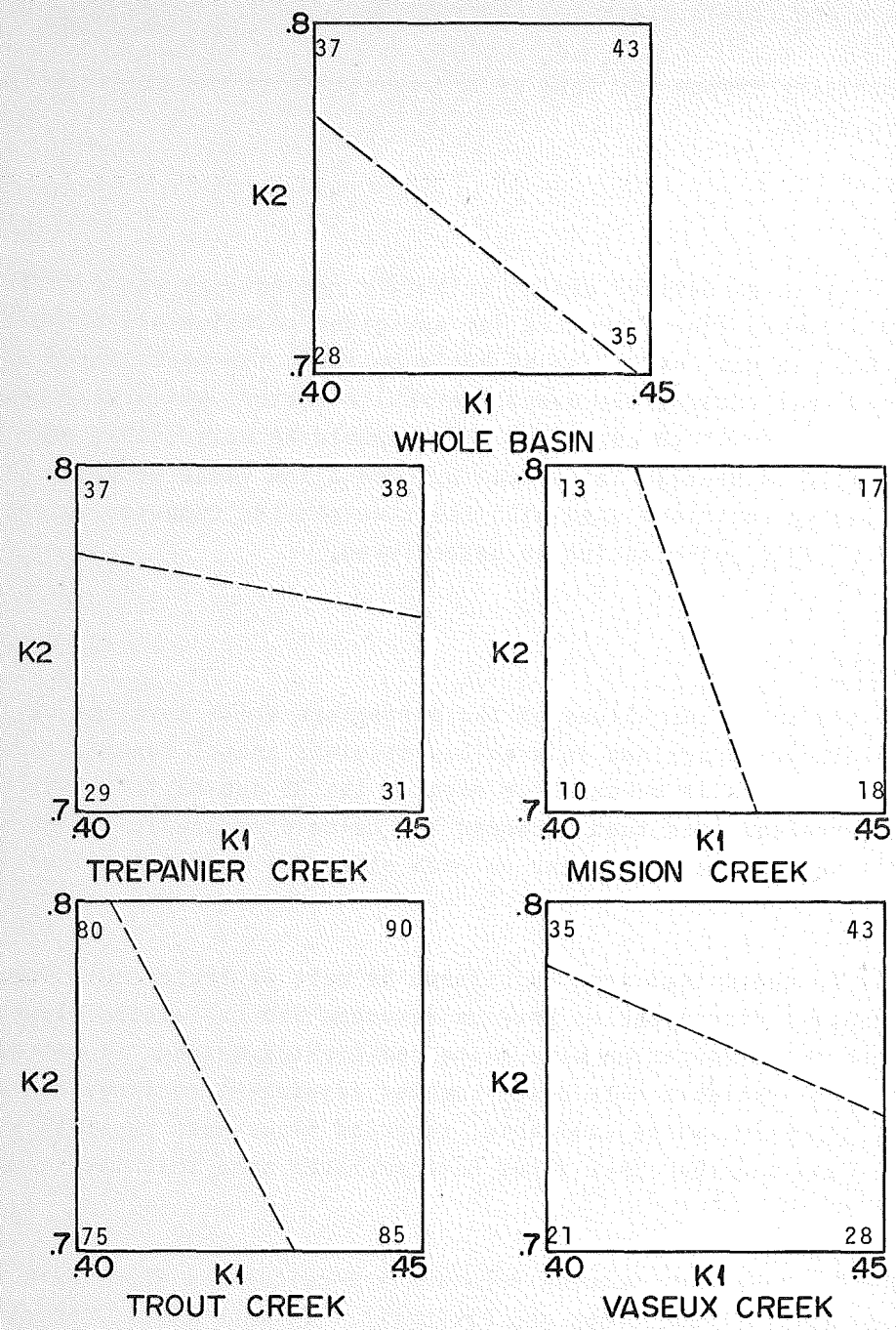
(8) Repeat steps (3) through (6) for the other three possible combinations of K1 and K2.

(9) Display the results in any of the following three options which the hydrologist selects.

(a) 4 values of the overall error indicator in the form of EVOP square as shown in Fig. 3.1;

(b) Error indicator for any of the sub-basins in the form of an EVOP square as shown in Fig. 3.1;

(c) List of computed and recorded runoff and their differences for all the years of record for any sub-basin.



The above typical error indicator displays show that in all cases the "contours of equal error" (shown as hatched lines) generally slope from top left to lower right although there are different slopes. Decreasing the values of K1 and K2 will apparently decrease the error in all cases. This procedure is repeated until errors are minimized.

TYPICAL "EVOP" ERROR INDICATORS Figure 3.1

(10) Revise the values of K1 and K2 in the light of the information available in (9) above and repeat steps (2) through (9).

(11) If necessary change the form of the equations in the model and repeat the entire procedures.

3.4.3 Results

With only seven sets of useful tributary records, it was a relatively quick process to optimize the parameters for any given relationship being tested. It was found that values for K1 and K2 could be found for most of the relationships investigated that reduced the overall error indicator, which were equivalent to a "standard error," to about 30%. (It should be noted, that this form of error indicator is heavily influenced by even a few large errors). It was found that the display technique used with the time-sharing computer worked well and enabled very rapid optimization to be achieved.

3.5 ANNUAL RUNOFF

Using the model and values of the parameters which gave the best results from the procedure described in previous sections annual runoff was computed for all the 50 years of records for each of the 35 sub-basins. The computer output was arranged such that recorded and calculated precipitation and run-off figures were printed adjacent to each other for easy comparison and ass-essment.

It was intended that some adjustment be made in those cases where there were substantial discrepancies between recorded and calculated flows. After considerable experimentation with quite complicated methods it was decided that, with the available data base, complex adjustment routines could not be justified. However, where available, recorded flows were substituted for computed values and the other flows were prorated such that the annual totals were correct.

Major discrepancies between recorded and calculated flows were apparent in two sub-basins, Trout Creek and Park Rill. In both cases, the mathematical model consistantly predicted considerably higher flows than had been recorded; in the case of Trout Creek by up to 200% and in Park Rill by up to 1000%. After considerable thought, it was decided that as the discrepancies were so great, the flows in these two creeks should be left as calculated by the model rather than changed to their recorded flows. Since the method always gave the correct total this meant the estimates for the other creeks would be, if anything, on the low side, thus giving a small factor of safety when matching supply and demand.

3.6 CONVERSION TO MONTHLY FLOWS

After the annual flows in all the sub-basins had been estimated the next step was to break them down into monthly flows. A procedure which could be computerised was necessary to deal with the large amount of data. The most obvious "information base" for making the distribution was the list of estimated monthly inflows to Okanagan Lake (4). As a first step the annual flows in the tributaries were therefore pro-rated among the months on the basis of these monthly inflows to Okanagan Lake. However, it was obvious that the pattern of runoff would vary from South to North and with elevation, since snow melts earlier in the south than the north and at low elevations before high elevations. After analysing the available sub-basin flow records the following adjustment procedure was adopted.

(1) Adjust monthly flows (up or down) by the following factor F where

$$F=1 - [E_i - 4500 - (X_m * D_{iy})] * y_m/1000$$

where

E_i = average basin elevation)
) for basin i
D_{iy} = distance of basin from base line)

(See equatn. 3.3.2)

and x_m and y_m are factors to allow for latitude and elevation influences on the rate of melt. They were varied as follows:

MONTH	x_m	y_m
April	5	0.5
May	10	0.2
June	20	0.1
July	20	0.05
Aug.	20	0.02

Other months: no adjustment

(2) Sum the adjusted flows from April to August and adjust them again such that they add up to the correct total.

This procedure was programmed and the resulting monthly flows in each of the 35 sub-basins for each of the 50 years of record listed in the computer output.

3.7 CONCLUSIONS

A method for distributing the annual inflow into the Okanagan Valley for 50 years of record among 36 sub-basins and then breaking these down into monthly flows was developed. With the exception of the figures for Trout Creek and Park Rill, two anomalous basins, these figures were sufficiently accurate for a preliminary matching of supply and demand and for other tasks in the study. The methodology developed in the course of this modelling proved useful in later work. The model also showed up some of the areas in which there were hydrologic problems and which required further investigation.

CHAPTER 4

Tributary Operating Model

4.1 INTRODUCTION

About 75 percent of the water used for irrigation in the Okanagan Basin is obtained directly from streams tributary to Okanagan Lake rather than by pumping from the main lake and river system. To ensure a reliable water supply through the irrigation season from April to September, reservoirs have been constructed on many of the headwaters of the tributaries. In a comprehensive study of water management it is therefore necessary to consider the individual tributaries as well as the basin as a whole, and also the distribution and management of water within the tributary basins.

Since there are many tributaries it was decided to begin with a detailed pilot study of multi-purpose water management of one tributary - Trout Creek. Unfortunately, the water quantity data base was particularly poor for Trout Creek. Nevertheless, Trout Creek was retained for detailed study together with Peachland, Powers, Equesis, Vernon, Kelowna, Mission and Penticton Creeks as shown on Figure 4.1.

To handle the large volume of work a computer program was developed to compute the natural flows and irrigation demands at selected points in the tributaries for a "dry", "average" and "wet" year, and simulate operation of the reservoir system in each tributary basin on a monthly basis for a range of present and future conditions. The program computed natural flows from area elevation data and relationships between elevation and runoff which were developed for each tributary.

Thus the objectives of the tributary water quantity modelling were:

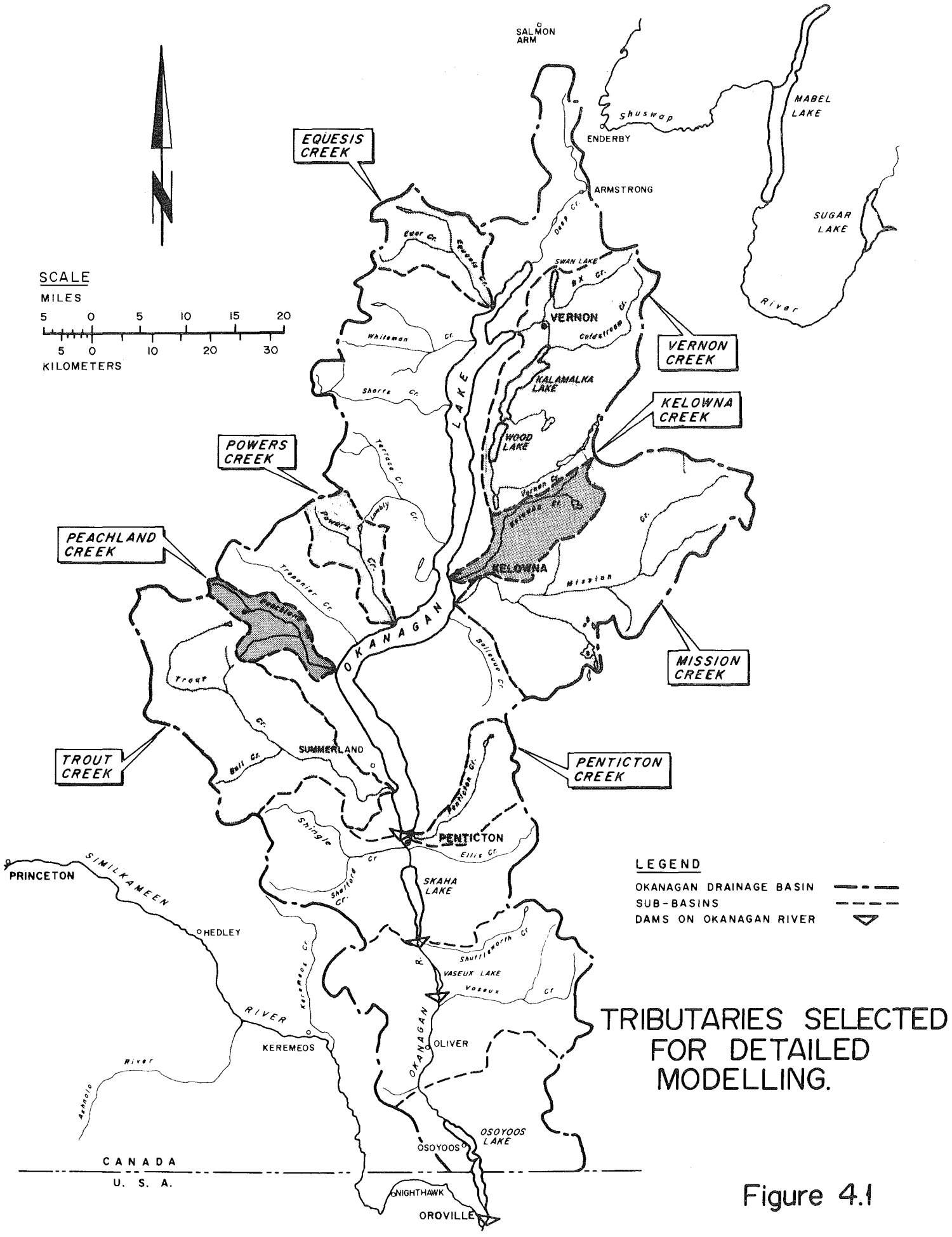
(1) to estimate natural flows under varying climatic conditions.

(2) to simulate the regulation of the natural flows in accordance with present day (1970) procedures to meet present and future water requirements.

(3) to develop improved methods of regulating natural flows to meet present and future water requirements.

4.2 SELECTION OF TYPICAL TRIBUTARIES

As time did not permit the detailed modelling of some 35 tributaries within the Okanagan Basin, the eight tributaries listed in Table 4.1 were selected for detailed modelling based primarily on the fact that they are the most heavily used streams within the Basin.



TRIBUTARIES SELECTED FOR DETAILED MODELLING.

Figure 4.1

TABLE 4.1

TRIBUTARIES SELECTED FOR DETAILED MODELLING WITHIN OKANAGAN LAKE BASIN

(see Figure 4.1 for Tributary Locations)

WEST SIDE	EAST SIDE
1. Trout Creek	5. Vernon Creek
2. Peachland Creek	6. Kelowna Creek
3. Powers Creek	7. Mission Creek
4. Equesis Creek	8. Penticton Creek

These streams contain 95% of all upland tributary storage within Okanagan Lake Basin and account for 60% of the total inflow, and, as shown in Table 4.2, some 37,000 acres out of 45,000 within Okanagan Lake Basin are irrigated from the above streams.

4.3 NATURAL FLOW ESTIMATES

4.3.1 General

In order to be able to determine the flow available at selected points in the eight creeks, it was apparent that a more detailed breakdown of the available flow was needed than that provided by the tributary model described in the preceeding chapter. The Department of Civil Engineering at UBC provided estimates of the runoff by elevation bands for the selected creeks for "dry", "average" and "wet" inflow years. These three conditions were defined as follows:

Dry Year Flows - Those roughly falling within the five driest of the 50-year study period and roughly equivalent to 1970.

Average Year Flows - Those falling within the middle five years of the 50-year study period and roughly equivalent to 1971.

Wet Year Flows - Those falling within the five wettest years of the 50-year study period and roughly equivalent to 1948 and 1972.

4.3.2 Data Available

As described in Chapter 3 of this Supplement, recorded flows in the various creeks are somewhat sparse and those records in general cannot be used as natural flows as the corresponding records of upstream diversion and reservoir fluctuations are not available. Considerable use was therefore made of the estimates of natural flow produced in the model described previously.

Probably the most critical flows are the low flows and it was fortunate that a considerable streamflow instrumentation program had been undertaken prior

TABLE 4.2

BASIC DATA FOR SELECTED TRIBUTARIES

		TROUT CR.	PEACHLAND CR.	POWERS CR.	EQUESIS CR.	VERNON CR.	KELOWNA CR.	MISSION CR.	PENTICTON CR.	TOTALS
Area	Sq. Miles	289	59	56	77	358	86	336	70	1,331
Natural Flow at Mouth Ac.Ft x 100	Dry Year	237	89	80	102	391	99	969	219	2,186
	Av. Year	544	150	138	178	678	170	1,429	348	3,635
	Wet Year	1,220	275	258	341	1,382	343	2,392	582	6,793
Storage (Ac. Ft)	1970	10,332	9,656	3,754	2,156	46,719	5,715	17,981	10,240	106,543
	1980	10,219	9,540	4,513	2,156	49,658	7,277	26,392	9,850	119,605
	2020	13,066	9,540	4,820	2,156	62,578	7,277	28,761	9,850	138,048
Area Under Irrigation (Acres)	1970	4,306	617	1,637	356	14,075	4,848	10,135	1,666	37,640
	1980	4,013	755	1,950	850	18,279	6,547	10,978	1,648	45,020
	2020 High	6,274	1,591	1,818	1,282	23,157	8,176	12,371	1,433	56,102
	2020 Med	5,354	1,236	1,719	1,189	20,021	5,905	9,678	1,464	46,566
	2020 Low	3,918	514	1,432	355	13,410	4,446	8,501	1,426	34,002
Population (Persons)	1970	5,960	1,444	3,490	90	24,360	10,420	10,340	18,146	74,250
	1980	8,630	1,900	2,450	155	36,820	4,565	18,330	24,400	97,250
	2020 High	21,360	4,670	6,510	410	100,050	15,335	48,940	51,850	249,125
	2020 Med	17,380	3,105	5,450	345	83,020	11,802	41,090	48,055	210,247
	2020 Low	13,400	1,540	4,390	280	65,990	8,270	33,240	44,260	171,370
Water Requirement (Diversion) Ac.Ft.	1970	13,384	3,416	5,293	1,021	33,525	12,888	31,814	11,173	112,514
	1980	14,326	4,085	6,623	2,379	49,158	18,867	38,555	11,840	145,833
	2020 High	25,169	7,527	7,372	3,613	72,887	26,432	51,315	19,036	213,351
	2020 Med	21,221	6,143	6,757	3,340	62,994	19,086	41,142	18,083	178,766
	2020 Low	15,718	3,536	5,576	1,027	46,115	13,704	35,377	16,924	137,977
Consumptive Use Deficiency in Dry Year Ac.Ft.	1970	0	0	0	0	1,540	2,296	0	0	3,836
	1980	384	0	0	0	5,858	6,081	0	0	12,323
	2020 High	2,059	0	111	0	26,301	12,946	8,103	1,517	51,037
	2020 Med	715	0	0	0	18,598	5,781	0	766	25,860
	2020 Low	0	0	0	0	5,649	1,093	0	0	6,742

to the 1970 freshet. This turned out to be one of the driest years to have occurred and good records were obtained of flows and reservoir fluctuations; diversions were either recorded or could be calculated.

The tributary natural flow model gave figures for the average flow at the mouth of each creek for each month over the 50 year period of the study and figures for the flows in the eight creeks were available for 1971, a slightly higher than average year. This, together with estimates of consumptive use and the change in storage in the major reservoirs, enabled estimates of the total 1971 flows to be made.

Had 1972 flow records been available at the time this work was undertaken they would have provided excellent data for assessing the likely high flows in the creeks as 1972 inflows were higher than any previously recorded. However, in the absence of these data, estimates were made using results from the natural flow tributary reconstitution model, looking particularly at the estimates of 1948 which was the year with the highest inflow prior to 1972.

Although regarded as a good first approximation, none of the estimates could be considered as being completely reliable, since most of the major creeks had diversions into or out of them, and minor storages which were not recorded. Also estimates of areas irrigated from each creek and the consumptive use of water per acre irrigated probably contained inaccuracies. It was therefore not possible to consider any particular piece of the data as being precise. Taken together, however, the data provided a considerable amount of information about the distribution of flows in 1970.

4.3.3 Method

(a) For a low inflow "dry" year - The basic method was to try and use all the available data and try to develop a consistent pattern for the runoff in 1970, the best documented dry year, and then relate flows during the drought period 1929-31 to the flows in 1970. Results are presented in a form which enables flows to be computed for any sub-basin in any of the main tributaries. There are almost certainly anomalies and inaccuracies in detail but the overall pattern is believed to be reasonably representative.

Area elevation data for the eight tributary basins are given in Table 4.3. The relationship between flows in the three years of the drought period 1929, 1930 and 1931 to the "base" year of 1970, the dry year with the most data, is given in Table 4.4. Using Table 4.7 data for 1970 can be converted to data for 1929, 1930 and 1931.

The variation of total annual runoff with elevation in 1970 for the various sub-basins is given in Table 4.5. It is believed that the figures tend to

TABLE 4.3

AREA ELEVATION DATA

ELEVATION BAND (ft)	DRAINAGE AREA (ACRES)							
	VERNON	KELOWNA	MISSION	PENTICTON	EQUESIS	POWERS	PEACHLAND	TROUT
Over 6500	--	--	1,297	404	--	--	--	57
6000 - 6500	19	--	16,821	5,694	--	12	7	4,524
5500 - 6000	374	--	24,107	10,442	292	520	1,455	20,662
5000 - 5500	4,054	2,378	24,172	11,797	5,141	1,750	3,268	33,910
4500 - 5000	28,712	13,478	42,696	5,858	7,596	9,100	3,928	41,038
4000 - 4500	23,874	6,417	42,377	2,261	11,636	8,720	9,623	30,147
3500 - 4000	17,424	3,478	20,684	1,892	8,455	4,250	5,958	10,597
3000 - 3500	17,560	3,724	15,480	1,719	5,862	1,770	5,270	14,541
2500 - 3000	15,879	2,891	9,599	1,559	4,637	2,110	3,261	10,207
2000 - 2500	19,390	3,923	5,168	1,435	3,309	1,100	1,442	9,941
1500 - 2000	32,243	7,202	7,589	937	1,837	1,050	277	4,334
Below 1500	27,270	8,809	5,038	417	622	360	90	1,121

TABLE 4.4

ESTIMATED OKANAGAN TRIBUTARY NATURAL FLOWS DURING 1929-31

EXPRESSED AS PERCENTAGE OF 1970 FLOW

Creek	Flows as % of 1970 Flow		
	1929	1930	1931
Vernon	97	92	78
Kelowna	98	93	79
Mission	98	94	80
Penticton	99	95	81
Equesis	97	92	78
Powers	98	93	80
Peachland	99	94	82
Trout	100	95	83

The above figures are based on output from Tributary Flow Distribution model.

underestimate the contribution from the high areas and overestimate the contribution from the lower areas - thus tending to err on the safe side for studies involving the regulation of upland reservoirs.

Table 4.6 gives the distribution of annual runoff by month for 1970. These distributions were obtained by plotting mass curves for selected tributaries and interpolating. The pattern of flow in any particular sub-basin is highly dependent on local conditions such as exposure, groundwater flow, etc., but the figures in Table 4.6 are considered to be broadly representative. The figures originally given for this table were changed by the BCWIB as more data became available.

(b) For an average inflow year- the form of the calculations was almost identical to those for a dry year except that comparisons were made with the 1971 data rather than 1970. Variation of total annual runoff with elevation is given in Table 4.5. As with the low inflow calculations, it is believed that the figures

TABLE 4.5

NATURAL RUNOFF FOR LOW, AVERAGE AND HIGH RUNOFF YEARS-INCHES

ELEVATION BAND	LOW YEAR (1970)	"BASE" RUNOFF IN INCHES AVERAGE YEAR	HIGH YEAR
Over 6500	19.6	23.0	33.6
6000 - 6500	15.0	19.2	28.0
6500 - 5000	11.1	15.1	22.8
5000 - 5500	7.7	11.3	18.1
4500 - 5000	5.0	7.9	13.8
4000 - 4500	3.0	5.2	9.9
3500 - 4000	1.5	3.3	6.8
3000 - 3500	0.7	1.6	4.5
2500 - 3000	0	0.4	2.5
2000 - 2500	0	0	1.1
1500 - 2000	0	0	0.1

The above figures multiplied by percentage factor indicated for appropriate creek[1]:

CREEK	LOW	AVERAGE	HIGH
Vernon	100	100	100
Kelowna	100	100	100
Mission	100	100	100
Penticton	75	85	90
Equesis	92.5	95	95
Powers	87.5	90	90
Peachland	87.5	90	90
Trout	33.3[2]	50[2]	65[2]

[1] Percentage reductions are different according to the type of year. Losses in the system will be similar from year to year and thus be a lesser proportion in an average inflow year than in a very dry year.

[2] Trout Creek is in a rain shadow and so has lower precipitation. Also there may be considerable groundwater - which does not show up in the Creek - and hence is not available for regulation.

tend to underestimate the contribution from the high areas and overestimate the contribution from the low areas thus erring on the safe side for studies involving the regulation of upland reservoirs. No further figures for the monthly distribution of annual runoff were suggested as there are insufficient data to allow differentiation between types of years.

(c) For a high inflow "wet" year - Even less information was available about high inflow years than existed about low and average years. Very heavy reliance was therefore placed on the flows calculated in the tributary reconstitution model for high inflow years such as 1928 and 1949. The variation of runoff with elevation are again given in Table 4.5.

4.3.4 Check Calculations

Table 4.7 gives a comparison of computed and "estimated from records" flows for the eight tributaries for a low flow year. The computed flows were calculated using Tables 4.3 and 4.5. It will be noted that there are some discrepancies but explanations for these are offered.

For an average year, calculations were made of the total inflow to each of the eight tributaries in 1971 and the resulting figures reduced by the ratio of the long-term average annual net natural inflow to the estimated 1971 net natural inflow as the 1971 inflow was about 10% above the long-term average.

As the eight tributaries investigated seem to be relatively representative of Okanagan Lake basin, a check was made to see if the ratio of the total area of the eight tributaries to the total catchment area of Okanagan Lake was similar to the ratio of the calculated average flow from the eight tributaries to the total average natural inflow to Okanagan Lake.

Table 4.8 shows a comparison between the results obtained from using tables and from the above mentioned checks as well as the average figures obtained from the previous calculations for the 37 sub-basins.

Check calculations were not made for the high inflow data presented other than with the previous computer simulation as, at the time of calculation, no data on high flows were published. The comparison is shown in Table 4.9.

4.3.5 Conclusion

Using Tables 4.3 through 4.6 estimates of the monthly natural flows for dry, average and wet years can be made for any part of Vernon, Kelowna, Mission, Penticton, Equesis, Powers, Peachland or Trout Creeks. It is recognized that local inaccuracies will occur but it was considered preferable to maintain a coherent overall pattern at the expense of some local discrepancies rather than match up the figures closely at the expense of coherence in the overall pattern.

4.4 BASIC DATA USED IN MODELLING

Areas under irrigation in 1970 were derived from the following sources:

(a) Provincial ARDA Present Land Use Project Mapping prepared by Canada Land Inventory in 1968 and updated to 1970;

TABLE 4.6

DISTRIBUTION OF ANNUAL RUNOFF BY MONTH

(Per Cent of Annual)

	EXCEEDENCE BAND ELEVATION								
	6500	6000	5500	5000	4500	4000	3500	3000	2500
Jan.	0.0	0.0	0.5	1.0	1.5	2.0	2.0	2.0	2.5
Feb.	0.0	0.0	0.5	1.5	2.0	2.0	2.5	3.0	3.0
Mar.	0.0	0.0	0.5	1.5	2.5	3.0	3.0	3.0	3.0
Apr.	0.0	0.5	1.5	2.5	4.0	6.5	9.5	11.5	12.5
May	54.0	53.5	52.5	51.0	49.5	48.0	45.5	43.0	41.0
June	46.0	44.0	38.0	31.0	26.0	22.5	20.0	18.5	17.5
July	0.0	0.5	2.0	3.5	4.5	6.0	7.5	9.0	10.5
Aug.	0.0	0.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0
Sept.	0.0	0.5	1.0	1.5	2.0	2.0	2.0	2.0	2.0
Oct.	0.0	0.5	1.0	1.5	2.0	2.0	2.0	2.0	2.0
Nov.	0.0	0.0	0.5	1.5	2.0	2.0	2.0	2.0	2.0
Dec.	0.0	0.0	0.5	1.5	2.0	2.0	2.0	2.0	2.0

TABLE 4.7

COMPARISON OF ESTIMATES OF RUNOFF FOR 1970
(in thousand acre feet)

CREEK	RECORDED[1] FLOW	IRRIGATION[2] REQUIREMENT	OVER YEAR[3] STORAGE CHANGE	NATURAL[4] FLOW	ESTI-[5] MATE	REMARKS
VERNON	15.5	17.0	11.0	21.5	24.1	Difficult to take account of diversions, etc.
KELOWNA	6.5	11.0	1.0	16.5	9.5	Probably overestimated irrigation need.
MISSION	72.5	28.5	3.0	98.0	93.3	
PENTICTON	--	7.0	1.0	--	21.2	Earlier records showed correct order of magnitude.
EQUESIS	8.6	1.2	--	9.8	9.9	
POWERS	7.5	4.6	.5	11.6	7.2	Diversions not counted in estimate - area irrigated probably over-estimated.
PEACHLAND	7.1	2.1	1.7	7.5	7.2	
TROUT	8.8	17.0	2.6	23.2	25.0	

NOTES: [1] In most cases recorded at the mouth

[2] Estimated by multiplying the area irrigated by the water use (water use estimated between licensed duty and consumptive use - depending on estimate of how much return water would appear in the creek). Appreciable errors possible.

[3] Estimated from records of major storages near beginning and end of 1970.

[4] Col. 1 + Col. 2 - Col. 3.

[5] Estimated by method explained in the text.

TABLE 4.8

COMPARISON OF AVERAGE NATURAL FLOW CALCULATIONS

AT MOUTH OF SELECTED TRIBUTARIES

CREEK	1971					ESTIMATE (6)	MEAN FROM PREVIOUS COMPUTER RUN
	RECORDED FLOWS (1)	STORAGE CHANGE (2)	CONSUMPTIVE USE (3)	TOTAL 94)	TOTAL x 0.744 (5)		
Vernon	18.8	14.0	17.0	49.8	37.1	41.2	46.0
Kelowna	9.7	2.7	11.0	23.3	17.3	15.4	15.6
Mission	155.5	0.9	28.5	184.9	137.6	137.8	137.1
Penticton	32.6	4.5	7.0	43.1	32.1	33.8	35.4
Equesis	18.9	0.2	1.2	20.3	15.1	17.6	21.7
Powers	21.2	1.4	4.6	27.2[o]	20.2	12.2	13.2
Peachland	9.8	0.5	2.1	12.4	9.2	12.7	13.1
Trout	52.8	2.2	17.0	71.9	53.5	56.5	

[o] Includes diversion from Lambly Creek.

NOTES (1) Recorded at mouths.

(2) From February 1971 and February 1972 Snow Survey Bulletins

(3) As for low flows.

(4) Col. (1) + Col. (2) + Col. (3).

(5) "0.744" is ratio of long-term average net virgin inflow to estimated 1971 net virgin inflow.

(6) Calculated using Table and area elevation data.

(7) Computer run is of flows in 36 sub-basins 1921-1970.

(8) Total area of 8 sub-basins = 804619 acres
Total area of whole basin =1449361 acres
Ratio = 0.55
Long-term mean virgin inflow = 568 kaf.
x 0.55 = 325.2
c.f. Total of colums (5) = 322.1
c.f. Total of column (6) = 327.2

TABLE 4.9

COMPARISON OF HIGH FLOW CALCULATIONS

(In Thousand Acre Feet)

CREEK	FLOW ESTIMATED FROM TABLE	ESTIMATE FOR 1948 FROM PREVIOUS COMPUTER RUN
Vernon	81.4	89.7
Kelowna	28.8	28.1
Mission	230.4	218.1
Penticton	56.6	--
Equesis	33.2	39.6
Powers	22.4	23.3
Peachland	23.7	23.7
Trout	125.3	156.4

(b) Colored air photographs flown in July 1970 at 1/4 mile to one inch;

(c) Field observation and examination of existing water licences.

Projections for 1980 were based on current trends and policies and in light of subsequent developments may be too high.

Projections for the horizon year 2020 were derived using three basic assumptions for growth rate.

(a) High Agricultural Growth Rate - an extremely high growth rate which assumes that all Canada Land Inventory appraisals of land in soil classifications 1 to 4 will be under irrigation.

(b) Low Agricultural Growth Rate - An extremely low estimate of the probable land use. It assumes that no new lands will be opened to irrigation and that the total amount of irrigated land will actually fall due to population encroachments on presently-irrigated lands.

(c) Medium Agricultural Growth Rate - This projection is probably the most realistic and, as its name suggests, it is based on a medium course between the high and low rates.

Table 4.10 summarizes the estimated natural flows for the three types of years, and the reservoir storage, area irrigated, population and water requirements for present and estimated future requirements for the eight tributaries. Table 4.11 lists the diversion duty of irrigation water assumed for the various creeks. These are equal to or slightly higher than those recommended by the Department of Agriculture for specific soil and/or are the depths allocated by water licence. Table 4.12 lists the factors used to convert annual irrigation requirements and annual domestic requirements.

4.5 DEVELOPMENT OF THE TRIBUTARY COMPUTER MODEL

4.5.1 Natural Flows

In the application of the elevation band runoff approach to modelling, it was first necessary to select points along each of the eight tributaries where flow information was required. These included control points such as headwater reservoirs, use points such as diversion locations, and finally, measuring points such as at or near the mouths of sub-tributaries or at hydrometric stations. These are illustrated in Figures 4.2 and 4.3 for Kelowna Creek.

As each of the eight tributaries is hydrologically unique, individual modelling of each was necessary. However, because of many similarities between models, they are discussed in a general manner unless some detail of a particular model requires special attention.

TABLE 4.10

BASIC DATA FOR SELECTED TRIBUTARIES

		TROUT CR.	PEACHLAND CR.	POWERS CR.	EQUESIS CR.	VERNON CR.	KELOWNA CR.	MISSION CR.	PENTICTON CR.	TOTALS
Area	Sq. Miles	289	59	56	77	358	86	336	70	1,331
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	Av. Year	544	150	138	178	678	170	1,429	348	3,635
	Wet Year	1,220	275	258	341	1,382	343	2,392	582	6,793
Storage (Ac. Ft)	1970	10,332	9,656	3,754	2,156	46,719	5,715	17,981	10,240	106,543
	1980	10,219	9,540	4,513	2,156	49,658	7,277	26,392	9,850	119,605
	2020	13,066	9,540	4,820	2,156	62,578	7,277	28,761	9,850	138,048
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	2020 Med	5,354	1,236	1,719	1,189	20,021	5,905	9,678	1,464	46,566
	2020 Low	3,918	514	1,432	355	13,410	4,446	8,501	1,426	34,002
Population (Persons)	1970	5,960	1,444	3,490	90	24,360	10,420	10,340	18,146	74,250
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	2020 Med	21,221	6,143	6,757	3,340	62,994	19,086	41,142	18,083	178,766
	2020 Low	15,718	3,536	5,576	1,027	46,115	13,704	35,377	16,924	137,977

TABLE 4.11

ANNUAL DIVERSION IRRIGATION WATER DUTY

CREEK	DIVERSION WATER DUTY (FEET)
Trout Creek	3.03
Peachland	3.03
Powers	3.03
Equesis	2.75
Vernon - Winfield and Wood Irrigation Districts	3.03
- Others	1.80
Kelowna - Glenmore Irrigation District	2.20
- Others	3.03
Mission	3.03
Penticton	3.03

TABLE 4.12

MONTHLY DISTRIBUTION FACTORS

MONTH	% OF ANNUAL REQUIREMENT	
	IRRIGATION	DOMESTIC
January	0	5
February	0	4
March	0	5
April	0	6
May	15	10
June	25	13
July	25	16
August	25	16
September	10	8
October	0	7
November	0	5
December	0	5

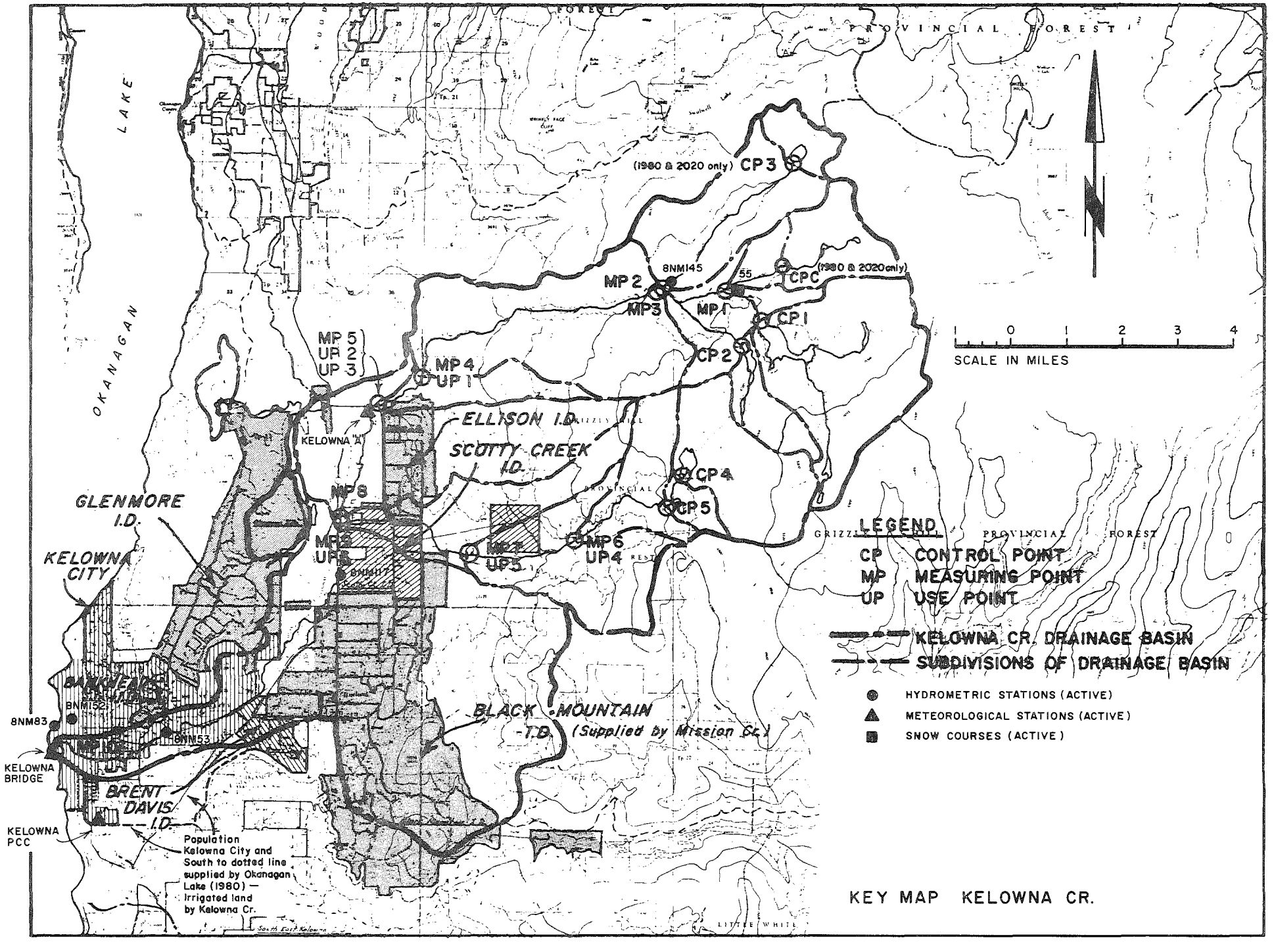
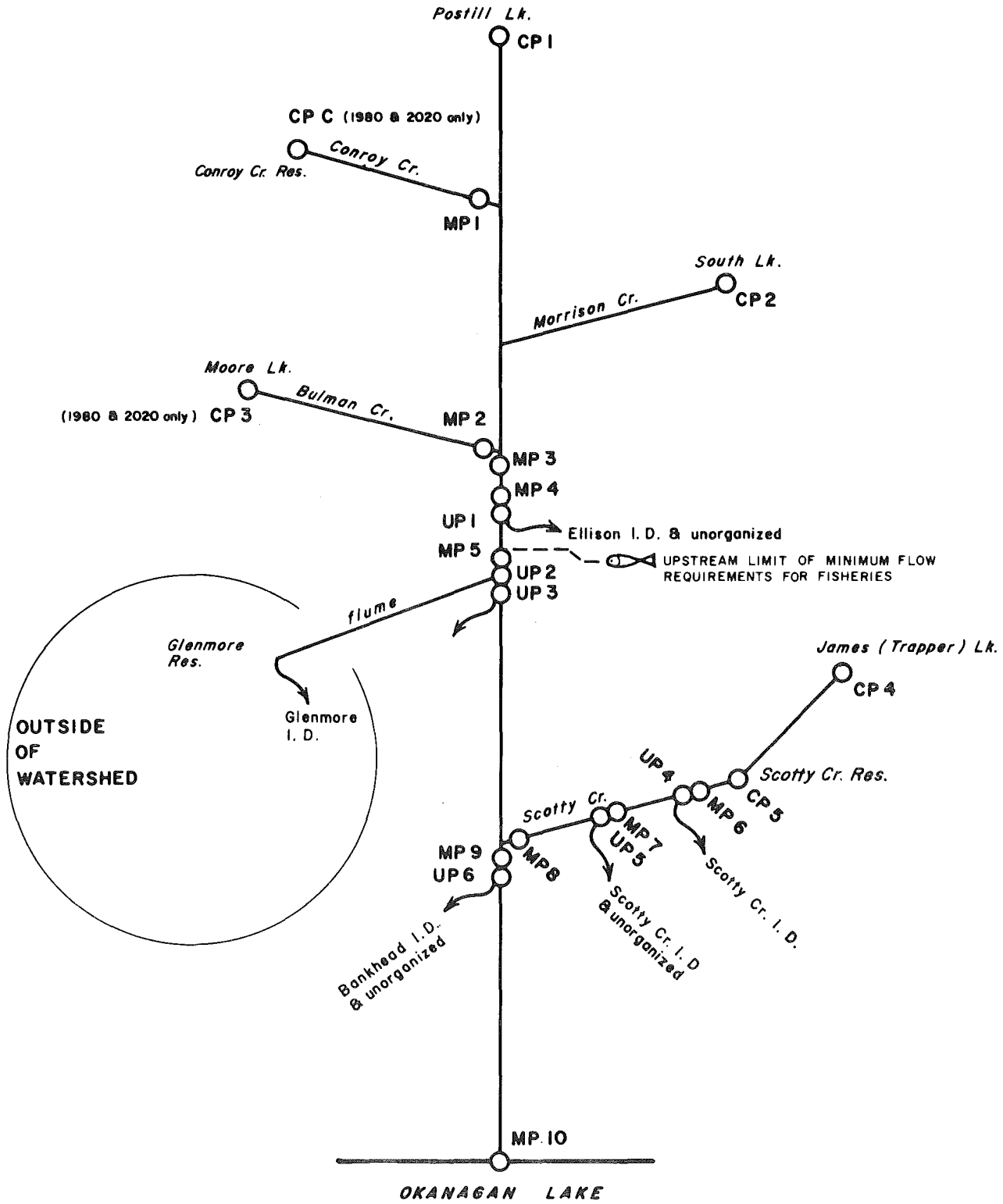

LAKE
OKANAGAN
PROVINCIAL FOREST
(1980 & 2020 only) CP3
8NM145
MP 2
55
CPC (1980 & 2020 only)
MP3
MP 1
CP 1
CP 2
MP 5
UP 2
UP 3
MP 4
UP 1
ELLISON I.D.
KELOWNA "A"
SCOTTY CREEK I.D.
CP 4
CP 5
MP8
GLENMORE I.D.
KELOWNA CITY
MP6
UP4
MP7
UP5
8NM117
BARKLEY I.D.
8NM152
8NM83
8NM53
KELOWNA BRIDGE
BRENT DAVIS I.D.
KELOWNA PCC
BLACK MOUNTAIN I.D. (Supplied by Mission Cr.)
Population Kelowna City and South to dotted line supplied by Okanagan Lake (1980) — Irrigated land by Kelowna Cr.
0 1 2 3 4
SCALE IN MILES
LEGEND
CP CONTROL POINT
MP MEASURING POINT
UP USE POINT
KELOWNA CR. DRAINAGE BASIN
SUBDIVISIONS OF DRAINAGE BASIN
HYDROMETRIC STATIONS (ACTIVE)
METEOROLOGICAL STATIONS (ACTIVE)
SNOW COURSES (ACTIVE)
KEY MAP KELOWNA CR.

Figure 4.2



KELOWNA CR. SCHEMATIC Figure 4.3

To estimate the natural runoff, physical functions, parameters and constants were determined for each of the eight selected tributaries. In order to apply the method outlined in Section 4.3, each tributary basin was split up in segments according to the selected points described previously and also in accordance with 500-foot elevation bands. The segment runoffs were then integrated to provide printouts of the natural runoffs. A sample printout of the natural flow of Kelowna Creek is given in Table 4.13 for an average runoff year. Complete natural flow data for all eight tributaries under dry, average and wet conditions are given in Technical Supplement 1 - Surface and Groundwater Supplies. This information is basic to the various studies in which the natural flows are regulated and used to meet water management objectives.

4.5.2 Regulated Flows: Present Operation and Use

In order to simulate the regulation of natural flows in accordance with present (1970) procedures, field and office studies were made to define this method of operation as closely as possible for the eight tributary systems. The areas irrigated and the population served had to be detailed with reference to the particular diversion point from which the irrigation, domestic, or industrial water was supplied. However, because of the lack of data on the water actually diverted, it was necessary to estimate these flows using both the estimated conveyance losses from diversion point to farm application area, and the recommended farm duties in accordance with the British Columbia Department of Agriculture recommendations for irrigation requirements. For domestic, municipal and industrial requirements it was necessary to use the per capita diversion requirements based on water measurements determined elsewhere in the Basin. The distribution of these various uses on a monthly basis provided estimates of the water requirements.

In addition to the diversion requirements described above, the maintenance of in-channel minimum flows was considered. These were only defined for fisheries and normally applied at or near the mouth of tributary streams which at present may be practically dry during the later summer and fall. The total diversion requirements for each of the selected tributaries are given in Table 4.2 while the additional fishery flows recommended by fishery scientists are contained in Table 4.14.

The regulation of natural flow to meet the diversion requirements under the present method of operation is obtained through storage reservoirs mostly located in the headwaters. A list of the 49 reservoirs within the eight selected tributaries is given in Table 4.15. The rule curves given in Table 4.15 were derived from field records obtained from some 18 irrigation districts, 14 major water user communities and two industrial water users covering a period of six years.

TABLE 4.13

KELOWNA CR. - AVERAGE YEAR (NATURAL FLOW)

LOCATION	AREA IN K. AC.	FLOWS IN AC. FT.												
		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
CPDA 1	5.0	49.	67.	78.	127.	1892.	1061.	154.	75.	67.	67.	67.	67.	3773.
MPDA 1	2.2	21.	26.	36.	58.	693.	362.	64.	28.	28.	28.	28.	28.	1403.
CPDA 2	1.0	10.	13.	16.	26.	357.	195.	30.	14.	13.	13.	13.	13.	715.
CPDA 3	0.7	7.	9.	12.	18.	228.	120.	21.	9.	9.	9.	9.	9.	416.
MPDA 2	3.8	36.	45.	59.	102.	1109.	569.	109.	45.	45.	45.	45.	45.	2254.
MPDA 3	13.9	134.	175.	216.	364.	4579.	2459.	410.	184.	175.	175.	175.	175.	9222.
MPDA 4	20.1	164.	211.	263.	486.	5319.	2803.	515.	216.	206.	207.	207.	207.	10802.
MPDA 5	21.3	168.	215.	267.	501.	5390.	2834.	528.	219.	210.	210.	210.	210.	10961.
CPDA 4	2.9	28.	39.	46.	75.	1038.	569.	88.	42.	39.	39.	39.	39.	2079.
CPDA 5	3.3	32.	44.	53.	85.	1168.	637.	100.	47.	44.	44.	44.	44.	2342.
MPDA 6	5.1	49.	63.	79.	134.	1628.	867.	149.	66.	63.	63.	63.	63.	3287.
MPDA 7	8.8	66.	83.	105.	203.	2050.	1063.	209.	84.	81.	81.	81.	81.	4187.
MPDA 8	11.3	75.	94.	115.	237.	2266.	1166.	239.	93.	90.	90.	90.	90.	4547.
MPDA 9	38.5	254.	323.	402.	790.	7911.	4115.	811.	324.	311.	311.	311.	311.	16176.
MPDA 10	55.4	274.	347.	428.	887.	8274.	4272.	891.	341.	328.	328.	328.	328.	17026.

TABLE 4.14

ESTIMATED MINIMUM WATER REQUIREMENTS FOR FISHERIES

(Acre Ft.)

	Trout	Peach-land	Powers	Equesis	BX Upper	Vernon		Cold-stream	Kelowna	Mission
						Upper	Lower			
Jan.	600	150	240	360	150	420	480	360	240	1,800
Feb.	600	150	240	360	150	420	480	360	240	1,800
Mar.	600	150	240	360	150	420	480	360	240	1,800
Apr.	600	150	240	360	150	420	480	360	240	1,800
May	900+	300+	300+	600+	240+	600+	600+	480+	300+	2,700+
June	600	150	240	360	150	420	480	360	240	1,800
July	600	150	240	360	150	420	480	360	240	1,800
Aug.	600	150	240	360	150	420	480	360	240	1,800
Sept.	600	270	300	360	150	420	480	360	240	2,400
Oct.	900	270	300	480	240	480	600	480	300	2,400
Nov.	600	150	240	360	150	420	480	360	240	1,800
Dec.	600	150	240	360	150	420	480	360	240	1,800
TOTAL	7,800	2,190	3,060	4,680	1,980	5,280	6,000	4,560	3,000	23,700

TABLE 4.15

RULE CURVE VALUES FOR STORAGE OPERATION

Tributary Basin	Reservoir Name	Capacity ac.ft. (1970 except where stated otherwise)	Rule Curve Values Expressed as a Percentage of Reservoir Capacity											
			J	F	M	A	M	J	J	A	S	O	N	D
Trout Creek	Headwaters	4,003	50	50	50	80	100	100	83	67	50	50	50	50
	Crescent	755	40	40	40	70	100	100	80	60	40	40	40	40
	Whitehead	920	0	0	0	40	100	100	67	33	0	0	0	0
	Thirsk	2,628	20	20	20	30	100	100	73	47	20	20	20	20
	Chapman	131	0	0	0	40	100	100	67	33	0	0	0	0
	Isintok	870	30	30	30	50	100	100	77	53	30	30	30	30
	Munro	80	0	0	0	40	80	100	67	33	0	0	0	0
	Darke	935	60	60	60	80	90	100	87	73	60	60	60	60
	Total (1970)	10,322												
Peachland Creek	Peachland	9,575	45	45	45	45	70	100	82	63	45	45	45	45
	Wilson	81	0	0	0	0	100	100	67	33	0	0	0	0
	Total (1970)	9,656												
Powers Creek	West	62	0	0	0	0	100	100	67	33	0	0	0	0
	Dobbin	104	0	0	0	0	100	100	67	33	0	0	0	0
	Islaht	343	0	0	0	0	100	100	67	33	0	0	0	0
	Paynter	384	0	0	0	0	100	100	67	33	0	0	0	0
	Jackpine	960	50	50	50	50	100	100	83	67	50	50	50	50
	Webber	100	0	0	0	0	100	100	67	33	0	0	0	0
	Lambly	1,801	30	30	30	65	100	100	77	53	30	30	30	30
	Total (1970)	3,754												
Equesis Creek	Pinaus	2,156	35	35	35	35	100	100	78	57	35	35	35	35
	Total (1970)	2,156												
Vernon Creek	Crooked	2,445	90	90	90	100	100	100	97	93	90	90	90	90
	Swalwell	9,585	60	60	60	70	100	100	87	73	60	60	60	60
	Oyama	4,988	60	60	60	70	100	100	87	73	60	60	60	60
	King Edward	1,253	50	50	50	65	100	100	83	67	50	50	50	50
	Kalamalka	13,080	80	80	80	90	100	100	93	87	80	80	80	80
	Aberdeen	9,040	40	40	40	60	100	100	80	60	40	40	40	40
	Haddo	2,037	10	10	10	40	100	100	70	40	10	10	10	10
	Dixon	208	40	40	40	60	100	100	80	60	40	40	40	40
	Swan	2,460	60	60	60	70	100	100	87	73	60	60	60	60
	Goose	1,623	30	50	70	100	100	90	70	50	30	30	30	30
	Total (1970	46,719												
Kelowna Creek	Postill	4,063	60	60	60	80	100	100	87	73	60	60	60	60
	South	400	60	60	60	80	100	100	87	73	60	60	60	60
	Moore (1980)	1,000	60	60	60	80	100	100	87	73	60	60	60	60
	James	1,112	30	30	30	50	100	100	77	53	30	30	30	30
	Scotty	140	0	0	0	0	100	100	67	33	0	0	0	0
	Total (1970)	5,715												
Mission Creek	Mission	600	0	0	0	0	0	100	67	33	0	0	0	0
	Graystoke	2,107	0	0	0	0	0	100	67	33	0	0	0	0
	Fish Hawk (1980)	1,700	0	0	0	0	0	100	67	33	0	0	0	0
	Loch Long	400	0	0	0	0	0	100	67	33	0	0	0	0
	Ideal	5,475	50	50	50	50	100	100	83	67	50	50	50	50
	Hydraulic #9	231	0	0	0	0	30	100	67	33	0	0	0	0
	Haynes	881	0	0	0	0	100	100	67	33	0	0	0	0
	McCulloch	7,555	30	30	30	50	100	100	77	30	30	30	30	30
	Long Meadow	153	0	0	0	0	100	100	67	33	0	0	0	0
	Browne	454	0	0	0	0	100	100	67	33	0	0	0	0
	Fish	125	0	0	0	0	100	100	67	33	0	0	0	0
	Canyon (1980)	304	15	15	15	15	15	100	72	43	15	15	15	15
	Total (1970)	17,981												
Penticton Creek	Penticton	0	0	0	0	0	0	0	0	0	0	0	0	0
	Corporation	0	0	0	0	0	0	0	0	0	0	0	0	0
	Greyback	10,240	50	50	50	50	80	100	83	67	50	50	50	50
	Howard	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total (1970)	10,240												

EXPLANATION: FOR ANY GIVEN MONTH—

1. WHEN RULE CURVE VALUE IS EXCEEDED, ALL EXCESS WATER IS RELEASED.
2. WHEN RULE CURVE VALUE IS NOT ACHIEVED, ONLY STATED WATER REQUIREMENTS ARE RELEASED.

NOTE: Information based on local irrigation district records for period 1965-1971

Run-of-the-river water with only minor releases from storage is available to the water users during April and May while the headwater reservoirs are filling and major releases from the upper reservoirs do not normally start until the latter part of June. These releases continue through July and August and in some instances, most of September, at which time the headwater reservoirs are closed down with carry-over storage ranging from zero for many of the smaller reservoirs, to 50% or higher for some of the larger ones. This carry-over storage serves as a cushion when subsequent drought years occur.

Six of the eight selected sub-basins have more than one reservoir, therefore most of the sub-basin simulation models were designed to accept multi-reservoir systems and to integrate their operation. The six tributaries where this integrated approach was required were:

(1) Penticton Creek - 4 reservoirs;
(2) Kelowna Creek - 5 reservoirs;
(3) Powers Creek - 7 reservoirs;
(4) Trout Creek - 8 reservoirs;
(5) Vernon Creek - 10 reservoirs;
(6) Mission Creek - 12 reservoirs.

In the first phase of the operation of the model, local monthly inflows between selected points are matched with the diversion requirements starting at the mouth of the tributary and working upstream to the headwater storages. Any accumulated deficit provide the monthly release requirements from the headwater reservoirs.

When the reservoir storage level specified by rule curve was exceeded in any month after meeting the diversion requirements, the surplus water was then released. Conversely, when there was insufficient storage to meet the demand, consumptive use deficiencies occurred. In most instances where there are several reservoirs a special routine was used to apportion the required releases among the reservoirs.

In the final phase, the model routes the reservoir releases through the system starting at the most upstream reservoir. The printout includes storage in the reservoirs, regulated flows at the selected points, diversions and minimum flow deficiencies at all use points. A sample output for Kelowna Creek in a dry year is given as Table 4.16. The demand deficiencies are totalled for the tributary and appear at the bottom of the printout.

4.5.3 Modified Method of Operation

Time permitted only a brief study of a modified method of operation which would still meet the diversion requirements to about the same degree as under

TABLE 4.16

KELOWNA CREEK-DRY YEAR (1970)

STORAGES GIVEN ARE FOR THE END OF THE MONTH
UNITS FOR DEMANDS, STORAGES, FLOWS, AND DEFICIENCIES ARE ACRE FEET

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
CONTROL POINT	1													
STORAGE		2438.	2438.	2438.	2520.	3757.	3507.	1333.	0.	0.	44.	88.	132.	
CONTROL POINT	2													
STORAGE		240.	240.	240.	257.	400.	0.	0.	0.	0.	9.	18.	27.	
CONTROL POINT	4													
STORAGE		334.	334.	334.	382.	1053.	1086.	504.	0.	0.	25.	50.	75.	
CONTROL POINT	5													
STORAGE		0.	0.	0.	0.	82.	0.	0.	0.	0.	0.	0.	0.	
MEASURING POINT	3													
FLOW		84.	112.	136.	131.	1537.	2223.	2433.	1450.	112.	59.	48.	59.	8395.
DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
MEASURING POINT	8													
FLOW		43.	54.	89.	88.	186.	58.	14.	5.	5.	28.	28.	28.	594.
DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
MEASURING POINT	10													
FLOW		151.	195.	242.	312.	603.	33.	13.	3.	3.	111.	111.	111.	2088.
DEFICIENCY (FISH)		89.	45.	0.	0.	0.	207.	227.	237.	237.	189.	129.	129.	1489.
USE POINT	1													
DEMAND, IRRIGATION		0.	0.	0.	0.	240.	401.	401.	401.	160.	0.	0.	0.	1603.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	240.	401.	401.	401.	160.	0.	0.	0.	1603.
FLOW, UPSTREAM		99.	130.	160.	190.	1921.	2404.	2484.	1466.	128.	75.	75.	75.	9207.
FLOW, DOWNSTREAM		99.	130.	160.	190.	1681.	2003.	2083.	1065.	0.	75.	75.	75.	7636.
DEMAND, DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	32.	0.	0.	0.	32.
DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
USE POINT	2													
DEMAND, IRRIGATION		0.	0.	0.	0.	706.	1177.	1177.	1177.	471.	0.	0.	0.	4708.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	706.	1177.	1177.	1177.	471.	0.	0.	0.	4708.
FLOW, UPSTREAM														
FLOW, DOWNSTREAM		(SAME AS UP 3)												
DEMAND, DEFICIENCY														
DEFICIENCY														
USE POINT	3													
DEMAND, IRRIGATION		0.	0.	0.	0.	314.	524.	524.	524.	210.	0.	0.	0.	2096.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	314.	524.	524.	524.	210.	0.	0.	0.	2096.
FLOW, UPSTREAM		100.	132.	162.	196.	1712.	2017.	2088.	1068.	1.	76.	76.	76.	7702.
FLOW, DOWNSTREAM		100.	132.	162.	196.	692.	316.	387.	0.	0.	76.	76.	76.	2213.
DEMAND, DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	635.	680.	0.	0.	0.	1315.
DEFICIENCY (FISH)		140.	108.	78.	44.	0.	0.	0.	240.	240.	224.	164.	164.	1402.
USE POINT	4													
DEMAND, IRRIGATION		0.	0.	0.	0.	206.	343.	343.	343.	137.	0.	0.	0.	1372.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	206.	343.	343.	343.	137.	0.	0.	0.	1372.
FLOW, UPSTREAM		30.	39.	49.	36.	279.	601.	675.	545.	39.	14.	14.	14.	2335.
FLOW, DOWNSTREAM		30.	39.	49.	36.	73.	258.	332.	202.	0.	14.	14.	14.	1061.
DEMAND, DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	98.	0.	0.	0.	98.
DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
USE POINT	9													
DEMAND, IRRIGATION		0.	0.	0.	0.	217.	361.	361.	361.	145.	0.	0.	0.	1445.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	217.	361.	361.	361.	145.	0.	0.	0.	1445.
FLOW, UPSTREAM		39.	49.	62.	69.	292.	361.	361.	281.	9.	23.	23.	23.	1522.
FLOW, DOWNSTREAM		39.	49.	62.	69.	75.	0.	0.	0.	0.	23.	23.	23.	363.
DEMAND, DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	150.	136.	0.	0.	0.	286.
DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
USE POINT	6													
DEMAND, IRRIGATION		0.	0.	0.	0.	250.	416.	416.	416.	166.	0.	0.	0.	1664.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	250.	416.	416.	416.	166.	0.	0.	0.	1664.
FLOW, UPSTREAM		148.	191.	237.	297.	979.	416.	416.	9.	9.	108.	108.	108.	3026.
FLOW, DOWNSTREAM		148.	191.	237.	297.	729.	0.	0.	0.	0.	108.	108.	108.	1926.
DEMAND, DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	407.	157.	0.	0.	0.	564.
DEFICIENCY (FISH)		92.	49.	3.	0.	0.	240.	240.	240.	240.	192.	132.	132.	1560.
GRAND TOTALS FOR ALL THE USE POINTS:														
DEMAND, IRRIGATION		0.	0.	0.	0.	1933.	3222.	3222.	3222.	1289.	0.	0.	0.	12888.
DEMAND, DOMESTIC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, INDUSTRIAL		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DEMAND, TOTAL		0.	0.	0.	0.	1933.	3222.	3222.	3222.	1289.	0.	0.	0.	12888.
DEMAND, DEFICIENCY		0.	0.	0.	0.	0.	0.	0.	1193.	1103.	0.	0.	0.	2296.

the present operation but which would appreciably reduce the minimum flow deficiencies. To accomplish this, the minimum flow as well as the diversion requirements were taken into consideration in the first phase of the model. The effect of this modified operation under 1970 development for dry and average years in Kelowna Creek is shown in Figure 4.4. It is obvious there is a considerable increase in minimum flow over the unmodified operation with only a minor deterioration in the ability to meet diversion requirements.

Such a modified operation has not been tested in the field, and weather conditions, access to the site, as well as existing gate structures in the dams may make it impractical. Nevertheless, it suggests the possibility of modifying the present storage operation in the more accessible and modern dams for those streams where fisheries are considered important.

4.5.4 Future Levels of Development

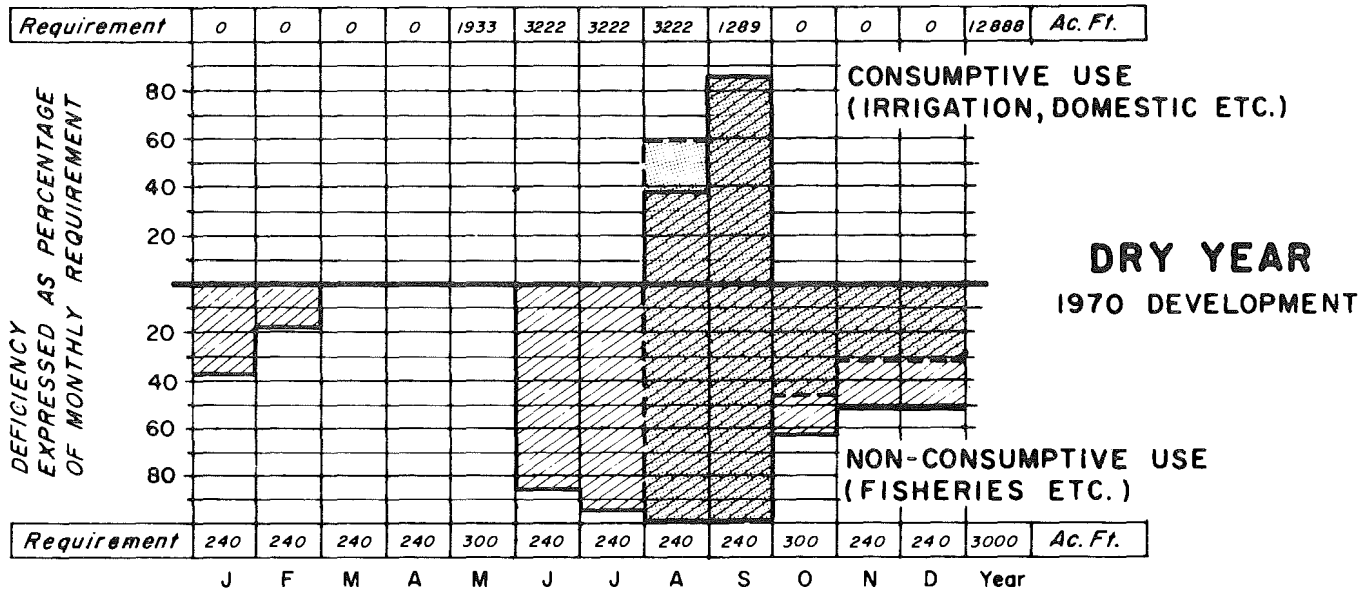
For 1980 and 2020 levels of development both the present and modified method of operation were used but certain increases in upstream storage were assumed as listed in Table 4.2. The same "measuring", "use" and "control" points were used and the basic data such as conveyance losses and farm duties remained the same although per capita consumption was increased. The effect of the two operations under 2020 development for Kelowna Creek is shown in Figure 4.5.

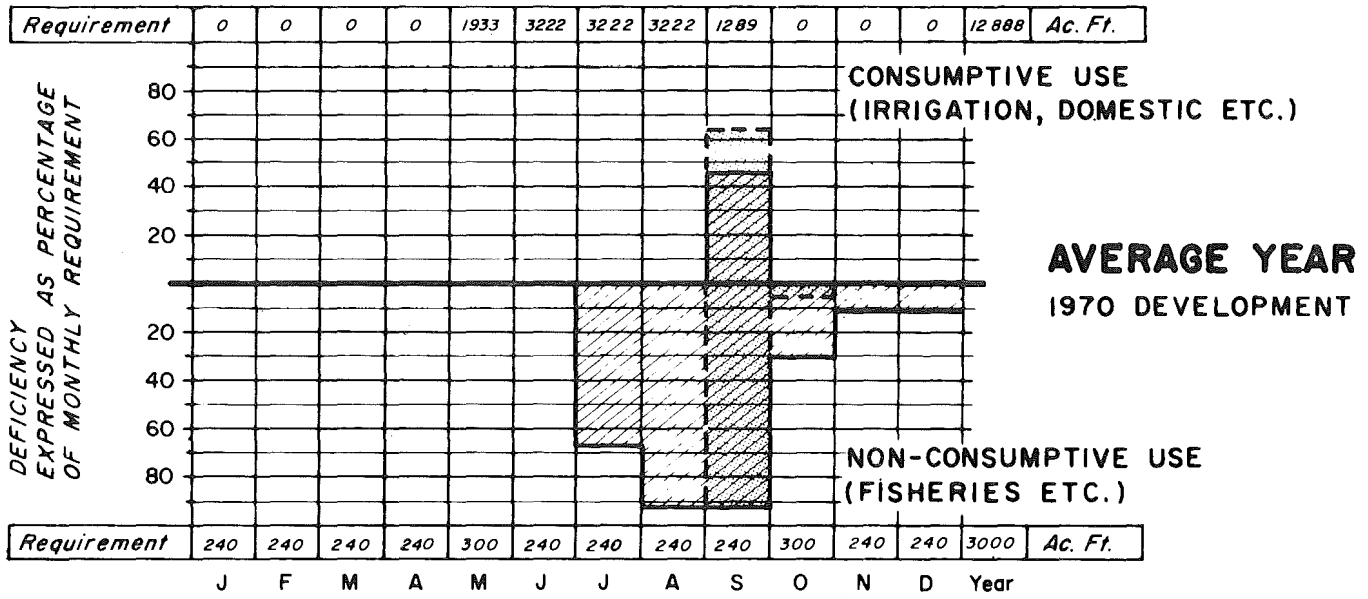
4.6 CONCLUSIONS

The modelling provides a first approximation of the monthly flows at a number of points in eight selected tributaries under varying climatic conditions. These were needed early in the study to provide some basis for determining the adequacy of major water use streams to meet consumptive and non-consumptive uses both now and in the future. The basic hydrometric and meteorological data particularly at higher elevations (above 4,000 feet) where most of the runoff occurs were sparse and data on water use were even more limited and had to be determined indirectly.

In general, the approach is considered to be conservative in that the estimated natural flows in a drought year are probably lower than those actually occurring and this, coupled with no allowance for return flow from the water diverted, provides a severe test for the eight tributaries selected. However, only single drought years have been studied in detail and the occurrence of two such years in a row could result in severe water shortages in the second season.

The operation of the Tributary Model under future developments was based on the assumption that existing diversion points would be maintained (with no

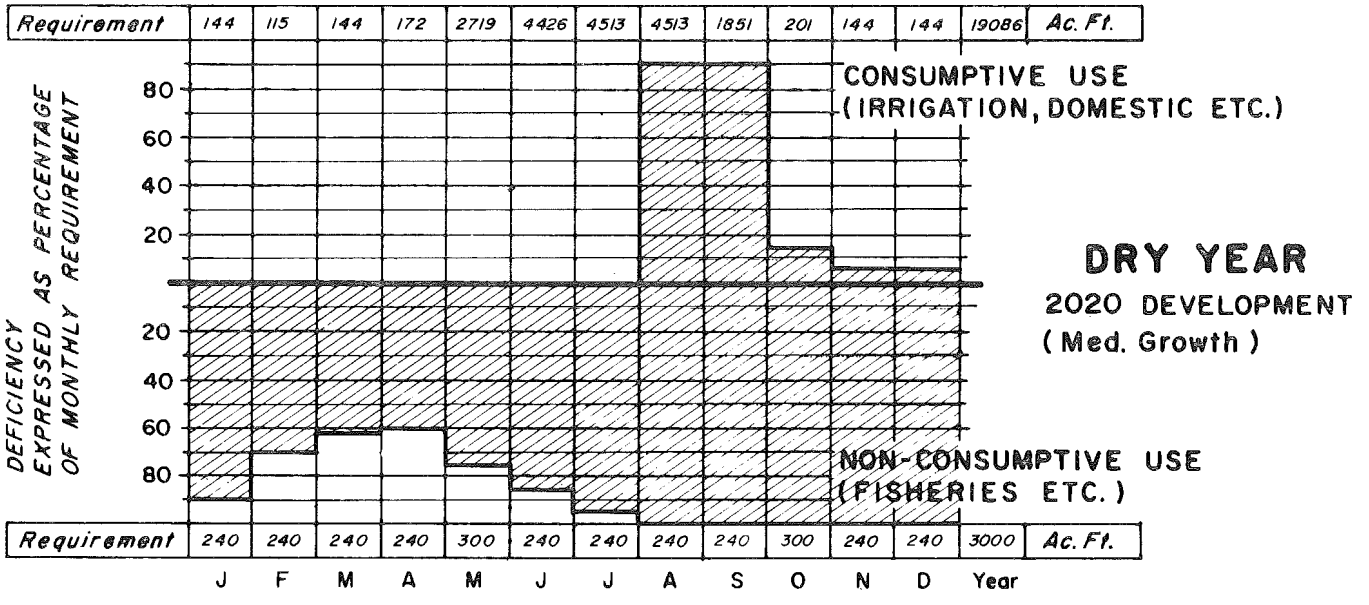


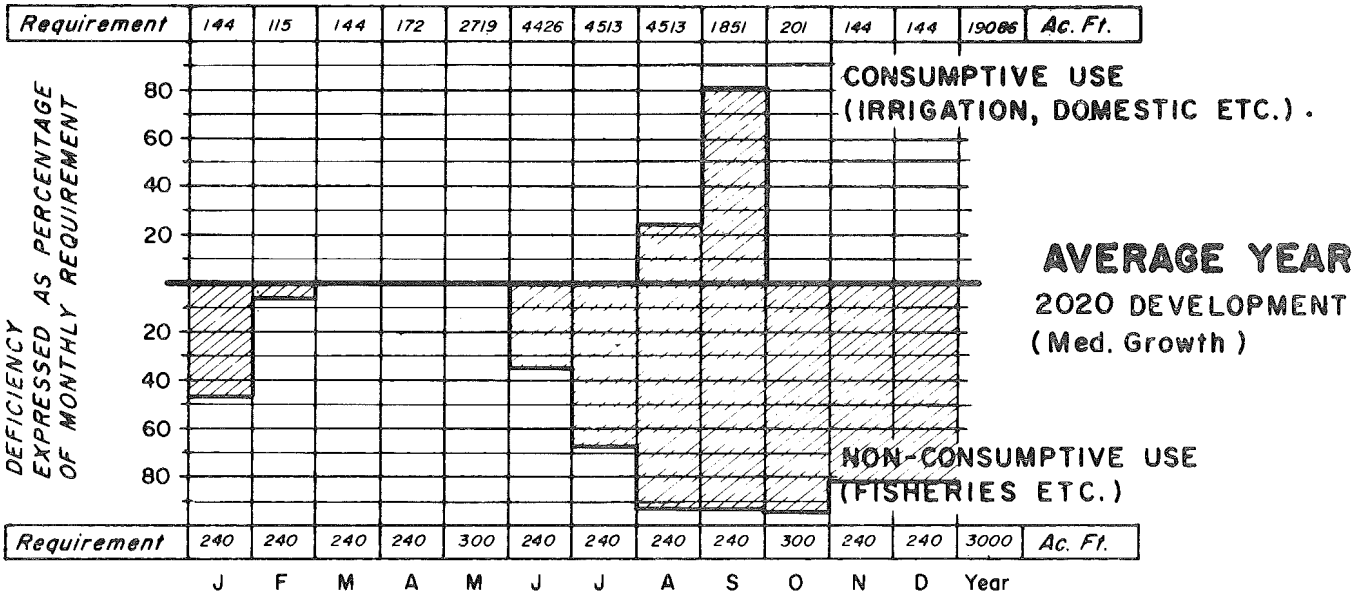


LEGEND ////// Historic (Null) Operation of Storage
▒▒▒▒ Modified Operation of Storage

NOTES: 1. Consumptive Use deficiencies are totals for whole basin.
2. Non-Consumptive deficiencies are those extant at creek mouth.
3. In a Wet Year, a fisheries deficiency of $^{161\ (Hist)}/_{0\ (Mod)}$ ac. ft. exists at mouth in each Aug. & Sept.

KELOWNA CR.
HYDROGRAPH UNDER 1970 DEVELOPMENT Figure 4.4





LEGEND ////// Historic (Null) Operation of Storage

NOTES:
1. Consumptive Use deficiencies are totals for whole basin.
2. Non-Consumptive deficiencies are those extant at creek mouth.
3. In a Wet Year, a fisheries deficiency exists at mouth of 161 ac.ft. in Aug. & Sept., 97 ac.ft. in Oct.

KELOWNA CR.
HYDROGRAPH UNDER 2020 DEVELOPMENT Figure 4.5

additions) and that methods of operating the increased storages anticipated in the future will not differ substantially from those followed at present. Time did not permit studies on other than one modified method of operation but this did show some promising results through improved minimum flows.

The method developed for estimating natural flows and regulating them within eight selected tributaries containing some 49 storage reservoirs could be applied to other tributaries within the basin or other basins providing certain basic data and runoff relationships can be established.

CHAPTER 5

Grid Square Hydrologic Model

5.1 INTRODUCTION

In planning water resources in areas such as the Okanagan Basin where there has been substantial water use development and little natural hydrometric data, there is need for new analytical methods for estimating flows. Most hydrologic regionalizing techniques are either not applicable due to the shortage of natural data (8) or inadequate for the nonhomogeneous characteristics of British Columbia's mountainous terrain. These limitations were recognized early in the Okanagan Study and it was decided to apply the Grid Square Method, a relatively new regionalizing technique, to provide estimates of mean temperature, precipitation, evapotranspiration and runoff distribution over large areas. The study area is divided into squares and physiographic parameters are determined for each. Available meteorological data are then compiled and a standard stepwise multiple regression program is used to derive equations which relate temperature and precipitation to physiographic parameters. From these equations temperature, precipitation and evaporation are estimated and runoff is obtained by subtracting evaporation from precipitation for each square. Runoff from all the squares is summed to obtain an estimate of the runoff for the basin. If the computed runoff disagrees with the recorded runoff, the precipitation for each square is adjusted and the procedure is repeated until the computed runoff approaches the observed runoff to the desired degree.

5.2 THE GRID SQUARE METHOD

5.2.1 General

The grid square method was first postulated by Solomon et al. (1) and first used by the Shawnigan Engineering Co. Ltd. in a study of the Province of Newfoundland (9) in 1968. It was first applied to British Columbia by T. Ingledow & Associates Ltd. in the "British Columbia Hydrometric Network Study" (10) in 1969. The method was developed further by Obedkoff (2) with the addition of snow course data and the estimation on a mean monthly basis of temperature, precipitation and evapotranspiration using the Thornthwaite method.

The area being studied is first divided into a grid, the size of which largely determines the accuracy of representation with six squares being the recommended minimum number per sub-basin. A finer grid results in greater accuracy but increases the costs of extracting and processing the hydrologic information. The grid system permits the storage and retrieval of basic data for computation of hydrologic parameters and for processing by means of simple computer operations.

Physiographic data are extracted for each grid square and for a square centered on each meteorological station. Temperature and precipitation data for each meteorological station and streamflow records for each sub-basin are obtained from available published records. The meteorological station data are then summarized into time periods which are compatible with streamflow records. The limiting factor in the compilation of hydrologic data is generally the period of record of the sub-basin hydrometric stations which are often sparsely distributed and frequently affected by man-made storages and diversions. Meteorological records are generally much more extensive than those of hydrometric stations.

The procedure for the iterative computation of mean annual runoff at any point within an area as originally conceived by Solomon (1) can be summarized by the following steps:

(1) Establish a preliminary relationship between mean annual precipitation at meteorological stations and the corresponding physiographic parameters by a standard multiple regression technique.

(2) Similarly, establish a relationship for mean annual temperature at meteorological stations.

(3) Compute mean annual evaporation as a function of precipitation and temperature for each square using a standard evapotranspiration formula.

(4) Make an initial estimate of runoff for each square in the study area by subtracting evaporation (from step 3) from precipitation (from step 1).

$$R_{j,i} = P_{j,i} - E_{j,i} \qquad (5.2.1)$$

where

$P_{j,i}$ = precipitation = f (physiographic parameters);

T_i = temperature = g (physiographic parameters);

$E_{j,i}$ = evapotranspiration = $h(P_{j,i}, T_i)$

$R_{j,i}$ = runoff;

j = number of estimate in the iterative computation;

i = number of grid square;

f, g and h are mathematical functions.

(5) Compute the mean annual runoff for the drainage area above the streamflow gauging station by summing runoff from each square within the watershed.

$$R_j = \sum_{i=1}^{n} R_{j,i} \qquad (5.2.2)$$

where

n = number of squares within the drainage area.

(6) Compute for the overall drainage basin the ratio

$$K_j = \frac{\text{recorded mean annual runoff}}{\text{computed mean annual runoff}} \qquad (5.2.3)$$

(7) Adjust the precipitation value for each square by the following formula:

$$P_{j,i} = (K_j)\ (R_{j,i}) + E_{j,i} \qquad (5.2.4)$$

where

$j = 2$ in $P_{j,i}$ and $j = 1$ in $R_{j,i}$ and $E_{j,i}$; i.e., $P_{2,i}$ is an adjusted value for $P_{1,i}$.

(8) Using the adjusted value of precipitation for each square and the precipitation data at meteorological stations, establish a new correlation between precipitation and physiographic parameters. More weight is given (usually 10 times) to the meteorological observations since they are actual observed data as compared to estimated data for the grid square observations.

(9) Compute a second estimate of runoff for each square as in Step 4 except for evaporation which is adjusted for each square by the following formula:

$$E_{j,i} = h\ (P_{j,i}, T_i) \qquad (5.2.5)$$

where for the second iteration the new adjusted value of $P_{2,i}$ is used. T_i remains constant since no adjustment is made for temperature in successive iterations. (This step was developed for the Okanagan Study since evaporation in such a large component of the water balance equation [Equation 5.2.1] in semi-arid regions).

(10) Compute a new value of K by repeating steps 5 and 6.

(11) Repeat steps 7,8,9 and 10 until a value of K as close to unity as practicable is obtained.

(12) Obtain the final regression equation between mean annual precipitation and physiographic parameters by repeating steps 7 and 8.

(13) Correlate the final estimate of the runoff in each of the squares with the physiographic characteristics to establish a final equation relating runoff to physiographic parameters. At this stage, additional physiographic parameters such as area of lakes, which may be correlated with runoff, can be introduced into the regression analysis.

This iterative technique is a useful tool, in that, all available continuous hydrologic information is efficiently used and successive runs tend to eliminate some of the inherent errors in the regression technique as well as errors of measurement in meteorological observations. Step 8 above calls for a new regression run with all independent variables. This procedure was adapted

such that those independent variables that were accepted in the first regression run were fixed in the equations in the iterated steps with new calculated regression coefficients as the only change for revised equations. This preserves the form of the original relationship between precipitation and the independent predictor variables.

With the development of the grid square method on a mean monthly basis, a monthly adjustment was necessary to the annual adjustment K ratio of step 6.

When the first estimate of runoff results in a uniform distribution (i.e. all sub-basins either over-estimated or under-estimated), subsequent estimates of sub-basin runoff approach the actual values with each iteration. However, when there is an inconsistent runoff distribution (sub-basin estimates with positive and negative errors) iteration increases some sub-basin errors as it decreases the overall basin error. To overcome this situation, sub-basin K ratios were computed and applied to adjust the precipitation in the discrepant sub-basins, but this met limited success. A closer examination revealed that the large sample of the Okanagan Lake sub-basin almost completely overshadowed the other smaller sub-basins and biased the regression. As a result, the regression analysis was extended to every sub-basin to produce a new set of equations using the precipitation squares of that sub-basin and any enclosed meteorological stations. With such localized sub-basin analysis the required convergence of runoff estimates with each iteration (usually in three iterations) was obtained.

5.2.2. Winter Precipitation

Snow course data were introduced into the grid square method (2) by considering the winter seasonal component in which the mean temperature was less than 32°F. The mean monthly precipitation totals of meteorological stations (most of which were in the valley bottoms) were lumped together to form a winter precipitation variable to which the snow course water equivalents of April 1st measurements (of the higher elevations) were added to produce a combined sample. This sample was then used to determine a winter season regression equation which covered the period from November to March. The remainder of the annual precipitation was considered on a mean monthly basis.

The above procedure was extended to include a varying winter interval for which equations were produced with the winter season starting either in November or December and ending in February, March or April. The winter equations were derived from low elevation meteorological station accumulated winter monthly precipitation and snow course data. The winter precipitation was then added to the monthly summer precipitation estimates to obtain the annual precipitation. Snow ablation was ignored as it is considered an insignificant portion of the winter precipitation quantity, especially for the upper elevation high runoff producing regions.

For both the Water Balance and Finite Difference Models which are explained in the following sections the winter season snowpack is melted in the summer season using the modified U.S. Corps of Engineers snowmelt equation used in Report 4 of Reference 5:

$$M = 1.8\ T(0.074N + 0.007P) \qquad (5.2.6)$$

where

M = monthly snowmelt (in. of water);
T = monthly temperature (°C.);
N = number of days in month;
P = total monthly precipitation (in.)

Each grid square is analysed independently to determine the length of the winter season. The snowpack is then melted on a monthly basis and transferred to run-off. The independent treatment of mean monthly runoff calculations of the two models is discussed below.

5.2.3 Water Balance Runoff Model

The Water Balance Runoff Model developed and incorporated into the grid square method is based on the Thornthwaite water balance method (11) and the variable season length and snowmelt features described above. The model is based on simple basic assumptions which preserve the continuity of flow of water within the year and satisfy simplified hydrologic cycle characteristics. Runoff is calculated by assuming different retention periods for water sources from snowmelt and precipitation.

For runoff originating from snowmelt, Thornthwaite's procedure assumes that for areas above 500-foot elevation, approximately 10% of the water will run off during the first melt month, 25% during the second month and 50% of the remainder in each of the following months until it is all gone. For the Okanagan basin the first two values were varied and were optimized by trial and error to values of 35% and 50% for the hydrologic zone surrounding the Okanagan watershed and 13% and 40% for a broader region including extra zone stations. The 50% value for the third and remaining months was assumed constant.

For runoff originating from rainfall, Thornthwaite's procedure assumes that for periods of one month, 50% of surplus water appears as runoff with the remaining water retained on the watershed for runoff during the next month. This assumption was adopted without change. Monthly runoff is calculated on a grid square basis and sub-basin totals are compared with observed tributary inflow.

Since only about 20% of the precipitation in the Okanagan Basin appears as runoff, the procedure used in the model required some form of soil moisture budget. Those grid squares which display a soil moisture deficit at the end of the summer are replenished first by fall rain when a water surplus condition

exists and second by snowmelt at the start of the melt season if a deficit still remains. Those squares which display a total annual moisture deficit (i.e., annual potential evapotranspiration greater than precipitation) have no resultant runoff and the model simply equates actual evapotranspiration to precipitation. This was the case for all grid squares with mean elevation below about 4,000 feet which includes all the mainstem lake region. No allowance for changes in lake storage is made in the method and changes in groundwater storage are also ignored since previous geological assessments in the Okanagan Study showed minimal net groundwater flow. Lake and groundwater storage changes are, however, considered indirectly by the model in the runoff retention factors used for delay of runoff from both snowmelt and rainfall

5.2.4 Finite Difference Runoff Model

The Finite Difference Runoff Model that was incorporated into the grid square method is based on the solution of a series of water content finite difference equations proposed by Danard in his work on the South Thompson River basin (Report No. 4, Reference 5). In this model, rainfall and snowmelt are calculated and added to give the runoff available at the source neglecting evaporation. This procedure is repeated for each square and totals of water source (S) and evapotranspiration terms (E) are accumulated for each sub-basin. The change with time of the total water content (W) of a sub-basin, is given by

$$\frac{dW}{dt} = -R + S - E \qquad (5.2.7)$$

where the runoff (R) is given by

$$R = kw \qquad (5.2.8)$$

An equation in finite difference form is assigned for each month and the water content terms (W) are then solved numerically for 12 unknowns.

$$\frac{W_{i+1} - W_i}{\Delta t} = \frac{k_i(W_i + W_{i+1})}{2} + S_i - E_i \qquad (5.2.9)$$

Here Δt = 1 month, W_i is the value of W at the start of the i^{th} month and S_i and E_i are values for the middle of the i^{th} month. For i = 12, i+1 = 1, therefore, the above equation represents 12 linear equations with 12 unknowns W_i. Runoff at the outlet is computed for each sub-basin from:

$$R_i = \frac{k_i(W_i + W_{i+1})}{2} \qquad (5.2.10)$$

where k_i is a runoff coefficient term for each month representing an exponential decay of runoff. Values of k_i were optimized by trial and error, but were constrained to represent a smooth variation within the year and provide a realistic physical explanation of the state of moisture in the watershed.

Simulated runoff from both the Water Balance Runoff model and the Finite Difference Runoff model is compared with observed runoff in four major sub-basins and on the total Okanagan Basin above Oroville.

5.3 DATA

5.3.1 General

The watershed area consists of the Okanagan River basin from its source to the hydrometric gauge at Oroville, Washington and is outlined in Figure 5.1.

As mentioned previously, the size of grid squares determines to a large extent the accuracy of representation and in other applications of the technique (1,2,9,10) the grid used had a 10-kilometer interval based on the standard military grid. Since the Okanagan watershed is much smaller than the basins previously studied and since greater accuracy of representation was required, it was decided to reduce the grid size to five kilometers. With this five-kilometer grid size 411 squares fall within or on the boundary of the Okanagan River basin. The five kilometer grid was superimposed on the 10-kilometer grid. The numbering system was designed for a computer program which used five-kilometer square raw data to compute physiographic parameters simultaneously for both the five-and 10-kilometer squares. This information was used to compare the two grid sizes for accuracy of estimates. A total of 125 ten-kilometer and 500 five-kilometer squares cover the study basin.

5.3.2 Physiographic Data

Raw physiographic data for the study basin were extracted manually from a series of National Topographic Government of Canada maps and United States Geological Survey maps. A master map with a scale of 1 inch = 2 miles was assembled and this,with bar graphs of station records were used to select the major sub-basins and the hydrometric and meteorological stations to be used in the study. These are shown in Figure 5.1.

The physiographic characteristics considered for the grid square model were as follows:

(a) mean elevation of each square;

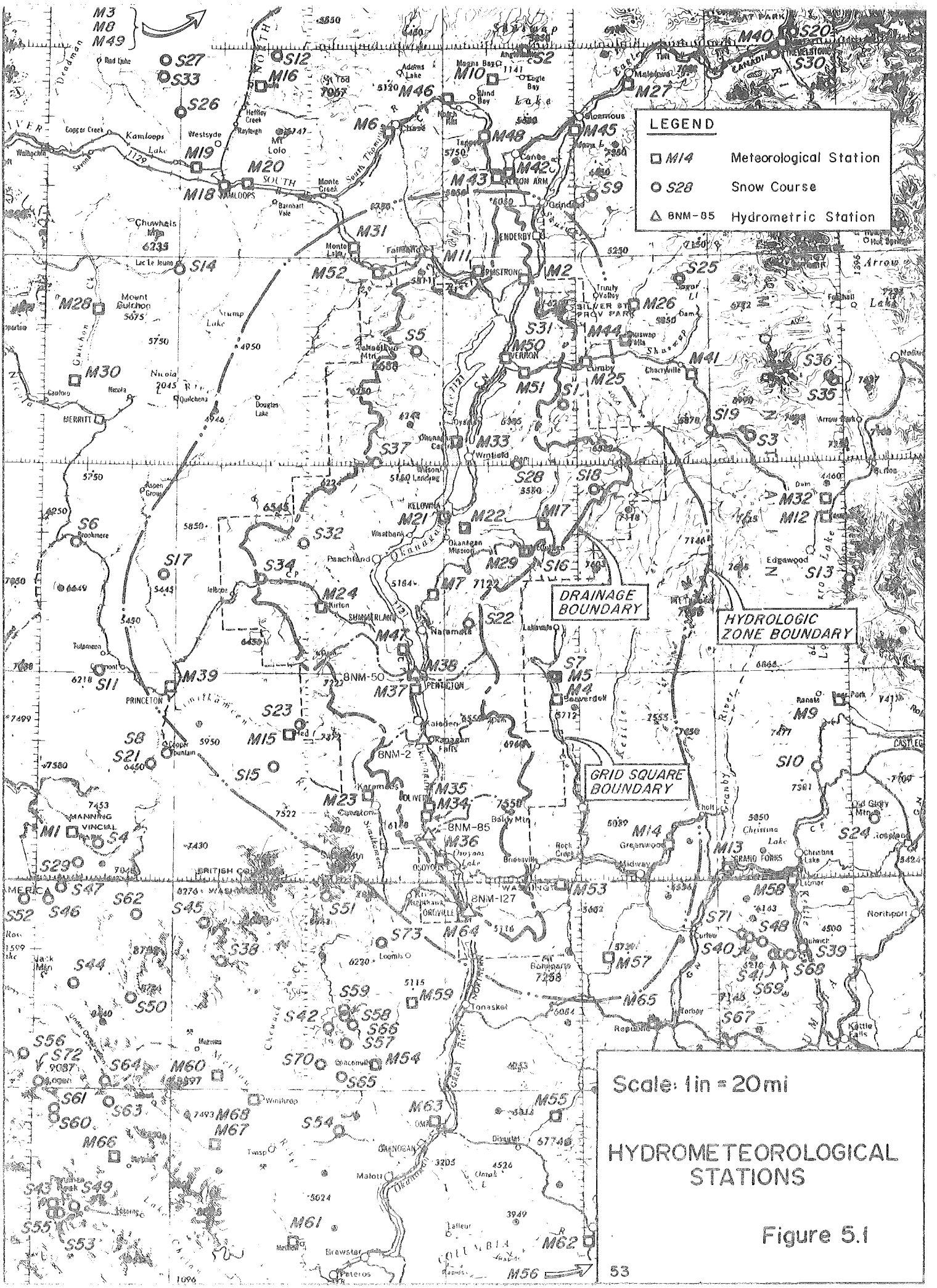
(b) land slope of each square (calculated both by Horton's Method and by the Plane Fitting Method);

(c) azimuth of slope;

(d) distance to barrier in directions 251°40' and 236°40';

(e) x and y co-ordinates from an origin off the coast;

(f) barrier height;


LEGEND
M14 Meteorological Station
S28 Snow Course
8NM-85 Hydrometric Station
DRAINAGE BOUNDARY
HYDROLOGIC ZONE BOUNDARY
GRID SQUARE BOUNDARY
Scale: 1 in = 20 mi
HYDROMETEOROLOGICAL STATIONS
Figure 5.1

(g) shield effect - a summation of barrier heights;

(h) partial sub-basin land and lake areas and total areas.

Detailed definitions and the formulae used to compute these parameters are given in Technical Supplement No. III. Physiographic information for meteorological and snow course stations were extracted from five- and 10-kilometer squares centered over the corresponding squares. The elevation at the climatological station was used rather than the average elevation of the square.

5.3.3 Meteorological Parameter P_{mH}

A new method for computing the distribution of monthly and annual precipitation over mountainous areas was developed by M.B. Danard (5) who calculated P_{mH} data for the Okanagan region for three study group periods. In addition to the other independent physiographic variables, the P_{mH} values were run in regression tests as independent variables first to test their significance and then to determine mean monthly precipitation regression equations.

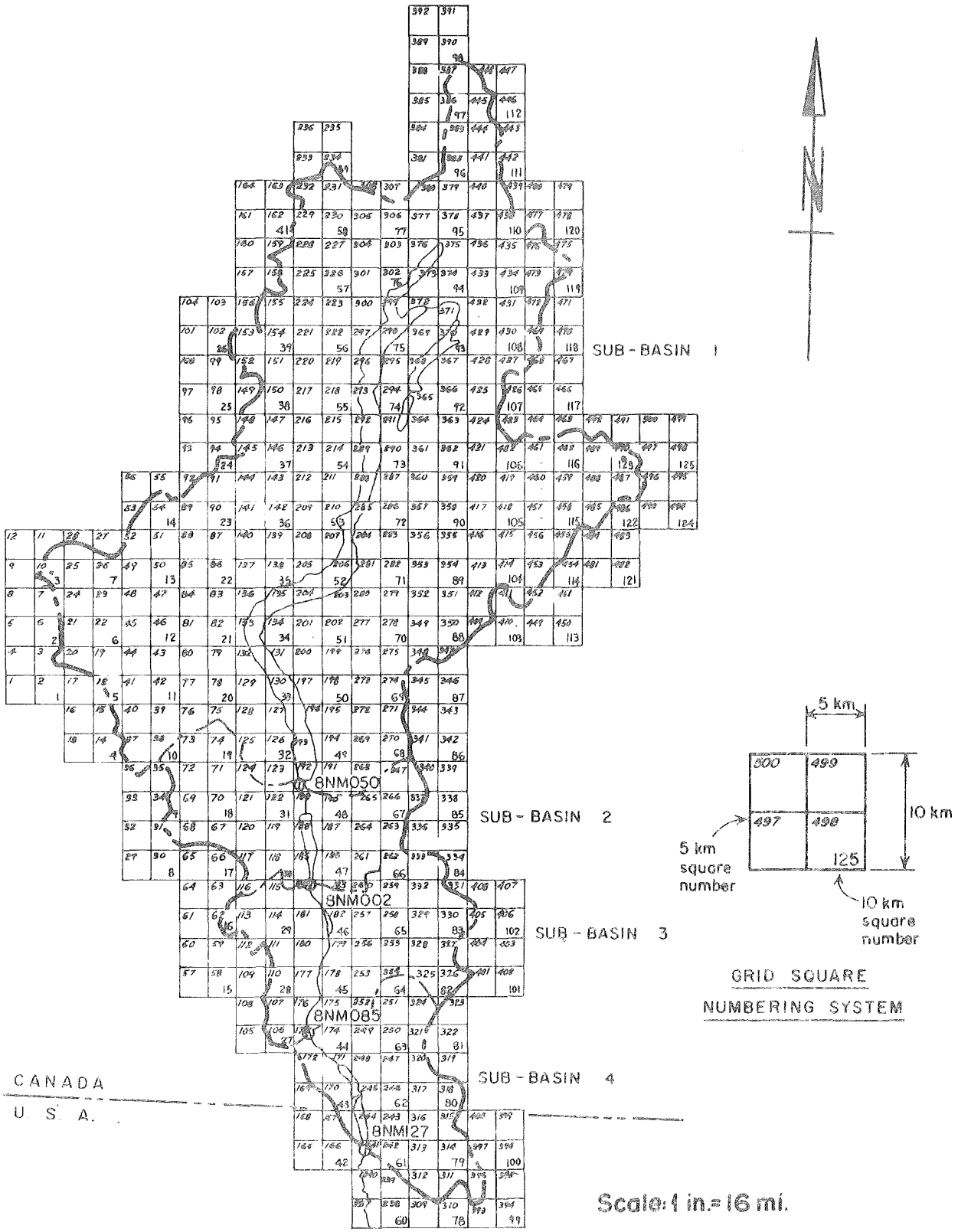
5.3.4 Streamflow Data

Long-term continuous hydrometric records in the Okanagan River basin are available from four streamflow gauges along the main stem of the river. Accordingly, the total study basin was divided into four major sub-basins with sufficient records for all sub-basins for three time base periods of study. The locations of these stations and sub-basins are shown in Figure 5.2 and station data are listed in Table 5.1. These measured data were used to derive natural flow data which were used in the grid square runoff model program to compute errors of estimate for the major sub-basins.

The flows measured at the gauging stations were adjusted such that estimates of the average natural flow were obtained for each of the five sub-basins. The adjustments included allowances for lake storage changes, consumptive use, lake evaporation and lake precipitation. Table 5.2 gives a summary of the figures used to derive the natural flows in each sub-basin and also gives the factors used to determine the mean monthly flows from annual runoff.

5.3.5 Meteorological Data

Precipitation records are available from a considerable number of meteorological stations in and adjacent to the Okanagan Basin although all stations with suitable lengths of record for this study are located below the 4,400 foot elevation. A list of meteorological stations used is given in Table 5.4 with the locations shown on Figure 5.1. An extensive examination of computer plots of the regression input data and a location map of the meteorological and snow



GRID SQUARE LAYOUT

Figure 5.2

TABLE 5.1

HYDROMETRIC STATION DATA

Station No.	Station Name	Drainage Area (sq.km.) (sq.mi.)	Mean Annual Flows (cfs) Time Base Period Groups				
			M	N	O	P	Q
			24-70	31-60	53-70	57-66	60-69
8NM050	Okanagan River at Penticton	6,018.0 2,323.5	491.3	550.8	512.3	494.8	441.8
8NM002	Okanagan River at Okanagan Falls	6,761.1 2,610.4	522.0	578.2	534.6	522.1	472.6
8NM085	Okanagan River near Oliver	7,584.2 2,928.2	-	-	572.0	545.5	493.1
8NM127	Okanagan River at Oroville	8,261.0 3,189.5	-	-	600.9	586.2	528.5

The time base periods of study are:

Group	Period	Years of Record	Reason for Choice
M	1924-70	47	Includes three-year drought (1929-31)
N	1931-60	30	Advance calculations of P_{mH}
O	1953-70	18	Data for four major sub-basins available
P	1957-66	10	Comparison with References and
Q	1960-69	10	Additional snow course and hydrometric data available

TABLE 5.2

COMPUTED FLOW DATA

A. Derivation of observed mean annual runoff (cfs)

SUB-BASIN NO.	LOCATION	STUDY GROUP*	OUTFLOW ± ΔSTORAGE	+ CONS. USE	+ LAKE EVAP.	- LAKE PREC.	COMPUTED NATURAL INFLOW
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Okanagan River above Penticton	N	551	69	319	119	820
		P	495	98	308	115	786
		Q	442	98	324	114	750
2	Penticton to Okanagan Falls	N	43.4		18.2	6.5	55.1
		P	39.8		17.6	6.2	51.2
		Q	39.3		18.5	5.9	51.9
3	Okanagan Falls to Oliver	N	97.4		-	-	97.4
		P	91.3		-	-	91.3
		Q	90.5		-	-	90.5
4	Oliver to Oroville	N					69.0
		P					63.0
		Q					60.5
5	Okanagan River above Oroville	N					1041.5
		P					991.5
		Q					952.9

B. Mean monthly distribution of annual runoff (%)

SUB-BASIN NO.	LOCATION	STUDY GROUP	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
1	Okanagan R. above Penticton	N	-0.2	0.7	3.2	13.2	37.9	23.8	9.4	5.7	3.1	2.1	0.7	0.4
		P	0.3	1.5	3.3	11.0	37.6	24.1	9.1	6.0	3.5	2.8	0.7	0.1
		Q	-0.1	1.5	3.5	11.3	36.2	26.8	9.4	6.0	2.9	2.2	0.8	-0.6
2	Penticton to Okanagan Falls	N	1.0	1.3	3.6	12.3	37.2	24.5	11.0	5.1	1.8	0.5	0.8	0.8
		P	0.3	1.8	3.0	9.2	39.4	27.6	11.6	6.1	1.4	-0.5	0.2	-0.1
		Q	0.9	3.2	3.3	7.5	31.0	30.0	11.7	7.6	3.2	-0.2	1.3	0.6
3	Okanagan Falls to Oliver	N	2.5	2.0	3.0	7.6	26.8	21.1	11.6	9.2	7.8	3.1	3.0	2.3
		P	1.9	0.8	1.4	3.4	30.2	24.9	11.0	10.4	9.0	3.3	2.0	1.6
		Q	1.5	1.0	2.3	4.5	31.1	25.2	9.9	9.7	7.6	2.8	2.1	2.2
4	Oliver to Oroville	N	2.5	2.0	3.0	7.5	26.5	20.8	11.4	9.1	7.7	4.2	2.9	2.3
		P	1.9	0.8	1.4	3.4	29.9	24.7	10.9	10.4	9.8	3.3	1.9	1.6
		Q	1.8	1.0	1.8	4.2	31.3	25.5	10.1	10.1	8.6	2.6	1.6	1.4
5	Okanagan R. above Oroville	N	0.4	1.0	3.2	12.1	35.8	23.4	9.9	6.3	3.8	2.3	1.1	0.8
		P	0.6	1.4	3.0	9.4	36.4	24.6	9.7	6.8	4.4	2.6	0.9	0.3
		Q	0.3	1.5	3.2	9.7	34.9	26.8	9.7	6.9	3.9	2.1	1.1	-0.1

*Study Group N (1931-60), P (1957-66), Q (1960-69).

course stations revealed a distinctive hydrologic zone encompassing the Okanagan watershed. This zone (outlined in Figure 5.1) ranges in distance approximately 14 to 25 miles from the Okanagan drainage boundary. The meteorological and snow course stations used in all study groups were reduced to those in this zone. The original Group N (1931-60) sample, which included some surrounding extra zone stations, was, however, retained due to accuracy of the resultant Group N grid square runoff estimates. Sample sizes are shown in Table 5.3 and actual zone observations are circled in the Study Group column of Table 5.4.

TABLE 5.3
STATION GROUP SAMPLES

Study Group	Meteorological Station		Snow Course
	Temp.	Prec.	
M	13	17	-
N(a)	28	38	16
N(b)	17	19	5
O	21	23	10
P	22	24	11
Q	23	27	12

N(a) sample including extra zone stations
N(B) sample including hydrologic zone stations only.
M,O,P,Q are hydrologic zone samples.

5.3.6 Snow Course Data

In the hydrologic zone area of the Okanagan River basin there are adequate snow courses above the 4000-foot level. Since all meteorological hydrologic zone stations are located below 4200 feet, the snow survey data provide the only observed information on precipitation at the higher runoff producing elevations. All snow course locations are shown in Figure 5.1 and listed in Table 5.4 with the hydrologic zone snow courses circled in the Study Group column.

5.4 REGRESSION ANALYSES AND RESULTS

5.4.1 Multiple Regression Programs

Two independent computer subroutine programs were used in the multiple regression analysis. The first, named STREG, is a modified IBM scientific

TABLE 5.4

HYDROMETEOROLOGICAL STATIONS

A. METEOROLOGICAL STATIONS

NO.	STATION NAME	STUDY GROUP TEMP.					STUDY GROUP PREC.					LATITUDE	LONGITUDE	ELEVATION (FEET)
1	Allison Pass				P	Q				P	Q	49°07'00"	120°52'12"	4,400
2	Armstrong	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	50°26'40"	119°11'54"	1,187
3	Barriere										Q	51°10'50"	120°07'20"	1,230
4	Beaverdell										(Q)	49°26'10"	119°05'10"	2,520
5	Carmi			O	(P)	(Q)			O	(P)	(Q)	49°29'30"	119°05'00"	4,084
6	Chase				P	Q				P	Q	50°48'00"	119°42'20"	1,165
7	Chute Lake		(N)		(P)			(N)		(P)		49°41'24"	119°32'06"	3,916
8	Darfield								O	P	Q	51°17'45"	120°10'45"	1,280
9	Deer Park				P	Q	M	N	O	P	Q	49°25'00"	118°02'12"	1,460
10	Eagle Bay						M	N	O	P	Q	50°55'36"	119°18'12"	1,160
11	Falkland Salmon River					(Q)					(Q)	50°28'00"	119°21'36"	1,500
12	Fauquier	M	N	O	P	Q	M	N	O	P	Q	49°52'12"	118°04'35"	1,550
13	Grand Forks			O	P	Q			O	P	Q	49°01'38"	118°27'50"	1,746
14	Greenwood	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°05'17"	118°40'38"	2,490
15	Hedley	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°21'24"	120°04'30"	1,720
16	Heffley Creek			O	P	Q			O	P	Q	50°54'42"	120°11'12"	2,240
17	Joe Rich Creek		(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°51'18"	119°07'30"	2,870
18	Kamloops	M	N	O	P	Q	M	N	O	P	Q	50°40'18"	120°19'36"	1,243
19	Kamloops CDA			O	P	Q			O	P	Q	50°42'48"	120°25'54"	1,150
20	Kamloops Valleyview										Q	50°40'38"	120°14'18"	1,140
21	Kelowna	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°52'36"	119°29'42"	1,160
22	Kelowna CDA			O	(P)	(Q)			O	(P)	(Q)	49°50'54"	119°24'48"	1,590
23	Keremeos	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°12'42"	119°46'54"	1,410
24	Kirton							(N)				49°39'42"	119°57'00"	2,900
25	Lumby					(Q)					(Q)	50°14'54"	118°57'42"	1,700
26	Mabel Lake						M	N	O	P	Q	50°22'54"	118°46'42"	1,310
27	Malakwa						M	N	O	P	Q	50°54'38"	118°47'30"	1,220
28	Mamit Lake				P		M	N		P		50°22'18"	120°47'42"	3,215
29	McCulloch		(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°47'36"	119°11'30"	4,100
30	Merritt Craigmont Mines					Q					Q	50°12'06"	120°53'12"	2,400
31	Monte Lake										(Q)	50°31'30"	119°49'50"	2,242
32	Needles (Whatshan P.H.)									P	Q	49°54'36"	118°04'12"	1,421
33	Okanagan Centre	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	50°03'36"	119°26'42"	1,140
34	Oliver			O	(P)	(Q)			O	(P)	(Q)	49°09'50"	119°33'50"	1,000
35	Oliver 2	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°10'54"	119°33'00"	997
36	Osoyoos			O	(P)	(Q)			O	(P)	(Q)	49°03'24"	119°31'00"	1,025
37	Penticton A			O	(P)	(Q)			O	(P)	(Q)	49°27'38"	119°36'10"	1,121
38	Penticton Sewage Plant								O	(P)	(Q)	49°29'40"	119°36'28"	1,129
39	Princeton A	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°28'00"	120°31'00"	2,279
40	Revelstoke	M	N	O	P	Q	M	N	O	P	Q	51°00'10"	118°11'50"	1,497
41	Richland					Q					Q	50°12'50"	118°34'10"	2,350
42	Salmon Arm	M	N	O	P	Q	M	N	O	P	Q	50°42'03"	119°14'48"	1,660
43	Salmon Arm 2			O	P	Q			O	P	Q	50°41'20"	119°17'15"	1,300
44	Shuswap Falls							N	O	P	Q	50°17'48"	118°48'48"	1,450
45	Sicamous			O	P	Q			O	P	Q	50°48'18"	118°59'36"	1,400
46	Sorrento						M	N	O	P	Q	50°52'48"	119°28'42"	1,280
47	Summerland Exp.Sta. & CDA	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°33'48"	119°38'48"	1,491
48	Tappen	M	N	O	P		M	N	O	P		50°47'24"	119°20'12"	1,220
49	Vavenby	M	N	O	P	Q	M	N	O	P	Q	51°34'38"	119°46'15"	1,465
50	Vernon	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	50°15'28"	119°15'45"	1,383
51	Vernon Coldstream Ranch	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	50°13'30"	119°11'30"	1,582
52	Westwold	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	50°27'48"	119°44'30"	2,020
53	Chesaw 4NNW		(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	49°00'	119°04'	3,900
54	Conconully	M	N	O	P	Q	M	N	O	P	Q	48°34'	119°45'	2,270
55	Disautel 9NE								O	P	Q	48°26'	119°06'	3,490
56	Inchelium 2NW			O	P	Q			O	P	Q	48°19'	118°13'	1,685
57	Irene Mtn. Waconda						M	(N)	O	(P)	(Q)	48°49'	118°54'	2,700
58	Laurier	M	N	O	P	Q	M	N	O	P	Q	49°00'	118°14'	1,644
59	Lemansky No.2							N				48°43'	119°37'	3,640
60	Mazama 6SE								O	P	Q	48°32'	120°20'	1,960
61	Methow 2W			O	P	Q			O	P	Q	48°08'	120°03'	1,230
62	Nespelem 2S	M	N	O	P	Q	M	N	O	P	Q	48°08'	118°59'	1,890
63	Omak 2NW	M	N	O	P	Q	M	N	O	P	Q	48°26'	119°32'	1,228
64	Oroville 1S	M	(N)	O	(P)	(Q)	M	(N)	O	(P)	(Q)	48°55'	119°26'	920
65	Republic	M	N	O	P	Q	M	N	O	P	Q	48°39'	118°44'	2,610
66	Stehekin 3NW	M	N	O	P	Q						48°20'	120°42'	1,150
67	Stockdill Randh	M	N				M	N				48°22'	120°20'	2,200
68	Winthrop 1WSW	M	N	O	P	Q	M	N	O	P	Q	48°28'	120°11'	1,755

Stations numbered 1 to 52 are located in British Columbia.

Stations numbered 53 to 68 are located in Washington.

Study Groups: M 1924-70
N 1931-60
O 1953-70
P 1957-66
Q 1960-69

(N) Circled study group letter means that the observation was used for that station in the hydrologic zone sample.

TABLE 5.4

HYDROMETEOROLOGICAL STATIONS (Cont'd)

B. SNOW COURSES

NO.	SNOW COURSE NAME	SNOW COURSE NO.	STUDY GROUP	LATITUDE	LONGITUDE	ELEVATION (FEET)
1	Aberdeen Lake	6A	(N) 0 (P) (Q)	50°08'42"	119°03'05"	4,300
2	Anglemont	84	0 P Q	50°59'53"	119°11'07"	3,900
3	Barnes Creek	90	P Q	50°04'12"	118°21'10"	5,300
4	Blackwall Peak	100	P Q	49°05'30"	120°46'25"	6,350
5	Bouleau Creek	31	0 (P) (Q)	50°16'30"	119°35'45"	5,000
6	Brookmere	27	0 P Q	49°49'00"	120°52'20"	3,200
7	Carmi	126	(Q)	40°29'50"	119°05'10"	4,100
8	Copper Mtn.	46	0 P Q	49°18'37"	120°31'10"	4,300
9	Enderby	130	Q	50°38'54"	118°56'00"	6,250
10	Farron	17	N 0 P Q	49°16'10"	118°07'50"	4,000
11	Hamilton Hill	107	Q	49°30'17"	120°46'46"	4,900
12	Knouff Lake	80	0 P Q	50°59'04"	120°07'50"	3,950
13	Koch Creek	101	P Q	49°43'00"	117°58'50"	6,100
14	Lac Le Jeune	85	0 P Q	50°28'15"	120°29'52"	4,300
15	Lost Horse Mtn.	105	(Q)	49°16'42"	120°07'45"	6,300
16	McCulloch	4	(N) 0 (P) (Q)	49°47'30"	119°11'30"	4,200
17	Missezula Mtn.	106	(Q)	49°44'22"	120°32'27"	5,100
18	Mission Creek	5A	(N) 0 (P) (Q)	49°57'20"	118°55'30"	5,850
19	Monashee Pass	48A	0 P Q	50°05'02"	118°30'05"	4,500
20	Mt. Revelstoke	15A	0 P Q	51°02'07"	118°08'50"	6,000
21	New Copper Mtn.	46A	P Q	49°17'05"	120°34'55"	4,300
22	New Penticton Res. No.2	183	0 (P) Q	49°37'44"	119°24'58"	5,225
23	Nickel Plate	47	0 (P) (Q)	49°22'47"	120°01'53"	6,200
24	Old Glory Mtn.	42	0 P Q	49°08'35"	117°54'48"	7,000
25	Park Mtn.	91	P Q	50°26'42"	118°36'24"	6,100
26	Pass Lake	57	0 P Q	50°51'00"	120°30'10"	2,950
27	Procupine Ridge	49	Q	50°58'25"	120°33'40"	6,000
28	Postill Lake	55	0 (P) (Q)	50°00'10"	119°13'30"	4,300
29	Quartette Lake	34	0 P Q	49°02'38"	120°51'00"	4,000
30	Revelstoke	15	N 0 P Q	50°59'00"	118°13'22"	1,850
31	Silver Star Mtn.	99	(P) (Q)	50°22'18"	119°03'38"	6,050
32	Summerland Res.	3A	(N) 0 (P) (Q)	49°48'42"	120°01'08"	4,200
33	Tranquille Lake	56	0 P Q	50°55'55"	120°33'40"	4,650
34	Trout Creek	3	(N) 0 (P) (Q)	49°43'53"	120°10'45"	4,700
35	Whatshan (Upper)	89A	0 P Q	50°11'40"	118°01'42"	4,850
36	Whatshan (Lower)	89B	0 P Q	50°12'00"	118°02'00"	4,100
37	White Rocks Mtn.	70	0 (P) Q	50°00'43"	119°45'00"	6,000
38	Billy Goat Pass	20A10a	Q	48°49'	120°20'	6,400
39	Boulder Road	18A02	Q	48°50'	118°11'	1,450
40	Butte Creek	18A03	Q	48°52'	118°23'	4,070
41	Cabin Creek	18A08	Q	48°49'	118°17'	3,170
42	Clarke	19A08a	Q	48°38'	119°53'	7,000
43	Cloudy Pass	20A22a	N P Q	48°12'	120°55'	6,500
44	Devils Park	20A04	0 P Q	48°45'	120°51'	5,900
45	Dollar Watch	29A29a	Q	48°53'	120°23'	7,000
46	Freezeout Creek Trail	20A01	0 P Q	48°57'	120°57'	3,500
47	Freezeout Meadows	20A02	0 P Q	48°59'	120°54'	5,000
48	Goat Creek	18A04	Q	48°51'	118°20'	3,600
49	Greenwood Flat	20A25a	N P	48°13'	120°50'	3,540
50	Harts Pass	20A05A	0 P Q	48°43'	120°39'	6,500
51	Horseshoe Basin	19A05a	P Q	48°58'	119°57'	7,000
52	Lake Hozomeen	21A02	0 P Q	48°57'	121°02'	2,600
53	Little Meadows	20A24A	N P Q	48°12'	120°54'	5,275
54	Loup Loup	19A07	P Q	48°24'	119°54'	4,650
55	Lyman Lake	20A23A	M N P Q	48°12'	120°55'	5,900
56	Meadow Cabins	20A08	0 P Q	48°35'	121°02'	1,900
57	Muckamuck	19A90a	Q	48°36'	119°52'	6,390
58	Mutton Creek No. 1	19A01	0 P Q	48°41'	119°52'	5,700
59	Mutton Creek No. 2	19A04	0 P Q	48°41'	119°52'	6,000
60	Park Creek Flat	20A13a	N P Q	48°26'	120°55'	2,220
61	Park Creek Ridge	20A12A	M N 0 P Q	48°27'	120°55'	4,600
62	Paysayten	20A28a	P Q	48°55'	120°38'	4,300
63	Petersons	20A16a	N P Q	48°28'	120°43'	3,730
64	Rainy Pass	20A09	N 0 P Q	48°31'	120°44'	4,780
65	Rusty Creek	19A03P	0 P Q	48°32'	119°52'	4,000
66	Salmon Meadows	19A02PM	0 P Q	48°39'	119°50'	4,500
67	Sherman Creek Pass	18A01	N 0 P Q	48°37'	118°29'	5,350
68	Snow Caps Creek	18A05	Q	48°49'	118°14'	2,150
69	Snow Caps Trail	18A06	Q	48°49'	118°16'	2,720
70	Starvation Mtn.	19A10a	Q	48°34'	119°57'	6,750
71	Summit G.S.	18A07	Q	48°52'	118°24'	4,600
72	Thunder Basin	20A07	0 P Q	48°31'	120°59'	4,200
73	Touts Coulee	19A06	P Q	48°51'	119°44'	2,845

Stations numbered 1 to 37 are located in British Columbia.

Stations numbered 38 to 73 are located in Washington.

subroutine which makes use of stepwise regression in multiple correlation analysis. STREG evaluates the significance of each independent variable in turn and either includes or excludes that variable from the regression equation depending on the significance level defined by the user but if desired an independent variable can be included in the regression equation regardless of its significance. All independent variables and their squared values were tested but of those that resulted in high inter-correlation, the less significant variable was excluded. In each monthly equation only the more significant of the two wind directions considered was included.

The second program was UBC TRIP, a library program of the University of British Columbia Computing Center. One of the subroutines of TRIP, called STPREG, makes use of a standard stepwise regression technique for multiple linear correlation. The routine is more sophisticated than STREG in that it calculates a new multiple regression equation with each step to test the contribution of a tested variable. This subroutine was used to define the regression equations that were used for the trial runs of the grid square program.

STPREG has no provision for iteration as required by the iterative component of the grid square method. STPREG was used to define the regression coefficients of the equations and STREG was then used to recalculate these coefficients in the iterations.

5.4.2 Temperature Distribution

STPREG was used to establish regional temperature regression equations. Relationships were established between mean monthly and annual temperature at meteorological stations (dependent variables) and their corresponding significant physiographic parameters (independent variables). Several trial regression runs at different significance levels were made on three groups of data, and the resulting sets of the best mean monthly temperature regression equations are given in Tables 5.6, 5.7 and 5.8 for Groups N, P and Q respectively. Table 5.5 gives definitions of the symbols used in the equations.

The samples used for all three Groups were derived from the hydrologic zone except for Group N in which a second extra zone sample consisting of additional surrounding meteorological stations adjacent to the hydrologic zone was included.

The Group N hydrologic zone sample shows a statistically more significant set of equations due to the confinement or limited range of the sample. The regression coefficients of the independent variables included in the equations have signs corresponding to their expected physical influence on temperature. A lapse rate ranging from 2.5°F. to 4.7°F/1,000 feet (depending on sample used)

TABLE 5.5

SYMBOLS USED IN TABLES 5.6 TO 5.11

T	= temperature in °F.
P	= precipitation in inches
E	= station elevation in thousands of feet
Y	= latitude index in hundreds of kilometers
HS	= Horton's slope in hundreds of feet per mile
AZ	= azimuth of plane fitted slope in radians
DB1 & DB2	= distance to barrier in hundreds of kilometers
BH1 & BH2	= barrier height in thousands of feet
SE1 & SE2	= shield effect in thousands of feet
1	indicates direction at 251°40'
2	indicates direction at 236°40'
PMH	= meteorological independent parameter
1 through 12 represent	January through December
N or D in the symbolic names represents November or December as the start of the winter season.	
A,M or F represent either April, March or February as the end of the winter season	
+Sc	= represents the addition of snow course data to winter seasonal meteorological observations.
ANN	= annual

TABLE 5.6
TEMPERATURE EQUATIONS - GROUP N (1931-60)

A. Sample Including Extra Zone Stations
28 observations

Month	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN T	$36.112 - 10.300E + 1.511E^2 - 0.284Y^2$	0.800	1.96	5
FEB T	$38.282 - 8.241E + 1.199E^2 - 0.281Y^2$	0.812	1.55	5
MAR T	$41.634 - 3.144E - 0.274Y^2 + 0.0525(BH1)^2$	0.825	1.43	5
APR T	$52.903 - 2.978E - 0.253Y^2$	0.810	1.43	1
MAY T	$60.030 - 2.691E$	0.755	1.57	1
JUN T	$66.265 - 2.949E$	0.761	1.69	1
JUL T	$73.944 - 3.266E - 0.319Y^2$	0.755	1.91	1
AUG T	$71.788 - 3.128E - 0.356Y^2$	0.750	1.90	1
SEP T	$62.951 - 2.482E - 0.349Y^2$	0.716	1.76	1
OCT T	$51.351 - 2.348E - 0.337Y^2$	0.771	1.42	1
NOV T	$39.862 - 3.041E - 0.204Y^2$	0.864	1.16	1
DEC T	$38.958 - 9.487E + 1.346E^2$	0.796	1.94	5
ANN T	$51.730 - 3.048E - 0.266Y^2$	0.818	1.42	1

B. Sample Including Hydrologic Zone Stations Only
17 observations

Month	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN T	$28.915 - 3.624E$	0.888	1.92	1
FEB T	$35.353 - 3.562E - 0.636Y^2$	0.955	1.20	1
MAR T	$45.842 - 4.362E - 0.674Y^2$	0.983	0.86	1
APR T	$57.084 - 4.325E - 1.767Y$	0.986	0.79	1
MAY T	$64.961 - 4.216E - 1.565Y$	0.981	0.88	1
JUN T	$70.977 - 4.427E - 1.440Y$	0.983	0.88	1
JUL T	$78.794 - 4.664E - 2.368Y$	0.977	1.11	1
AUG T	$75.101 - 4.630E - 0.777Y^2$	0.976	1.12	1
SEP T	$66.335 - 3.948E - 0.794Y^2$	0.973	1.03	1
OCT T	$53.586 - 3.274E - 0.644Y^2$	0.966	0.96	1
NOV T	$40.171 - 3.590E$	0.961	1.05	1
DEC T	$39.108 - 9.024E + 1.075E^2$	0.957	1.25	1
ANN T	$54.142 - 4.094E - 0.550Y^2$	0.980	0.88	1

For explanation of symbols see Table 5.5

TABLE 5.7

TEMPERATURE EQUATIONS - GROUP P (1957-66)

22 observations

Month	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN T	$35.776 - 9.524E + 1.247E^2$	0.927	1.55	1
FEB T	$37.809 - 3.190E - 0.523Y^2$	0.948	1.21	1
MAR T	$43.128 - 4.368E + 0.208(HS)$	0.976	1.03	1
APR T	$52.992 - 4.438E + 0.177(HS)$	0.981	0.95	1
MAY T	$61.225 - 4.327E + 0.154(HS)$	0.975	1.04	1
JUN T	$69.254 - 4.308E$	0.960	1.32	1
JUL T	$76.180 - 4.376E - 0.557Y^2$	0.959	1.44	1
AUG T	$73.802 - 4.214E - 0.576Y^2$	0.961	1.35	1
SEP T	$64.947 - 3.675E - 0.687Y^2$	0.955	1.30	1
OCT T	$53.267 - 3.154E - 0.531Y^2$	0.954	1.12	1
NOV T	$40.342 - 3.637E$	0.936	1.45	1
DEC T	$40.016 - 9.194E + 1.143E^2$	0.947	1.36	1
ANN T	$54.002 - 3.848E - 0.473Y^2$	0.968	1.10	1

TABLE 5.8

TEMPERATURE EQUATIONS - GROUP Q (1960-69)

23 observations

Month	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN T	$36.262 - 10.326E + 1.456E^2$	0.898	1.67	1
FEB T	$38.392 - 3.139E - 0.508Y^2$	0.911	1.42	1
MAR T	$45.643 - 4.093E - 0.585Y^2$	0.960	1.18	1
APR T	$52.276 - 4.385E + 0.164(HS)$	0.975	0.97	1
MAY T	$62.434 - 4.295E - 0.428Y^2$	0.972	1.01	1
JUN T	$70.849 - 4.510E - 0.404Y^2$	0.969	1.12	1
JUL T	$76.038 - 4.412E - 0.562Y^2$	0.951	1.41	1
AUG T	$74.081 - 4.158E - 0.570Y^2$	0.956	1.26	1
SEP T	$65.478 - 3.642E - 0.716Y^2$	0.947	1.26	1
OCT T	$53.159 - 3.157E - 0.489Y^2$	0.934	1.21	1
NOV T	$42.814 - 3.683E - 0.469Y^2$	0.947	1.23	1
DEC T	$39.106 - 9.789E + 1.286E^2$	0.930	1.42	1
ANN T	$54.053 - 3.862E + 0.500Y^2$	0.960	1.12	1

For explanation of symbols see Table 5.5

is implied by the elevation (E) coefficients. Where both the variable and its square have been retained in the equation as significant, a specific mathematical (second degree parabolic) function is implied for that component of the equation.

5.4.3 Precipitation Distribution

STPREG was used to establish regional precipitation regression equations. Relationships were established between mean monthly and annual precipitation at meteorological stations (dependent variables) and their corresponding significant meteorological and physigraphic parameters (independent variables). Six mean winter seasonal equations were also defined consisting of different season lengths starting either in November or December and ending in February, March or April. The winter season precipitation samples were derived by accumulating winter monthly precipitation at the lower elevation meteorological stations. This approach allowed upper elevation snow course information to be combined directly with the meteorological station data in the regression analysis thus increasing the representativeness of the precipitation relationships. Various winter seasonal equations were derived with and without snow course information depending on the availability of appropriate snow course data.

Trial regression runs were made on three study groups of data and the resulting sets of mean monthly, seasonal and annual precipitation regression equations are given in Tables 5.9, 5.10 and 5.11 for Groups N, P and Q respectively. These are the equations which gave the best correlation coefficients for each month and different length of winter.

The most common independent variables included in the precipitation equations by STPREG were station elevation E (significant in all equations), latitude index Y, distance to barrier (DB1 or DB2) and the meteorological predictor variable P_{mH}. Generally, a high intercorrelation exists between the distance to barrier and the P_{mH} variables due to the nature of the derivation of the latter. However, a backward stepwise regression run with STPREG on the Group N data showed that the order of inclusion of independent variables did not substantially alter the presence of those variables in the equation accepted by a forward stepwise regression run.

The samples used for all three Groups were derived from the hydrologic zone except for Group N in which a second extra zone sample was included. The statistics of both Group N sample equation sets are approximately the same since the range in the actual precipitation data was approximately the same for both samples. The regression variable computer plots show that Group N extra zone stations are more hydrologically representative than Groups P and Q which contain more observations due to the shorter 10-year study periods. The restriction of the Group P sample to the hydrologic zone resulted in a significant improvement of the Group P precipitation equations. No extra zone preliminary

TABLE 5.9

PRECIPITATION EQUATIONS - GROUP N (1931-60)

A. Sample Including Extra Zone Stations
38 observations

Period	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN P	$1.195 + 0.0624E_2^2 + 0.316(PMH1) + 0.178(PMH1)^2$	0.848	0.54	1
FEB P	$0.904 + 0.0579E_2^2 + 0.275(PMH2) + 0.179(PMH2)^2$	0.820	0.41	1
MAR P	$0.420 + 0.0661E_2^2 + 0.103(PMH3) + 0.0747(DB1)^2$	0.856	0.27	1
APR P	$0.471 + 0.0537E^2 - 0.211Y + 0.164(DB1)^2$	0.885	0.18	1
MAY P	$-0.100 + 0.3046E - 0.0510Y^2 + 0.616(DB1)$	0.878	0.20	1
JUN P	$0.009 + 0.3449E_2 - 0.219Y + 0.854(DB1)$	0.914	0.21	1
JUL P	$0.036 + 0.0323E_2^2 + 0.184Y + 0.320(DB1)$	0.893	0.18	1
AUG P	$0.534 + 0.0378E_2^2 + 0.187Y + 0.0844(PMH8)$	0.927	0.14	1
SEP P	$0.786 + 0.0418E_2^2 + 0.136(PMH9) + 0.0123(PMH9)^2$	0.925	0.21	1
OCT P	$1.002 + 0.0448E_2^2 + 0.124(PMH10) + 0.0244(PMH10)^2$	0.924	0.26	1
NOV P	$1.059 + 0.0552E_2^2 + 0.0980(PMH11) + 0.0572(PMH11)^2$	0.791	0.45	5
DEC P	$4.574 + 0.0881E^2 - 4.680(DB1) + 1.501(DB1)^2$	0.914	0.43	1
N-A P	$7.340 + 0.0247(PMHNA)^2$	0.721	2.90	1
N-M P	$5.100 + 0.3046E_2^2 + 0.199(PMHNM) + 0.0231(PMHNM)^2$	0.833	2.21	1
N-F P	$4.447 + 0.2407E_2^2 + 0.215(PMHNF) + 0.0279(PMHNF)^2$	0.822	2.00	1
D-A P	$4.732 + 0.2961E_2^2 + 0.217(PMHDA) + 0.0298(PMHDA)^2$	0.856	1.85	1
D-M P	$4.059 + 0.2483E_2^2 + 0.240(PMHDM) + 0.0359(PMHDM)^2$	0.842	1.76	1
D-F P	$3.407 + 0.1840E^2 + 0.275(PMHDF) + 0.0483(PMHDF)^2$	0.828	1.56	1
ANN P	$21.872 + 0.7682E^2 - 19.060(DB1) + 7.140(DB1)^2$	0.934	2.38	1

B. Sample Including Hydrologic Zone Stations Only
19 meteorological observations
5 April 1st snow course observations

Period	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN P	$1.240 + 0.0731E_2^2 + 0.264(PMH1)$	0.826	0.34	1
FEB P	$0.226 + 0.0745E_2^2 + 0.394Y$	0.821	0.31	1
MAR P	$0.466 + 0.0640E_2^2 + 0.0117(AZ)^2$	0.812	0.28	5
APR P	$0.122 + 0.0510E^2 + 0.0728(SE1)$	0.856	0.20	5
MAY P	$-0.019 + 0.3523E + 0.423(DB1)$	0.878	0.23	1
JUN P	$-0.078 + 0.3569E + 0.909(DB1) - 0.133Y^2$	0.941	0.19	1
JUL P	$0.364 + 0.0391E^2 + 0.298Y$	0.817	0.18	1
AUG P	$0.213 + 0.1875E_2 + 0.269Y$	0.904	0.11	1
SEP P	$0.869 + 0.0389E_2^2 + 0.139(PMH9)$	0.800	0.24	1
OCT P	$0.551 + 0.0498E_2^2 + 0.174(DB1)^2$	0.856	0.21	1
NOV P	$1.103 + 0.0585E_2^2 + 0.103(PMH11)$	0.793	0.28	5
DEC P	$1.390 + 0.0698E_2^2 + 0.278(PMH12)$	0.880	0.31	1
N-A P	$5.883 + 0.3863E_2^2 + 0.215(PMHNA)$	0.837	1.65	1
N-M+Sc	$5.108 + 0.2719E_2^2$	0.708	2.44	1
N-F P	$4.645 + 0.2688E_2^2 + 0.216(PMHNF)$	0.838	1.21	1
D-A P	$4.779 + 0.3271E^2 + 0.259(PMHDA)$	0.840	1.38	1
D-M+Sc	$7.361 - 2.831E + 0.7264E^2 + 0.225(PMHDM)$	0.880	1.73	5
D-F P	$3.546 + 0.2103E^2 + 0.273(PMHDF)$	0.849	0.94	1
ANN P	$11.881 + 0.6608E^2 + 0.190(PMHANN)$	0.854	2.64	1

For explanation of symbols see Table 5.5

TABLE 5.10

PRECIPITATION EQUATIONS - GROUP P (1957-66)

24 meteorological observations
6 March 1st and May 1st snow course observations
11 April 1st snow course observations

Period	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN P	$0.904 + 0.0836E_2^2 + 0.173(DB1)^2$	0.816	0.36	1
FEB P	$0.711 + 0.0886E_2^2$	0.877	0.25	1
MAR P	$0.127 + 0.0579E_2^2 + 0.0601(SE2)$	0.832	0.24	5
APR P	$0.229 + 0.0399E^2 + 0.322(DB2) - 0.242(PMH4)$	0.853	0.15	5
MAY P	$0.731 + 0.3382E$	0.799	0.26	1
JUN P	$0.168 + 0.2963E + 0.428(DB2)$	0.866	0.22	1
JUL P	$0.252 + 0.1967E_2 + 0.290Y$	0.821	0.18	1
AUG P	$0.581 + 0.0670E_2^2 + 0.115Y^2 + 0.0778(PMH8)^2$	0.888	0.20	1
SEP P	$0.061 + 0.0599E_2^2 + 0.476Y_2$	0.886	0.21	1
OCT P	$0.415 + 0.0446E_2^2 + 0.100Y^2$	0.866	0.17	1
NOV P	$1.137 + 0.0820E_2^2$	0.840	0.27	1
DEC P	$1.255 + 0.0776E_2^2$	0.771	0.33	1
N-A P	$5.756 + 0.4404E_2^2$	0.838	1.48	1
N-M+Sc	$2.567 + 0.2604E_2^2 + 1.005(DB1)_2^2$	0.783	2.94	5
N-F+Sc	$2.620 + 0.1972E^2 + 0.831(DB1)^2$	0.750	2.26	5
D-A P	$6.232 - 2.7910E + 0.9035E_2^2 + 0.470(DB1)_2^2$	0.887	1.09	5
D-M+Sc	$4.204 - 3.2063E_2 + 0.7724E^2 + 1.293(DB2)^2$	0.864	2.54	5
D-F+Sc	$1.091 + 0.2305E^2 + 0.836(DB1)^2$	0.826	1.97	1
ANN P	$8.594 + 0.7451E^2 + 1.124(DB1)^2$	0.907	2.00	1

TABLE 5.11

PRECIPITATION EQUATIONS - GROUP Q (1960-69)

27 meteorological observations
12 March, April and May 1st snow course observations

Period	Regression Equation	Correlation Coefficient	Standard Error	% F-Level
JAN P	$0.802 + 0.0799E_2^2 + 0.190(DB1)^2$	0.738	0.42	1
FEB P	$0.618 + 0.0684E_2^2$	0.778	0.25	1
MAR P	$0.058 + 0.0450E_2^2 + 0.325(DB2)$	0.767	0.22	5
APR P	$0.845 + 0.0349E^2$	0.631	0.19	1
MAY P	$0.161 + 0.2583E + 0.348(DB2)$	0.796	0.23	5
JUN P	$0.327 + 0.2467E + 0.349(DB2)$	0.784	0.23	5
JUL P	$0.050 + 0.2183E_2 + 0.372Y$	0.914	0.13	1
AUG P	$0.762 + 0.0511E_2^2 + 0.133(DB1)^2$	0.836	0.20	1
SEP P	$0.942 + 0.0294E_2^2 + 0.173(PMH9)$	0.877	0.20	1
OCT P	$0.685 + 0.0296E^2 + 0.132(PMH10)$	0.867	0.15	1
NOV P	$1.282 - 0.5744E_2 + 0.1894E^2 + 0.105(DB1)^2$	0.862	0.23	5
DEC P	$1.646 + 0.0744E_2^2$	0.611	0.42	1
N-A P	$4.528 + 0.3792E_2^2 + 0.529(DB1)_2^2$	0.789	1.48	5
N-M+Sc	$0.881 + 0.2298E_2^2 + 1.548(DB2)_2^2$	0.747	2.86	1
N-F+Sc	$0.982 + 0.2129E^2 + 1.306(DB2)^2$	0.773	2.38	1
D-A+Sc	$5.835 - 5.280E + 0.9652E_2^2 + 1.978(DB2)_2^2$	0.733	3.32	1
D-M+Sc	$2.913 - 2.800E + 0.6678E^2 + 1.630(DB2)^2$	0.816	2.61	5
D-F+Sc	$0.586 + 0.2440E^2 + 0.985(DB1)^2$	0.818	2.28	1
ANN P	$8.179 + 0.6643E^2 + 1.251(DB1)^2$	0.871	2.01	1

For explanation of symbols see Table 5.5

regression runs were made with Group Q data since the analysis of Group Q variable plots showed that extra zone correlations would be much worse due to more distant and unrepresentative stations (as with Group P).

5.4.4 Runoff Distribution

The equations for temperature and precipitation were used in the runoff model to calculate mean monthly values of evapotranspiration, snowmelt, runoff available at the source and resultant runoff for each square. The grid square runoff values were then summed for each of the four sub-basins and the total basin for use in the Finite Difference Runoff Model. These sub-basin runoff totals represented the first estimate with no iteration applied and were used to compare the individual estimates of study Groups N, P and Q with their respective observed sub-basin runoff totals.

The results of the runs of sub-basin hydrologic first estimates using the grid square runoff model program for Groups N, P and Q are given in Table 5.12. Sub-basin estimates are given in the table on a mean monthly and annual basis and were calculated from grid square estimates weighted by encompassed grid square drainage areas. Two runoff model listings are given for Group N, the first of which includes the trial run for the sample of extra zone stations and the second for the sample of hydrologic zone stations only. The final two computer listings for Groups P and Q are both second run, hydrologic zone sample results. Plots of the input variables and trial multiple regression runs showed that the Group P and Q extra zone samples gave poorer correlations and resultant runoff estimates. Group N extra zone sample did not produce poorer correlations or estimates because it has smaller areal coverage (closer to the hydrologic zone) with a longer (30-year study) period than Groups P and Q.

The first computer listing of Group N (Table 5.12) shows that the total mean annual runoff estimate error for sub-basin 5 (Okanagan basin above Oroville) is -5.0% for the Finite Difference Model and -6.7% for the Water Balance Model. Analysis of the monthly runoff errors shows that the mean monthly estimates for the high runoff producing months of April to July are relatively low. The errors for some of the remaining months are somewhat high, but they produce very little runoff. The Water Balance Runoff Model produced the more accurate runoff simulation, especially in the April to September period. This accurate simulation is also reflected in sub-basin 1 (Okanagan Lake region) which is by far the largest region where the Water Balance Model produced monthly runoff errors of less than 13%, for the April-September season except for July with 30%.

Sub-basin 3 (Okanagan Falls to Oliver) gave good results but sub-basin 2 (Lake) was overestimated by 33% and sub-basin 4 (Osoyoos Lake) was underestimated by 54%. These latter two sub-basins are very small and relatively dry with few grid squares producing runoff. No iteration was applied in the procedure and the results are thus presented on a first-estimate basis.

TABLE 5.12

ESTIMATED SUB-BASIN RUNOFF

GROUP N (1931-60) FIRST RUN

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 1 WITH AREA OF 2323.5 SQ.MI. AND AVERAGE ELEVATION OF 3563 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.1	25.1	29.8	41.3	50.4	55.8	61.1	59.3	52.8	41.7	28.2	24.6	40.8	°F	
B-PE	0.0	0.0	0.1	1.8	3.1	3.9	4.8	4.1	2.7	1.2	0.0	0.0	21.3	IN	
B-PREC	2.3	1.9	1.6	1.3	1.9	2.3	1.4	1.5	1.5	1.8	2.0	2.4	21.8	IN	
B-MELT	0.0	0.0	1.3	7.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	IN	
B-SURC	0.0	0.0	1.6	8.7	2.9	2.3	1.4	1.5	1.5	1.8	0.3	0.0	21.9	IN	
B-AE	0.0	0.0	0.1	1.3	2.9	3.6	3.6	2.7	1.8	1.2	0.0	0.0	17.3	IN	
F.D. B-R	0.0	0.0	0.2	0.7	1.8	1.3	0.6	0.1	-0.1	-0.1	0.0	0.1	4.6	IN OR	799.1 CFS
W.B. B-R	0.0	0.0	0.0	0.6	1.6	1.2	0.6	0.3	0.1	0.1	0.0	0.0	4.5	IN OR	771.2 CFS
TRUE B-R	-0.0	0.0	0.2	0.6	1.8	1.1	0.4	0.3	0.1	0.1	0.0	0.0	4.8	IN OR	820.0 CFS
T M B-R%	-0.2	0.7	3.2	13.2	37.9	23.8	9.4	6.7	3.1	2.1	0.7	0.3	100.0	%	
F.D.PR%E	-479.5	10.4	9.8	16.1	0.1	9.6	28.0	-75.5	-168.2	-162.2	-12.1	216.7	-3.8	%	
W.B.BR%E	-181.4	-85.6	-97.9	-9.0	-12.5	2.5	30.1	6.8	-2.1	-27.0	8.5	11.6	-6.0	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 2 WITH AREA OF 286.9 SQ.MI. AND AVERAGE ELEVATION OF 3760 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.5	25.5	29.9	41.2	49.9	55.2	61.1	59.3	53.0	41.9	28.0	24.4	40.8	°F	
B-PE	0.0	0.0	0.1	1.4	3.0	3.9	4.8	4.1	2.7	1.2	0.0	0.0	21.2	IN	
B-PREC	2.0	1.7	1.5	1.3	1.7	2.1	1.2	1.3	1.3	1.6	1.9	2.4	20.1	IN	
B-MELT	0.0	0.0	0.8	7.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	IN	
B-SURC	0.0	0.0	1.1	8.6	2.6	2.1	1.2	1.3	1.3	1.6	0.2	0.0	19.9	IN	
B-AE	0.0	0.0	0.0	1.3	2.8	3.5	3.5	2.5	1.7	1.2	0.0	0.0	16.5	IN	
F.D. B-R	-0.0	-0.0	0.1	0.6	1.6	1.1	0.5	-0.0	-0.2	-0.1	-0.1	-0.0	3.4	IN OR	72.5 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.2	0.9	0.4	0.2	0.1	0.1	0.0	0.0	3.5	IN OR	73.3 CFS
TRUE B-R	0.0	0.0	0.1	0.3	1.0	0.6	0.3	0.1	0.0	0.0	0.0	0.0	2.6	IN OR	55.1 CFS
T M B-R%	1.0	1.3	3.6	12.3	37.2	24.5	11.0	5.1	1.8	0.5	0.8	0.8	100.0	%	
F.D.BR%E	-194.9	-155.8	-14.5	96.8	70.0	73.0	58.9	-124.6	-464.6	******	-382.8	-241.9	31.7	%	
W.B.BR%E	-74.5	-89.4	-83.8	45.8	26.0	38.6	54.6	66.8	133.2	300.4	27.8	-37.6	33.1	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 3 WITH AREA OF 317.8 SQ.MI. AND AVERAGE ELEVATION OF 3772 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	21.2	26.1	30.5	41.3	49.9	55.1	61.2	59.5	53.1	42.0	28.1	24.9	41.1	°F	
B-PE	0.0	0.0	0.1	1.4	3.0	3.9	4.8	4.1	2.8	1.2	0.0	0.0	21.3	IN	
B-PREC	2.1	1.8	1.6	1.4	1.8	2.2	1.2	1.2	1.3	1.6	2.0	2.4	20.5	IN	
B-MELT	0.0	0.0	1.3	6.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	IN	
B-SURC	0.0	0.0	1.6	8.0	2.9	2.2	1.2	1.2	1.3	1.6	0.4	0.0	20.4	IN	
B-AE	0.0	0.0	0.1	1.2	2.7	3.4	3.4	2.5	1.7	1.1	0.0	0.0	16.3	IN	
F.D. B-R	0.0	0.0	0.2	0.7	1.7	1.2	0.6	0.0	-0.1	-0.1	-0.0	0.0	4.1	IN OR	95.8 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.4	1.1	0.5	0.1	0.1	0.1	0.0	0.0	4.1	IN OR	96.0 CFS
TRUE B-R	0.1	0.1	0.1	0.3	1.1	0.9	0.5	0.4	0.3	0.1	0.1	0.1	4.2	IN OR	97.4 CFS
T M B-R%	2.5	2.0	3.0	7.6	26.8	21.1	11.6	9.2	7.8	3.1	2.9	2.3	100.0	%	
F.D.BR%E	-84.8	-84.2	21.9	112.7	51.5	36.7	14.9	-90.1	-141.7	-188.0	-113.5	-80.3	-1.6	%	
W.B.PR%E	-92.0	-94.9	-98.4	71.8	29.3	20.5	9.9	-31.2	-59.4	-48.1	-73.1	-83.1	-1.4	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 4 WITH AREA OF 261.3 SQ.MI. AND AVERAGE ELEVATION OF 3251 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.3	25.5	32.6	43.0	51.3	56.7	63.1	61.3	54.6	43.4	29.8	24.1	42.1	°F	
B-PE	0.0	0.0	0.2	1.5	3.1	4.0	5.0	4.3	2.8	1.3	0.0	0.0	22.2	IN	
B-PREC	1.8	1.5	1.3	1.2	1.7	2.1	1.0	1.0	1.1	1.4	1.8	2.0	18.1	IN	
B-MELT	0.0	0.0	1.6	5.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	IN	
B-SURC	0.0	0.0	2.0	7.1	1.9	2.1	1.0	1.0	1.1	1.4	0.4	0.0	18.1	IN	
B-AE	0.0	0.0	0.1	1.4	2.8	3.5	3.4	2.4	1.6	1.2	0.0	0.0	16.4	IN	
F.D. B-R	-0.1	-0.1	0.1	0.6	1.4	0.8	0.2	-0.3	-0.3	-0.3	-0.2	-0.1	1.7	IN OR	32.0 CFS
W.B. B-R	0.0	0.0	0.0	0.2	0.6	0.4	0.2	0.1	0.1	0.0	0.0	0.0	1.6	IN OR	31.2 CFS
TRUE B-R	0.1	0.1	0.1	0.3	1.0	0.7	0.3	0.3	0.3	0.1	0.1	0.1	3.5	IN OR	69.0 CFS
T M B-R%	2.5	1.9	3.0	7.5	26.5	20.8	11.4	9.1	7.7	4.2	2.9	2.3	100.0	%	
F.D.BR%E	-216.0	-220.7	-2.8	122.0	42.2	6.5	-50.4	-177.5	-218.7	-300.1	-287.3	-250.3	-53.6	%	
W.B.BR%E	-96.4	-97.7	-99.2	-11.2	-41.1	-44.9	-49.7	-68.5	-81.4	-82.8	-87.7	-92.3	-54.7	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 5 WITH AREA OF 3188.5 SQ.MI. AND AVERAGE ELEVATION OF 3576 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.3	25.3	30.1	41.4	50.4	55.7	61.2	59.5	53.0	41.9	28.3	24.6	41.0	°F	
B-PE	0.0	0.0	0.1	1.4	3.0	3.9	4.8	4.1	2.7	1.2	0.0	0.0	21.3	IN	
B-PREC	2.2	1.8	1.6	1.3	1.8	2.2	1.3	1.4	1.4	1.7	2.0	2.4	21.2	IN	
B-MELT	0.0	0.0	1.3	7.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	IN	
B-SURC	0.0	0.0	1.6	8.5	2.8	2.2	1.3	1.4	1.4	1.7	0.3	0.0	21.3	IN	
B-AE	0.0	0.0	0.1	1.3	2.9	3.6	3.6	2.6	1.8	1.2	0.0	0.0	17.0	IN	
F.D. B-R	0.0	0.0	0.2	0.7	1.8	1.2	0.5	0.0	-0.1	-0.1	-0.0	0.0	4.2	IN OR	989.5 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.5	1.1	0.5	0.3	0.1	0.1	0.0	0.0	4.1	IN OR	971.8 CFS
TRUE B-R	0.0	0.0	0.1	0.5	1.6	1.0	0.4	0.3	0.2	0.1	0.1	0.0	4.4	IN OR	1041.5 CFS
T M B-R%	0.4	1.0	3.2	12.1	35.8	23.4	9.7	6.3	3.8	2.3	1.1	0.8	100.0	%	
F.D.BR%E	38.1	-55.7	8.1	32.0	10.4	15.4	21.0	-89.6	-176.4	-195.2	-102.1	-18.3	-5.0	%	
W.B.BR%E	-47.9	-90.0	-97.2	-0.2	-5.2	3.4	21.9	-4.0	-21.5	-31.7	-32.0	-49.2	-6.7	%	

For list of symbols see end of Table

TABLE 5.12 (Cont'd)

ESTIMATED SUB-BASIN RUNOFF

GROUP N (1931-60) SECOND RUN

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 1 WITH AREA OF 2323.5 SQ.MI. AND AVERAGE ELEVATION OF 3563 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR			
B-TEMP	16.0	20.2	27.7	38.2	46.9	52.4	57.6	55.6	49.2	39.4	27.4	22.5	37.8	°F		
B-PE	0.0	0.0	0.1	1.0	2.8	3.7	4.5	3.9	2.5	1.0	0.0	0.0	19.6	IN		
B-PREC	2.4	2.1	1.5	1.3	2.0	2.2	1.5	1.4	1.5	1.8	2.0	2.5	22.2	IN		
B-MELT	0.0	0.0	1.0	4.0	3.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	9.3	IN		
B-SORC	0.0	0.0	1.3	5.0	5.9	2.6	1.5	1.4	1.5	1.8	0.3	0.0	21.3	IN		
B-AE	0.0	0.0	0.1	1.0	2.7	3.5	3.6	2.6	1.8	1.0	0.0	0.0	16.2	IN		
F.D. B-R	0.1	0.1	0.2	0.5	1.7	1.4	0.6	0.2	0.0	0.1	0.1	0.1	5.1	IN	OR	868.9 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.9	1.4	0.7	0.4	0.2	0.1	0.0	0.0	5.3	IN	OR	902.0 CFS
TRUE B-R	-0.0	0.0	0.2	0.6	1.8	1.1	0.4	0.3	0.1	0.1	0.0	0.0	4.8	IN	OR	820.0 CFS
T M B-R%	-0.2	0.7	3.2	13.2	37.9	23.8	9.4	5.7	3.1	2.1	0.7	0.3	100.0	%		
F.D.BR%E	*****	180.8	20.8	-22.8	-4.7	18.3	32.2	-31.5	-91.2	-50.2	294.2	715.0	6.0	%		
W.B.BR%E	-208.4	-80.9	-98.0	-24.4	5.4	25.4	59.1	30.6	19.7	-2.8	44.5	48.6	10.0	%		

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 2 WITH AREA OF 286.9 SQ.MI. AND AVERAGE ELEVATION OF 3760 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR			
B-TEMP	15.3	20.7	28.2	38.4	46.9	52.3	58.0	56.2	50.0	40.0	26.7	22.0	37.9	°F		
B-PE	0.0	0.0	0.1	1.0	2.8	3.7	4.5	3.9	2.6	1.1	0.0	0.0	19.7	IN		
B-PREC	2.2	1.9	1.6	1.4	1.8	2.2	1.4	1.3	1.3	1.6	1.9	2.2	20.8	IN		
B-MELT	0.0	0.0	0.8	4.4	3.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	9.3	IN		
B-SORC	0.0	0.0	1.0	5.6	5.7	2.4	1.4	1.3	1.3	1.6	0.1	0.0	20.4	IN		
B-AE	0.0	0.0	0.0	1.0	2.6	3.4	3.5	2.5	1.7	1.1	0.0	0.0	15.8	IN		
F.D. B-R	0.0	0.0	0.1	0.5	1.7	1.3	0.6	0.2	-0.0	-0.0	0.1	0.1	4.6	IN	OR	96.9 CFS
W.B. B-R	0.0	0.0	0.0	0.3	1.8	1.2	0.6	0.3	0.2	0.1	0.0	0.0	4.6	IN	OR	96.8 CFS
TRUE B-R	0.0	0.0	0.1	0.3	1.0	0.6	0.3	0.1	0.0	0.0	0.0	0.0	2.6	IN	OR	55.1 CFS
T M B-R%	1.0	1.3	3.6	12.3	37.2	24.5	11.0	5.1	1.8	0.5	0.8	0.8	100.0	%		
F.D.BR%E	76.7	20.3	20.7	43.4	80.2	109.3	99.8	25.8	-129.5	-113.6	170.0	164.3	75.9	%		
W.B.BR%E	-64.4	-85.2	-97.5	8.8	81.7	93.7	116.1	133.1	225.9	459.6	78.7	-12.8	75.7	%		

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 3 WITH AREA OF 317.8 SQ.MI. AND AVERAGE ELEVATION OF 3772 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR			
B-TEMP	15.2	21.0	28.5	38.7	47.2	52.6	58.4	56.6	50.4	40.4	26.6	22.4	38.2	°F		
B-PE	0.0	0.0	0.1	1.0	2.8	3.7	4.6	3.9	2.6	1.1	0.0	0.0	19.9	IN		
B-PREC	2.1	1.9	1.7	1.5	1.9	2.3	1.3	1.2	1.3	1.7	1.9	2.1	20.8	IN		
B-MELT	0.0	0.0	1.1	3.5	4.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.2	IN		
B-SORC	0.0	0.0	1.4	4.6	6.3	2.5	1.3	1.2	1.3	1.7	0.3	0.0	20.6	IN		
B-AE	0.0	0.0	0.1	0.9	2.5	3.2	3.4	2.5	1.7	1.0	0.0	0.0	15.2	IN		
F.D. B-R	0.1	0.1	0.2	0.5	1.7	1.4	0.7	0.3	0.1	0.1	0.1	0.1	5.4	IN	OR	125.6 CFS
W.B. B-R	0.0	0.0	0.0	0.4	2.0	1.5	0.7	0.4	0.2	0.1	0.0	0.0	5.3	IN	OR	125.0 CFS
TRUE B-R	0.1	0.1	0.1	0.3	1.1	0.9	0.5	0.4	0.3	0.1	0.1	0.1	4.2	IN	OR	97.4 CFS
T M B-R%	2.5	2.0	3.0	7.6	26.8	21.1	11.6	9.2	7.8	3.1	2.9	2.3	100.0	%		
F.D.BR%E	6.1	9.8	53.6	48.7	56.4	64.9	39.4	-34.8	-83.4	-48.8	10.7	36.8	29.0	%		
W.B.BR%E	-88.9	-93.0	-97.7	35.0	77.7	66.8	52.3	-4.7	-43.7	-28.1	-62.7	-76.6	28.3	%		

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 4 WITH AREA OF 261.3 SQ.MI. AND AVERAGE ELEVATION OF 3251 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR			
B-TEMP	17.1	23.2	31.1	41.4	49.8	55.3	61.5	59.4	52.8	42.4	28.5	22.5	40.4	°F		
B-PE	0.0	0.0	0.2	1.4	3.0	3.9	4.9	4.1	2.7	1.2	0.0	0.0	21.4	IN		
B-PREC	1.7	1.5	1.4	1.3	1.7	2.2	1.1	1.1	1.1	1.5	1.6	1.6	17.8	IN		
B-MELT	0.0	0.0	1.1	5.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	IN		
B-SORC	0.0	0.0	1.5	6.5	2.8	2.2	1.1	1.1	1.1	1.5	0.2	0.0	17.9	IN		
B-AE	0.0	0.0	0.1	1.2	2.6	3.3	3.3	2.3	1.6	1.1	0.0	0.0	15.5	IN		
F.D. B-R	-0.1	-0.1	0.1	0.5	1.5	0.9	0.3	-0.1	-0.2	-0.2	-0.1	-0.1	2.4	IN	OR	46.0 CFS
W.B. B-R	0.0	0.0	0.0	0.5	0.8	0.5	0.2	0.1	0.1	0.0	0.0	0.0	2.3	IN	OR	43.8 CFS
TRUE B-R	0.1	0.1	0.1	0.3	1.0	0.7	0.4	0.3	0.3	0.1	0.1	0.1	3.6	IN	OR	69.0 CFS
T M B-R%	2.5	1.9	3.0	7.5	26.5	20.8	11.4	9.1	7.7	4.2	2.9	2.3	100.0	%		
F.D.BR%E	-170.1	-172.9	-22.3	92.0	62.0	16.0	-38.4	-133.2	-188.3	-239.9	-213.2	-190.8	-33.3	%		
W.B.BR%E	-95.7	-97.2	-99.1	81.9	-16.0	-33.9	-39.7	-62.2	-77.7	-79.4	-85.2	-90.8	-36.5	%		

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 5 WITH AREA OF 3189.5 SQ.MI. AND AVERAGE ELEVATION OF 3575 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR			
B-TEMP	16.0	20.6	28.1	38.5	47.2	52.6	58.0	56.1	49.7	39.8	27.3	22.4	38.0	°F		
B-PE	0.0	0.0	0.1	1.1	2.8	3.7	4.6	3.9	2.5	1.1	0.0	0.0	19.8	IN		
B-PREC	2.3	2.0	1.5	1.3	1.9	2.2	1.4	1.4	1.4	1.8	1.9	2.4	21.6	IN		
B-MELT	0.0	0.0	1.0	4.1	3.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	9.2	IN		
B-SORC	0.0	0.0	1.3	5.1	5.7	2.6	1.4	1.4	1.4	1.7	0.3	0.0	20.8	IN		
B-AE	0.0	0.0	0.1	1.0	2.6	3.4	3.5	2.6	1.8	1.0	0.0	0.0	16.0	IN		
F.D. B-R	0.1	0.1	0.2	0.5	1.7	1.3	0.6	0.2	-0.0	0.0	0.1	0.1	4.8	IN	OR	1137.5 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.8	1.3	0.7	0.3	0.2	0.1	0.0	0.0	5.0	IN	OR	1167.6 CFS
TRUE B-R	0.0	0.0	0.1	0.5	1.6	1.0	0.4	0.3	0.2	0.1	0.1	0.0	4.4	IN	OR	1041.5 CFS
T M B-R%	0.4	1.0	3.2	12.1	35.8	23.4	9.9	6.3	3.8	2.3	1.1	0.8	100.0	%		
F.D.BR%E	459.8	75.5	20.7	-9.3	8.2	27.3	30.2	-39.8	-103.7	-73.6	115.7	233.4	9.2	%		
W.B.BR%E	-30.3	-86.6	-98.0	-13.8	14.4	29.4	52.5	20.2	-1.7	-8.7	-9.1	-32.1	12.1	%		

For list of symbols see end of Table

TABLE 5.12 (Cont'd)

ESTIMATED SUB-BASIN RUNOFF

GROUP P (1957-66)

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 1 WITH AREA OF 2323.5 SQ.MI. AND AVERAGE ELEVATION OF 3563 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	19.9	24.4	29.7	39.0	47.4	53.9	58.4	56.6	49.2	40.0	27.4	23.8	39.1	°F	
B-PE	0.0	0.0	0.2	1.1	2.8	3.9	4.6	3.9	2.5	1.1	0.0	0.0	20.0	IN	
B-PREC	2.6	2.0	1.4	1.3	1.9	1.9	1.5	2.1	1.9	1.4	2.3	2.4	22.8	IN	
B-MELT	0.0	0.0	1.8	3.7	3.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	9.5	IN	
B-SORC	0.0	0.0	2.1	4.8	5.5	2.4	1.5	2.1	1.9	1.4	0.3	0.0	22.0	IN	
B-AE	0.0	0.0	0.1	1.0	2.7	3.6	3.5	2.8	1.8	1.0	0.0	0.0	16.6	IN	
F.D. B-R	0.1	0.1	0.3	0.6	1.8	1.3	0.5	0.2	0.1	0.1	0.2	0.2	5.5	IN OR	939.6 CFS
W.B. B-R	0.0	0.0	0.0	0.6	1.9	1.5	0.7	0.4	0.2	0.1	0.1	0.0	5.5	IN OR	936.7 CFS
TRUE B-R	0.0	0.1	0.2	0.5	1.7	1.1	0.4	0.3	0.2	0.1	0.0	0.0	4.6	IN OR	786.0 CFS
T M B-R%	0.3	1.5	3.3	11.0	37.6	24.1	9.1	6.0	3.5	2.8	0.7	0.1	100.0	%	
F.D.BR%E	974.9	64.2	78.5	14.0	3.1	17.7	29.8	-26.8	-32.6	1.8	391.7	3841.4	19.5	%	
W.B.BR%E	8.7	-90.0	-95.0	19.6	9.9	32.5	75.0	33.3	14.1	-14.9	58.6	552.1	19.2	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 2 WITH AREA OF 286.9 SQ.MI. AND AVERAGE ELEVATION OF 3760 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	19.5	24.8	29.0	38.3	46.7	53.1	58.7	56.9	49.8	40.4	26.7	23.3	38.9	°F	
B-PE	0.0	0.0	0.1	1.0	2.7	3.7	4.6	4.0	2.5	1.1	0.0	0.0	19.8	IN	
B-PREC	2.5	2.1	1.5	1.4	2.0	1.9	1.4	2.0	1.7	1.3	2.4	2.5	22.5	IN	
B-MELT	0.0	0.0	1.2	3.0	4.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	9.2	IN	
B-SORC	0.0	0.0	1.6	4.0	6.2	2.7	1.4	2.0	1.7	1.3	0.2	0.0	21.0	IN	
B-AE	0.0	0.0	0.1	1.0	2.7	3.6	3.6	2.8	1.8	1.1	0.0	0.0	16.6	IN	
F.D. B-R	0.0	0.0	0.2	0.4	1.5	1.3	0.5	0.1	0.0	0.0	0.1	0.1	4.3	IN OR	91.4 CFS
W.B. B-R	0.0	0.0	0.0	0.2	1.6	1.6	0.9	0.4	0.2	0.1	0.1	0.0	5.1	IN OR	107.1 CFS
TRUE B-R	0.0	0.0	0.1	0.2	1.0	0.7	0.3	0.1	0.0	-0.0	0.0	-0.0	2.4	IN OR	51.2 CFS
T M B-R%	0.3	1.8	3.0	9.2	39.4	27.6	11.6	6.1	1.4	-0.5	0.2	-0.1	100.0	%	
F.D.BR%E	521.4	-13.5	131.5	91.2	61.2	88.0	84.2	1.7	9.1	-337.2	1198.4	*******	78.6	%	
W.B.BR%E	71.0	-85.6	-95.6	6.5	71.9	137.8	184.0	170.2	470.4	-P71.0	1147.2	-P57.2	109.2	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 3 WITH AREA OF 317.8 SQ.MI. AND AVERAGE ELEVATION OF 3772 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	19.9	25.1	29.1	38.3	46.7	53.0	58.9	57.1	50.1	40.6	26.6	23.8	39.1	°F	
B-PE	0.0	0.0	0.2	1.0	2.7	3.7	4.6	4.0	2.6	1.1	0.0	0.0	19.9	IN	
B-PREC	2.6	2.1	1.5	1.4	2.0	1.9	1.3	2.0	1.6	1.3	2.5	2.5	22.7	IN	
B-MELT	0.0	0.0	1.3	2.7	4.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	9.8	IN	
B-SORC	0.0	0.0	1.7	3.5	6.9	2.8	1.3	2.0	1.6	1.3	0.3	0.0	21.4	IN	
B-AE	0.0	0.0	0.1	0.9	2.5	3.4	3.5	2.7	1.8	1.1	0.0	0.0	16.0	IN	
F.D. B-R	0.1	0.1	0.2	0.4	1.6	1.4	0.7	0.3	0.1	0.1	0.1	0.1	5.5	IN OR	128.1 CFS
W.B. B-R	0.0	0.0	0.0	0.3	1.9	1.9	0.9	0.5	0.2	0.1	0.1	0.0	6.0	IN OR	139.7 CFS
TRUE B-R	0.1	0.0	0.1	0.1	1.2	1.0	0.4	0.4	0.4	0.1	0.1	0.1	3.9	IN OR	91.3 CFS
T M B-R%	1.9	0.8	1.4	3.4	30.2	24.9	11.0	10.4	9.0	3.3	1.9	1.6	100.0	%	
F.D.BR%E	59.6	227.5	304.8	223.9	38.0	49.2	57.1	-29.6	-58.2	-8.9	87.1	131.2	40.3	%	
W.B.BR%E	-80.2	-75.9	-93.4	131.0	58.3	95.5	121.3	16.6	-32.6	-7.8	-22.0	-53.0	53.0	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 4 WITH AREA OF 261.3 SQ.MI. AND AVERAGE ELEVATION OF 3251 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	19.6	27.0	30.8	40.1	48.5	55.2	61.5	59.6	52.4	42.6	28.5	23.7	40.8	°F	
B-PE	0.0	0.0	0.2	1.2	2.8	3.9	4.9	4.2	2.7	1.3	0.0	0.0	21.1	IN	
B-PREC	2.2	1.8	1.4	1.2	1.8	1.8	1.2	1.7	1.2	1.0	2.1	2.2	19.6	IN	
B-MELT	0.0	0.2	1.1	4.5	1.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	7.3	IN	
B-SORC	0.0	0.3	1.5	5.6	3.2	1.9	1.2	1.7	1.2	1.0	0.4	0.0	18.0	IN	
B-AE	0.0	0.0	0.1	1.1	2.6	3.4	3.5	2.6	1.7	1.2	0.0	0.0	16.2	IN	
F.D. B-R	-0.1	-0.1	0.1	0.5	1.5	0.8	0.2	-0.2	-0.3	-0.3	-0.2	-0.1	1.9	IN OR	36.0 CFS
W.B. B-R	0.0	0.0	0.0	0.4	0.8	0.6	0.3	0.1	0.1	0.0	0.0	0.0	2.4	IN OR	45.8 CFS
TRUE B-R	0.1	0.0	0.0	0.1	1.0	0.8	0.4	0.3	0.3	0.1	0.1	0.1	3.3	IN OR	63.0 CFS
T M B-R%	1.9	0.8	1.4	3.4	29.9	24.7	10.9	10.4	9.8	3.3	1.9	1.6	100.0	%	
F.D.BR%E	-265.2	-321.3	132.6	334.5	48.3	1.1	-51.8	-145.8	-180.3	-346.8	-414.0	-336.7	-42.8	%	
W.B.BR%E	-92.8	-91.1	-97.6	267.0	-15.0	-29.3	-20.1	-58.0	-77.7	-67.1	-71.6	-83.2	-27.3	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 5 WITH AREA OF 3189.5 SQ.MI. AND AVERAGE ELEVATION OF 3576 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	19.8	24.7	29.7	39.0	47.1	53.8	58.7	56.9	49.6	40.3	27.3	23.7	39.2	°F	
B-PE	0.0	0.0	0.2	1.1	2.8	3.9	4.6	4.0	2.5	1.1	0.0	0.0	20.1	IN	
B-PREC	2.6	2.0	1.4	1.3	1.9	1.9	1.5	2.1	1.8	1.4	2.3	2.4	22.5	IN	
B-MELT	0.0	0.0	1.6	3.6	3.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	9.3	IN	
B-SORC	0.0	0.0	2.0	4.7	5.5	2.4	1.5	2.1	1.8	1.4	0.3	0.0	21.6	IN	
B-AE	0.0	0.0	0.1	1.0	2.6	3.5	3.5	2.8	1.8	1.1	0.0	0.0	16.5	IN	
F.D. B-R	0.1	0.1	0.2	0.5	1.7	1.3	0.5	0.2	0.1	0.1	0.1	0.1	5.1	IN OR	1195.1 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.8	1.4	0.7	0.4	0.2	0.1	0.1	0.0	5.2	IN OR	1229.3 CFS
TRUE B-R	0.0	0.1	0.1	0.4	1.5	1.0	0.4	0.3	0.2	0.1	0.0	0.0	4.2	IN OR	991.5 CFS
T M B-R%	0.6	1.4	3.0	9.4	36.4	24.6	9.7	6.8	4.4	2.5	0.9	0.3	100.0	%	
F.D.BR%E	334.4	54.1	96.8	35.5	11.7	23.0	28.3	-38.6	-58.7	-19.9	225.8	774.3	20.5	%	
W.B.BR%E	-46.9	-88.9	-95.0	31.8	16.2	39.7	77.2	26.1	-1.9	-5.1	34.1	75.0	24.0	%	

For list of symbols see end of Table

TABLE 5.12 (Cont'd)

ESTIMATED SUB-BASIN RUNOFF

GROUP Q (1960-69)

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 1 WITH AREA OF 2323.5 SQ.MI. AND AVERAGE ELEVATION OF 3563 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.5	25.2	28.8	38.3	45.5	53.2	58.1	57.1	49.7	40.0	27.9	22.8	38.9	*F	
B-PE	0.0	0.0	0.1	1.0	2.5	3.8	4.6	4.0	2.5	1.1	0.0	0.0	19.7	IN	
B-PREC	2.5	1.7	1.2	1.3	1.6	1.8	1.6	1.9	1.4	1.1	2.3	2.7	21.2	IN	
B-MELT	0.0	0.0	1.2	3.7	3.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	8.9	IN	
B-SORC	0.0	0.1	1.4	4.7	5.0	2.4	1.6	1.9	1.4	1.1	0.3	0.0	20.0	IN	
B-AE	0.0	0.0	0.1	1.0	2.4	3.4	3.5	2.8	1.7	1.0	0.0	0.0	15.9	IN	
F.D. B-R	0.0	0.0	0.2	0.5	1.6	1.2	0.5	0.1	0.0	-0.0	0.0	0.0	4.1	IN OR	697.3 CFS
W.B. B-R	0.0	0.0	0.0	0.3	1.3	1.2	0.6	0.3	0.2	0.1	0.0	0.0	4.1	IN OR	707.1 CFS
TRUE B-R	-0.0	0.1	0.2	0.5	1.6	1.2	0.4	0.3	0.1	0.1	0.0	-0.0	4.4	IN OR	750.0 CFS
T M B-R%	-0.1	1.5	3.5	11.3	36.2	26.8	9.4	6.0	2.9	2.2	0.8	-0.6	100.0	%	
F.D.BR%E	-688.4	-50.5	2.3	-7.6	-1.0	-0.5	16.3	-48.0	-94.5	-118.2	-59.0	-234.8	-7.0	%	
W.B.BR%E	-287.3	-92.3	-98.4	-31.5	-16.0	4.5	49.8	16.2	19.2	-19.7	7.0	-170.2	-5.7	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 2 WITH AREA OF 286.9 SQ.MI. AND AVERAGE ELEVATION OF 3760 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.2	25.6	29.1	37.6	45.5	53.1	58.4	57.4	50.4	40.4	28.1	22.4	39.0	*F	
B-PE	0.0	0.0	0.1	0.9	2.5	3.8	4.6	4.0	2.6	1.1	0.0	0.0	19.7	IN	
B-PREC	2.4	1.7	1.2	1.4	1.6	1.7	1.4	1.8	1.1	1.0	2.3	2.8	20.4	IN	
B-MELT	0.0	0.0	0.7	2.9	4.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	8.5	IN	
B-SORC	0.0	0.1	1.0	3.8	5.3	2.4	1.4	1.8	1.1	1.0	0.2	0.0	18.6	IN	
B-AE	0.0	0.0	0.1	0.9	2.4	3.4	3.4	2.6	1.7	1.1	0.0	0.0	15.7	IN	
F.D. B-R	-0.0	-0.0	0.1	0.3	1.3	1.1	0.4	0.1	-0.1	-0.1	-0.1	-0.0	2.9	IN OR	61.8 CFS
W.B. B-R	0.0	0.0	0.0	0.1	1.2	1.3	0.6	0.3	0.2	0.1	0.0	0.0	3.8	IN OR	81.4 CFS
TRUE B-R	0.0	0.1	0.1	0.2	0.8	0.7	0.3	0.2	0.1	-0.0	0.0	0.0	2.5	IN OR	51.9 CFS
T M B-R%	0.3	3.3	3.3	7.5	31.0	30.0	11.7	7.6	3.2	-0.2	1.3	0.5	100.0	%	
F.D.BR%E	-280.9	-129.9	-11.9	70.2	74.5	49.2	44.5	-59.6	-184.0	-210.6	-367.4	-431.6	19.1	%	
W.B.BR%E	-54.6	-93.7	-96.9	-40.3	54.4	74.4	123.3	72.8	104.8	******	27.6	36.1	56.8	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 3 WITH AREA OF 317.4 SQ.MI. AND AVERAGE ELEVATION OF 3772 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.8	25.9	29.4	37.7	45.6	53.3	58.6	57.6	50.8	40.6	28.3	22.9	39.3	*F	
B-PE	0.0	0.0	0.2	0.9	2.5	3.9	4.6	4.1	2.6	1.1	0.1	0.0	19.9	IN	
B-PREC	2.4	1.7	1.3	1.4	1.7	1.8	1.3	1.8	1.1	1.0	2.4	2.8	20.7	IN	
B-MELT	0.0	0.1	1.0	2.4	4.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	9.0	IN	
B-SORC	0.0	0.1	1.3	3.3	6.4	2.5	1.7	1.8	1.1	1.0	0.3	0.0	19.2	IN	
B-AE	0.0	0.0	0.1	0.8	2.3	3.3	3.3	2.7	1.7	1.0	0.0	0.0	15.2	IN	
F.D. B-R	0.0	0.0	0.1	0.4	1.4	1.3	0.6	0.2	0.0	-0.0	0.0	0.0	4.1	IN OR	95.1 CFS
W.B. B-R	0.0	0.0	0.0	0.2	1.4	1.6	0.8	0.4	0.2	0.1	0.0	0.0	4.7	IN OR	109.7 CFS
TRUE B-R	0.1	0.0	0.1	0.2	1.2	1.0	0.4	0.4	0.3	0.1	0.1	0.1	3.9	IN OR	90.5 CFS
T M B-R%	1.5	1.0	2.3	4.5	31.1	25.2	9.9	9.7	7.6	2.8	2.1	2.2	100.0	%	
F.D.BR%E	-54.1	-21.0	65.1	100.7	19.3	31.2	45.5	-47.9	-89.2	-124.6	-93.6	-63.0	5.1	%	
W.B.BR%E	-78.8	-85.0	-96.6	-13.0	18.4	59.6	103.3	3.9	-33.6	-11.4	-39.8	-71.9	21.2	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 4 WITH AREA OF 261.1 SQ.MI. AND AVERAGE ELEVATION OF 3251 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.0	27.8	31.8	39.5	48.1	55.9	61.2	60.1	53.0	42.5	30.4	22.6	41.1	*F	
B-PE	0.0	0.0	0.2	1.1	2.7	4.0	4.8	4.2	2.8	1.3	0.1	0.0	21.1	IN	
B-PREC	2.1	1.4	1.1	1.3	1.6	1.7	1.1	1.5	1.0	1.0	1.9	2.5	18.2	IN	
B-MELT	0.0	0.4	0.8	4.2	1.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	7.1	IN	
B-SORC	0.0	0.6	1.1	5.4	3.2	1.7	1.1	1.6	1.0	1.0	0.3	0.0	17.0	IN	
B-AE	0.0	0.0	0.1	1.0	2.4	3.4	3.3	2.5	1.6	1.1	0.0	0.0	15.5	IN	
F.D. B-R	-0.1	-0.1	0.1	0.4	1.4	0.8	0.1	-0.2	-0.3	-0.3	-0.2	-0.2	1.5	IN OR	29.1 CFS
W.B. B-R	0.0	0.0	0.0	0.2	0.7	0.5	0.3	0.1	0.1	0.0	0.0	0.0	2.0	IN OR	37.6 CFS
TRUE B-R	0.1	0.0	0.1	0.1	1.0	0.8	0.3	0.3	0.3	0.1	0.1	0.0	3.1	IN OR	60.5 CFS
T M B-R%	1.8	1.0	1.8	4.1	31.3	25.5	10.1	10.1	8.6	2.6	1.6	1.4	100.0	%	
F.D.BR%E	-334.3	-271.5	68.6	235.5	40.5	-3.6	-54.9	-151.9	-201.6	-470.1	-548.3	-476.9	-51.8	%	
W.B.BR%E	-93.0	-94.0	-98.3	93.1	-28.3	-37.4	-20.8	-60.6	-76.8	-61.0	-69.6	-81.6	-37.8	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 5 WITH AREA OF 3189.5 SQ.MI. AND AVERAGE ELEVATION OF 3576 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	20.5	25.5	29.1	38.3	45.7	53.4	58.5	57.4	50.2	40.3	28.1	22.8	39.1	*F	
B-PE	0.0	0.0	0.1	1.0	2.5	3.8	4.6	4.0	2.6	1.1	0.1	0.0	19.8	IN	
B-PREC	2.5	1.6	1.2	1.4	1.6	1.8	1.5	1.9	1.3	1.1	2.3	2.7	20.8	IN	
B-MELT	0.0	0.1	1.1	3.5	3.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	8.7	IN	
B-SORC	0.0	0.1	1.4	4.6	5.1	2.4	1.5	1.9	1.3	1.1	0.3	0.0	19.5	IN	
B-AE	0.0	0.0	0.1	0.9	2.4	3.4	3.4	2.7	1.7	1.1	0.0	0.0	15.8	IN	
F.D. B-R	0.0	0.0	0.1	0.4	1.5	1.1	0.5	0.1	-0.0	-0.1	-0.0	0.0	3.8	IN OR	883.3 CFS
W.B. B-R	0.0	0.0	0.0	0.3	1.3	1.2	0.6	0.3	0.2	0.1	0.0	0.0	4.0	IN OR	935.7 CFS
TRUE B-R	0.0	0.1	0.1	0.4	1.4	1.1	0.4	0.3	0.2	0.1	0.0	-0.0	4.1	IN OR	952.9 CFS
T M B-R%	0.3	1.5	3.2	9.7	34.9	26.8	9.7	6.9	3.9	2.1	1.1	-0.1	100.0	%	
F.D.BR%E	-7.8	-68.8	9.6	3.9	7.6	4.9	15.1	-59.5	-112.8	-159.9	-134.5	-517.6	-7.3	%	
W.B.BR%E	-17.6	-92.3	-98.2	-25.7	-9.7	10.9	53.6	8.3	-4.4	-10.0	-11.4	-710.3	-1.8	%	

For list of symbols see end of Table

TABLE 5.12

ESTIMATED SUB-BASIN RUNOFF (cont'd.)

LIST OF SYMBOLS USED

B-TEMP	basin temperature
B-PE	basin potential evapotranspiration
B-PREC	basin precipitation
B-MELT	basin snowmelt
B-SORC	basin water content source
B-AE	basin actual evapotranspiration
F.D. B-R	Finite Difference Model basin runoff
W.B. B-R	Water Balance Model basin runoff
TRUE B-R	observed (true) basin runoff
T M B-R%	observed (true) monthly basin runoff percentages
F.D. BR%E	Finite Difference Model basin runoff percentage errors
W.B.BR%E	Water Balance Model basin runoff percentage errors

The computer listings of the hydrologic zone station samples for Groups N, P and Q (Table 5.12) show similar accurate runoff results. Total basin runoff estimate errors for the Water Balance Runoff Model for Groups N, P and Q are 12%, 24% and -2% respectively and for the Finite Difference Runoff Model, 9%, 20% and -7%. The magnitude and pattern of errors for the three group hydrologic zone sample runs are similar to those of the Group N extra zone sample run discussed above.

5.4.5 Use of Grid Square Estimates

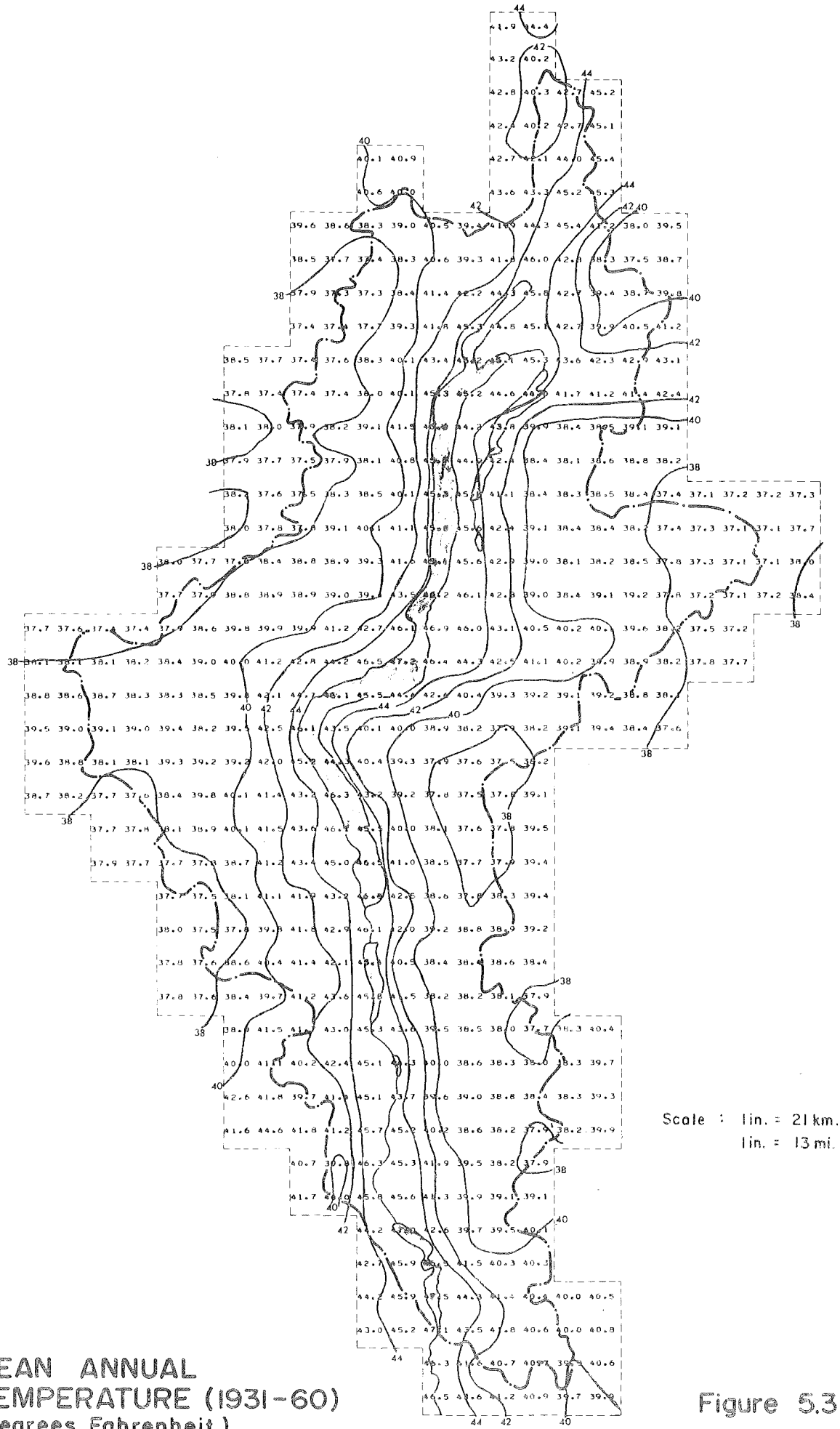
Detailed grid square estimates for each 5km. grid square are given in Technical Supplement No. III for:

(a) mean monthly and annual temperatures;
(b) mean monthly, winter season and annual precipitation;
(c) mean monthly and annual actual evapotranspiration;
(d) mean monthly and annual runoff.

The mean annual Group N estimates are also presented in map form as grid square point sources through which isopleths were drawn to display regional hydrologic maps. Figures 5.3, 5.4, 5.5 and 5.6 show mean annual temperature, precipitation, actual evapotranspiration and runoff, respectively. The decimal point of each number is located in the centre of the grid square that it represents. Grid squares and their numbers are not shown, but they can be determined by reference to Figure 5.2. Figure 5.5 shows actual evapotranspiration derived by the grid square program for land areas only; therefore, the estimates and isopleths superimposed on the lakes do not represent lake evaporation.

Mean monthly runoff estimates for any desired Okanagan tributary can be obtained simply by considering those squares covering the sub-basin and weighting the runoff of each square by its encompassed area. This has been done for some selected tributary sub-basins of the Okanagan Lake region and the estimates are shown in Table 5.13.

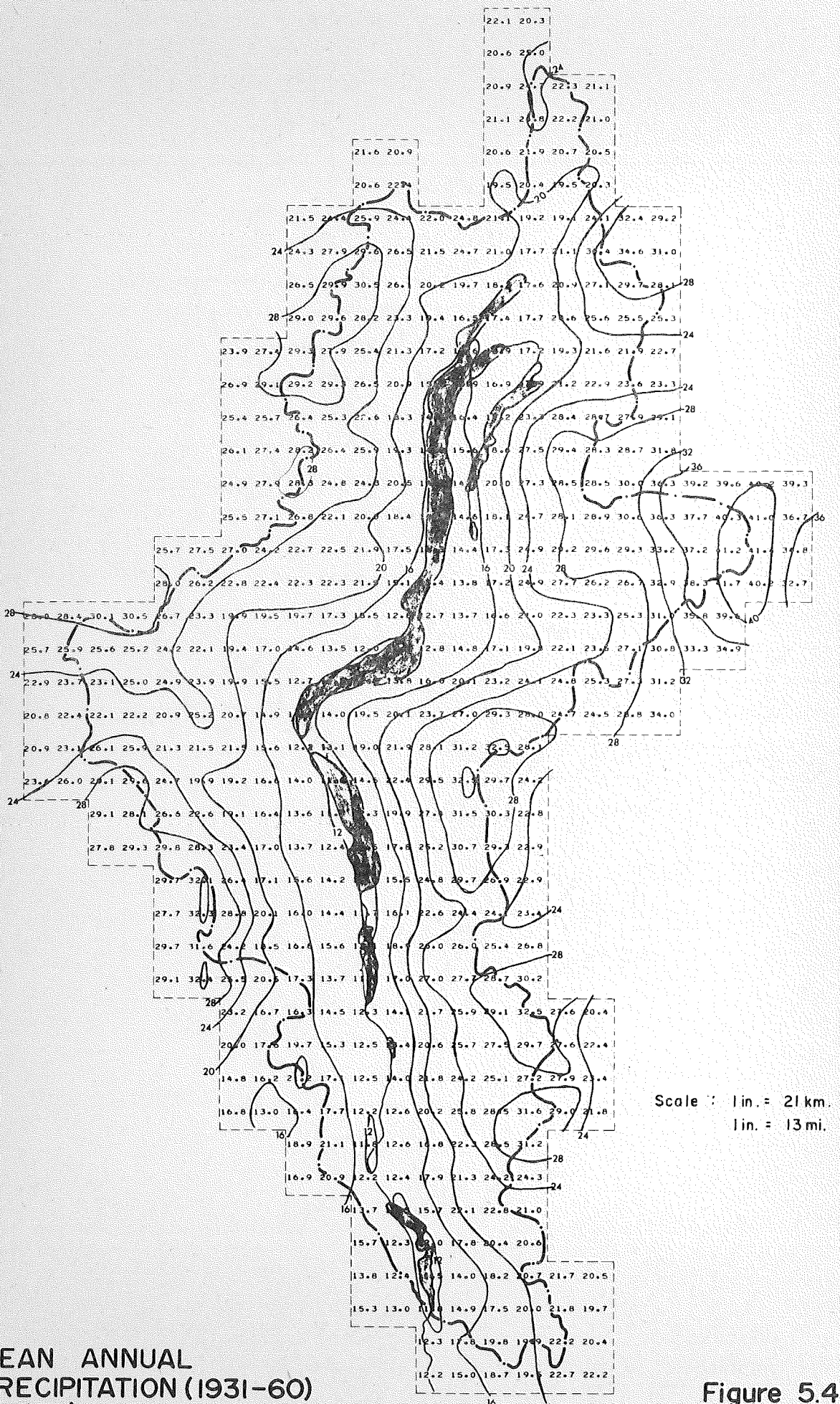
The mean monthly runoff estimates as derived by the Water Balance Runoff Model could be used for monthly flow estimates of typical drought and flood years by applying a known or assumed series of monthly coefficients to the monthly distribution derived by the runoff model. For example, the grid square mean annual runoff estimate could be increased a known amount (e.g., the ratio of the 1972 Okanagan Lake inflow to the 1931-60 mean inflow) for a flood year and monthly adjustment coefficients could be applied to the grid square monthly distribution to simulate a known flood hydrograph pattern. Adjustment to the Group N runoff figures to produce mean annual data for the standard Okanagan Study period, 1921 to 1970 (4) could probably be determined by multiplying by 0.94 which is the ratio of the mean annual inflow, 1921-70, to the mean annual inflow, 1931-60, to Okanagan Lake.



Scale : 1 in. = 21 km.
1 in. = 13 mi.

MEAN ANNUAL TEMPERATURE (1931-60)
(Degrees Fahrenheit.)

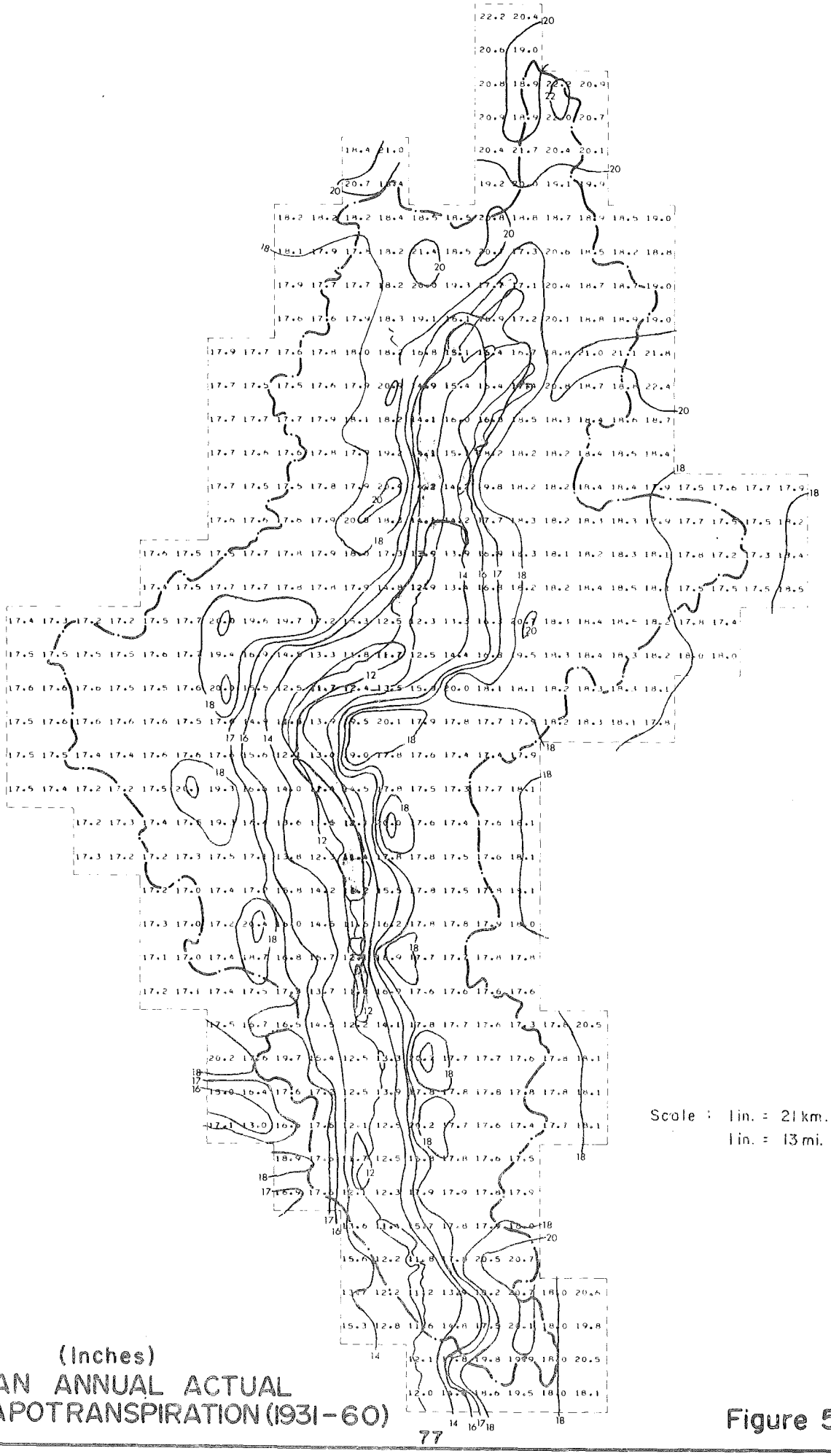
Figure 5.3



Scale : 1 in. = 21 km.
1 in. = 13 mi.

MEAN ANNUAL
PRECIPITATION (1931-60)
(Inches)

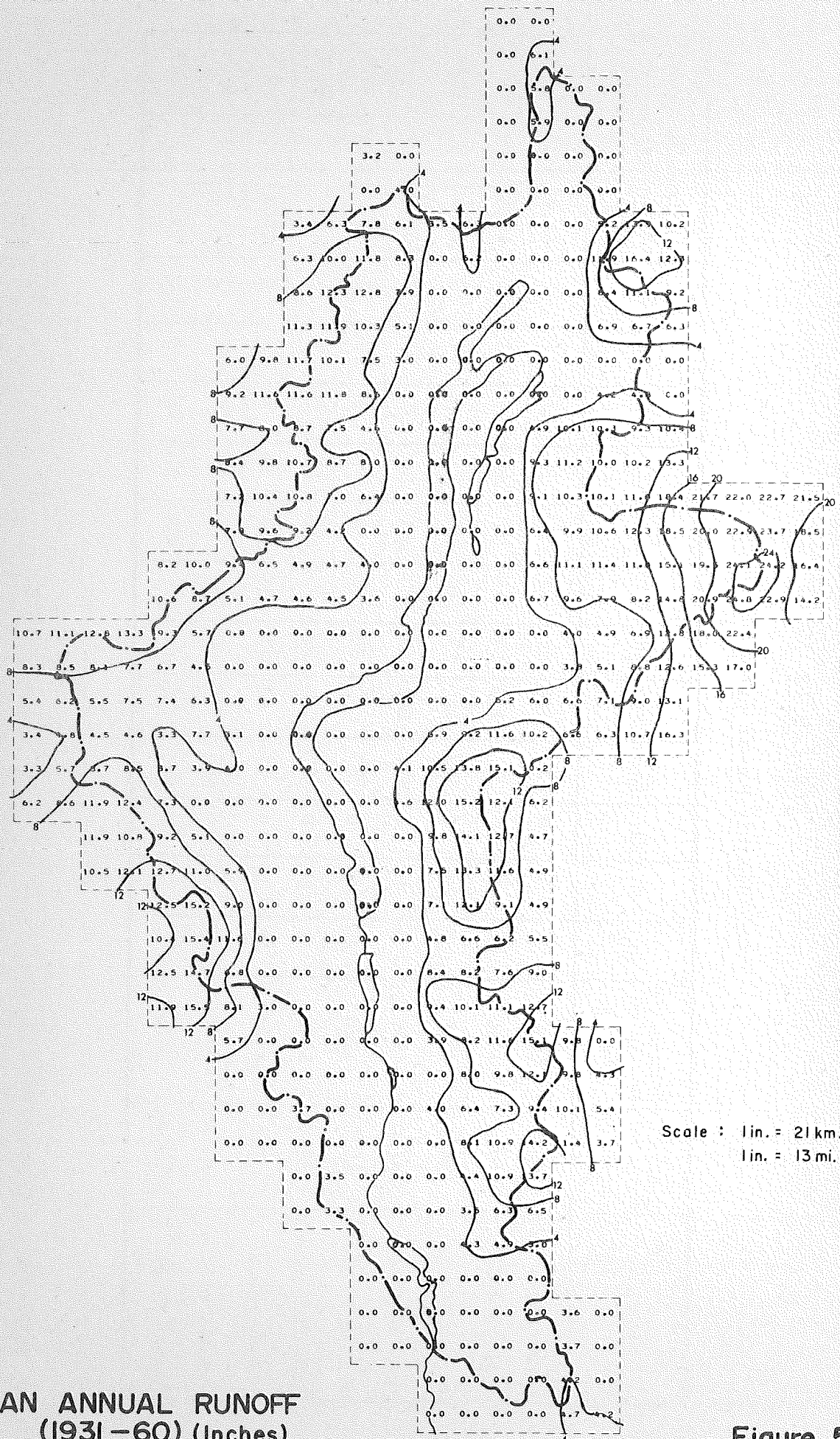
Figure 5.4



(Inches)

MEAN ANNUAL ACTUAL EVAPOTRANSPIRATION (1931-60)

Figure 5.5



Scale : 1 in. = 21 km.
1 in. = 13 mi.

MEAN ANNUAL RUNOFF
(1931–60) (Inches)

Figure 5.6

TABLE 5.13

Mean Monthly Runoff (1931-60) in cfs

Sub-Basin	Area (sq.mi.)	Mean Basin Elevation (feet)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean Annual Runoff		
															(cfs)	(in.)	(KAF)*
Deep Creek	105.6	1880	0	0	0	20	48	37	18	9	4	2	1	0	11.6	1.5	8.4
Equesis Creek	77.3	4060	0	0	0	52	123	95	47	21	12	6	3	2	30.1	5.3	21.8
Kelowna Creek	84.1	3740	0	0	0	49	112	85	40	20	11	6	4	0	27.2	4.4	19.7
Mission Creek	341.0	4580	2	0	2	324	1005	762	370	184	96	53	25	9	236.0	9.4	171.0
Peachland Creek	55.5	4220	0	0	0	23	47	36	17	9	4	3	1	0	11.7	2.9	8.5
Penticton Creek	69.2	5240	0	0	0	67	208	159	77	38	19	9	5	3	48.8	9.6	35.4
Powers Creek	49.5	4300	0	0	0	27	61	47	23	11	6	4	1	0	15.0	4.1	10.9
Trout Creek	301.4	4600	0	0	0	185	473	360	174	88	43	22	12	2	113.2	5.1	82.0
Vernon Creek	289.8	3030	0	0	0	140	315	264	119	58	31	15	9	0	79.2	3.7	57.4

* Thousands of acre-feet.

5.4.6 Ten Kilometer Grid Square Analysis

A minor objective of this study was the comparison of the grid square method with two grid sizes, five and 10 kilometers to see if the finer grid would give more accurate representation of hydrologic estimates.

The ten-kilometer analysis was carried out on the Group N second run equations since Group N resulted in a more prolific study group and the second run equations were slightly better statistically. Except for one Group N equation, the five- and 10-kilometer equations were identical because the independent variables accepted into the stepwise regression were variables common to both five- and 10-kilometer meteorological station squares. The only different equation was for March precipitation:

$$P\ MAR = 0.654 + 0.0643E^2$$

with the following statistics:

F = 5% r = 0.742 s.e. = 0.31

The results of the run on the 10-kilometer grid square system are given in Table 5.14. This table is directly comparable to the second run Group N listing in Table 5.12. The results show that, contrary to the original hypothesis, the 10-kilometer system gives more accurate estimates than the five. This, however, is not entirely conclusive since both runs give relatively accurate water balances in this semi-arid region. The five-kilometer is the finer of the two estimates with four grid square estimates for each 10-kilometer square. This enables smaller sub-basins to be analyzed while satisfying the six square per basin criterion.

5.5 CONCLUSIONS

The application of the grid square method to the Okanagan River basin has resulted in the same degree of success as its application to other basins such as the South Thompson River basin. The method has been developed to simulate snowmelt and resultant runoff on a mean monthly basis. Reasonably accurate estimates were obtained without iteration in spite of the complex nature of the Okanagan basin.

The main computer program accepts input from multiple regression equations which relate temperature and precipitation data to physiographic data of grid squares centered on meteorological stations. The program uses the Thornthwaite evaporation method to calculate evapotranspiration, and a water balance to determine runoff for each square. This water balance approach when used on a mean annual basis minimizes natural inconsistencies (e.g., changes of surface and groundwater storages) especially when long time periods of study are used. The fact that the Okanagan region is semi-arid makes large runoff errors conceivable when a water balance approach is used on a first estimate basis but the mean monthly runoff results obtained appear to be very good. The development of this method to simulate drought and flood years would appear to be the next step.

TABLE 5.14

ESTIMATED 10 KM SUB-BASIN RUNOFF

Group N (1931-60) Second Run

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 1 WITH AREA OF 2323.5 SQ.MI. AND AVERAGE ELEVATION OF 3597 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	15.9	20.1	27.5	38.1	46.7	52.2	57.4	55.4	49.0	39.3	27.3	22.0	37.6	°F	
B-PE	0.0	0.0	0.1	1.0	2.8	3.7	4.5	3.8	2.5	1.0	0.0	0.0	19.5	IN	
B-PREC	2.4	2.1	1.6	1.3	2.0	2.3	1.5	1.4	1.5	1.8	2.0	2.5	22.3	IN	
B-MELT	0.0	0.0	0.8	4.5	3.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.2	IN	
B-SORC	0.0	0.0	1.0	5.5	5.7	2.5	1.5	1.4	1.5	1.8	0.3	0.0	21.2	IN	
B-AE	0.0	0.0	0.0	1.0	2.7	3.5	3.6	2.7	1.8	1.1	0.0	0.0	16.6	IN	
F.D. B-R	0.1	0.1	0.1	0.5	1.7	1.3	0.5	0.1	-0.0	-0.0	0.1	0.1	4.6	IN OR	783.6 CFS
W.B. B-R	0.0	0.0	0.0	0.4	1.8	1.3	0.6	0.3	0.2	0.1	0.0	0.0	4.8	IN OR	819.0 CFS
TRUE B-R	-0.0	0.0	0.2	0.6	1.8	1.1	0.4	0.3	0.1	0.1	0.0	0.0	4.8	IN OR	820.0 CFS
T M B-R%	-0.2	0.7	3.2	13.2	37.9	23.8	9.4	5.7	3.1	2.1	0.7	0.3	100.0	%	
F.D.BR%E	-786.7	98.3	-7.1	-24.9	-4.8	13.5	18.5	-53.9	-130.2	-105.0	150.4	475.5	-4.4	%	
W.B.BR%E	-196.4	-83.0	-98.2	-32.5	-1.5	12.0	42.1	16.6	6.9	-13.5	28.5	32.2	-0.1	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 2 WITH AREA OF 286.9 SQ.MI. AND AVERAGE ELEVATION OF 3769 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	15.3	20.7	28.1	38.3	46.9	52.3	57.9	56.1	49.9	40.0	26.6	21.4	37.8	°F	
B-PE	0.0	0.0	0.0	1.1	2.8	3.7	4.5	3.9	2.6	1.1	0.0	0.0	19.7	IN	
B-PREC	2.1	1.9	1.6	1.4	1.9	2.2	1.4	1.3	1.3	1.6	1.9	2.1	20.6	IN	
B-MELT	0.0	0.0	0.6	5.2	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	IN	
B-SORC	0.0	0.0	1.0	6.6	4.9	2.2	1.4	1.3	1.3	1.6	0.0	0.0	20.1	IN	
B-AE	0.0	0.0	0.0	1.1	2.7	3.5	3.5	2.6	1.7	1.1	0.0	0.0	16.3	IN	
F.D. B-R	-0.0	-0.0	0.1	0.5	1.8	1.2	0.5	0.1	-0.1	-0.1	-0.0	-0.0	3.9	IN OR	81.7 CFS
W.B. B-R	0.0	0.0	0.0	0.4	1.7	0.9	0.5	0.2	0.1	0.1	0.0	0.0	3.9	IN OR	82.3 CFS
TRUE B-R	0.0	0.0	0.1	0.3	1.0	0.6	0.3	0.1	0.0	0.0	0.0	0.0	2.6	IN OR	55.1 CFS
T M B-R%	1.0	1.3	3.6	12.3	37.2	24.5	11.0	5.1	1.8	0.5	0.8	0.8	100.0	%	
F.D.BR%E	-163.3	-143.1	-21.5	55.3	85.1	91.9	63.3	-47.2	-313.7	-715.6	-224.0	-194.6	48.2	%	
W.B.BR%E	-73.3	-88.9	-98.1	22.2	70.3	45.2	62.0	74.8	144.4	319.6	38.0	-34.6	49.4	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 3 WITH AREA OF 317.8 SQ.MI. AND AVERAGE ELEVATION OF 3749 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	15.3	21.1	28.6	38.8	47.3	52.7	58.5	56.7	50.4	40.4	26.7	21.9	38.2	°F	
B-PE	0.0	0.0	0.1	1.1	2.8	3.7	4.6	3.9	2.6	1.1	0.0	0.0	19.9	IN	
B-PREC	2.1	1.8	1.6	1.5	1.9	2.3	1.3	1.2	1.2	1.6	1.8	2.0	20.5	IN	
B-MELT	0.0	0.0	1.1	4.2	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	IN	
B-SORC	0.0	0.0	1.4	5.2	5.8	2.3	1.3	1.2	1.2	1.6	0.2	0.0	20.4	IN	
B-AE	0.0	0.0	0.1	0.9	2.6	3.3	3.4	2.5	1.7	1.1	0.0	0.0	15.5	IN	
F.D. B-R	0.1	0.1	0.2	0.5	1.8	1.4	0.6	0.2	-0.0	0.0	0.1	0.1	4.8	IN OR	112.4 CFS
W.B. B-R	0.0	0.0	0.0	0.5	1.7	1.3	0.6	0.3	0.2	0.1	0.0	0.0	4.7	IN OR	110.3 CFS
TRUE B-R	0.1	0.1	0.1	0.3	1.1	0.9	0.5	0.4	0.3	0.1	0.1	0.1	4.2	IN OR	97.4 CFS
T M B-R%	2.5	2.0	3.0	7.6	26.8	21.1	11.6	9.2	7.8	3.1	2.9	2.3	100.0	%	
F.D.BR%E	-38.7	-36.6	28.5	54.3	58.6	55.7	22.1	-54.5	-103.7	-99.2	-41.6	-21.0	15.4	%	
W.B.BR%E	-90.4	-93.9	-98.0	45.8	53.0	44.8	32.2	-17.3	-51.2	-37.6	-67.6	-79.7	13.2	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 4 WITH AREA OF 261.3 SQ.MI. AND AVERAGE ELEVATION OF 3258 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	17.1	23.2	31.0	41.4	49.8	55.2	61.4	59.3	52.8	42.4	28.5	22.0	40.3	°F	
B-PE	0.0	0.0	0.1	1.4	3.0	3.9	4.8	4.1	2.7	1.2	0.0	0.0	21.3	IN	
B-PREC	1.7	1.4	1.4	1.2	1.7	2.3	1.1	1.1	1.1	1.5	1.5	1.6	17.6	IN	
B-MELT	0.0	0.0	1.1	5.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	IN	
B-SORC	0.0	0.0	1.6	6.4	2.4	2.3	1.1	1.1	1.1	1.5	0.3	0.0	17.7	IN	
B-AE	0.0	0.0	0.1	1.3	2.8	3.5	3.4	2.3	1.5	1.2	0.0	0.0	16.1	IN	
F.D. B-R	-0.1	-0.1	0.1	0.5	1.4	0.7	0.1	-0.2	-0.3	-0.3	-0.2	-0.1	1.6	IN OR	30.2 CFS
W.B. B-R	0.0	0.0	0.0	0.3	0.6	0.3	0.1	0.1	0.0	0.0	0.0	0.0	1.5	IN OR	28.1 CFS
TRUE B-R	0.1	0.1	0.1	0.3	1.0	0.7	0.4	0.3	0.3	0.1	0.1	0.1	3.6	IN OR	69.0 CFS
T M B-R%	2.5	1.9	3.0	7.5	26.5	20.8	11.4	9.1	7.7	4.2	2.9	2.3	100.0	%	
F.D.BR%E	-210.7	-215.2	-34.1	88.0	50.7	-3.3	-66.6	-164.3	-218.0	-291.0	-274.2	-243.4	-56.3	%	
W.B.BR%E	-97.4	-98.3	-99.5	13.0	-41.6	-59.9	-63.4	-77.1	-86.4	-87.5	-91.0	-98.4	-59.3	%	

AVERAGE BASIN ESTIMATES FOR SUB-BASIN 5 WITH AREA OF 3189.5 SQ.MI. AND AVERAGE ELEVATION OF 3600 FT.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR		
B-TEMP	15.9	20.5	28.0	38.4	47.1	52.5	57.9	55.9	49.6	39.7	27.2	21.9	37.9	°F	
B-PE	0.0	0.0	0.1	1.1	2.8	3.7	4.5	3.9	2.5	1.1	0.0	0.0	19.7	IN	
B-PREC	2.3	2.0	1.6	1.3	1.9	2.3	1.4	1.4	1.4	1.7	1.9	2.4	21.5	IN	
B-MELT	0.0	0.0	0.9	4.6	3.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.0	IN	
B-SORC	0.0	0.0	1.1	5.6	5.4	2.4	1.4	1.4	1.4	1.7	0.3	0.0	20.7	IN	
B-AE	0.0	0.0	0.0	1.0	2.7	3.5	3.6	2.6	1.8	1.1	0.0	0.0	15.8	IN	
F.D. B-R	0.1	0.0	0.1	0.5	1.7	1.2	0.5	0.1	-0.1	-0.0	0.1	0.1	4.3	IN OR	1007.8 CFS
W.B. B-R	0.0	0.0	0.0	0.4	1.7	1.2	0.6	0.3	0.1	0.1	0.0	0.0	4.4	IN OR	1039.7 CFS
TRUE B-R	0.0	0.0	0.1	0.5	1.6	1.0	0.4	0.3	0.2	0.1	0.1	0.0	4.6	IN OR	1041.5 CFS
T M B-R%	0.4	1.0	3.2	12.1	35.8	23.4	9.9	6.3	3.8	2.3	1.1	0.8	100.0	%	
F.D.BR%E	231.4	3.9	-6.8	-10.3	8.1	20.6	13.8	-64.7	-141.0	-134.7	5.2	97.4	-3.2	%	
W.B.BR%E	-39.4	-88.4	-98.3	-22.2	5.1	12.5	32.6	4.5	-14.5	-20.6	-21.0	-41.0	-0.2	%	

CHAPTER 6

Precipitation and Evapotranspiration Models By The Atmospheric Environment Service

6.1 INTRODUCTION

The spatial distribution of precipitation in the Okanagan valley depends to a considerable extent on the topography and orographic features of the region. The considerable difference between the valley bottom and mountain top precipitation and the scarcity of observations in the higher regions of the valley suggested the need for models to estimate precipitation at ungauged points. The data from the newly established high level meteorologic stations (see Technical Supplement No. I) with very short records were utilised in a model which using standard stepwise regression techniques, produced equations relating mean monthly and mean annual precipitation to certain topographic features. The selected precipitation model differed from that described in the previous chapter in that no snow course data were used but the data from the new stations installed for the Okanagan Study were incorporated. Techniques for mapping isohyetal lines using computer interpolation and smoothing techniques enabled mean precipitation to be estimated for any grid square or point in the valley. The same smoothing techniques were also used to produce estimates of the deviation of monthly precipitation from the mean for each month in 1971 for each grid square in the valley.

A second problem examined was that of the variation of evapotranspiration over the Okanagan watershed. Details of land cover were added to the complexities of topography in developing models. Mean lake evaporation based upon Class A evaporation pan data was used as an intermediate field in the development of mean actual evapotranspiration values.

The following sections outline the development of the precipitation and evapotranspiration models and their melding to fit the water balance of the area. Methods of adjusting rainfall and snowfall gauge undercatch factors as well as the rate of decrease of lake evaporation with elevation to achieve optimum water balance results are explained.

6.2 THE PRECIPITATION MODEL (OKAGN6)

6.2.1 Preliminary Modelling

A grid square system developed by the B.C. Water Resources Service, Water Investigation Branch, was adopted for use with the regression analysis. This grid system consists of 500 grid squares of 5.0 km per side, overlapping the entire Okanagan Basin. The system has a specific numbering scheme and position

as derived from the standard 10 km military grid shown on the Federal Government 1:250,000 scale map series. Twelve physiographic parameters were extracted by BCWRS for 85 observing stations, 70 snow courses, and the 500 grid squares. These parameters include:

CX = longitude index (km)
LAT = latitude index (km)
EL = average elevation (feet)
HS = average land slope by Horton's method (feet/mile)
SS = average land slope by Plane Fitting method (feet/mile)
AZSS = average azimuth of slope by Plane Fitting method (radians)
DB1 = distance to barrier (km)) at 251.6° measured from true north
BH1 = barrier height (feet)) at longitude 119°30'
SE1 = shield effect (feet))
DB2 = distance to barrier (km)) at 236° measured from true north
BH2 = barrier height (feet)) at longitude 119°30'
SE2 = shield effect (feet))

With these grid square parameters as independent variables, several sets of dependent precipitation normals were utilized for development of a series of basin precipitation models (OKAGN1 - OKAGN6) leading to the selection of OKAGN6 as the best model at the current stage of development. Each developmental model was a function of the data set used in the regression analysis. Details are listed in brief below to permit some perspective regarding the choice involved in OKAGN6. Complete information on the observational network is available in Technical Supplement I.

(1) OKAGN1: This set consisted of 45 observing stations located in or near the Okanagan Basin. Precipitation normals for these stations are based on at least a 10-year period.

(2) OKAGN2: This set consisted of 72 stations which included those in OKAGN1 plus snow courses located in or near the Okanagan Basin. The snow course data consisted of average snowpack accumulation at March 1st. These averages were based on at least four years of record but not adjusted to correspond to the period of 1931-60.

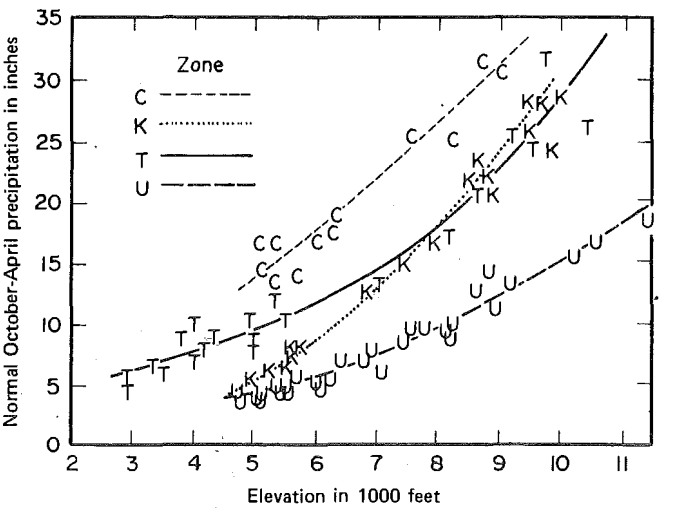
(3) OKAGN3: This set consisted of 29 observing stations located in or very near the Okanagan Basin. Twenty-five of these stations have precipitation normals based on a 25-30 year record.

(4) OKAGN4: This set consisted of 13 observing stations in the Okanagan Basin with at least 20 years of precipitation data within the period 1931-60. Independent variables were limited to the following six grid-square parameters: $(EL)^2$, SS, AZSS, $(DB)^2$, BH2, SE2.

(5) OKAGN5: This set included the 13 stations from OKAGN4 plus six snow courses within the Okanagan Basin. The six grid-square parameters used in OKAGN4 were used.

(6) OKAGN6: This set consisted of 24 long-term precipitation stations within or very near the Okanagan Basin plus an additional 31 short term stations similarly located whose data were adjusted to the 1931-60 normal period.

Regarding the relative merits of different kinds of data base, length of record is an important factor but it sacrifices better sampling of the terrain made possible by inclusion of shorter term stations. If one uses stations from outside the basin, variations in the precipitation distribution may occur and obscure the "true" relationships. This has been found by Peck and Brown (12), as illustrated in Figure 6.1 and by Dawdy and Langbein (13).



October-April precipitation-elevation relationship for various zones within the state of Utah, after Peck and Brown (11)

Figure 6.1

With regard to the inclusion of snow course data in precipitation models, the basic approach used in OKAGN2 and OKAGN5 was similar to that of Danard (5). Refinements were based on relationships between precipitation, temperature and snowpack at McCulloch. However snow course data were not used in OKAGN6.

An IBM package program called STEPR was utilized for the regression analysis. This subroutine selects independent variables in the order of their importance. The criterion for selection is based on the reduction of sums of squares,and the independent variable most important in this reduction in a given step is entered in the regression. A limit can be chosen so that when the proportion of the sum of squares attributable to an entering variable is less than this limit, the variable will not be entered. In the analysis, this limit was set to 0.01.

This subroutine outputs the mean, the standard deviation, and a correlation coefficient matrix for all variables. For each step of the regression, it gives the sum of squares reduced, proportion reduced, multiple correlation coefficient, F-value for analysis of variance standard error of estimate, regression coefficients, standard errors of regression coefficients, and computed t-values. A table of residuals is also available.

Multiple regressions were performed on the precipitation normals of the sets of observing stations against the twelve physiographic parameters mentioned earlier as the independent variables. Regression equations for total annual precipitation and total monthly precipitation were developed for each of the sets of observing stations.

6.2.2 Description of the Precipitation Model

The quality and representativeness of the data base used in regression analyses are all-important. In effect, the derived model equations are only as representative as the raw observations on which they have been used. Models OKAGN1 through OKAGN5 illustrate this point in that the continual search for measured or derived data representative of higher elevations is a connecting thread between them. The attempt to introduce snow course data into the data set of precipitation gauge measurements represents a fairly sophisticated effort in this direction. Ideally, however, an adequate distribution of gauge measurements of precipitation in space and by elevation zone would, by reason of internal consistency in observational technique, be expected to produce a superior data base. This rationale led to the development of the OKAGN6 model which is considered to be the best method at the present stage of development.

This model represents a further development of the physiographic-climatic regression approach to precipitation mapping. It has been made possible by the gradual acquisition of precipitation measurements from the high elevation climatic stations especially installed for the Okanagan Basin Study. Two additional refinements have been introduced in OKAGN6:

(a) the use of short-period (1971-72) measurements from high level stations to produce an internally consistent data set for regression analysis.

(b) the deliberate adjustment of measured and estimated precipitation figures in an attempt to take account of precipitation gauge undercatch. The actual methodology used in OKAGN6 may be summarized as follows:

(i) Records of measured precipitation during 1971-72 were tabulated for all long term and short term stations within and adjacent to the Okanagan basin. Missing values in individual station records were estimated by double mass curve analysis.

(ii) the 30-year mean annual precipitation was estimated for all short-term stations. The first step in this estimation procedure was to compute the ratio, R, for adjacent short-term and long-term stations where:

$$R = \frac{P_{ST}}{P_{LT}} \qquad (6.2.1)$$

and P_{ST} = the total measured precipitation at a short term station for the period of the record (1971-72)

P_{LT} = the total measured precipitation at an adjacent long-term station for the same period.

the 30-year mean annual precipitation at the short-term station was then estimated as:

$$\overline{P}_{ST} = \overline{R}\, P_{LT} \qquad (6.2.2)$$

where the overbar indicates the 30-year mean value.

(iii) The 30-year mean annual precipitation at short-period stations was broken down into monthly values by using double mass curve relationships (assumed linear) with adjacent long-term stations.

(iv) Regression analysis was performed on the complete (measured and estimated) data set of 30-year mean monthly values of precipitation. The regression equations obtained are listed in Table 6.1.

(v) Mean monthly values of grid square precipitation were obtained directly from the regresssion equations. These monthly values were summed to produce an annual mean map which was checked for consistency against a hand analysis of the annual precipitation totals of step 2. (Table 6.2).

(vi) Monthly precipitation values at each grid square were adjusted for undercatch using different assumed correction values for rain and snow. Discrimination between rain and snow was carried out on the basis of the simple assumption that if the mean monthly temperature was below 32°F, all precipitation for that month was snow.

The OKAGN6 model represents an attempt to develop precipitation regression equations from an internally consistent data set and to correct for undercatch in a rational manner. The exclusive use of gauge precipitation measurement is a natural consequence of the first objective. Incorporation of snow course data into the data set for regression analysis has not been attempted in OKAGN6.

The incorporation of information from the short-term network of gauges, installed specifically for this project, has resulted in a relatively good sampling of all the elevation zones within the Okanagan basin. Table 6.3 lists

TABLE 6.1

REGRESSION EQUATIONS FOR MEAN MONTHLY PRECIPITATION ON THE OKANAGAN BASIN - OKAGN 6 MODEL

MONTH	EQUATION	CORRELATION COEFFICIENT	STANDARD ERROR OF ESTIMATE
J	PM1 = 0.00034E - 0.00022 BH2 + 0.00384DB1 + 1.22773	.856	.411
F	PM2 = 0.00028E - 0.00015 BH2 + 0.00289DB2 + 0.86649	.850	.332
M	PM3 = 0.00023E + 0.00104 DB2 - 0.00012BH2 + 0.00006SE2 + 10.40628	.815	.287
A	PM4 = 0.00017E + 0.00008 SE1 - 0.00005BH2 + 0.13128	.813	.211
M	PM5 = 0.00026E + 0.00010 SE1 - 0.00011BH2 + 0.5128	.838	.287
J	PM6 = 0.0003E + 0.00332 DB2 + 0.00006SE1 - 0.00009BH2 + 10.47456	.838	.345
J	PM7 = 0.00022E + 0.0024 DB2 - 0.00009BH2 + 0.00005SE1 + 10.28572	.870	.221
A	PM8 = 0.00017E + 0.00474 DB2 - 0.00007BH2 + 0.18493	.774	.275
S	PM9 = 0.0002E + 0.00744 DB2 - 0.00006BH1 - 0.26782	.870	.237
O	PM10 = 0.00025E + 0.00676 DB2 - 0.00013BH2 + 0.00003SE2 + 10.00913	.897	.245
N	PM11 = 0.0003E - 0.00023 BH2 + 0.0030DB2 + 0.00009BH1 +10.96285	.861	.343
D	PM12 = 0.00037E - 0.00027 BH2 + 0.0059DB1 +1.16774	.874	.433

TABLE 6.2

MEAN ANNUAL PRECIPITATION BY ELEVATION BAND

Elevation Zone	Mean Annual Precipitation		
	Unadjusted OKAGN 6	Adjusted	
		RUC = 5% SUC = 20%	RUC = 7% SUC = 40%
2000	15.48	16.97	18.14
2-3000	18.25	20.27	21.97
3-4000	20.44	22.93	25.09
4-5000	23.22	26.07	28.55
5-6000	26.34	29.63	32.52
6000	29.07	32.87	36.25
TOTAL BASIN	21.35	23.88	26.06

TABLE 6.3

STATIONS USED FOR THE DEVELOPMENT OF REGRESSION EQUATIONS OF OKAGN 6 MODEL

	LONG TERM CLIMATIC STATIONS	STATION ELEVATION (feet)
1.	Salmon Arm	1660
2.	Salmon Arm 2	1300
3.	Westwold	2020
4.	Armstrong	1187
5.	Vernon	1383
6.	Vernon CSR	1582
7.	Okanagan Centre	1140
8.	Kelowna	1133
9.	Rutland Mission Creek	3000
10.	Kelowna CDA	1150
11.	Joe Rich Creek	2870
12.	Peachland Trepanier Creek	1800
13.	McCulloch	4100
14.	Adra	3289
15.	Osprey Lake	3606
16.	Chute Lake	3916
17.	Kirton	2900
18.	Summerland CDA	1491
19.	Carmi	4084
20.	Penticton A	1121
21.	Keremeos	1410
22.	Oliver	1000
23.	Oroville	920
24.	Hedley	1720

	SHORT TERM CLIMATIC STATIONS	STATION ELEVATION (feet)
1.	Enderby	1180
2.	Falkland Salmon River	1500
3.	Vernon Silver Star	5300
4.	Bouleau Lake	4500
5.	Lumby	1670
6.	Oyama	1300
7.	Esperon Creek	4600
8.	Winfield Wood Lake	1330
9.	Vernon Swalwell Lake	4450
10.	Winfield	1650
11.	White Rock Mountain Lodge	6000
12.	Postill Lake	4300
13.	Mission Creek	5850
14.	Peachland Brenda Mountain	4790
15.	Kelowna PCC	1134
16.	Okanagan Mission	1340
17.	Peachland	1250
18.	Trout Creek	4700
19.	New Penticton Res.	5100
20.	Naramata	1200
21.	Isintok Microwave	6300
22.	Arawana	1700
23.	Beaverdell	2520
24.	Apex Mountain Lodge	6200
25.	Okanagan Falls	1650
26.	Venner Meadows	4600
27.	Vaseux Creek	3800
28.	Oliver 2	997
29.	Mt. Kobau	6116
30.	Osoyoos	1025
31.	Osoyoos W	1030

the stations used in the regression analysis along with their elevations, and shows that a total of 55 stations were used in the development of regression equations for precipitation. If one assumes that the estimates of long-term mean precipitation at the special network stations are reasonable then the regression equations are based on a representative and adequately-sized sample of data. Since no consideration of gauge catch characteristics has been made up to this point, precipitation values calculated from the regression equations and based on measurements are biased on the low side.

During water balance investigations, it is desirable that the "true" precipitation field over a watershed be known. This requires that gauge measurements be adjusted for the effects of undercatch. The adjustment problem is a complex one involving factors such as the gauge exposure, the wind climatology of the site and the character of the precipitation. In particular, gauges display quite different responses to rain and snow.

Rodda (14,15) has summarized studies of the undercatch problem for rainfall. His works suggest that the undercatch by 1-foot high gauges may range from near zero to as high as 20% in windy and exposed areas. The majority of locations, however, experience a rainfall undercatch between 3 and 7%.

Snowfall measurement presents much more serious problems. In exposed areas, even shielded gauges may undercatch by more than 50%. Dyck (16) carried out studies on the treeless Canadian Prairies which indicated that a shielded Fischer-Porter gauge caught only 47% of the actual winter snowfall. Similar undercatches of monthly snowfall were noted by Ferguson and Storr(17) who studied Fischer-Porter, Nipher gauge, ruler and snow course measurements at a number of Canadian stations. Much earlier, Wilson (18) found a crude relationship between gauge catch deficiency and wind speed which suggested an undercatch of 20% at 5 mph rising to near 70% at 50 mph. Russian work, reported by Rodda (15), implies that annual precipitation in that country has been underestimated by 10 to 50% as a result of undercatch by gauges. Official climatological means of precipitation in the U.S.S.R. have been "corrected" to take account of undercatch. Clearly, extremely large errors in snowfall measurements are possible.

Using the undercatch values from the above studies as a guide, the OKAGN6 model was adjusted for rain and snow undercatch. Initial calculations using a rain undercatch (RUC) = 5% and snow undercatch (SUC) = 20% gave encouraging results. Subsequently, it was found that values of RUC = 7% and SUC = 40% provided better agreement with the observed run-off data. It should be stressed that these undercatch adjustments to the Okanagan data are oversimplified and experimental. Nevertheless, they are not inconsistent with undercatch studies and result in a model which fit water balance criteria reasonably well. A more detailed and sophisticated approach to the undercatch problem has not been

possible to date due to inadequacies in knowledge and lack of detailed wind information. Efforts will have to be made to improve undercatch estimates by examining instrumentation and exposure characteristics at individual sites.

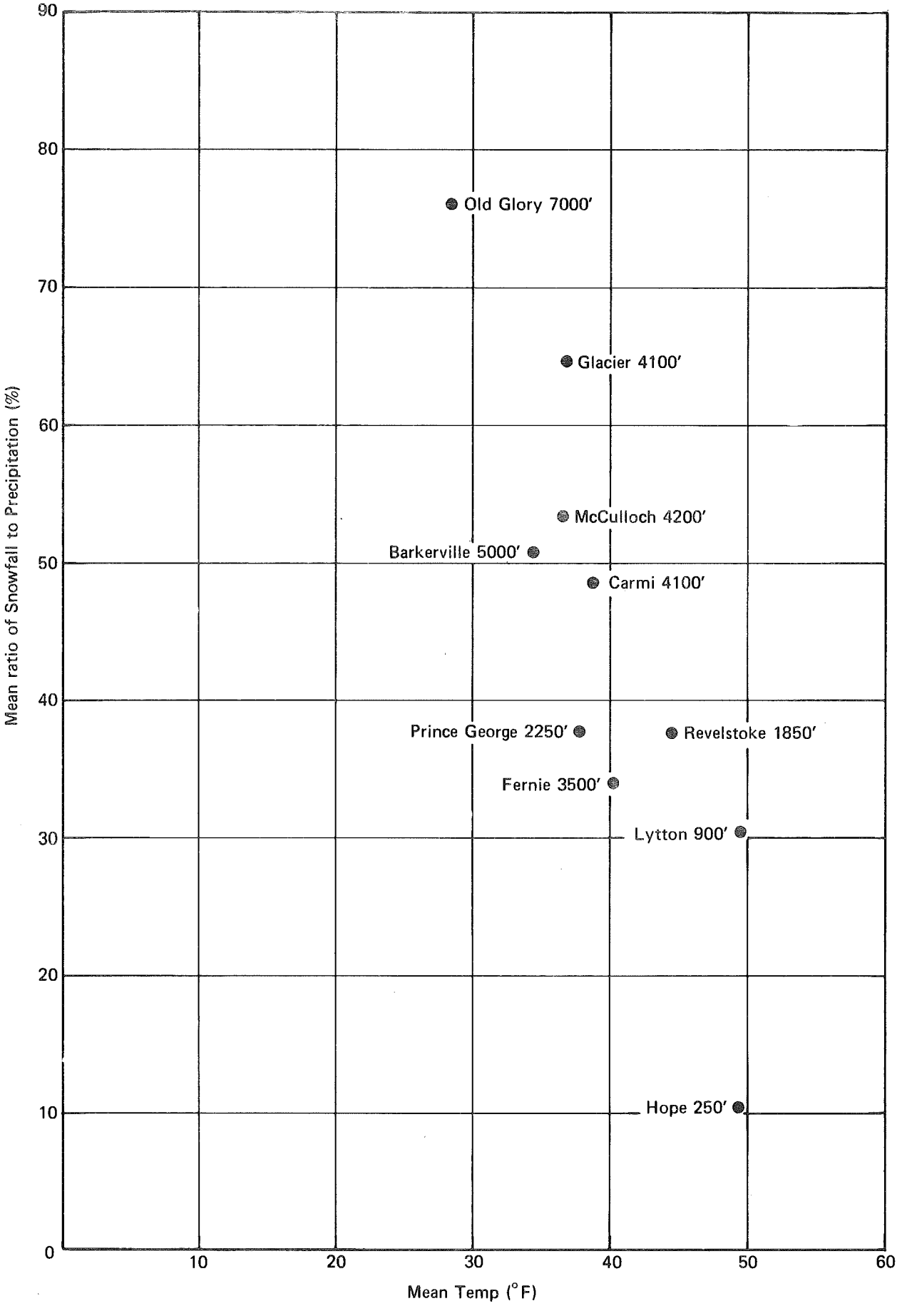
The use of a 32°F mean monthly temperature to discriminate between rain and snow introduces another possible source of error in the analysis. Figure 6.2 illustrates the relationship between mean monthly temperature and the ratio of snowfall to total precipitation as observed at a number of British Columbia stations. The figure indicates that a 32°F value, on the average, gives about a 70% probability that precipitation will be in the form of snow. This seems an acceptable level of uncertainty, particularly since the borderline cases are likely to arise only during transitional fall and spring months.

6.2.3 Data Processing and Presentation

It was desirable to obtain computer output from the regression models in a convenient graphical form. A subroutine called OKGRID was developed to accomplish this. This subroutine prints out a 50 x 27 rectangular grid system which is parallel to the standard 10 km military grid on the Federal Government 1:250,000 scale map series. Observing stations, snow courses, and the 500 grid squares were located on the co-ordinates of this grid system so that precipitation data and physiographic parameters could be plotted by computer and then analyzed by hand. The dimensions of the grid meshes are 1.01 cm in the west-east direction and 0.90 cm in the north-south direction. These grid meshes when representing 5.0 km grid squares gives an approximate map scale of 1:500,000.

Using the best regression equations developed by the STEPR subroutine, precipitation amounts were calculated by computer for each of the 500 grid squares. The precipitation values corresponding to each of these grid squares were printed out on the 50 x 27 grid system using the OKGRID subroutine. Isohyetal analyses were initially performed by hand. As a further refinement, however, a more sophisticated method was successfully applied to present the data in graphical form. An IBM package program called STAMPEDE was available and has been modified at AES Headquarters. This complex program can draw isolines of a given input field. In this function, the program overlaps the input data points with a square grid system. The grid size of this system is specified by the user. The program then interpolates and extrapolates the input data points to obtain values at each mesh point of its grid system. Using the data values at each mesh point, the program then prints out a map of isolines generated by bands of printer characters. The output map scale, the reference isoline character, and the isoline spacing are specified by the user.

Computer printer map displays of Okanagan isohyetal patterns were obtained from the regression equations and the STAMPEDE program.



RELATIONSHIP BETWEEN MEAN MONTHLY TEMPERATURE AND THE RATIO SNOWFALL TO TOTAL PRECIPITATION FOR SELECTED STATIONS IN BRITISH COLUMBIA.

Figure 6.2

6.2.4 Procedure for Mapping Monthly Precipitation

Convenient methods for processing input data and presenting output data have been made possible by use of the subroutines OKGRID and STAMPEDE. Input of current monthly data along with mean patterns produced by OKAGN6 results in output of a completely objective analysis of the monthly isohyetal patterns. By summation annual patterns may also be produced.

It would be expected that monthly mean precipitation would correlate more highly with physiographic variables than individual monthly data. This has been verified experimentally. Deviations from mean values for a given month tend to be distributed more randomly over the basin than the means themselves. The following steps were followed, therefore, in carrying out the analysis for a given month:

(1) A monthly mean precipitation map was obtained using the current adjusted regression model. Values were printed out for every grid square based on the appropriate regression equation and the assumed undercatch adjustments.

(2) A map of the deviations from the mean was obtained, based on adjusted station observations. Deviations converted to grid square values were obtained from the STAMPEDE interpolation and smoothing program.

(3) The required monthly map was then obtained by adding the two fields.

6.2.5 The Mean Annual Precipitation Pattern

Figure 6.3 shows the annual precipitation distribution over the Okanagan as determined by summing monthly values from the OKAGN6 regression equations. Figure 6.4 shows the same field with undercatch adjustments of RUC = 5% and SUC = 20%. Figure 6.5 shows the same field using RUC = 7% and SUC = 40%.

As might be expected, the adjusted fields are very similar in appearance to the unadjusted OKAGN6 field. The adjustment procedure for undercatch does, however, affect the relative distribution of precipitation between high and low elevations. Annual precipitation totals at the higher elevations have been adjusted upwards by a much greater amount than in the valley bottom as shown in Table 6.2. This uneven adjustment for undercatch reflects the greater significance of snowfall in the annual precipitation as elevation increases.

6.2.6 Mean Monthly Precipitation Pattern

Figures were prepared to show the mean monthly precipitation distributions, adjusted for undercatch, over the Okanagan basin as obtained from the OKAGN6 model (complete model output is available in Technical Supplement III). Figure 6.6 presents the mean January isohyets as an example of the mapped model output with undercatch factors of 7 per cent for rain and 40 per cent for snow.

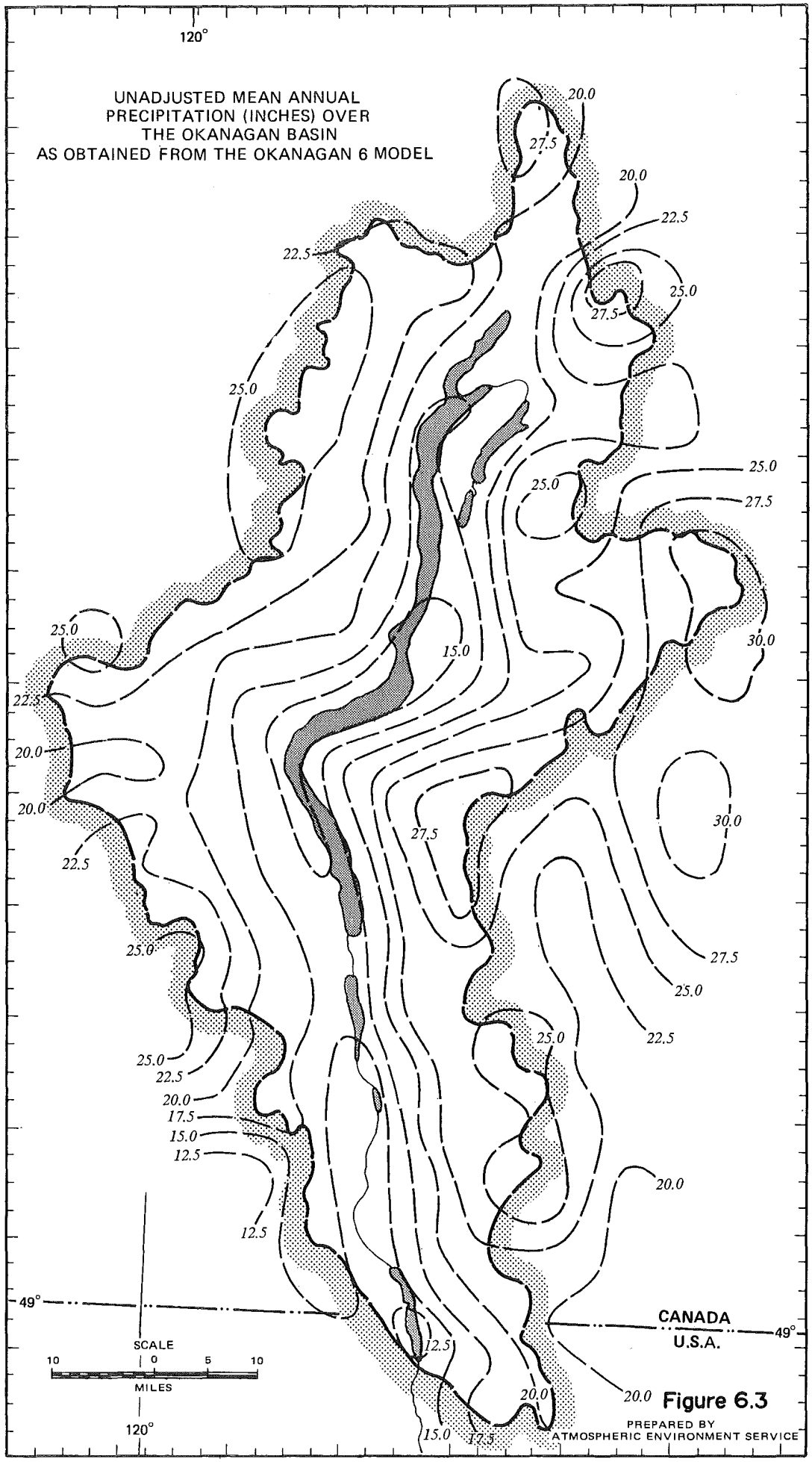


Figure 6.3

PREPARED BY
ATMOSPHERIC ENVIRONMENT SERVICE

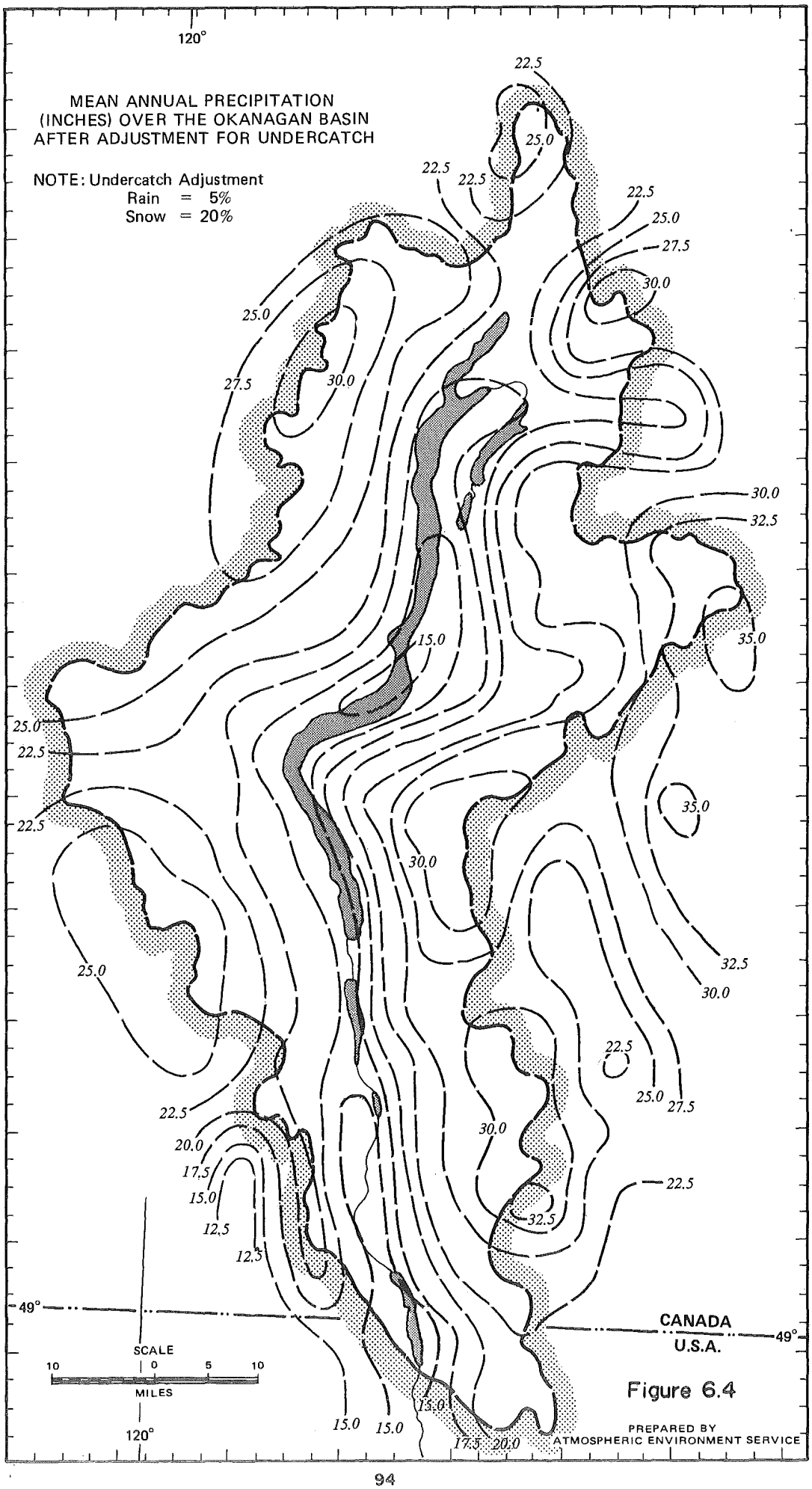


Figure 6.4

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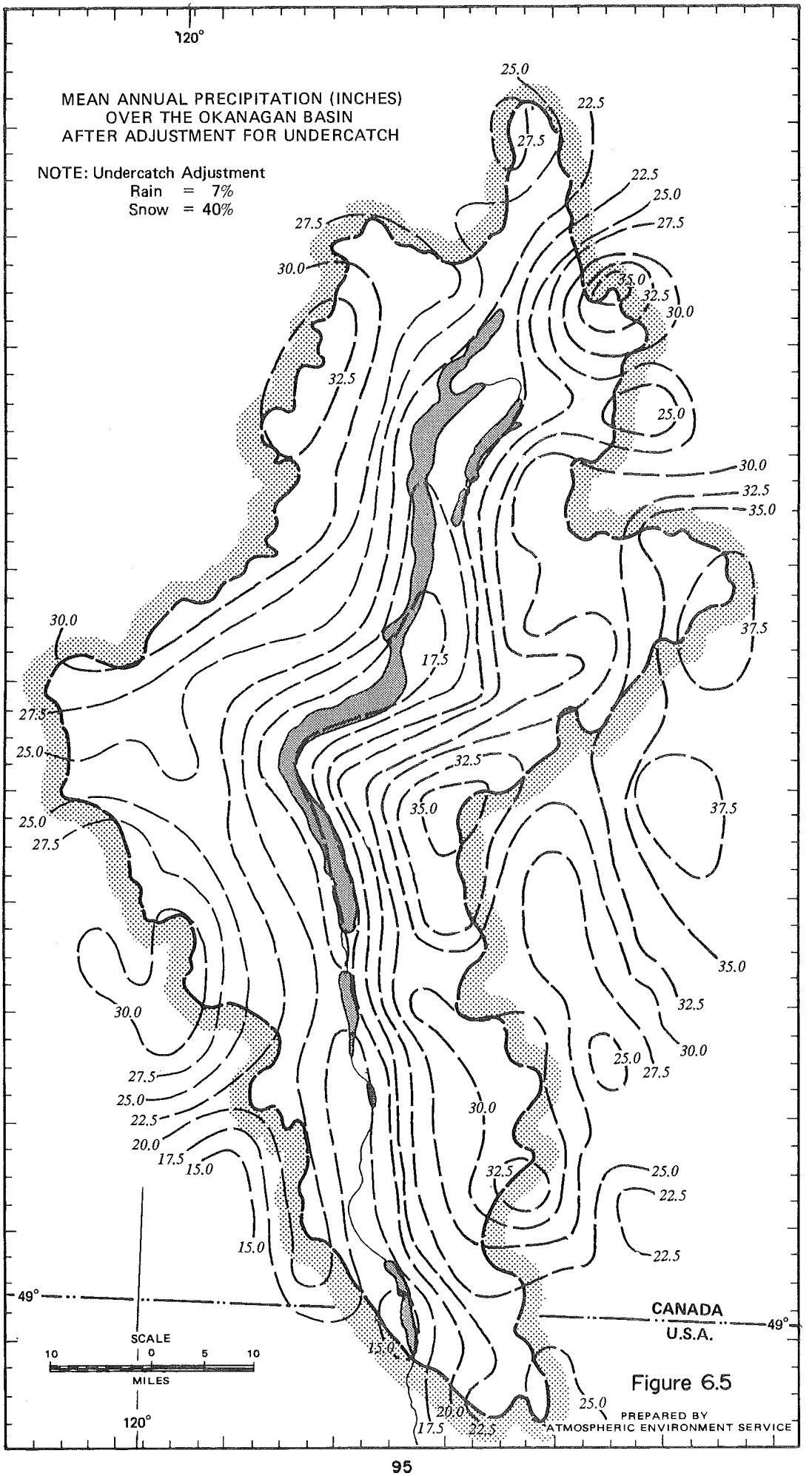

MEAN ANNUAL PRECIPITATION (INCHES)
OVER THE OKANAGAN BASIN
AFTER ADJUSTMENT FOR UNDERCATCH
NOTE: Undercatch Adjustment
Rain = 7%
Snow = 40%
120°
49°
CANADA
U.S.A.
SCALE
10 0 5 10
MILES
PREPARED BY
ATMOSPHERIC ENVIRONMENT SERVICE

Figure 6.5

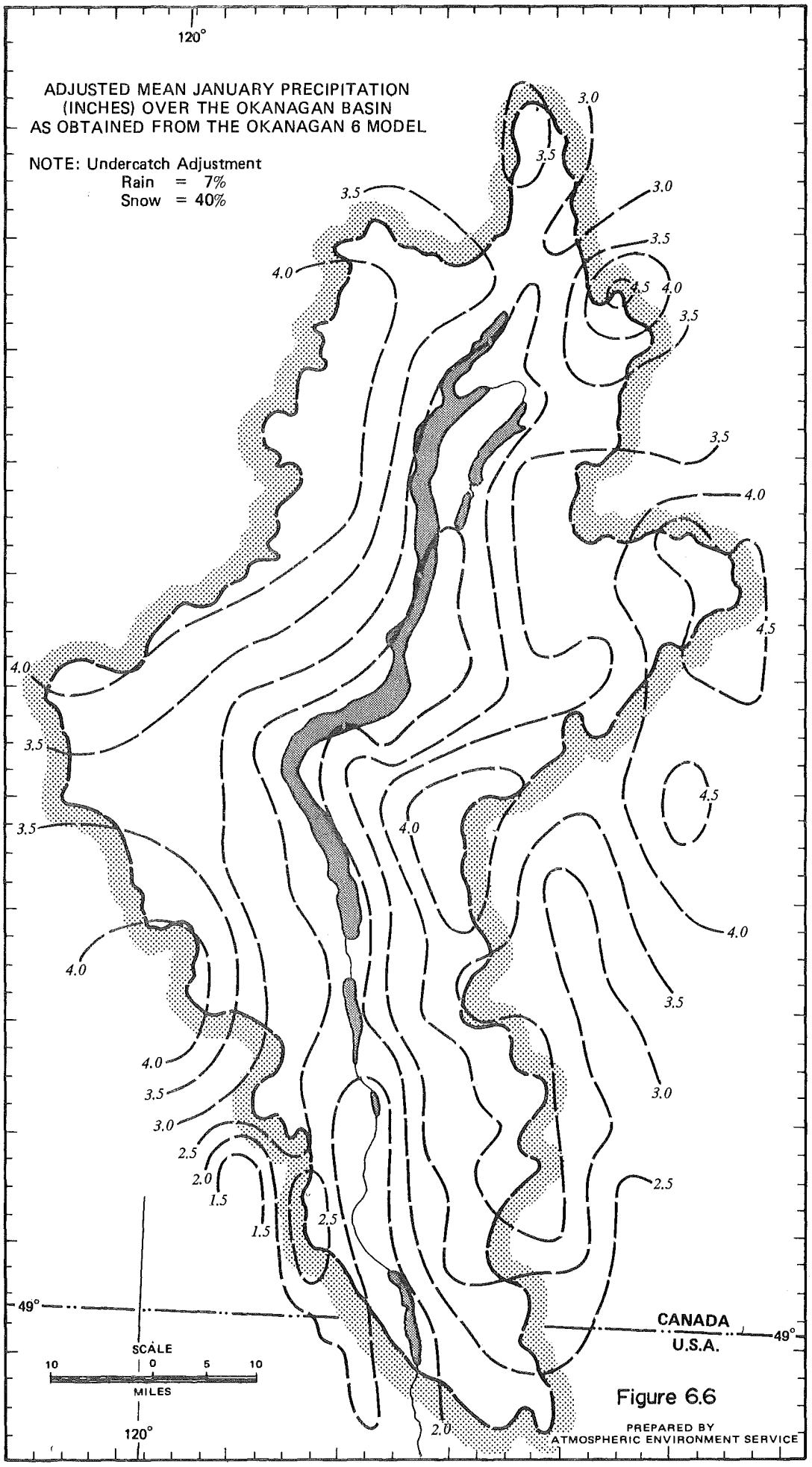


Figure 6.6

PREPARED BY
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As might be expected with a regression model based on topographic parameters, all of the monthly mean maps display a high degree of association between the precipitation patterns and the basin relief. In general, the smallest amount of precipitation occurs in the valley bottom with more or less well-defined maximum values being associated with the highest terrain. This pattern is particularly evident during months with relatively high precipitation, such as January and June.

6.2.7 Monthly and Annual Precipitation for 1971

Figures were prepared to display the monthly and annual precipitation fields for 1971, including adjustment for gauge undercatch of 7% for rain and 40% for snow. These were produced following the mapping of deviations from normal at measurement points, as described in 6.2.4 above. Figures 6.7 and 6.8 show the deviation from normal for January 1971 along with the resultant isohyetal map for that month. Figures 6.9 and 6.10 present similar fields for the 1971 calendar year.

As in the case of the mean monthly values, there is a reasonable degree of association between the map fields and the topography. Some offsets in peak precipitation from peak elevations are, however, evident for individual months. These apparent anomalies are, at least in part, due to the interpolation routine used to map the precipitation deviations. The STAMPEDE routine used for this latter operation carries out a linear interpolation procedure which ignores the effects of elevation on the deviation field. In addition to such computer induced effects, however, precipitation during an individual month (particularly a summer month) may be expected to display considerable variability in spatial pattern from year to year. At present, there would seem to be some merit in mapping the deviation fields by manual methods as a means of reducing the former influence. Alternatively an increased observation density would likely increase the validity of the STAMPEDE interpolation process.

6.3 THE EVAPOTRANSPIRATION MODEL

6.3.1 The Approach Used

Many methods are available for estimating evapotranspiration. Among the most popular and easiest to use are the Thornthwaite and Turc methods. Examination of the ways in which these empirical formulae were developed reveals that in both bases estimated evapotranspiration depends, implicitly or explicitly on precipitation. Considering the discussion of precipitation undercatch in the previous section, it is obvious that these techniques are generally biased and underestimate evaporation. Furthermore, such bias will be most pronounced in snowy climates, and will not be apparent when "verification" involves water balance estimates which use measured precipitation as an input. An additional

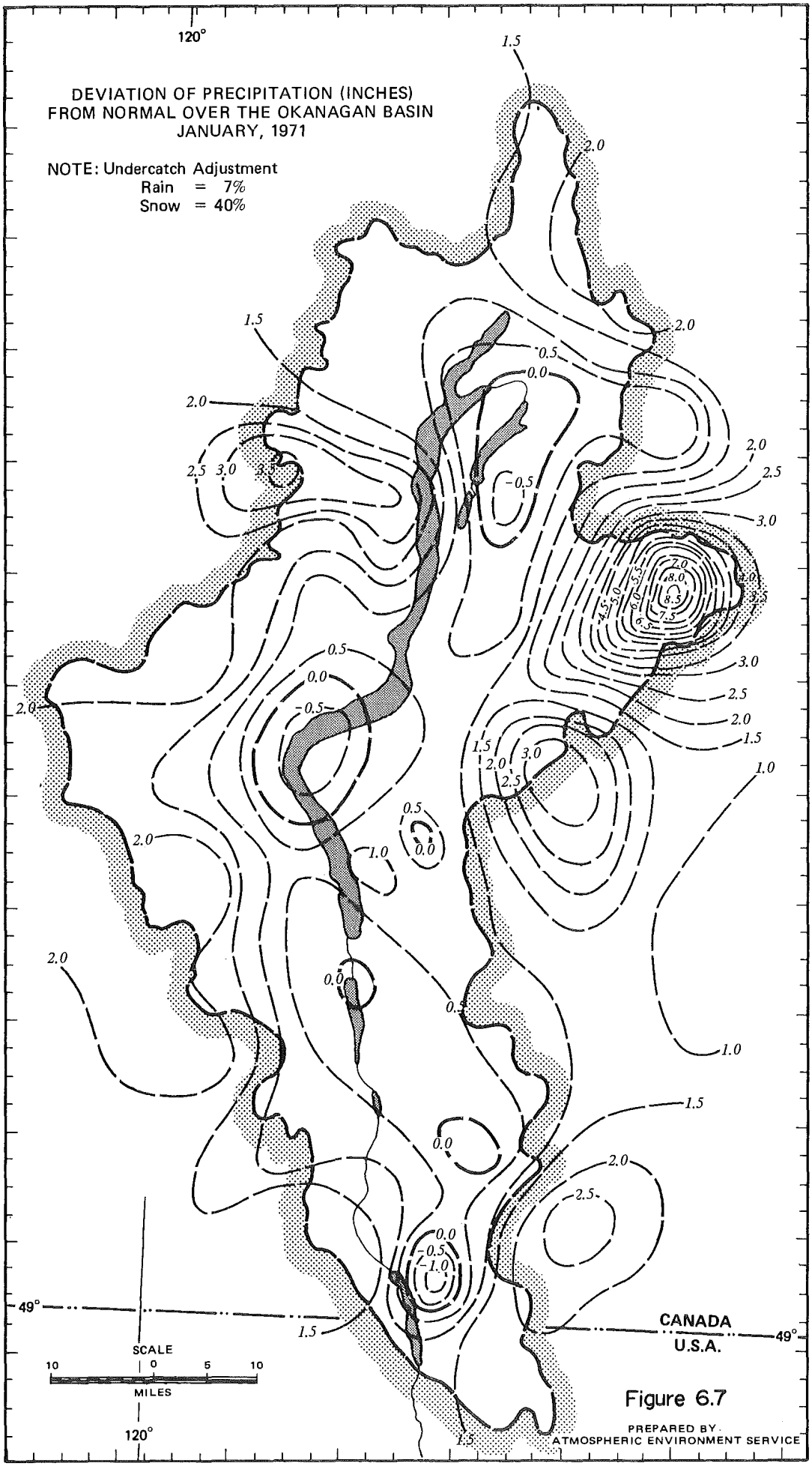

120°
DEVIATION OF PRECIPITATION (INCHES)
FROM NORMAL OVER THE OKANAGAN BASIN
JANUARY, 1971
NOTE: Undercatch Adjustment
Rain = 7%
Snow = 40%
49°
CANADA
U.S.A.
SCALE
10 0 5 10
MILES
120°
PREPARED BY
ATMOSPHERIC ENVIRONMENT SERVICE

Figure 6.7

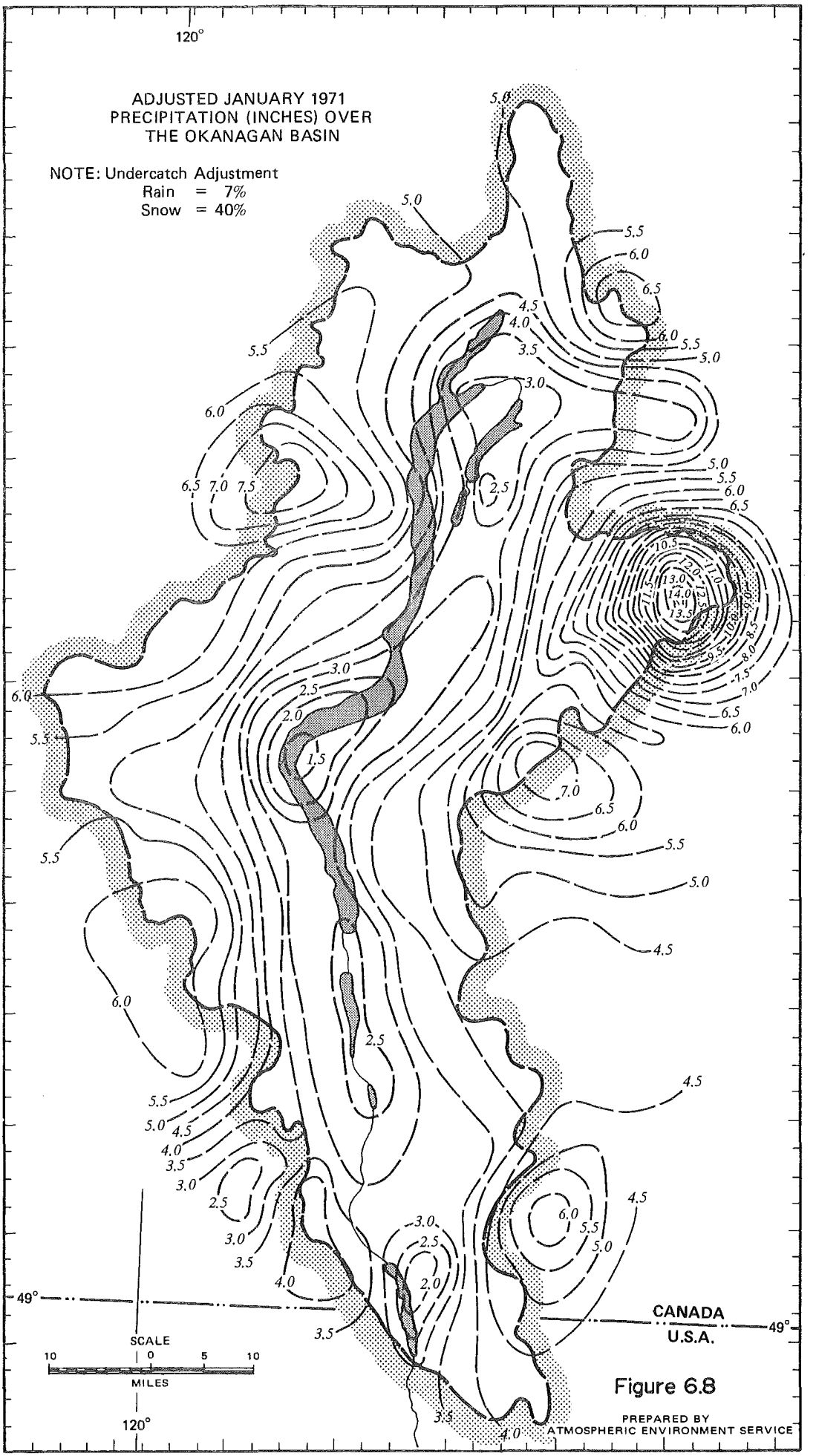
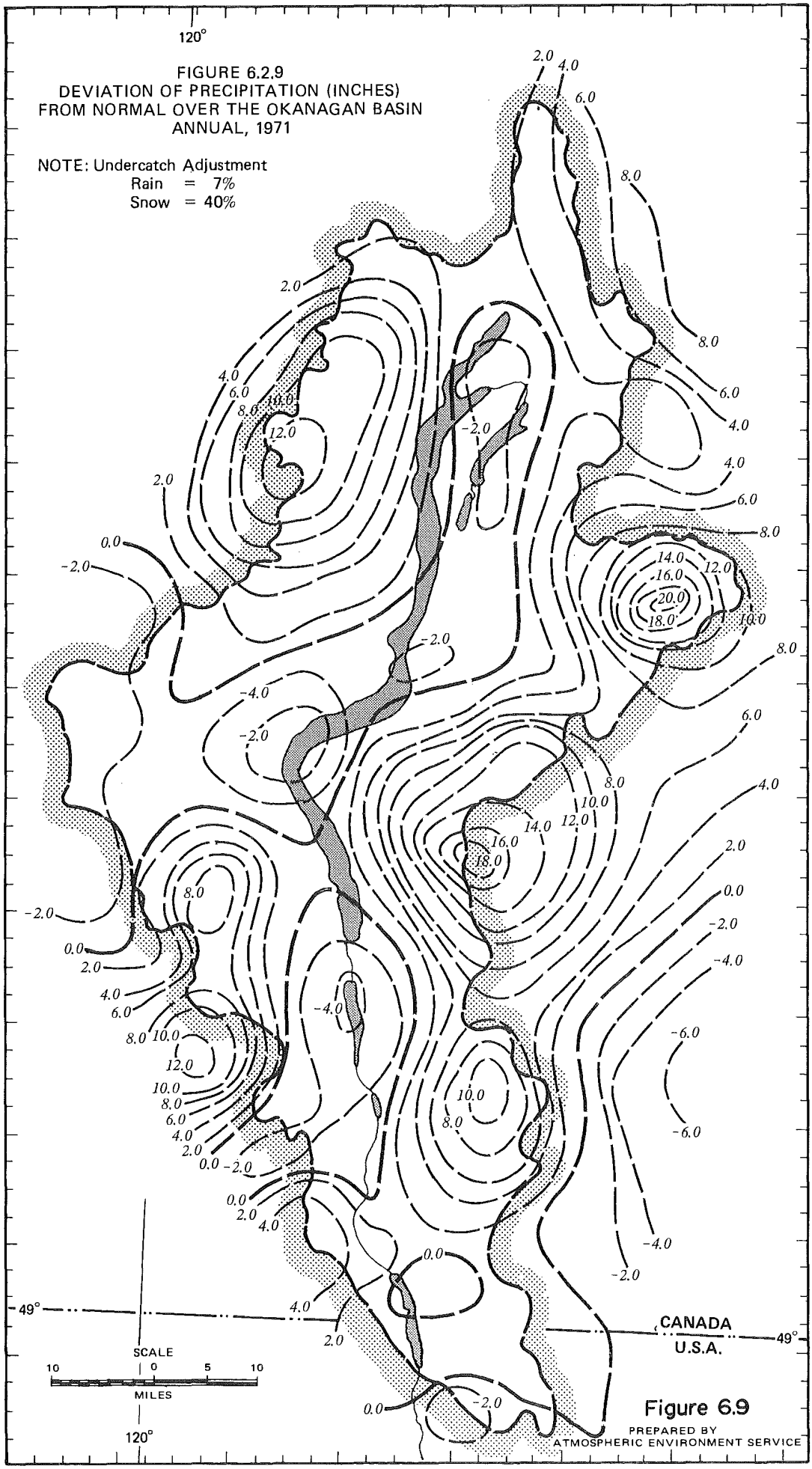

120°
ADJUSTED JANUARY 1971
PRECIPITATION (INCHES) OVER
THE OKANAGAN BASIN
NOTE: Undercatch Adjustment
Rain = 7%
Snow = 40%
49°
CANADA
U.S.A.
49°
SCALE
10 0 5 10
MILES
120°
PREPARED BY
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Figure 6.8


120°
FIGURE 6.2.9
DEVIATION OF PRECIPITATION (INCHES)
FROM NORMAL OVER THE OKANAGAN BASIN
ANNUAL, 1971
NOTE: Undercatch Adjustment
Rain = 7%
Snow = 40%
49°
CANADA
U.S.A.
49°
SCALE
10 0 5 10
MILES
120°
Figure 6.9
PREPARED BY
ATMOSPHERIC ENVIRONMENT SERVICE

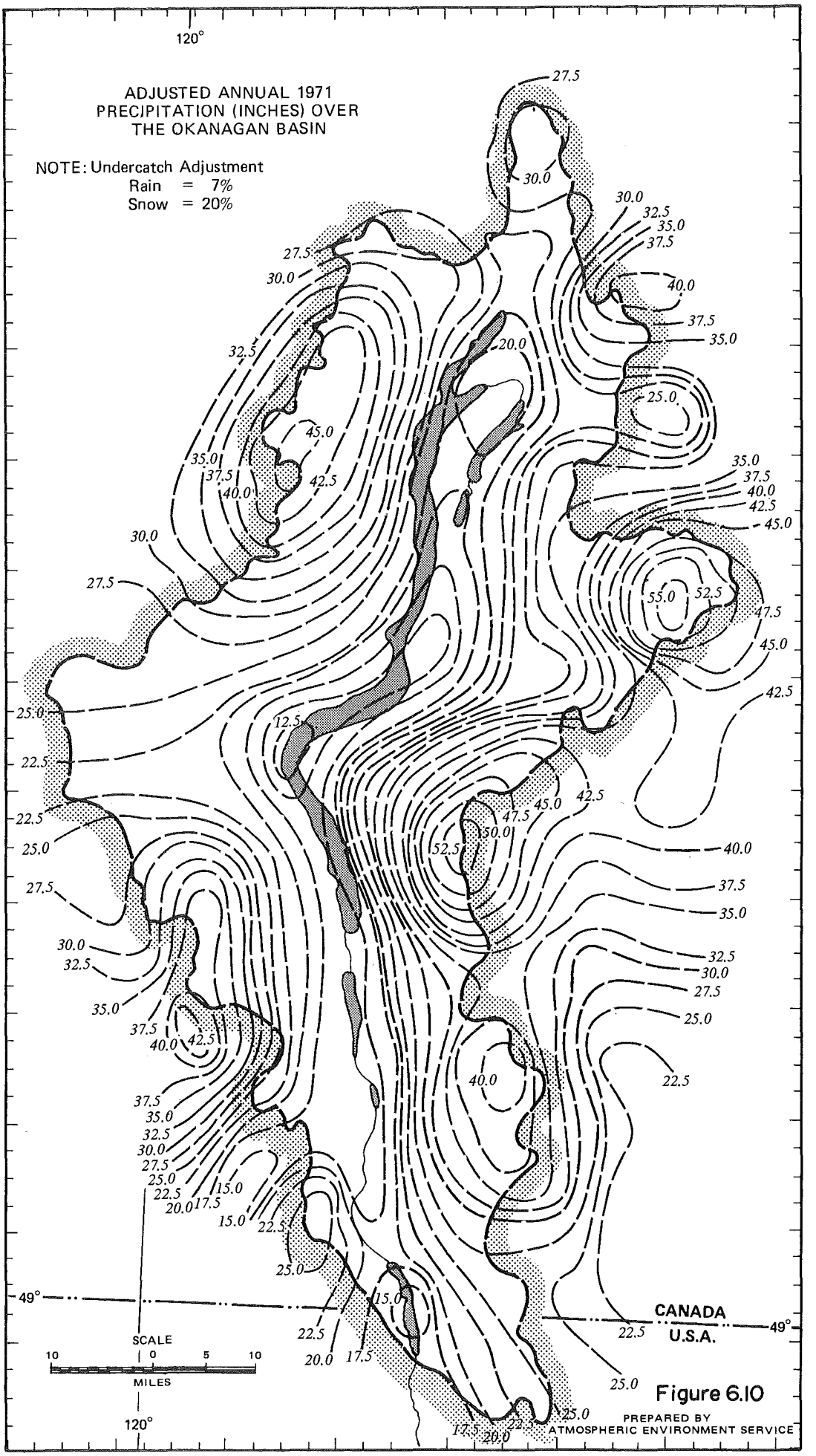

ADJUSTED ANNUAL 1971
PRECIPITATION (INCHES) OVER
THE OKANAGAN BASIN
NOTE: Undercatch Adjustment
Rain = 7%
Snow = 20%
120°
49°
CANADA
U.S.A.
SCALE
10 0 5 10
MILES
PREPARED BY
ATMOSPHERIC ENVIRONMENT SERVICE

Figure 6.10

problem involves the application of these "generalized" formulae to a particular region. For example, the simplified Turc method provides an estimate of annual evaporation based on precipitation and temperature. Turc's data were drawn from temperate humid climatic regions. Application to a region of pronounced continentality, such as the Okanagan (involving relatively cold winters and hot summers) provides another source of error - again contributing to an underestimate of evapotranspiration.

From a theoretical point of view the Penman equation and subsequent refinements of his "combination method" for estimating evapotranspiration have considerable appeal. Unfortunately, such equations involve a number of variables (such as albedo, wind and soil moisture) which may be very difficult to evaluate or transpose over regions of varying cover and elevation. As in the case of the Thornthwaite, Turc, Blaney and Criddle and other formulae, these equations are usually applied in a manner which takes insufficient account of relationships between cover types, soil moisture, depth of root zones and evapotranspiration.

The AES approach to modelling mean annual evapotranspiration was based on four principles:

(1) The model should be initially independent of precipitation
(2) The model should be related directly to observable cover characteristics
(3) The model should be related to measurements obtainable using the standard network method (i.e., Class A pan observations)
(4) The model should avoid dependence on a hypothetical "potential evapotranspiration", a term which is interpreted differently by different people.

It was realized that the latter stages of model development would involve an iterative water balance technique, so that the precipitation and evapotranspiration models would become interdependent. However, the approach followed here ensured a rational relationship between the model and features of cover which are available in detail and which are manifestations of environmental factors including the water balance, and also independently consistent with the physical principles of meteorology and with other environmental factors.

6.3.2 Variations of Evapotranspiration with Topography

The distribution of evapotranspiration over a region of varied topography is extremely complex. Inadequacies in physical understanding combined with a sparse data network limit our ability to model spatial variations even in potential evapotranspiration. When actual evapotranspiration is considered, the difficulties are further increased.

Scientific literature contains many references to the interrelationships between potential evapotranspiration, actual evapotranspiration, lake evaporation (referring to the actual evaporation from small shallow water bodies having negligible heat storage effect) and evaporation from larger lakes. Little work has been done, however, on the problem of evaluating the dependence of these variables on elevation and other topographical factors such as slope and aspect. It is to be expected that topographic factors influence evapotranspiration since they clearly affect related variables such as atmospheric pressure, temperature, vapour pressure, and radiation.

For the purpose of accurately evaluating the water balance over regions of strong relief, such as the Okanagan, an insight into the influence of topography on evapotranspiration as well as runoff and precipitation, must be sought.

One approach is to consider the many theoretical and empirical equations which have been suggested for determining evapotranspiration from vapour pressure, water temperature, wind, radiation, soil moisture and cover factors. Differentiating these equations with respect to elevation, could, in theory, produce the desired information. Unfortunately the variations of these independent variables with surface elevation are not very well-known. For example, wind generally increases with height in the free atmosphere but the variation of near-surface winds in mountainous terrain depends more on exposure than on surface elevation. It is, therefore, difficult to conceive of a satisfactory surface wind "model" which would have more than limited, local-scale applicability. Hare (19) has outlined some of the problems involved in the theoretical approach in a report prepared under contract with the AES. In his report, particular reference is made to the role of radiation in evapotranspiration and the general lack of information regarding variations in radiation fields over mountainous terrain. Studies of such problems are being carried out by the AES in Marmot Creek Basin, Alberta, and in the Okanagan ,but more observational data are needed in this and other mountainous locations.

Some success has been achieved in estimating evaporation from lakes (E_L) using mass transfer equations of the form:

$$E_L = f(U)\,(e_w - e_a) \qquad (6.3.1)$$

where f (U) is a function of wind speed and $(e_w - e_a)$ is the vapour pressure difference between the water surface and the air at some specified level above it and e_w is the saturation vapour pressure at the water surface temperature. On a monthly or seasonal basis, for small Canadian lakes, results are fairly consistent with estimates based on evaporation pan data or on the Penman Equation (20,21). In general equations of this type have been developed for locations at low elevations and their usefulness in mountainous areas is open to doubt.

A variation of eq. 6.3.1 eliminates the need for water surface temperature, using instead the saturation vapour pressure of the air e_s. The Meyer Equation is an example, being of the form

$$E_L = f(U)(e_s - e_a) \qquad (6.3.2)$$

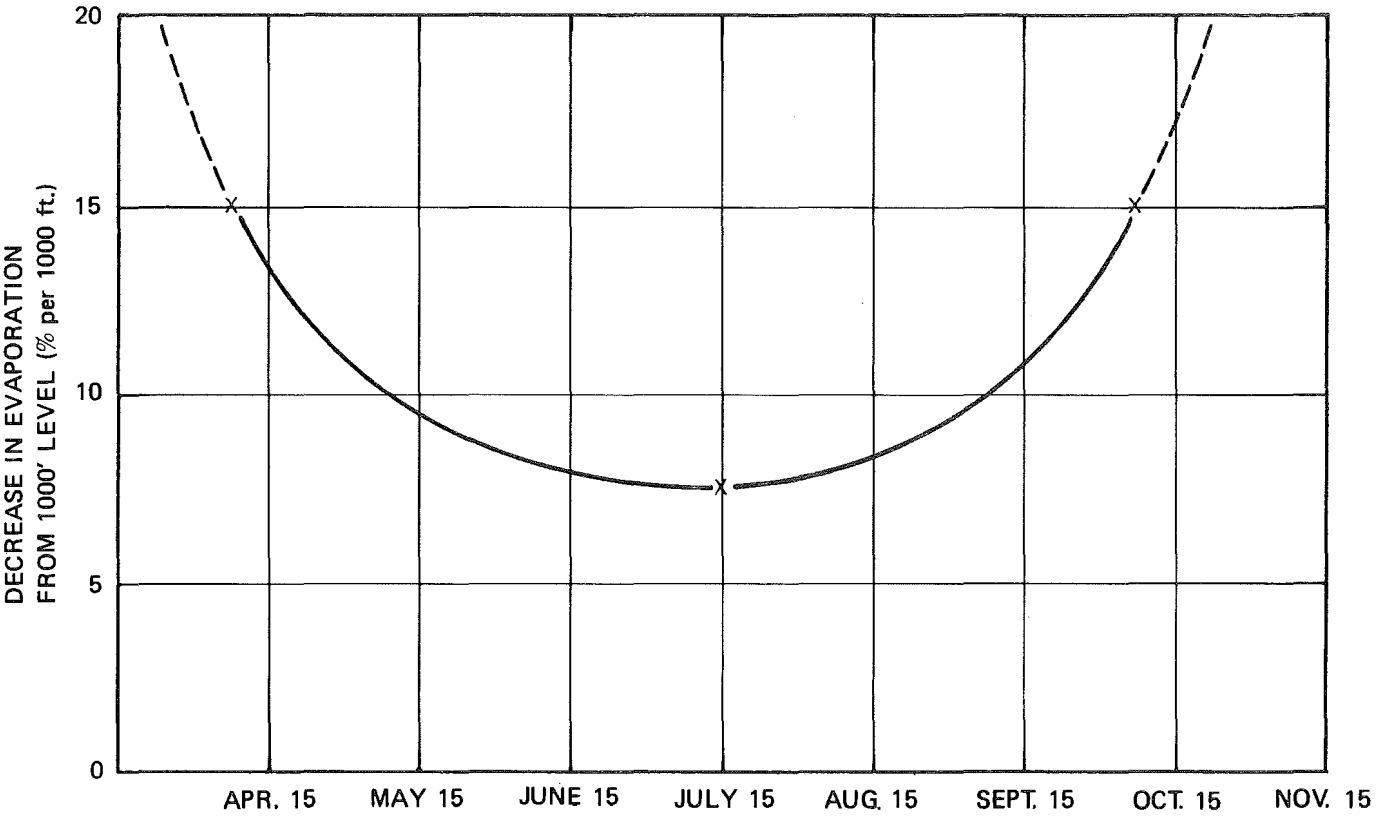
The right hand side of eq. 6.3.2 has been evaluated using climatological data for Penticton (1,120 feet) and Old Glory (7,700 feet) for July. Assuming a linear change in evaporation with elevation from a base level of 1,000 feet an average decrease of 7.8% per thousand feet was obtained. While eq. 6.3.2 should be valid through most of the evaporation season, it is apparent that evaporation from water surfaces will be negligible for a certain period between Fall and Spring. The "evaporation season" will be relatively long at low elevations and progressively shorter at higher elevations. The length of the season will be controlled mainly by mean air temperature. At Old Glory the mean daily air temperature is normally less than 25°F between the middle of October and the first few days in April. Assuming negligible evaporation under these conditions, an average decrease of about 15% per thousand feet from a base level of 1,000 feet would be required on April 7 and October 7. Figure 6.11 illustrates the decrease in evaporation with elevation indicated from a consideration of climatological means of atmospheric pressure, vapour deficit, and temperature at Penticton and Old Glory.

The United States Weather Bureau Class A Evaporation Pan is the standard network evaporation instrument in the United States and Canada. A correction factor is applied to pan data to obtain "lake evaporation". Climatological mean maps of lake evaporation for the United States and Canada have been prepared based on Class A Pan data (20,23). These national maps depict average conditions over larger areas and do not attempt to show small-scale variations in mountainous areas, where most of the data were collected at valley locations. In Canada, very few pan data are available for elevations above 3,500 feet. In the Okanagan Basin, elevations extend to over 6,000 feet.

Table 6.4 shows monthly lake evaporation, based on pan data, for six locations at varying elevations in Southern Alberta, for the years 1967 to 1970.

TABLE 6.4
MONTHLY LAKE EVAPORATION FROM CLASS A PAN DATA FOR SELECTED STATIONS IN SOUTHERN ALBERTA (inches)

	1967			1968			1969			1970		
	JUNE	JULY	AUG.	JUNE	JULY	AUG.	JUNE	JULY	AUG.	JUNE	JULY	AUG.
Vauxhall 2555' 50°03'N 112°08'W	5.52	8.14	6.63	5.48	6.69	5.20	5.16	6.89	8.17	7.05	7.05	7.35
Drumheller 2670' 51°25'N 112°41'W	-	-	-	-	-	-	6.40	5.98	7.41	M	M	8.15
Calgary 3540' 51°06'N 114°01'W	4.77	5.87	5.52	4.66	5.70	3.36	4.79	5.30	5.48	5.97	5.77	6.15
Kananaskis 4560' 51°02'N 115°03'W	4.49	6.17	4.95	M	4.79	3.45	3.46	4.77	5.87	M	M	M
Mt. Eisenhower 4675' 51°15'N 115°57'W	4.12	4.72	4.11	M	3.91	3.09	3.71	3.97	3.34	4.19	4.29	3.99
Marmot Creek 5750' 50°56'N 115°14'W	4.50	6.94	5.61	4.43	5.71	3.58	4.04	4.63	5.83	5.18	5.95	5.86



DECREASE IN EVAPORATION WITH ELEVATION IMPLIED BY MEAN ATMOSPHERIC PRESSURES, VAPOUR PRESSURES AND TEMPERATURES AT PENTICTON AND OLD GLORY, B.C.

Figure 6.11

Only June, July and August data are shown since few other complete monthly totals are available at higher elevations due to the formation of ice in pans. A general decrease in evaporation with elevation is evident, but it is difficult to assess quantitatively due to other influences. Vauxhall is sufficiently farther south than the other locations to raise the possibility of a significant latitudinal effect. In many mountain areas it is impossible to find "standard exposure" sites which are completely free of shadow effects from surrounding terrain and/or forest cover. The influence of these factors on pan evaporation varies from one location to another, and seasonally. They may completely mask variations due to elevation. A comparison of data for Kananaskis and Marmot Creek illustrates the point. These stations are only about 7 miles apart. Considering all data in Table 6.4 an average percentage decrease in lake evaporation with elevation of the order of 5 to 10% per thousand feet (from a base level of 1,000 feet) appears reasonable.

In the Okanagan Basin a few months of pan observations were made at Mount Kobau in 1967 and 1968. These are compared to simultaneous observations at Summerland in Table 6.5. Assuming for simplicity a linear decrease of evaporation

TABLE 6.5

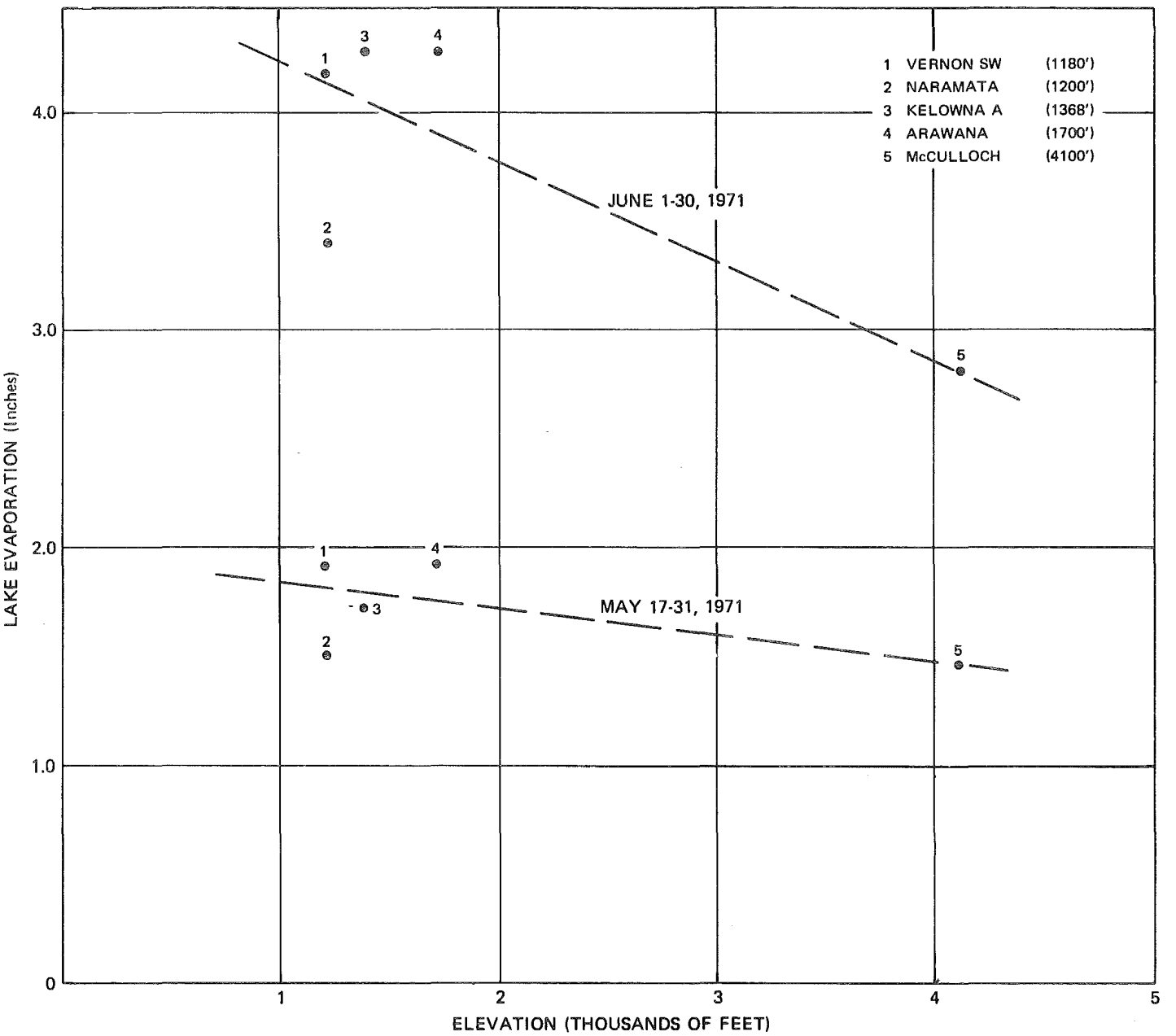
COMPARISON OF LAKE EVAPORATION VALUES (INCHES), BASED ON CLASS A PAN DATA, FOR MT. KOBAU (ELEVATION 6116 ft) AND SUMMERLAND CDA (1491 ft).

	SUMMERLAND	MT. KOBAU	DIFFERENCE
August 1967	7.42	6.06	1.36
September 1967 (13 days)	2.38	1.70	0.68
June 1968 (18 days)	3.24	2.34	0.90
July 1968	7.70	5.60	2.10
August 1968	5.16	4.19	0.97
September 1968	1.95	1.60	0.35

with elevation the average rate, adjusted to a base level of 1,000 feet, is 4.7% per thousand feet. As implied in the preceding paragraph, one cannot rely very heavily on results from only two stations, since they may be seriously affected by other local factors.

Evaporation pans specially installed for the Okanagan Project have also produced data. Figure 6.12 shows monthly lake evaporation for five stations in the basin for the periods May 17-31 and June 1-30, 1971 plotted against elevation. Considerable scatter is evident in the data for the 4 lower-level stations. Best fit lines imply a rate of decrease of lake evaporation with elevation of 6.7% per thousand feet in the latter half of May and 10.8% in June, adjusted to a base level of 1,000 feet.

Lake evaporation, as previously defined, is usually considered to be nearly equal to "potential evapotranspiration" over long periods of time (24).



VARIATION OF LAKE EVAPORATION WITH ELEVATION AT OKANAGAN PROJECT STATIONS IN MAY AND JUNE, 1971, BASED ON CLASS A PAN DATA.

Figure 6.12

Lysimeter studies by Baumgartner (25,26) in Germany suggest that mean annual lake evaporation, potential evapotranspiration and actual evapotranspiration may be very nearly equal over moist temperate forested areas. Potential and actual evapotranspiration have been studied in two IHD projects in southern British Columbia.

Pipes (27) has described evaporation studies in the Carr's Landing IHD Watershed on the east side of Okanagan Lake between Kelowna and Vernon. The variation of potential evapotranspiration with elevation which he obtained appears consistent with the results of pan data studies previously discussed, as shown in Figure 6.12. Actual evapotranspiration values were also estimated for the Carr's landing basin, using soil moisture data. Actual evapotranspiration was found to increase with elevation, implying a rapid increase with elevation in the ratio of actual to potential evapotranspiration.

The other study of topographicaphical influences on evaporation is being carried out in the IHD Trapping Creek Basin just east of the Okanagan. The basin aspect is south-southwest, the area is 57.1 sq. mi., and elevations range from 3,000 to 7,500 feet. Twelve carborundum block evaporimeters have been installed at elevations between 3,000 and 6,000 feet. Elevation, exposure, slope and aspect have all been found to influence evaporation and there is a seasonal variation in these effects (S.Y. Shiau, personal communication). The evaporimeter data were used to define monthly potential evapotranspiration (P.E.) indices at grid points from topographical variables. Distributions of P.E. over the basin can be obtained from these indices by first calculating a P.E. value at one grid point by some standard method. The Penman Equation was used for this purpose. It was found that the decrease of P.E. with elevation followed an exponential curve. However, a linear variation is a fairly good approximation within the range of values encountered. Estimates of average potential evapotranspiration for a three-year period were 25.06 inches/year at a reference station at 3,000 feet and 21.78 inches/year for the basin mean (elevation 4,630 feet). This indicates an average decrease of P.E. with elevation of 7.4% per thousand feet from a base level of 1,000 feet. This seasonal average value is in good agreement with the monthly data from other locations shown in Figure 6.13.

In summary, the variation of evaporation and evapotranspiration with elevation and other topographical parameters is of primary importance in assessing the water balance in mountainous terrain. Little research has been carried out on these effects, partly because of the difficulty of obtaining observations of evaporation and related variables in such regions. Studies of lake evaporation, potential evapotranspiration and actual evapotranspiration in southeastern British Columbia and southwestern Alberta provide a useful indication of monthly evaporation variations. Lake evaporation, based on pan data, and potential evapotranspiration estimates show a reasonably consistent decrease with elevation. The average value in southern British Columbia and Alberta is

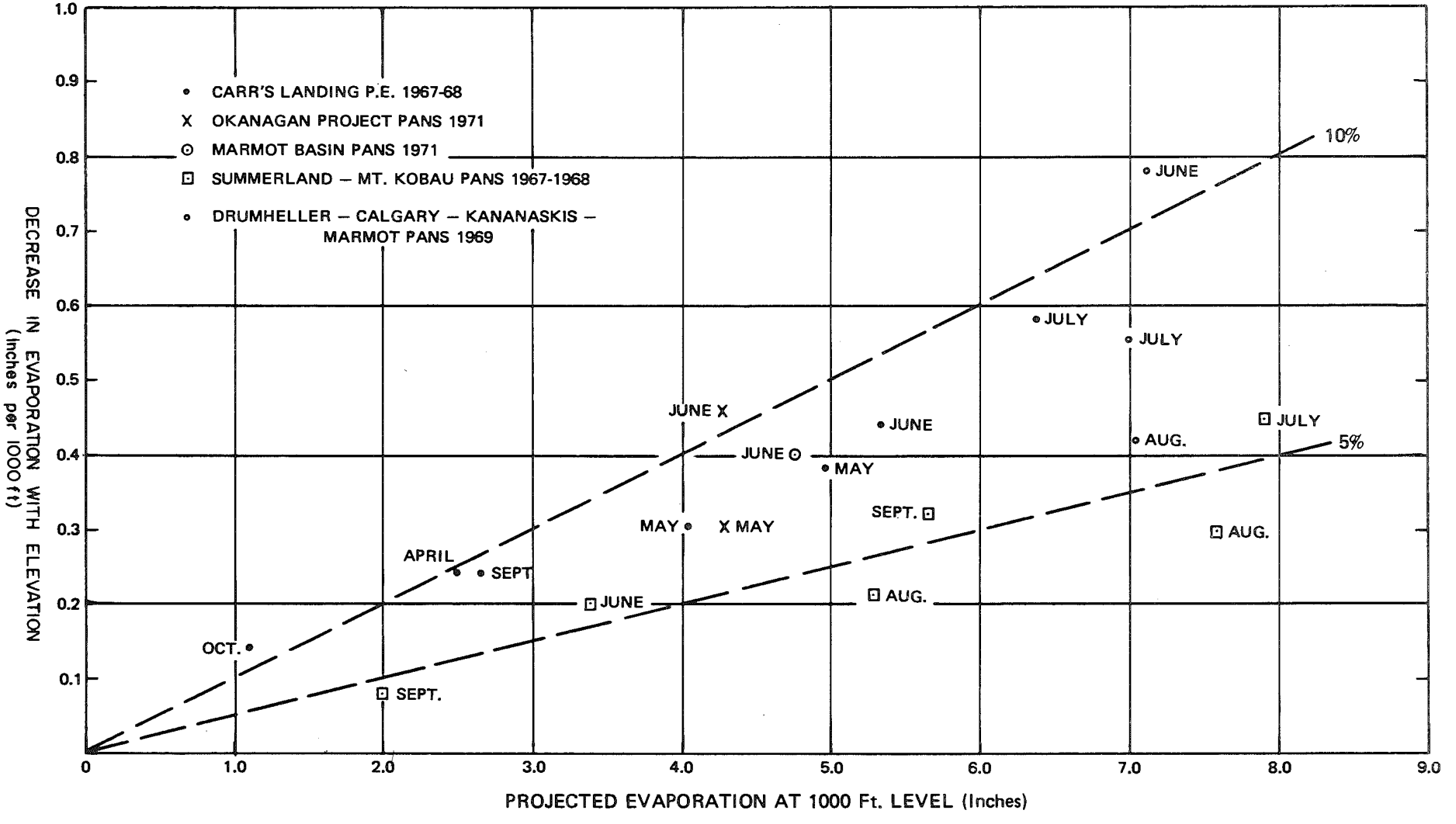


Figure 6.13

Variation of evaporation with elevation in southern Alberta and British Columbia. Values represent potential evapotranspiration (P.E.) or lake evaporation determined from Class A pan data. The lines represent percentage decreases in evaporation with elevation from a projected base level of 1000 ft. above sea level.

in the range from 5 to 10% per thousand feet. It must be stressed that, locally, the variation may be significantly different, depending on exposure, slope and aspect.

The actual evapotranspiration is, of course, highly dependent on the water supply (or, looked at from another viewpoint, the cover characteristics, which are largely dictated by water availability). Under natural conditions in the Okanagan Basin, which is water deficient at lower elevations, an increase of actual evapotranspiration with elevation is indicated up to at least the 3,000 foot level.

6.3.3 The Mean Lake Evaporation Model

The AES approach is based on cover analysis and pan measurements of free water evaporation. Major advantages of this method are its capacity for rational adaptation and the fact that the likelihood of gross errors is reduced because of the natural energy balance determines the water loss from the pan. The following sections outline the development and details of the current version of the model.

As mentioned earlier, it has been suggested by Bruce and Clark (24) and others that, for long periods, potential evapotranspiration and lake evaporation are nearly the same, although it is clear that evaporation and transpiration respond in different ways to meteorological factors. As a first step towards mapping the actual evapotranspiration, therefore, a model was developed to describe the variation in lake evaporation LE (PE) over the Okanagan. Based on earlier studies, the following assumptions were made:

(a) Lake evaporation decreases with increasing latitude at 6% per degree of latitude using the Summerland CDA normal lake evaporation adjusted to 1,000 feet above sea level as a reference.

(b) Lake evaporation decreases with elevation at the rates listed in Table 6.6 again using the Summerland CDA normals as the reference.Using these assumptions

TABLE 6.6

DECREASE IN LAKE EVAPORATION WITH ELEVATION BY INDIVIDUAL MONTHS

MONTH	J	F	M	A	M	J	J	A	S	O	N	D	Y
Summerland CDA Normal Lake Evaporation	0.10	0.20	0.90	3.43	5.14	5.98	6.76	5.67	3.76	1.86	0.50	0.20	34.5
6% decrease/10^3 ft. from a base value at 1000 ft	13.0	13.0	13.0	8.0	5.0	4.0	4.0	3.0	5.0	8.0	13.0	13.0	5.2

grid square values of mean monthly lake evaporation were calculated from the Summerland data using the model equation:

$$LE_{ij} = LE_{sj} \left\{(1 + 0.491\ D_j) \left([1 - D_j \frac{(Z_i - 1.0)}{100}] - 0.06\ (\phi_i - 49.57)\right)\right\} \quad (6.3.3)$$

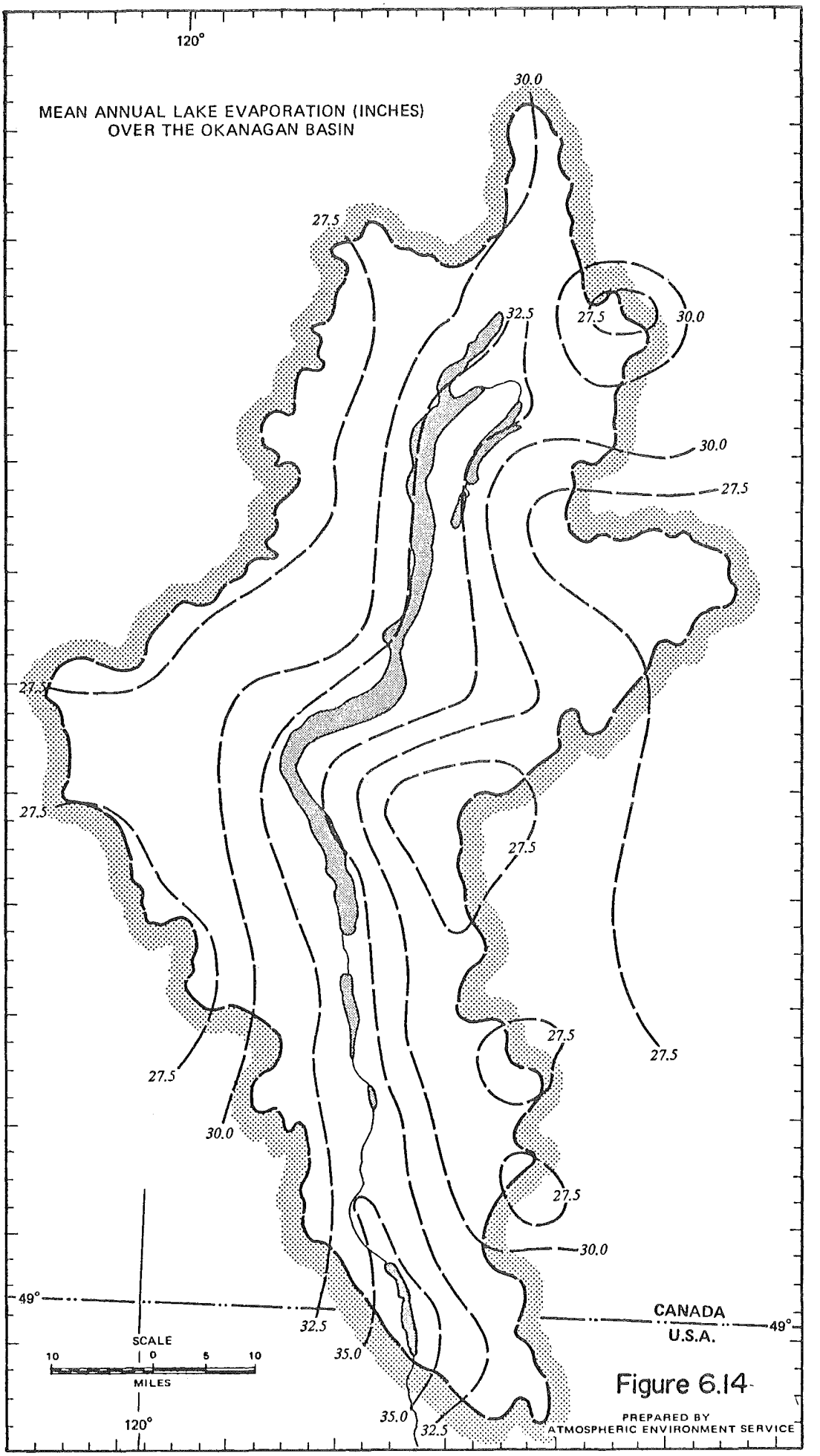


Figure 6.14

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where: LE_{ij} = mean lake evaporation of ith grid square for jth month.

LE_{sj} = mean lake evaporation for Summerland for jth month.

D_j = percentage decrease of LE per 10^3 ft. from a base of 1000 ft for jth month.

Z_i = mean elevation of ith grid square in thousands of feet.

ϕ_i = mean latitude of ith grid square.

In situations where equation 6.3.3 results in negative values, LE is taken as zero. The pattern of mean annual lake evaporation computed by means of equation 6.3.3 is presented in Figure 6.14.

6.3.4 The Mean Actual Evapotranspiration Model

Baumgartner (25,26) has tabulated comparative data on actual evapotranspiration from various types of surfaces, including a free water surface, based on lysimeter measurements in Europe. Nielson (28) has described the water requirements of various kinds of irrigated crops in southern Alberta, as well as the efficiency of irrigation. O'Riordan (29) studied irrigation efficiency and strategies in the Okanagan Basin. Both Pipes (27) in the Okanagan Basin and Shiau (30) in adjacent Trapping Creek Basin provide data which can be used to estimate the ratio of actual to potential evapotranspiration for characteristic elevations and cover types. Standard textbooks provide useful information concerning gross features of mean energy balance, Bowen Ratio, and climatological controls of major cover types. All of these sources were tapped in developing the AES model of mean actual evapotranspiration. The procedure was as follows:

(a) The cover type on the Okanagan was analysed and subdivided into 5 basic categories.

(b) A mean ratio of actual evapotranspiration to lake evaporation was obtained and tabulated for each month and for the year, based on the above references.

(c) Multiplication of a grid square value of mean lake evaporation, obtained from the lake evaporation model, by the appropriate weighted (AE/LE) ratios based on the distribution of cover within the grid square yielded estimates of the mean grid square evapotranspiration. The analysis was applied to all grid squares for all months, and for the whole year.

The five cover types utilized in the analysis procedure were:

(1) Water in the valley bottom

(2) Water above the valley bottom (i.e. above the 2,000 foot elevation level)

(3) Irrigated land, including orchards, vineyards, improved pastures, horticultural land and crop land.

(4) Forested land, including mature timber, immature timber, and non-commercial stands.

(5) Open land, which is any area not in the above types, including urban areas.

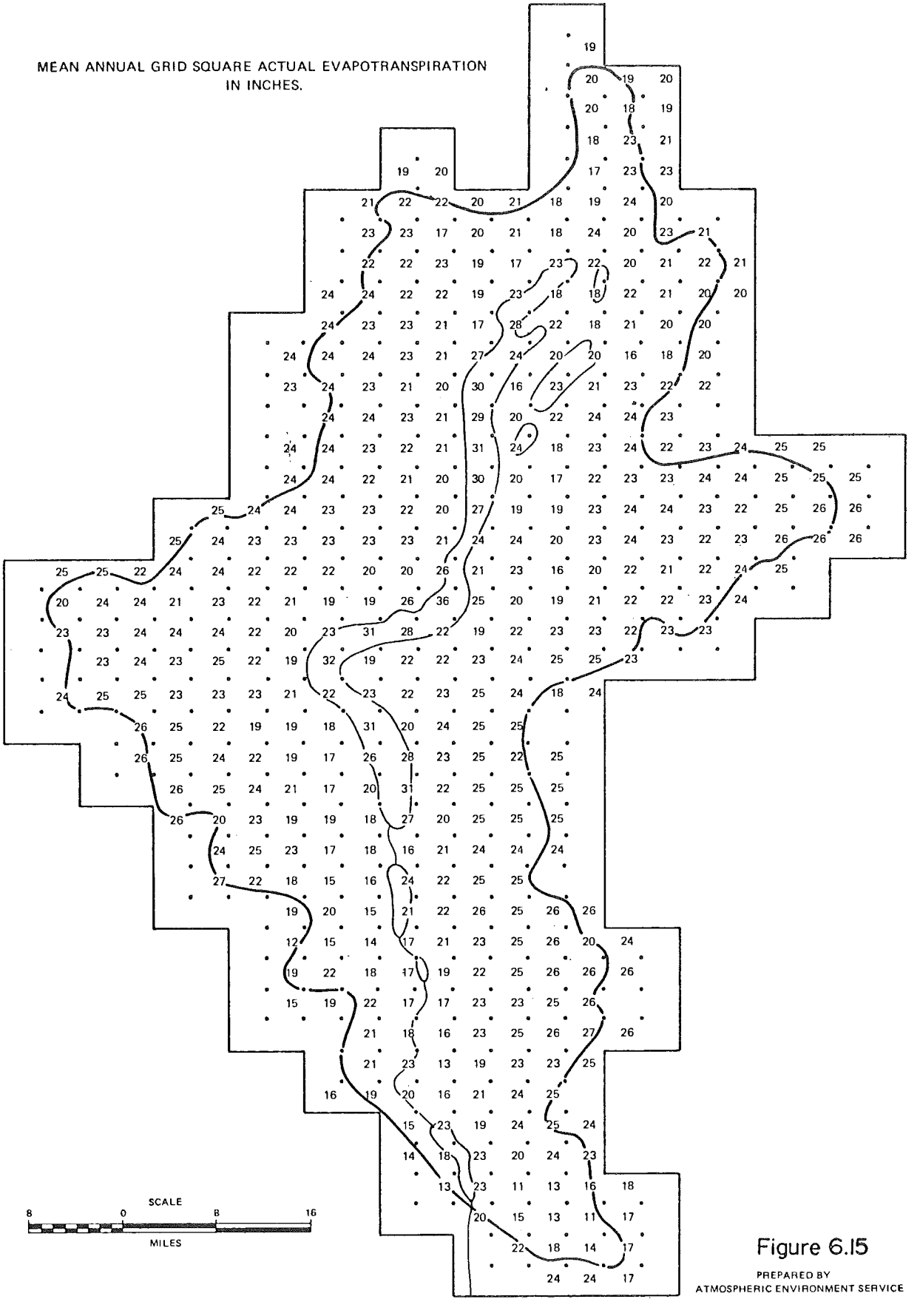


Figure 6.15

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This cover analysis was based upon aerial photographs and maps, some of which were supplied by the BCWRS. It is believed that the cover-type area estimates (Tables 6.7 to 6.11) are within ±20% of the true area of the type in question. The accuracy is significantly better in some valley bottom areas where more aerial photographs are available. A need exists for more extensive photography and mapping.

The mean ratios AE/LE used for the various cover types are listed in Table 6.12. Using these ratios the mean actual evapotranspiration for an individual grid square for an individual month can be calculated from the equation:

$$AE_{ij} = LE_{ij} \sum_{k=1} C_{ik} \cdot R_{jk} \qquad (6.3.4)$$

where:

AE_{ij} = mean actual evapotranspiration for ith grid square and jth month.

LE_{ij} = mean lake evaporation for ith grid square and jth month.

C_{ik} = fraction of ith grid square having cover type k.

R_{jk} = ratio AE/LE for kth type cover the jth month.

The mean monthly and annual actual evapotranspiration values obtained from this model are listed by grid square in Technical Supplement III. The mean annual actual evapotranspiration pattern is presented in Figure 6.15.

The use of the above model avoids dependency on observed precipitation as an input into the evapotranspiration computations. The widely used Thornthwaite approach (31), in its moisture budget, requires knowledge of precipitation. It follows that undercatch by precipitation gauges will result in values of evapotranspiration computed by the Thornthwaite techniques being biased on the low side.

6.4 ADJUSTMENT OF MODELS TO THE WATER BALANCE

A test of the reliability of precipitation, evapotranspiration and run-off models can be made by applying water balance equations. Ideally, the models should satisfy the following criteria:

(1) They should fit observational data

(2) The individual fields should be rational

(3) They should satisfy water balance criteria

With regard to items (1) and (2) it should be noted that models involve interpolation and extrapolation, usually with a less-than-ideal data base. Furthermore, observational data are subject to error and their limitations should be taken into account. Each individual field should be compatible with scientific theory and should make maximum use of hydrological and meteorological expertise.

TABLE 6.7

PERCENTAGES OF VARIOUS COVER TYPES OF ELEVATION BANDS
OKANAGAN SUB-BASIN #1

ELEVATION RANGE (ft)	NO. OF GRID SQ.	% OF BASIN AREA	MEAN EL.	WVB	WAV	FOREST	OPEN	IRRIG.
1000-2000	49	16.67	1615.69	27.71	.00	34.44	14.58	23.27
2000-3000	48	16.32	2530.54	.00	3.85	76.84	9.52	9.79
3000-4000	49	16.67	3553.10	.00	.23	95.43	3.78	.57
4000-5000	87	29.59	4512.79	.00	1.11	95.98	2.89	.02
5000-6000	57	19.39	5418.67	.00	.31	95.66	4.04	.00
6000-7000	4	1.36	6152.75	.00	.63	99.37	.00	.00
Total Sub-basin	294		3744.30	4.62	1.06	82.49	6.25	5.58

WVB - Water, Valley Bottom
WAV - Water, Above Valley Bottom

TABLE 6.8

PERCENTAGES OF VARIOUS COVER TYPES BY ELEVATION BANDS
OKANAGAN SUB-BASIN #2

ELEVATION RANGE (ft)	NO. OF GRID SQ.	% OF BASIN AREA	MEAN EL.	WVB	WAV	FOREST	OPEN	IRRIG.
1000-2000	3	9.1	1707.33	22.07	.00	36.60	32.00	9.33
2000-3000	5	15.2	2802.20	.00	.14	70.66	28.40	.80
3000-4000	8	24.2	3369.62	.00	.31	75.81	21.75	2.12
4000-5000	8	24.2	4537.5	.00	.34	92.16	7.50	.00
5000-6000	6	18.2	5268.33	.00	.11	95.55	4.33	.00
6000-7000	3	9.1	6092.33	.00	.00	83.67	16.33	.00
Total Sub-basin	33		4008.39	2.01	.20	79.73	16.58	1.48

WVB - Water, Valley Bottom
WAV - Water, Above Valley Bottom

TABLE 6.9

PERCENTAGES OF VARIOUS COVER TYPES BY ELEVATION BANDS
OKANAGAN SUB-BASIN #3

ELEVATION RANGE (ft)	NO. OF GRID SQ.	% OF BASIN AREA	MEAN EL.	WVB	WAV	FOREST	OPEN	IRRIG.
1000-2000	7	15.56	1863.57	.64	.00	43.79	38.42	17.14
2000-3000	5	11.11	2517.60	.00	2.12	62.28	29.80	5.80
3000-4000	9	20.	3418.33	.00	.44	62.22	34.33	3.00
4000-5000	10	22.22	4438.90	.00	.01	87.69	12.30	.00
5000-6000	14	31.11	5477.00	.00	.14	94.93	4.93	.00
6000-7000	0	0.	.00	.00	.00	.00	.00	.00
Total Sub-basin	45		3943.67	.10	.37	75.20	20.42	3.91

WVB - Water, Valley Bottom
WAV - Water, Above Valley Bottom

TABLE 6.10

PERCENTAGES OF VARIOUS COVER TYPES OF ELEVATION BANDS
OKANAGAN SUB-BASIN #4

ELEVATION RANGE (ft)	NO. OF GRID SQ.	% OF BASIN AREA	MEAN EL.	WVB	WAV	FOREST	OPEN	IRRIG.
1000-2000	8	20.51	1612.50	10.22	.00	20.02	46.63	23.13
2000-3000	5	12.82	2571.40	.00	.80	41.20	57.00	1.00
3000-4000	14	35.90	3577.00	.00	.05	61.38	33.36	5.21
4000-5000	11	28.21	4318.18	.00	.17	80.47	19.36	.00
5000-6000	1	2.56	5411.00	.00	.00	81.00	19.00	.00
6000-7000	0	00	.00	.00	.00	.00	.00	.00
Total Sub-basin	39		3301.18	2.10	.17	56.20	34.79	6.74

WVB - Water, Valley Bottom
WAV - Water, Above Valley Bottom

TABLE 6.11

PERCENTAGES OF VARIOUS COVER TYPES BY ELEVATION BANDS
TOTAL OKANAGAN BASIN

ELEVATION RANGE (ft)	NO. OF GRID SQ.	% OF BASIN AREA	MEAN EL.	WVB	WAV	FOREST	OPEN	IRRIG.
1000-2000	67	16.30	1645.31	22.54	.00	33.79	21.68	21.99
2000-3000	63	15.33	2554.32	.00	3.18	72.36	16.40	8.06
3000-4000	80	19.47	3523.77	.00	.23	83.77	14.19	1.81
4000-5000	116	28.22	4489.67	.00	.87	93.53	5.58	.02
5000-6000	78	18.98	5417.47	.00	.26	95.33	4.41	.00
6000-7000	7	1.70	6126.86	.00	.36	92.64	7.00	.00
Total Sub-basin	411		3745.29	3.67	.83	78.98	11.34	5.18

WVB - Water, Valley Bottom
WAV - Water, Above Valley Bottom

TABLE 6.12

THE RATIO $(^{AE}/_{LE})$ FOR THE VARIOUS COVER TYPES BY INDIVIDUAL MONTHS

	SUB-BASIN	J	F	M	A	M	J	J	A	S	O	N	D
Water valley bottom	1	1.10	2.35	1.57	0.87	0.89	0.96	1.00	1.14	1.34	1.68	2.14	1.30
	2	1.03	1.36	1.15	0.97	0.97	0.99	1.00	1.03	1.09	1.18	1.31	1.08
	3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	4	1.01	1.19	1.08	0.98	0.99	1.00	1.00	1.01	1.05	1.09	1.16	1.04
Water above valley bottom	All Sub-basins	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Irrigated land	All Sub-basins	1.00	0.80	0.62	0.54	0.73	1.03	1.01	1.09	0.87	0.38	0.65	1.00
Open	All Sub-basins	1.00	0.75	0.54	0.43	0.36	0.30	0.21	0.19	0.21	0.35	0.65	1.00
Forest		J = 0.26E + 0.47 F = 0.18E + 0.43 M = 0.16E + 0.38 A = 0.15E + 0.35 M = 0.14E + 0.32 J = 0.13E + 0.26					J = 0.12E + 0.22 A = 0.11E + 0.21 S = 0.10E + 0.20 O = 0.09E + 0.25 N = 0.10E + 0.45 D = 0.14E + 0.72						
		(E = elevation in ft/1000)											

The simplest water balance criterion pertains to mean annual conditions

$$\overline{P} - \overline{AE} - \overline{R} = 0 \qquad (6.4.1)$$

where

$\overline{P}$ = mean annual precipitation

$\overline{AE}$ = mean annual evapotranspiration

$\overline{R}$ = mean annual runoff

applied to the whole basin.

More useful and complex criteria can be imposed on the model; for example, equation 6.4.1 may be applied to sub-basins or individual grid squares. At the present stage of development, the OKAGN6 precipitation model and the AES evapotranspiration model have been "fitted" to mean annual runoff for the basin and four sub-basins as specified by BCWRS. This "fitting" was accomplished through adjustment of the following model parameters:

(1) the undercatch factor for rainfall (RUC)

(2) the undercatch factor for snowfall (SUC)

(3) the rate of decrease of lake evaporation with elevation (LEF)

It would be possible, in arriving at a "final" water balance model of the basin to consider other adjustments, for example:

(4) adjustment of runoff

to satisfy equation 6.4.1. It will be noted that the adjustable factors of the precipitation and evapotranspiration models simply distort the fields without producing major changes in relative distributions. Furthermore, the adjustable factors are those in which we have least confidence, and which we hope are capable of improvements in resolution with further research work. The models are adaptable and easily responsive to improvements in our knowledge.

As noted previously the present model uses the mean adjustment factors RUC = 7%, SUC = 40% and LEF = 5.2% per thousand feet from a base level of 1,000 feet.

Table 6.13 lists the mean "measured" annual runoff for four sub-basins and the total basin, together with corresponding values of $\overline{P} - \overline{AE}$ obtained from the AES models. It should be noted that the "measured" runoff includes adjustments for various consumptive uses and may be subject to certain errors (e.g. definition of basin boundaries, unmonitored diversions, etc.) The data in Table 6.13 show close agreement between estimated and "measured" mean annual runoff for the total basin and for sub-basin 1 which occupies about 72% of the basin area. For sub-basins 1 to 4 and the total basin, respectively, the estimates are 101%, 190%, 83%, 86% and 103% of the measured values. The poorer results for

TABLE 6.13

COMPARISON OF OBSERVED ANNUAL RUNOFF (ins.) AND ESTIMATED RUNOFF

	SUB-BASIN 1	SUB-BASIN 2	SUB-BASIN 3	SUB-BASIN 4	TOTAL BASIN
Measured Runoff	4.8	2.6	4.2	3.6	4.4
Water Balance Estimate	4.76	5.01	3.89	3.09	4.53

the smaller sub-basins could be attributed to relative difficulties in determining both the runoff and the meteorological variables (due perhaps to fewer stations and sampling problems). In general, however, the results shown in Table 6.13 are encouraging.

The mean monthly and annual water balances obtained from all AES models have been presented in Technical Supplement III. These results represent the stage of development as of January, 1973. It is anticipated that revisions and refinements will be made as the result of continuing studies.

6.5 SUMMARY

Testing of regression models for precipitation based upon several data sets led to the selection of OKAGN6 as the preferred model at the current stage of development. Although it does not utilize snow course data it is based upon the largest possible set of precipitation data from within or very near to the Okanagan watershed. Long term stations are located mainly at lower elevations but higher elevation terrain was sampled by inclusion of short term data from stations established for the study. All short term data were adjusted to the 1931-60 normal period. An important aspect of OKAGN6 is the inclusion of parameters to correct for undercatch of rainfall and snowfall by precipitation gauges.

The AES evapotranspiration model was developed in two stages. First a lake evaporation model (for small shallow lakes) was developed. It was based upon empirical latitudinal and vertical gradients indicated by Class A evaporation pan data. These gradients were then applied to the long term mean lake evaporation data from Summerland CDA. In the second stage ratios of actual evapotranspiration to lake evaporation were derived for each month for various land cover types. These ratios were used to convert mean lake evaporation values to mean actual evapotranspiration patterns.

Precipitation fields based upon undercatch factors of 7 percent for rainfall and 40 per cent for snowfall and independent actual evapotranspiration maps based upon a lake evaporation decrease of 5.2 percent per 1,000 ft. from a 1,000 ft. base resulted in a mean runoff estimate of 103 percent of the measured value over the total watershed.

It is planned to test the model on data for individual years and to adapt it to shorter time periods and smaller areas. This would involve additional terms in the water balance equation to account for localized diversions, groundwater flows and consumptive use factors.

In the future remote sensing by satellite and aircraft should lead to improved analyses of snowcover, definition of ground cover characteristics, measurement of albedo and radiation components and measurement of lake surface temperatures. These inputs should go a long way in aiding those developing models to come ever closer to "true" precipitation and evapotranspiration fields over the Okanagan watershed.

CHAPTER 7

Basin Characteristic Modelling

7.1 INTRODUCTION

One obvious way of estimating runoff from ungauged basins such as many of the tributary basins in the Okanagan is to collect streamflow data on a sampling basis from several representative basins and then regionalize the data. This chapter describes an attempt to regionalize annual runoff data on the basis of physical characteristics of the drainage basins and some precipitation data. The basic method used was multiple linear regression, a technique which is very simple to use with large modern computers, in an attempt to find correlations between streamflow characteristics (the dependent variables) and basin characteristics (the independent variables). One of the most difficult problems with this type of analysis is to find appropriate measures for characterizing the various basins. A review of the literature in this field, known as Morphometric Analysis, was made to find those characteristics most likely to produce significant results.

As part of the Okanagan Basin Study, 14 new gauging stations were established in the fall of 1970 at sites selected to provide natural streamflow data. These stations together with the 11 existing natural flow stations, provided runoff data for 19 sub-basins. Due to time limitations, the only streamflow characteristic considered in this study was the April-July unit runoff (acre-feet/square mile) for 1971 and 1972 runoff data.

Multiple regression analysis was performed on untransformed and log-transformed data to derive separate relationships for 1971 and 1972 runoff. Of the basin characteristics studied (Table 7.1), it was found that median basin elevation, latitude, basin azimuth and area of lakes and swamps were the most significant and could explain up to 77% of the basin-to-basin variation in April-July unit runoff. Transforming the data to natural logarithms results in some improvement in the reliability of the runoff estimates, especially for those sub-basins with very low runoff amounts.

When the available, though limited, precipitation data were included, they were found to improve the correlations somewhat. A method is suggested in Section 7.5 for adjusting the results to obtain an estimate of the long-term mean annual streamflow, from the various sub-basins. It is believed that this method offers a simple and promising tool for regionalising streamflow characteristics such as mean annual flows.

TABLE 7.1

PRELIMINARY BASIN CHARACTERISTICS

NAME	SYMBOL	REFERENCE	SOURCE OF DATA	METHOD OF COMPUTATION	UNITS
Latitude	LAT	4	1:50,000 map sheets	Location of gauging station	Degrees N
Basin Area	AR	3,6	1:50,000 map sheets	Planimetered	Sq. Mi.
Forested Area	AF	3,4	1:50,000 map sheets	Planimetered	Sq.Mi.,% of AR
Surface Storage	SS	3	1:50,000 map sheets	Planimetered	Sq.Mi.,% of AR
Area Above 5000' 4500' 4000' 3500'	AR50 AR45 AR40 AR35	3,4	1:50,000 map sheets, area-elevation graphs	Planimetered	Sq.Mi.,% of AR
Median Basin Elevation	BELEV	3,4	1:50,000 map sheets, area-elevation graphs	Elevation above which 50% of basin area lies	ft.
Basin Height	BHT	5		BELEV minus elevation of gauging station	ft.
Basin Rise	BRISE	4	1:50,000 map sheets, area-elevation graphs	Difference between elevation below which 10% of the area lies and 85% of the area lies	ft.
Basin Length	BLEN	4	1:50,000 map sheets	Longest distance from gauging station to major drainage divide	miles
Basin Slope	BSL	1,4,5,6	 Reference 1 Reference 1	BRISE/BLEN = BBSL 2BHT/CLEN = BGSL BHT/CLEN = BUSL Horton's Method = BHSL Plane Fitting Method = BPSL	ft/mile
Basin Azimuth	BAZ	1,4,6		Plane-fitting method Slope aspect Normal to basin's topographic barrier Basin polygon	radians
Median Channel Elevation	CELEV	5	1:50,000 map sheets channel profile	Elevation at ½ CLEN	ft.
Channel Rise	CRISE	3,5	1:50,000 map sheets	Difference between elevations at 10% and 85% CLEN from Mouth	ft.
Channel Length	CLEN	3,5	1:50,000 map sheets	Distance measured along main channel from mouth to basin divide	mile
Channel Slope	CBSL	3,4,5		CRISE/CLEN CELEV-Elevation of gauging station/CLEN	ft/mile
Drainage Density	DD	2,6	1:50,000 map sheets	Total length of Channels/AR	miles/sq. mile

7.2 BASIC DATA

7.2.1 Streamflow Data

Early in 1970, several Okanagan sub-basins were selected to determine the natural sub-basin runoff. Eleven existing gauging stations were found suitable for this purpose and fourteen new stations were established in late 1970. Of these 25 stations, 3 were not used due to incomplete data. Of the remaining 22, 3 were needed to measure runoff above the outlet of Swalwell Lake and 2 to measure the runoff into Greyback Mountain Reservoir on Penticton Creek. The stations are listed in Table 7.2 and Figure 7.1 shows the 19 sub-basins for which they provided runoff data. On some streams there are two gauging stations, which were used to estimate runoff from the upper and lower sub-tributary basins which were then treated as independent observations.

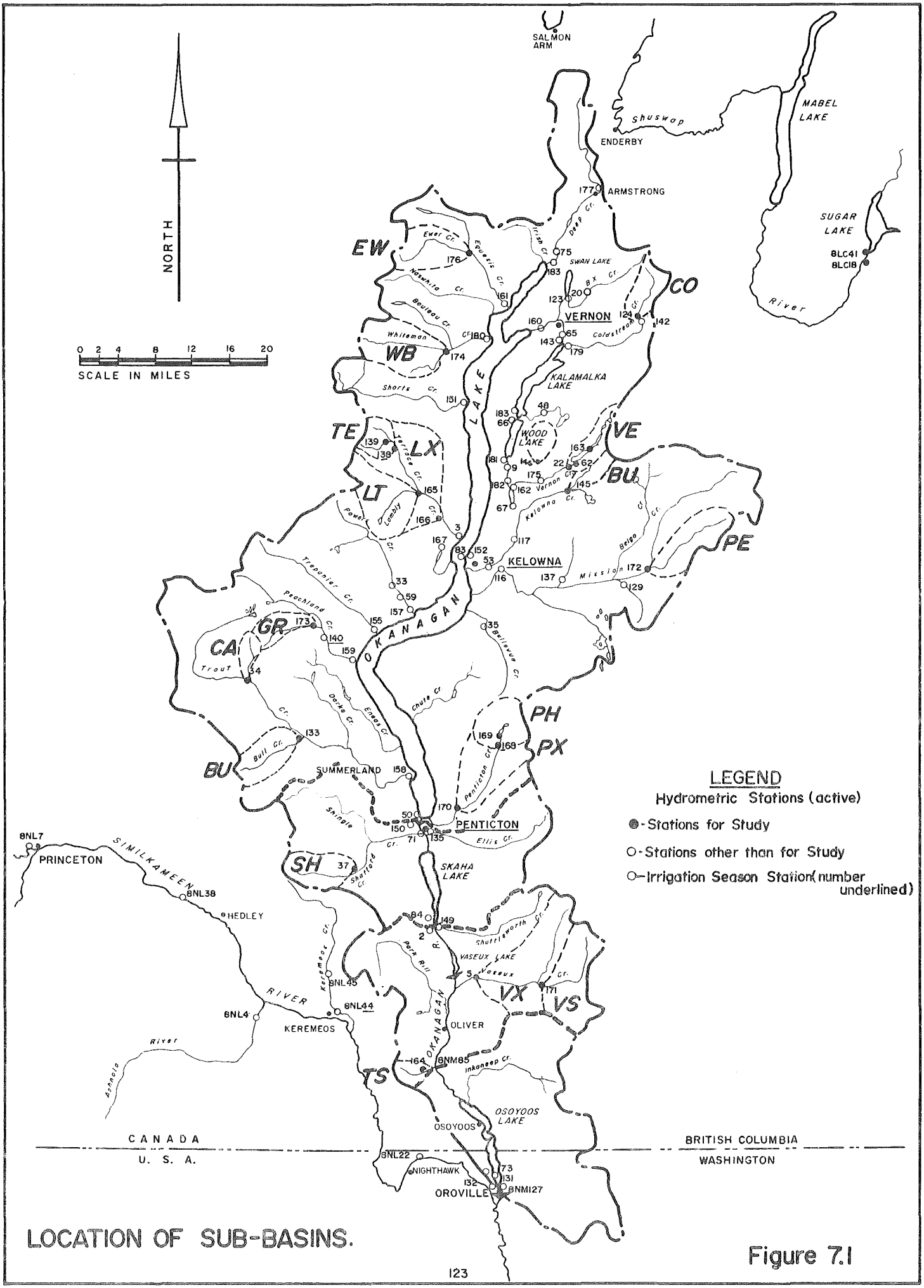
TABLE 7.2

SUB-BASIN STREAM GAUGING STATIONS

STATION NUMBER	STATION NAME	MAIN SUB-BASIN	SYM-BOL	YEAR ESTAB-LISHED	TYPE OF GAUGE
08NM-138	Terrace Cr. near Kelowna	Lambly	TE	1965	M
08NM-165	Lambly Cr. above Terrace Cr.	"	LT	1970	R
08NM-166	Lambly Creek below Bald Range Cr.	"	LB	1970	R
08NM-174	Whiteman Cr. above Bouleau Cr.	Whiteman	WB	1971	R
08NM-172	Pearson Cr. near the Mouth	Mission	PE	1970	R
08NM-146	Clark Cr. near Winfield	Vernon	CL	1968	R
08NM-142	Coldstream Cr.above Municipal Intake	"	CO	1967	M
08NM-176	Ewer Cr. near the Mouth	Equesis	EW	1971	R
08NM-022	Vernon Cr.at Outlet of Swalwell L.	Vernon	VE	1960	R
08NM-062	Swalwell Lake near Okanagan Centre	"	SW	1970	M
08NM-163	Crooked Lake at the Outlet	"	CR	1970	M
08NM-145	Bulman Cr. at the Mouth	Kelowna	BU	1968	R
08NM-165	Testalinden Cr. in Canyon	Testalinden	TS	1965	M
08NM-037	Shatford Cr. near Penticton	Shingle	SH	1965	M
08NM-134	Camp Cr. at Mouth near Thirsk	Trout	CA	1965	R
08NM-133	Bull Cr. near Crump	"	BL	1965	R
08NM-173	Greata Cr. near the Mouth	Peachland	GR	1970	R
08NM-171	Vaseux Cr. above Solco Cr.	Vaseux	VS	1970	R
08NM-015	Vaseux Cr. above Dutton Cr.	"	VD	1958	R
08NM-168	Penticton Cr. above Dennis Cr.	Penticton	PD	1970	R
08NM-169	Greyback Lake at the Outlet	Penticton	GB	1970	R
08NM-170	Penticton Cr. below Harris Cr.	Penticton	PH	1970	R

M - Manual gauge
R - Recording gauge
All stations operate continuously

Since annual runoff data for 1972 were not available in time, April-July runoff, which forms 80 to 95% of the annual runoff was the streamflow characteristic (dependent variable) used. Unit runoff (acre-feet/square mile) was used instead of volume runoff (acre-feet) in order to eliminate "area" as an independent variable in the multiple regression analysis since otherwise it would have dominated the analysis. The April-July unit runoff data for 1971 and 1972 are summarized in Technical Supplement III.



LEGEND

Hydrometric Stations (active)

● - Stations for Study

○ - Stations other than for Study

○ - Irrigation Season Station (number underlined)

LOCATION OF SUB-BASINS.

Figure 7.1

7.2.2 Basin Characteristics

Literature on the correlation of streamflow with basin characteristics and meteorological data was reviewed using the Water Resources Service Library as the main source of information. All relevant papers are listed in the Bibliography. The one which was found to be most useful was by D.M. Thomas and M.A. Benson (32).

Based on information obtained from the literature review, and considering the streamflow characteristics, the availability of physiographic data, and past experience, a preliminary selection of basin characteristics was made. These are listed in Table 7.1, together with the corresponding reference and method of computation.

7.2.3 Climatological Data

It is logical to expect that precipitation as the source of runoff would be an important factor in determining the variability of unit runoff in a region. Hence an attempt was made to include it.

Monthly precipitation estimates for 1971 were made by the Atmospheric Environment Service, Canada Department of the Environment on a five-kilometer grid square basis, as described in Chapter 6 of this Supplement. From these, estimates of sub-basin precipitation were made for January-March, April-July, and January-December and included in the analysis of 1971 runoff as independent variables. Since 1972 monthly precipitation estimates were not available in time only September to October, September to November, and October to December 1971 precipitation estimates have been included in the 1972 analysis as indicators of antecedent soil moisture and early winter snowpack conditions in the sub-basin.

7.3 PRELIMINARY ANALYSIS

Using 1971 streamflow data, some preliminary multiple regression and simple correlation analyses were made to determine the more important basin characteristics, the effect of using log-transformed data and the effect of including precipitation. Analyses were also made with other dependent runoff variables such as volume runoff, annual maximum flow and monthly flows. In these preliminary analyses, a total of 52 independent variables (44 basin characteristics and 8 precipitation characteristics) and 24 dependent variables (streamflow characteristics), including log-transformations, were studied. From these, it was found that equations with log-transformed data could be more significant than those using non-transformed data and that precipitation variables were significant independent variables.

To obtain an understanding of the interaction between the dependent and independent variables used in this study, the intercorrelation of basin characteristics, the correlation of precipitation with basin characteristics, and the correlation of runoff with basin characteristics and precipitation were studied in some detail as described in the following sections.

7.3.1 Intercorrelation of Basin Characteristics

The degree of intercorrelation between basin characteristics indicates the degree to which they lack independence from each other in a multiple regression analysis and also indicates, in a rough way, the representativeness of the group of 19 sub-basins used in the analysis. The simple correlation coefficients for the relevant basin characteristics are tabulated in Table 7.3. The high correlation between area (AR) and main channel length (CLEN)

TABLE 7.3
INTERCORRELATION OF BASIN CHARACTERISTICS

	AR	BLEN	CLEN	LAT	BELEV	BHSL	AR45P	SSP	BAZ	BAZE
AR	1.00									
BLEN	.90	1.00								
CLEN	.86	.95	1.00							
LAT	-.15	.06	-.11	1.00						
BELEV	.18	.21	.31	-.40	1.00					
BHSL	.18	.08	.24	-.33	-.40	1.00				
AR45P	.05	.09	.12	-.27	.92	-.61	1.00			
SSP	-.19	.12	-.21	.17	.18	-.58	.36	1.00		
BAZ	.16	.10	.17	-.26	.30	-.16	.24	.02	1.00	
BAZE	.21	.08	.10	-.26	.36	-.20	.28	-.02	.96	1.00

AR Area of basin
BLEN Basin Length
CLEN Main Channel Length
LAT Latitude
BELEV Median Basin Elevation
BHSL Basin Slope
AR45P Percent of Basin Area above 4500 ft.
SSP Percent of Basin Area Covered by Lakes and Swamps
BAZ Basin Azimuth (Clockwise from North)
BAZE Basin Azimuth (Clockwise and Counterclockwise from East)

of 0.86 and between basin length (BLEN) and channel length (CLEN) of 0.95 indicate a geometric similarity in all the sub-basins analysed. The high inverse correlation of 0.61 between basin slope (BHSL) and percent area above 4,500 feet (AR45P) is a reflection of the flattening off, or plateau, in the Okanagan Valley at about elevation 4500 to 5000 feet. As median basin elevation (BELEV) and area above 4500 feet (AR45P) are highly correlated, the decrease in basin slope with increasing area above 4500 feet is reasonable. The percent area of lakes and swamps (SSP) is also inversely related to basin slope (BHSL) which is in agreement with the Okanagan Basin in general. At higher elevations where basin slopes are less, a greater area of lakes and swamps is apparent.

On the basis of these intercorrelations it appears that the sample of 19 sub-basins is fairly representative of the geomorphological aspects of the Okanagan Basin as a whole.

7.3.2 Correlation of Precipitation with Basin Characteristics

It is logical to expect that precipitation characteristics such as winter, summer and fall precipitation, will be significant independent variables with respect to runoff. At the same time, it can be expected that the causes of variation in regional runoff will also explain the regional variation in precipitation. But a high intercorrelation between precipitation variables and basin characteristics would prohibit use of both as independent variables in a multiple regression equation.

For the 1971 analyses, January-March precipitation (PPN1) was used as an index of winter precipitation, and April-July precipitation (PPN2) for the summer period. January-December or annual values (PPNA) were also tested. For the 1972 analyses September-October (PPNSO), September-November (PPNSN) and October-December (PPNOD) 1971 precipitation values were tested as indicators of fall and early winter precipitation. The precipitation values for the above seasonal periods are listed in Technical Supplement III for each sub-basin.

Simple correlation coefficients for these precipitation variables and 4 basin characteristics are tabulated in Table 7.4. Based on experience, these

TABLE 7.4

CORRELATION OF PRECIPITATION WITH BASIN CHARACTERISTICS

	1971 ANALYSIS			1972 ANALYSIS		
	PPN 1	PPN 2	PPN A	PPN SO	PPN SN	PPN OD
BELEV	0.51	0.59	0.45	0.57	0.50	0.31
BHSL	-0.21	-0.36	-0.36	-0.52	-0.56	-0.50
LAT	0.21	-0.19	0.25	0.15	0.41	0.56
BAZE	0.31	0.69	0.42	0.11	-0.06	-0.06

PPN 1 - January - March precipitation
PPN 2 - April-July "
PPN A - January-December "
PPN SO - September-October "
PPN SN - September-November "
PPN OD - October-December "
BELEV - Median basin elevation
BHSL - Basin slope
LAT - Latitude
BAZE - Basin azimuth

4 basin characteristics (median basin elevation, basin slope, latitude, azimuth) are the ones most likely to correlate with precipitation. It can be seen from this table that precipitation variable PPN2 cannot be included in the same

multiple regression with basin characteristics BELEV and BAZE as they are not independent. Other combinations which fall in the same category are underlined in the table.

The high intercorrelation (r=0.69) between April-July precipitation (PPN2) and basin azimuth referenced to the east direction (BAZE) indicates that summer precipitation is higher on sub-basins facing in a westerly direction. This is in agreement with the westerly flow of air prevailing in the Okanagan Valley which produces downslope conditions on east-facing and upslope conditions on the west-facing basins.

For determining a precipitation-latitude relationship, the same NW-SE line described in Chapter 3 was used as a base line. In Figure 7.2, annual precipitation (PPNA) and September-November precipitation (PPNSN) are plotted against median basin elevation (BELEV). If the sub-basins are designated north and south on the basis of this base line, the trend to higher precipitation in the north than in the south can be seen.

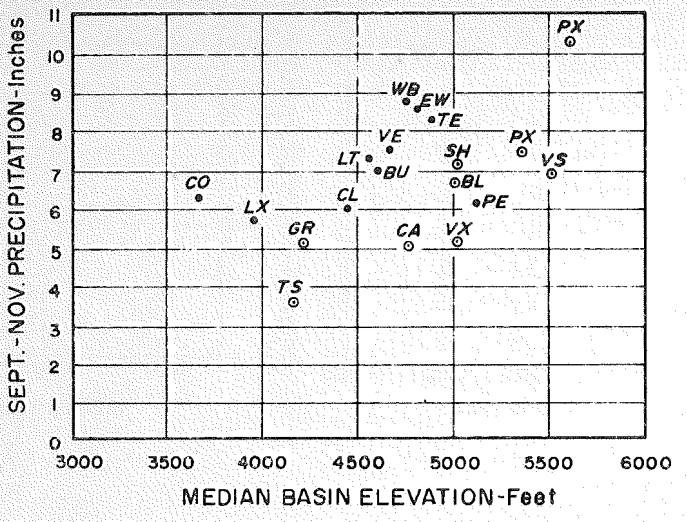
7.3.3 Correlation of Runoff with Basin Characteristics and Precipitation

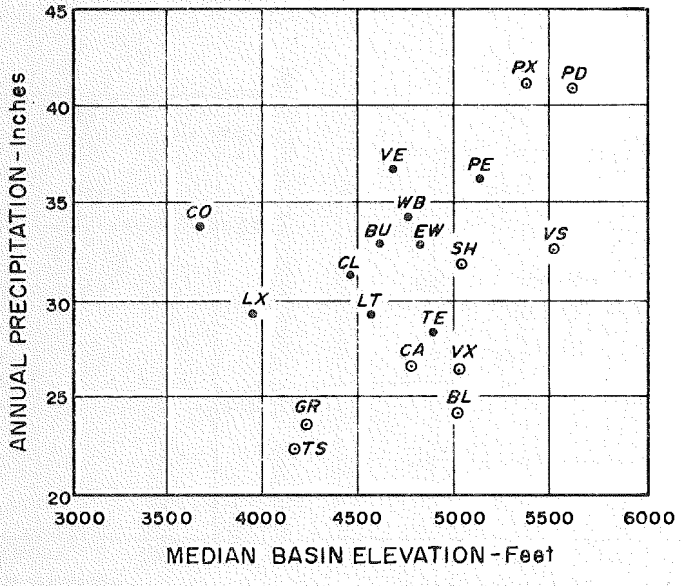
April-July unit runoff (SURO2) is plotted against median basin elevation (BELEV) and area above 4500 feet (AR45P) for 1971 and 1972 in Figures 7.3 and 7.4. These were found to be most important basin characteristics although they are not independent. These graphs show the same north-south division of sub-basins mentioned previously with the distinction more evident in the log-log plots. Sub-basins Clark Creek (CL) and Bulman Creek (BU) although considered to be in the northern portion, appear to be in a transition zone, or are influenced substantially by a factor other than elevation. The evidence of two regions in the Okanagan Basin may indicate that they should be analyzed separately, but data for a much greater number of sub-basins in each region would then be required to make a reliable analysis.

The most important precipitation variables available for 1971 and 1972 runoff are plotted in Figure 7.5 and Figure 7.6. In 1971, Terrace Creek (TE) and Coldstream Creek (CO) stand out as sub-basins which yield more and less runoff respectively than winter and annual precipitation would indicate. In 1972, Pearson Creek (PE) and Clark Creek (CL) are anomalies on the same basis.

7.4 MULTIPLE REGRESSION ANALYSES

The use of multiple regression analysis for studying the dependence of runoff on a variety of physiographic and climatological parameters is well documented and generally accepted, although with qualification. Many papers have been produced which point out the inherent deficiencies and the care which must be exercised when performing multiple regression analysis on hydrologic data.

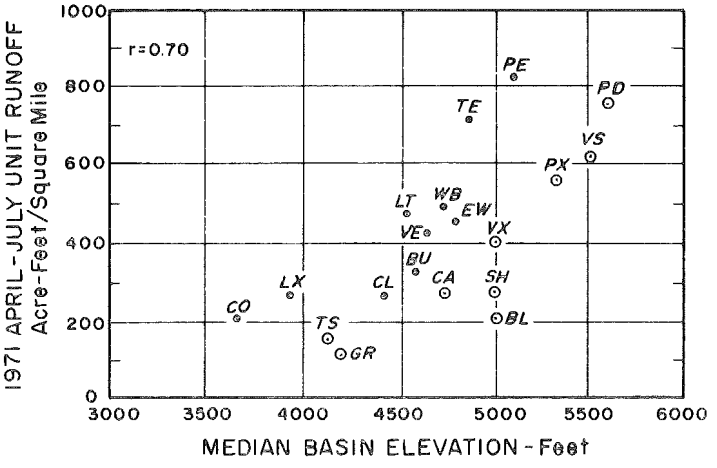


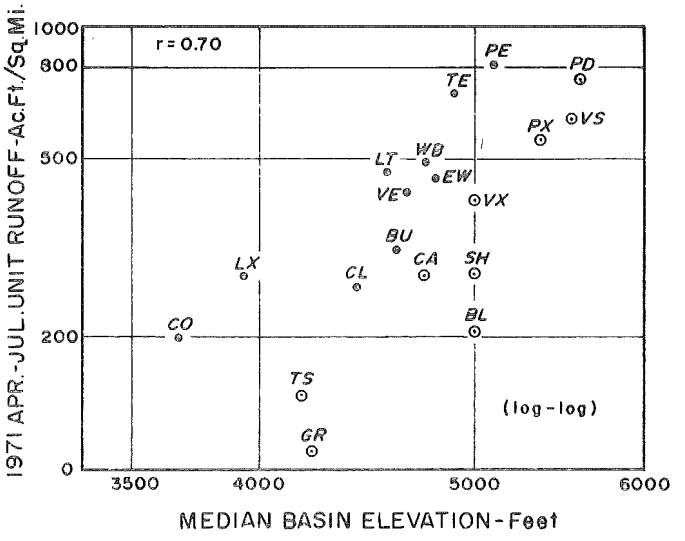


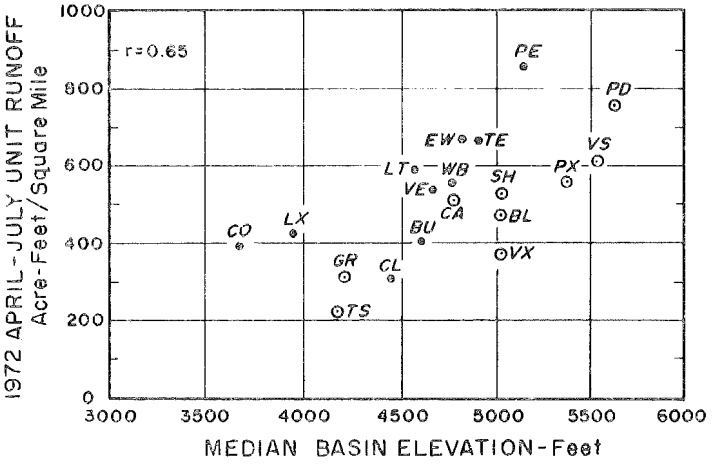
NORTH SUB-BASINS — •

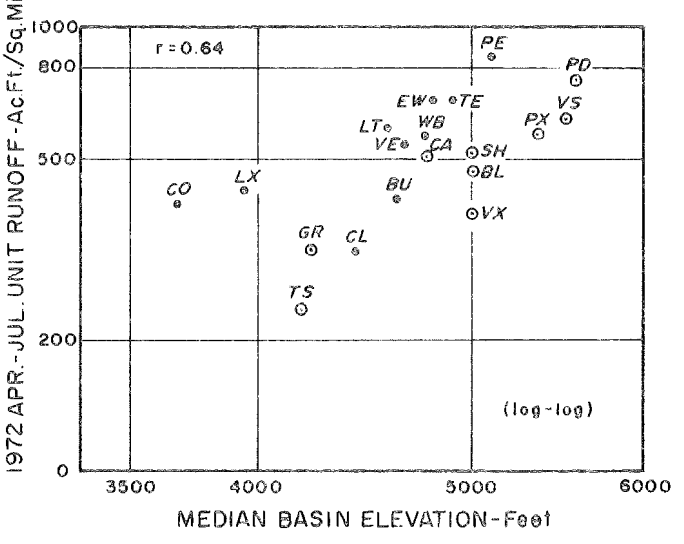
SOUTH SUB-BASINS — ⊙

CORRELATION OF PRECIPITATION AND MEDIAN BASIN ELEVATION. Figure 7.2









LINEAR

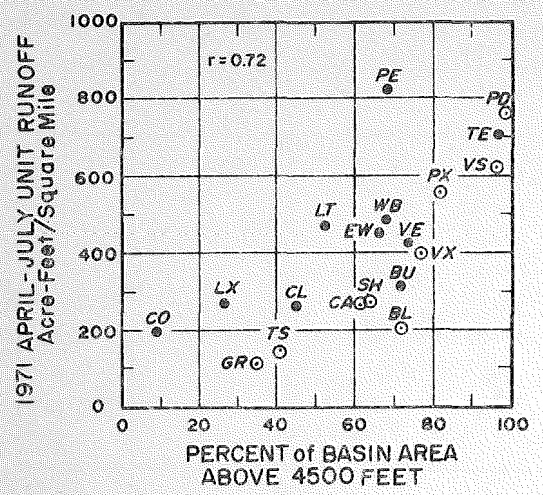
LOGARITHMIC

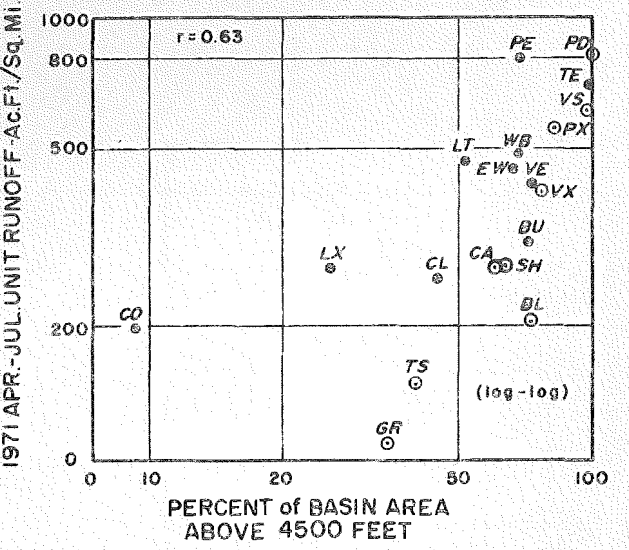
NORTH SUB-BASINS — ●

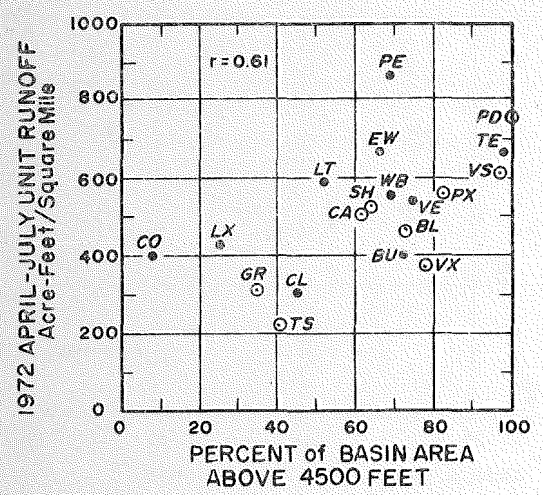
SOUTH SUB-BASINS — ⊙

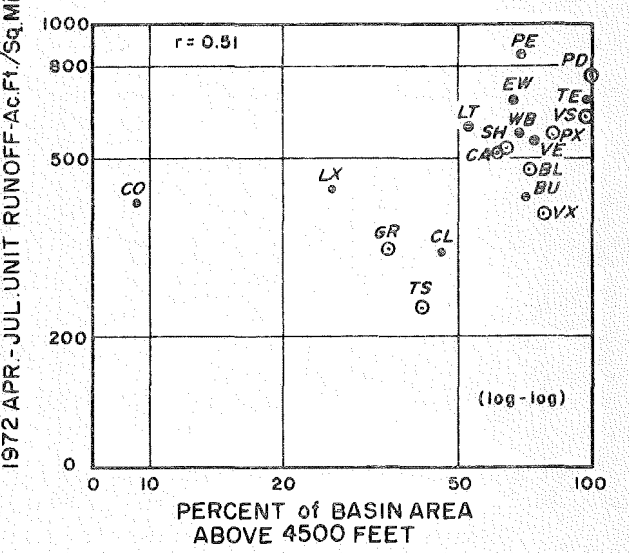
CORRELATION OF 1971 and 1972 RUNOFF WITH MEDIAN BASIN ELEVATION

Figure 7.3









LINEAR

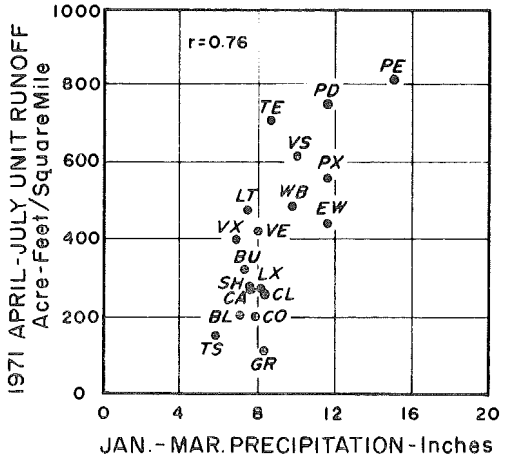
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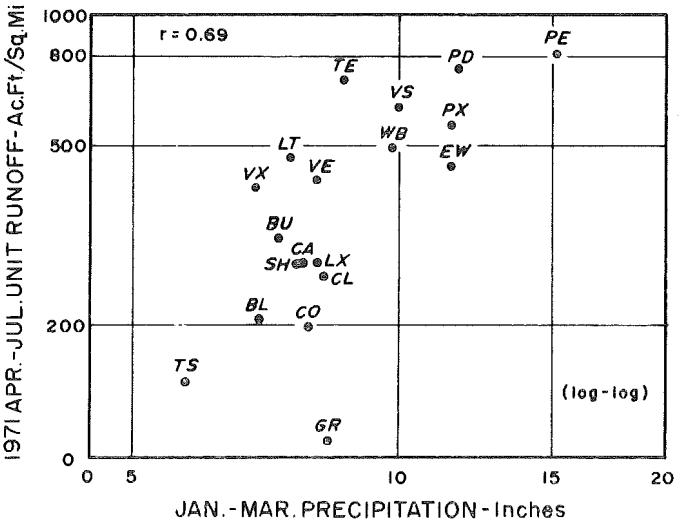
NORTH SUB-BASINS — •

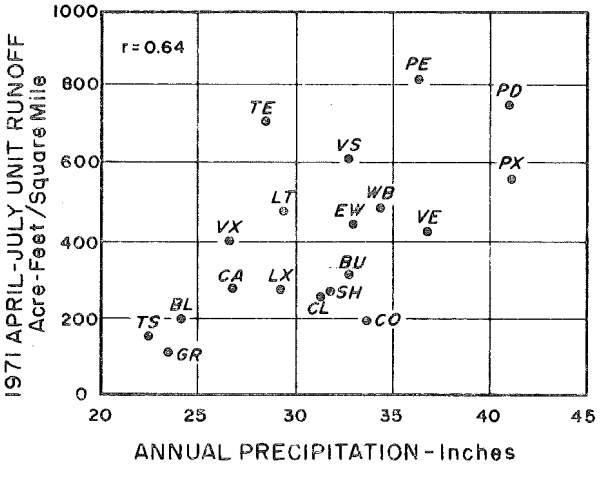
SOUTH SUB-BASINS — ⊙

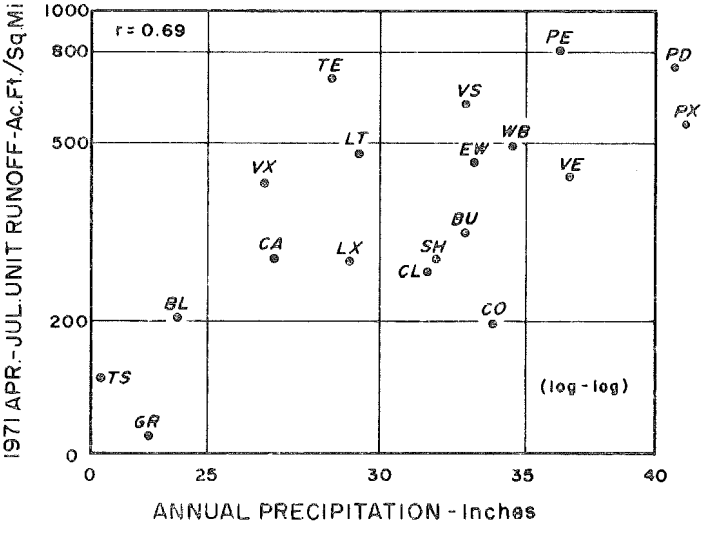
CORRELATION OF 1971 and 1972 RUNOFF WITH AREA ABOVE 4500 FEET

Figure 7.4







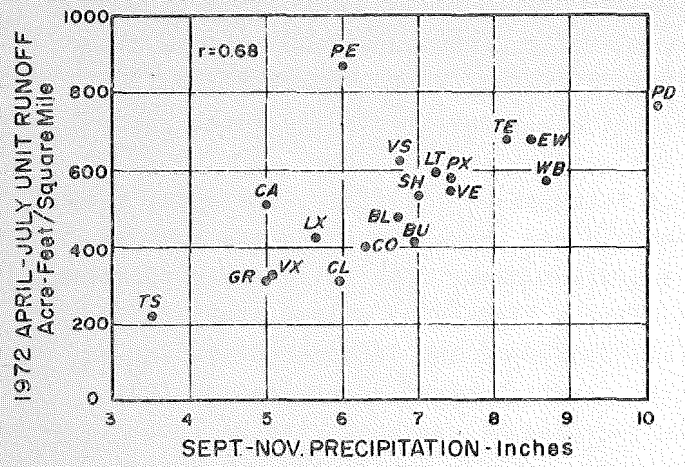


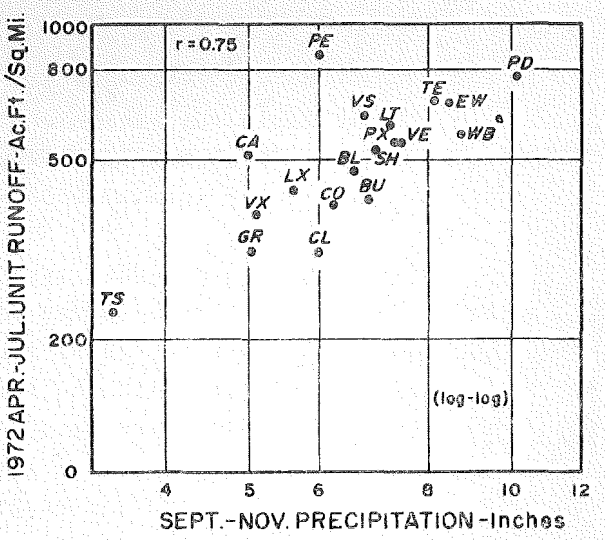
LINEAR

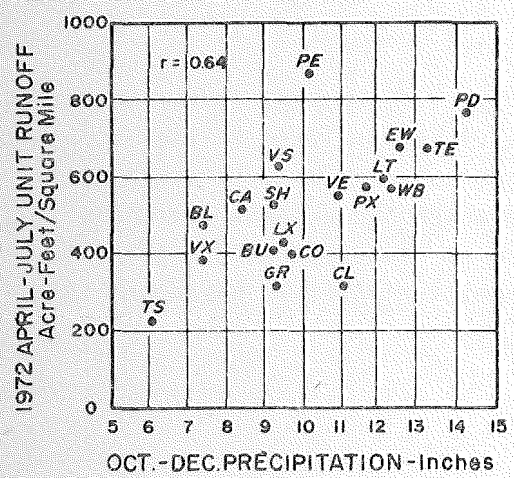
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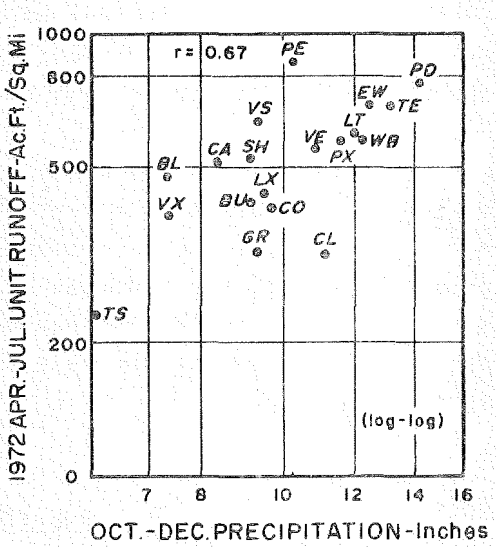
CORRELATION OF 1971 RUNOFF AND PRECIPITATION

Figure 7.5









LINEAR

LOGARITHMIC

CORRELATION OF 1972 RUNOFF AND PRECIPITATION Figure 7.6

7.4.1 Computer Program Description

The multiple regression analyses for this study were made using a computer program developed by the Hydrology Division, Water Investigations Branch, B.C. Water Resources Service, primarily for streamflow forecasting.

This computer program consists of five phases. Firstly, the input data can be modified or transformed with the second phase computing the sums of squares and cross products of the transformed data. The third phase performs a simple correlation with the output being a listing of means, standard deviations and simple correlations of all dependent and independent variables. The fourth phase produces and lists the coefficient of determination (R^2) for every possible combination of the independent variables chosen to predict the selected dependent variable. The final phase computes the regression equation and performs significance tests. The printed output contains the equation, the standard deviation of the X (independent variable) co-efficients, the T-test statistic, partial regression coefficients, multiple regression coefficient (R), coefficient of determination (R^2), standard error of the equation and the F value. Also listed are the observed data, the estimated data and the corresponding percent errors.

This program is not a stepwise regression type of program, as the selection of the best combination of variables is done by visual analysis of the output data. This enables one to eliminate any spurious correlations, to study the change in R with the addition or deletion of selected independent variables and to ensure that the independent variables are as "independent" as possible. The criteria on which the selection of significant variables is based are left to the hydrologist.

7.4.2 Analysis of 1971 and 1972 Runoff Data

On the basis of the preliminary analyses, described in Section 7.3, the variables listed in Table 7.5 were selected for inclusion in the final multiple regression analyses. Although some independent variables have low simple correlation coefficients with April-July unit runoff (SURO2), they were included as the preliminary analysis indicated they might be significant when used with other variables in a multiple regression equation.

Coefficients of determination (R^2) were derived by the computer for all possible combinations of up to four variables using the nine precipitation and basin characteristic variables available for 1971 and 1972. This was done for both untransformed and log-transformed data. Combinations which included highly intercorrelated variables were deleted from further analysis.

TABLE 7.5

SELECTED VARIABLES FOR MULTIPLE REGRESSION ANALYSIS

SYMBOL	DESCRIPTION	UNITS	MEAN	STANDARD DEVIATION	SIMPLE R WITH SURO2		REDUCTION FACTOR
					1971	1972	
SURO2	April-July runoff	ac.ft./ sq. mi.	1971-409 1972-520	209 161	- -	- -	x0.01 x0.01
PPN 1 PPN2 PPN A	Jan-Mar precipitation Apr-Jul precipitation Jan-Dec precipitation	inches inches inches	8.88 8.74 31.35	2.23 2.52 5.35	.76 .32 .64		x1 x1 x1
PPN SO PPN SN PPN OD	Sep-Oct precipitation Sep-Nov precipitation Oct-Dec precipitation	inches inches inches	4.24 6.72 10.22	1.01 1.56 2.14		.45 .68 .64	x1 x1 x1
AR45P	Area of basin above 4500 feet	% (of area)	63.9	24.4	.72	.61	x0.01
BELEV	Median basin elevation	ft.	4740	51	.70	.65	x0.01
BAZ	Azimuth from North (0 to 6.28)	radians	2.97	1.38	.37	.09	x1
BAZE	Azimuth from North (0 to 3.14)	radians	1.51	1.14	.33	.11	x1
SSP	Area of lakes and swamps	% (of area)	10.4	20.0	.30	.28	x1
LAT	Latitude north	Degrees	49.798	0.360	.05	.21	x1

Equations with up to four independent variables were analysed and the equation with the lowest standard error was selected as the most significant for each of four categories. These categories and the best equations are listed in Table 7.6 with the statistics of the equation. Also included are the statistics for the equation using the best single independent variable in each category in order to indicate the improvement made by adding more variables. The computer printouts for each equation in Table 7.6 are given in Technical Supplement III.

7.4.3 Discussion

In 1971, the inclusion of January-March precipitation provides a more reliable equation than when only basin characteristics are used as independent variables. In fact, the standard error is much less for the equation with January-March precipitation (PPN1) and area above 4500 ft. (AR45P) than for the equation with three basin characteristics. If precipitation is included, the log equation does not improve the original relationship. If only basin characteristics are used, the log equation is slightly more significant reducing the standard error from 33% to 27% for the same variables in both types of equation.

For estimating 1971 runoff for ungauged sub-basins, the equation A6 is the most significant. This equation explains 81% of the variation in runoff with a standard error of 24%. If one were to use only basin characteristics to estimate runoff, the log equation A4 would explain 77% of the variation with a standard error of 27%.

TABLE 7.6

MULTIPLE REGRESSION ANALYSIS RESULTS

YEAR	INDEPENDENT VARIABLES USED	EQUATION	R	R^2	STANDARD ERROR ac.-ft./sq.mi.	STANDARD ERROR %	EQU'N NO.
1971	Basin characteristics only	SURO2 = 3.310BELEV + 2.551LAT + 0.354BAZ - 139.713	.823	.68	133	33	A2
		SURO2 = 0.062AR45P + 0.122	.725	.53	148	36	A3
		LSURO2 = 4.220LBELEV + 38.476LLAT + 0.335LBAZ - 155.964	.879	.77	109	27	A4
		LSURO2 = 3.536LBELEV - 4.214	.701	.49	153	37	A5
	Precipitation included	SURO2 = 0.534PPN1 + 0.044AR45P - 3.482	.899	.81	97	24	A6
		SURO2 = 0.711PPN1 - 2.230	.760	.58	140	34	A7
		LSURO2 = 1.093PPN1 + 0.371LAR45P + 0.130LBAZE + 0.050LLSP - 2.603	.892	.80	107	26	A8
		LSURO2 = 3.536LBELEV - 4.214	.701	.49	153	37	A9
1972	Basin characteristics only	SURO2 = 2.779BELEV + 2.506LAT - 132.791	.830	.69	95	18	A10
		SURO2 = 2.066BELEV - 4.607	.653	.43	126	24	A11
		LSURO2 = 2.480LBELEV + 24.921LLAT + 0.025LSSP - 99.652	.877	.77	85	16	A12
		LSURO2 = 1.933LBELEV - 1.400	.658	.43	125	24	A13
	Precipitation included	SURO2 = 0.027PPNSN + 2.713BELEV + 2.419LAT - 128.336	.830	.69	98	19	A14
		SURO2 = 0.703PPNSN + 0.473	.681	.46	122	23	A15
		LSURO2 = 0.239LPPNSN + 2.076LBELEV + 18.864LLAT + 0.023LSSP - 75.803	.848	.72	98	19	A16
		LSURO2 = 1.023LPPNSN - 0.321	.680	.46	121	23	A17

SURO2	April-July unit runoff
BELEV	Median basin elevation
LAT	Latitude
BAZ	Basin Azimuth
BAZE	Basin Azimuth referenced to east
AR45P	Percent area of basin above 4500 feet
SSP	Percent area of basin covered by lakes and swamps
PPN1	January-March precipitation
PPNSN	September-November precipitation
L.....	Log transformed data

In 1972, the inclusion of September-November precipitation does not contribute to the significance of the equations. In the case of the log equations, adding September-November precipitation (PPNSN) actually increases the standard error. If precipitation is included, log-transformed data does not improve the equations over those using untransformed data. For equations using only basin characteristics, some improvement results but an additional variable is involved.

For estimating 1972 runoff, the best equation is A12 using log-transformed data. This equation explains 77% of the variation in 1972 runoff with a standard error of 16%.

In applying the above equations to estimate runoff from an ungauged sub-basin, some consideration should be given to the percent error of the estimated runoff over that observed for each gauged sub-basin as determined by the equation being used. For example, in Figure 7.7 the percent error for each sub-basin as determined by the 1971 equation A6 is noted at the center of each sub-basin. Although the density of gauged sub-basin is too small to obtain a detailed picture and there is no obvious regional pattern, it is apparent from this map that:

(a) estimated runoff for ungauged sub-basins in the Lambly Creek watershed could be 23% to 40% too low;

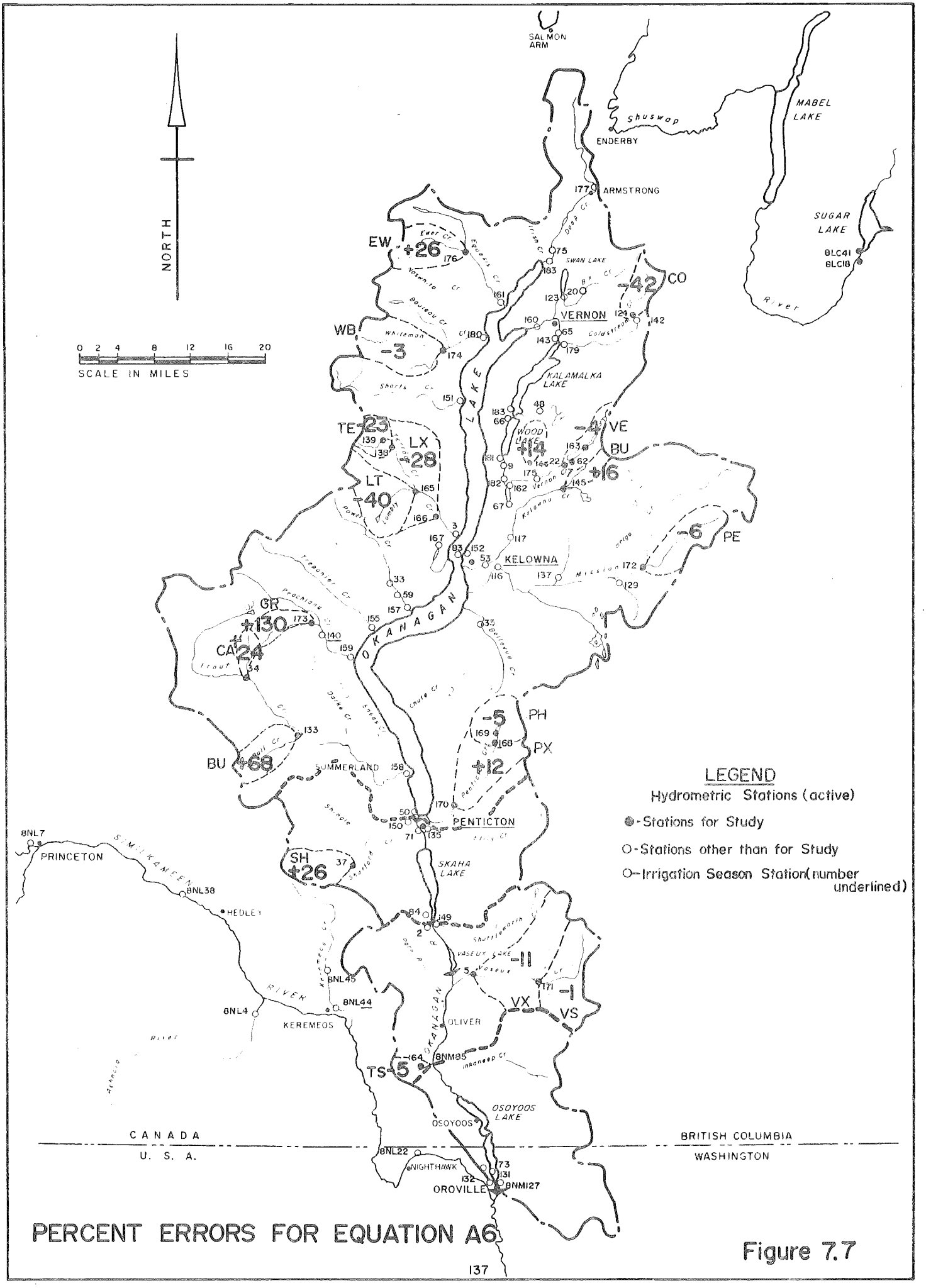
(b) estimated runoff for the portion of the Okanagan Basin on the west side from Peachland Cr. to Skaha Lake could be much too high;

(c) estimated runoff for the Coldstream Creek sub-basin is much too low and one should keep this in mind when using the equation to estimate runoff for a sub-basin in the Coldstream Creek-BX Creek region.

In Figure 7.8 the same information is illustrated for the 1972 equation A12. The percent errors are generally smaller than in Figure 7.7 but one can conclude that estimates in the Lambly Creek basin could be on the low side while those for sub-basins in the upper reaches of the Vernon Creek basin could be too high.

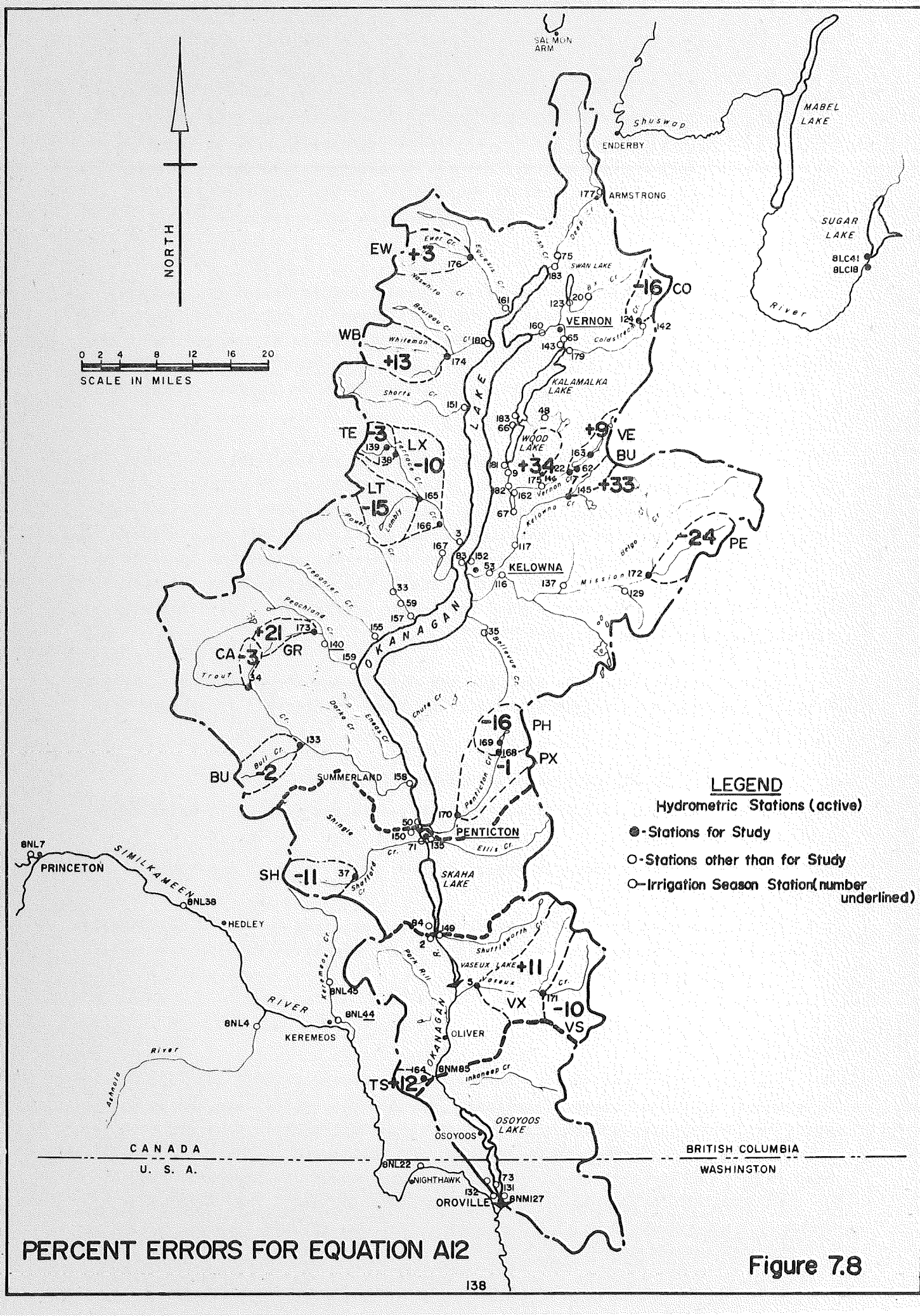
7.5 ESTIMATING MEAN ANNUAL RUNOFF

Although estimating the long-term mean annual runoff from only two years of April-July data is not too reliable, a method which could be used to do this for the period 1921-71 is suggested. First, the 1971-72 mean April-July runoff is used to estimate 1921-71 mean April-July runoff; then a factor based on median basin elevation is used to estimate annual runoff from April-July runoff.



PERCENT ERRORS FOR EQUATION A6

Figure 7.7



PERCENT ERRORS FOR EQUATION A12

Figure 7.8

There are 7 gauged sub-basins in the Okanagan Basin with five years (1967-71) of natural or near natural April-July streamflow data as noted on Table 7.7. Estimated Okanagan Lake natural tributary inflow data for the period 1921-71 show that the 1967-71 mean is 97% of the long-term 1921-71 mean which is close enough to use the 1967-71 mean as an estimate of the long-term mean.

1971 and 1972 April-July runoff for these 7 gauged basins are averaged and the ratio of the 1967-71 mean to the 1971-72 mean is calculated (Table 7.7). The departures are plotted on a map of the Okanagan basin at the centre of the corresponding sub-basin (Figure 7.9), and, by interpolation and extrapolation a ratio for different areas is arbitrarily assigned as designated by the hatching in Figure 7.9.

To estimate the mean annual runoff, the ratio of April-July to annual runoff is calculated for 12 gauged sub-basins in 1970 and 19 gauged sub-basins in 1971 with all-year streamflow records. These data are divided into 500 ft.elevation bands on the basis of median basin elevation and averaged for each band. (By averaging all the ratios regardless of whether for 1970 or 1971 more weight is given to 1971 ratios due to the greater number of sub-basins. This is roughly compensated for by the greater departure from average of 1970 runoff than for 1971 runoff).

Table 7.8 lists the data used and the results are shown in Figure 7.10. Although the method is unsophisticated, the graph in Figure 7.10 appears reasonable.

In summary, to estimate mean annual runoff:

(1) Average 1971 and 1972 April-July runoff estimates obtained from multiple regression equations.

(2) Multiply by ratio shown in Figure 7.9 for areas in which sub-basin is located.

(3) Divide the mean April-July runoff estimate obtained in Step 2 by the ratio in Figure 7.10 corresponding to the median basin elevation for the sub-basin to obtain mean annual runoff estimate.

7.6 CONCLUSIONS

The most significant basin characteristic related to 1971 and 1972 April-July runoff is median basin elevation. The addition of latitude, basin azimuth and percent area of lakes and swamps can reduce the standard error of the multiple regression equation by up to 11%. Estimated precipitation data used in conjunction with basin characteristics reduced the standard error by up to 8% in 1971, but by an insignificant amount in 1972. The use of log-

TABLE 7.7

RATIO OF 1967-1971 MEAN TO 1971-1972 MEAN APRIL-JULY RUNOFF

GAUGING NUMBER	STATION NAME	MEDIAN BASIN ELEVATION	APRIL-JULY RUNOFF (ac.ft.)					1967-71 MEAN	1972	1971-72 MEAN	1967-71 MEAN / 1971-72 MEAN
			1967	1968	1969	1970	1971				
8NM-138	Terrace	4,880	7,698	7,857	6,971	5,378	9,486	7,478	9,046	9,266	.806
8NM-020	BX	3,780	5,485	5,097	6,111	2,963	7,056	5,343	10,968	9,012	.593
8NM-138	Daves	4,260	1,342	1,358	988	669	2,782	1,428	3,544	3,163	.452
8NM-129	Joe Rich	4,260	3,353	2,939	3,311	1,427	4,154	3,037	5,015	4,584	.662
8NM-134	Camp	4,770	2,788	2,871	2,656	1,369	3,865	2,710	7,264	5,564	.487
8NM-037	Shatford	5,020	7,595	7,094	7,290	3,658	10,324	7,192	19,880	15,102	.476
8NM-015	Vaseux	5,240	39,788	25,525	41,870	17,004	49,020	34,642	48,000	48,510	.714

TABLE 7.8

RATIO OF APRIL-JULY TO ANNUAL RUNOFF

ELEVATION BAND	SUB-BASIN	MEDIAN BASIN ELEVATION	APR-JUL/ANNUAL 1970	APR-JUL/ANNUAL 1971	
5,000 - 5,500	Vaseux	5,250	.96	.94	
	Esperon	5,180	.94	.96	
	Shatford	5,020	.83	.92	
	Bull	5,010	.77	.94	
	Pearson		-	.91	
	Average		.85	.93	.90
4,500 - 5,000	Terrace	4,880	.92	.96	
	Camp	4,770	.70	.85	
	Ewer		-	.85	
	Whiteman Cr. ab. Bouleau Cr.		-	.92	
	Whiteman Cr. at mouth		-	.95	
	Lambly Cr. ab. Terrace Cr.		-	.90	
	Average		.81	.90	.88
4,000 - 4,500	Clark	4,450	.96	.96	
	Lambly Cr. bel. Terrace Cr.	4,400	.89	-	
	Joe Rich	4,260	.68	.79	
	Daves	4,260	.81	.91	
	Lambly Cr. bel. Bald Range Cr.		-	.92	
	Greata		-	.81	
	Testalinden		-	.82	
	Average		.83	.88	.86
3,500 - 4,000	BX	3,780	.79	.89	
	Coldstream	3,670	.76	.89	
	Average		.78	.87	.83

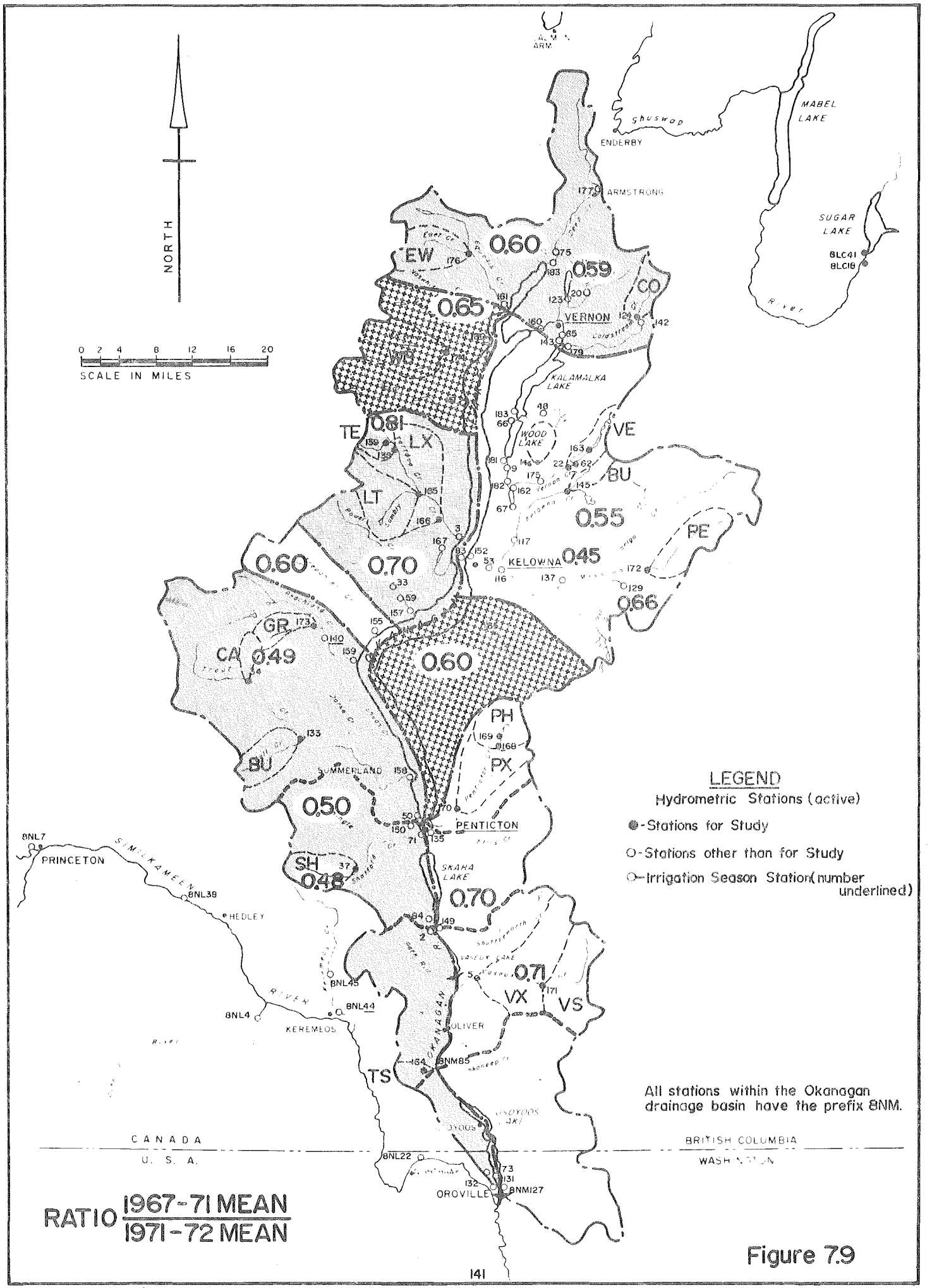
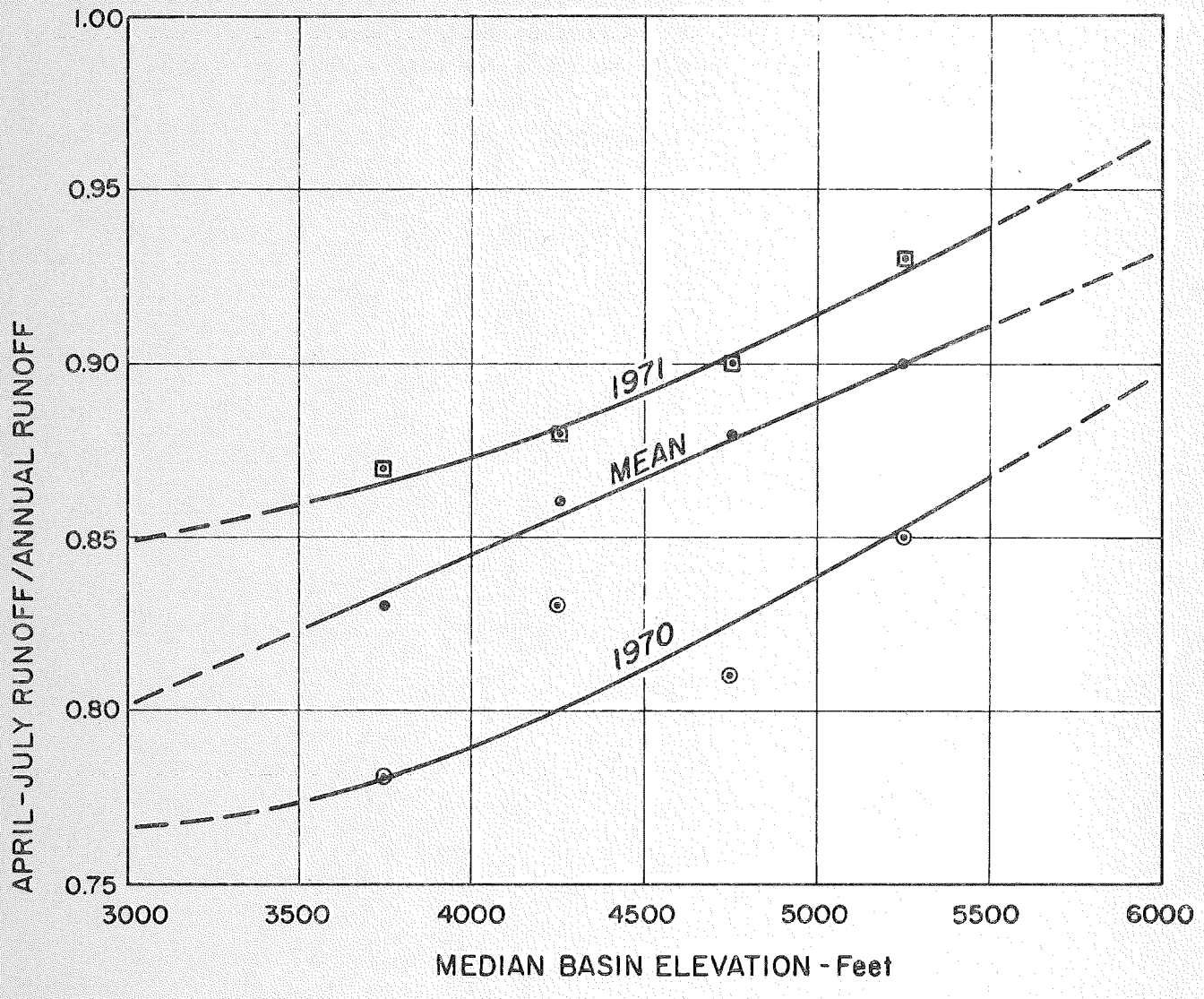

NORTH
0 2 4 8 12 16 20
SCALE IN MILES
ENDERBY
MABEL LAKE
SUGAR LAKE
ARMSTRONG
VERNON
KALAMALKA LAKE
WOOD LAKE
KELOWNA
SUMMERLAND
PENTICTON
SKAHA LAKE
PRINCETON
HEDLEY
KEREMEOS
OLIVER
OSOYOOS
OROVILLE
0.60
0.59
0.65
0.81
0.55
0.70
0.45
0.66
0.49
0.50
0.48
0.71
EW
CO
WB
TE
LX
LT
VE
BU
PE
GR
CA
PH
PX
SH
VX
VS
TS
LEGEND
Hydrometric Stations (active)
●-Stations for Study
○-Stations other than for Study
○—Irrigation Season Station(number underlined)
All stations within the Okanagan drainage basin have the prefix 8NM.
CANADA
U. S. A.
BRITISH COLUMBIA
WASHINGTON
RATIO 1967-71 MEAN / 1971-72 MEAN

Figure 7.9



VARIATION OF APRIL-JULY / ANNUAL RUNOFF
WITH MEDIAN BASIN ELEVATION

Figure 7.10

transformed data significantly improved the standard error for equations using only basin characteristics, but did not improve the error in equations which include precipitation variables.

The multiple regression analysis results for 1972 data were much better than for 1971 data. As 1972 was an extremely high run-off year, it is possible that this type of analysis is more reliable for high runoff years than low runoff years.

CHAPTER 8

Mainstem Operating Model

8.1 INTRODUCTION

This model was developed to provide comparative data on the performance of the various alternative schemes for managing water quantity in the mainstem of the Okanagan system, the mainstem being defined as Okanagan, Skaha, Vaseux and Osoyoos Lakes and the Okanagan River connecting them.

The model was a time simulation one operating on a monthly basis, using historic data for the period 1921-70. It was designed to answer questions of the "what if?" type, or rather "what would have happened to water levels in Okanagan Lake and flows in Okanagan River during the period of record under the various management alternatives, and under various levels of development?"

In practice every attempt is made to limit Okanagan Lake to a 4 ft. operating range and full use is made of inflow forecasts. Therefore, to keep the model operation as realistic as possible, quite elaborate operating rules and a forecast simulation procedure were built into the model. This meant that on occasions -as happens in practice, the normal upper level of Okanagan Lake was exceeded during very high inflow years. However, water levels in the lake were allowed to go as low as necessary to meet the demands - something which might not happen in practice - the minimum levels thus providing an indication of the merits of any particular management alternative.

An important component of the model was the arrangement of the computer output. This was provided both in a summary format in the form of frequency tables and in detail - in the form of lists of monthly lake levels and river flows. As a result, all the participants in the evaluation task, who had also helped formulate the alternatives, were able to examine the computer output at their leisure and make themselves as familiar with it as they wished. This was an important consideration for the evaluation process since many people tend to be inhibited and defensive when confronted with computer printout.

8.2 PRINCIPLES OF OPERATION

The basic time period of operation of the model was one month. This is the conventional time unit for this type of study and the basic data were available on a monthly basis. Although this had the effect of making

the model operation somewhat more "coarse" than occurs in reality when discharges can be adjusted at more frequent intervals in the light of the latest information, the results were considered adequate for this type of Study.

The assumption was made that all demands under any condition being modelled would be met at all times, irrespective of the level of Okanagan Lake. Thus, the lake level was used as the measure of the effect of different operating assumptions or assumed levels of development. All runs were made using data derived from the historically recorded data for the 50-year period 1921-70.

For the model, the Okanagan Basin was divided into four regions, namely:

Region 1: Okanagan Lake (all parts of the valley north of Penticton.)

Region 2: South end of Okanagan Lake to south end of Skaha Lake;

Region 3: South end of Skaha Lake to south end of Vaseux Lake (SOLID Dam);

Region 4: SOLID Dam to Water Survey of Canada Gauge 08NM-85 south of Oliver, the last river gauging station in Canada.

It was assumed that no storage was available in either Skaha or Vaseux Lakes (i.e., lake level remained constant). Minimum flows for agricultural purposes applied at all points along the river, but were only checked at the point at which flows entered and left the various regions. Fisheries flows only applied to Region 4 as there are no fish passage facilities at SOLID Dam.

Consideration was given to adding a fifth region to the model - from Oliver to the outlet from Osoyoos Lake at Oroville in Washington State. The Okanagan (now the Okanogan south of the Border) is joined by the Similkameen River just below Oroville and, as a result, the outflow from Osoyoos Lake is affected by high flows in the Similkameen. Because of rapid changes in flow in the Similkameen and the limited storage in Osoyoos Lake the monthly time period proved to be much too coarse for modelling this complex situation during the flood period. To have modelled the flows and water level changes in Osoyoos Lake accurately it would have been necessary to make computations on a daily or, possibly, weekly basis and this would have involved an enormous amount of additional computer output. Unfortunately there was not time to undertake this work, nor would the available data have "supported" it.

8.3 DATA

8.3.1 Basin Inflows

Historic inflows to the basin for the period of the study (1921-70) assuming no man-made diversions, storage, etc. were provided by the B.C. Water Investigations Branch (4). It was necessary to divide the inflows occurring

between Okanagan Falls and Oliver given in Reference (4) into the inflows between Okanagan Falls and SOLID Dam and between SOLID Dam and Oliver, and this was done on the ratio of drainage areas.

For each run, these "natural" inflows were then reconverted to whatever level of development was being modelled, e.g., for a run simulating 1970 conditions, the inflows for each month of the period 1921-1970 were calculated as though the consumptive demands (irrigation, domestic and industrial) and tributary storage changes estimated for the equivalent month in 1970 had taken place.

8.3.2 Consumptive Water Usage

Estimates of present and future populations, areas irrigated and industrial development were made by the Department of Fisheries and Forestry (33) (now the Department of the Environment). Figures for both water withdrawals and the volume consumed were given on an annual basis for four sub-regions. Since the boundaries of these regions did not coincide with those of the model some adjustment was necessary. The annual figures were converted to monthly ones by use of conversion coefficients derived by the B.C. Water Investigations Branch (3). These data are summarized in Tables 8.1 through 8.3.

TABLE 8.1
BASIC DATA

OKANAGAN RIVER CHANNEL CAPACITIES	RUNS 0 - 32	RUNS 33 - 42
Region 2	1680 cfs	1470 cfs
Region 3	2160 cfs	1890 cfs
Region 4	2720 cfs	2380 cfs
STANDARD ERROR OF FORECAST		
March - June inflow	90,100 acre ft.	
April - June inflow	93,100 acre ft.	
May - June inflow	59,900 acre ft.	
RETURN FLOWS (% of Withdrawals)		
Domestic	65	
Agricultural	48	
AREA OF OKANAGAN LAKE	84200 acres	
Starting elevation, March 1, 1921	1120.8 ft. (+1.0)	

TABLE 8.2

LEVELS OF DEVELOPMENT DATA

	REGION	PRESENT (1970)	2020 DEVELOPMENT SCENARIO				
			1	2	3	4	5
Population	1	67500	340100	275000	252600	340100	37500
	2	20440	22800	25400	16900	22800	25400
	3	1800	8100	8600	6500	8100	8600
	4	4500	11200	11700	8400	11200	11700
Domestic water withdrawals (Gallons/person/day)	1	200	220				
	2	200	230				
	3	200	230				
	4	200	230				
Area Irrigated (Acres)	1	39950	39020	25230	39020	47420	46000
	2	8250	2630	2400	2600	5780	2700
	3	1800	4970	4520	4910	4970	5080
	4	7700	420	380	820	2160	430
Farm duty of water ft/acre/year	1	2.5	2.36				
	2	3.0	2.90				
	3	3.25	5.26				
	4	4.0	5.06				
Industrial Consumptive Use (Acre ft/year)	1	3528	17870	19710	13260	17870	19710
	2	908	110	130	70	110	130
	3	57	30	40	20	30	40
	4	104	70	80	50	70	80

TABLE 8.3

COEFFICIENTS TO REDUCE ANNUAL FIGURES TO MONTHLY FIGURES

	REGION	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
Irrigation Withdrawals	ALL	0	0	.15	.25	.25	.25	.10	0	0	0	0	0
Irrigation Return Flow	ALL	.03	.04	.11	.14	.15	.14	.12	.09	.05	.05	.04	.04
Domestic Withdrawals	1 & 2	.05	.06	.10	.13	.16	.16	.08	.07	.05	.05	.05	.04
Domestic Withdrawals	3 & 4	.06	.07	.11	.13	.15	.13	.09	.06	.05	.05	.05	.05
Domestic Return Flow	ALL	.06	.07	.09	.10	.13	.12	.10	.08	.07	.06	.06	.06
Industrial Consumptive Use	ALL	.07	.07	.08	.09	.10	.11	.12	.08	.07	.07	.07	.07
Tributary Storage Change	ALL	0	.20	.30	0	-.16	-.18	-.16	0	0	0	0	0

8.3.3 Non-Consumptive Water Usage

It is necessary to release water into the Okanagan River, over and above that required for withdrawal for consumptive use, to maintain sufficient depth of water for wildlife and vegetation and to submerge the pump intakes. These are referred to as residual flows. Preferred residual flows were established by the Canada Department of Fisheries (34,35) for certain months to provide the best conditions during migration, spawning and incubation of the river's sockeye salmon. Further residual flow requirements were established throughout the year for other users and in the case of any conflicts it was assumed that the larger residual flow would be released. Since it would be possible to change the pump intakes to allow them to operate with smaller flows in the river several alternative minimum flows were modelled.

8.3.4 Shuswap River Flows

For the runs to assess the effect of importing water from the Fraser River system, it was necessary to know the flows which had occurred historically in the Shuswap River at Enderby. The available records were extended by the B.C. Water Investigations Branch by correlation and estimation and were made available for the model.

8.4 RULE CURVES FOR OKANAGAN LAKE

8.4.1 General

In the operation of Okanagan Lake and River there are two distinct phases each year. During the spring freshet, Okanagan Lake is operated as a flood control reservoir and then, for the remainder of the year, the operation is concerned with conservation of the water that has been stored during the freshet to supply the downstream demands. Due to limited channel capacity downstream of Penticton, it is usually necessary to draw down the reservoir each year prior to March 1 to provide sufficient storage space to accomodate the most likely spring freshets. Thus, before an operational model of the system could be constructed it was necessary to devise computer rule curves for the operation of the lake.

8.4.2 Flood Season Target Elevations (April - June)

If perfect forecasts were available, it would be a simple matter to set target elevations for each month of the flood season. However, due to the uncertainty of the forecasts, it was necessary to devise a method of determining target elevations which included a safety margin to allow for inaccurate forecasts. For study purposes, a method which would result in a 10% probability of exceeding the normal top level was selected. In practice, the exceedence

rate is less than this since, when there is a low inflow, the reservoir is unable to reach the target elevations and the possibility of flooding is thereby avoided. The following paragraphs describe the method developed to give the target elevations.

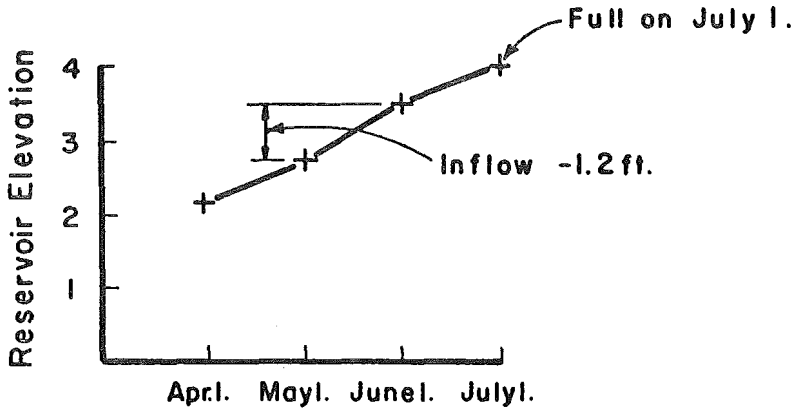
With hindsight it is easy to calculate the maximum level at which the reservoir could have been on any date during the runoff period without flooding occurring. This was done for each year of the period of the study by assuming that the major inflow was always complete by July 1 and that the reservoir was full at that time. The maximum possible reservoir levels on June 1, May 1 and April 1 to avoid flooding were then calculated for each year of the period of study by working backwards in time from July 1, knowing the actual inflow that occurred in each month and assuming that 101,000 acre ft. (1680 cfs months) was released from the lake. Obviously, if the lake is higher than this level, it is not possible to avoid flooding prior to the end of the runoff season.

It was then possible to plot the elevation on any date against the inflow to come for the remainder of the runoff season and, while there was some scatter from a straight line, a linear regression gave an equation linking date, inflow and lake level. This, however, assumed perfect knowledge of inflows which is unrealistic. Knowing the standard error of forecast for each of the March-June, April-June and May-June forecast periods, the inflows were adjusted by subtracting 1.28 times the standard error from the perfect forecast. This resulted in equations linking date, forecast inflow and lake level which ensured that flooding would not occur for 90% of the occasions. It was found that there was a reasonably good correlation if the maximum lake elevation on April 1 was plotted against March-June inflows, May 1 against April-June inflows, etc., it was therefore possible to set target elevations one month in advance given a forecast inflow for the remainder of the inflow season.

This procedure is illustrated in Figure 8.1.

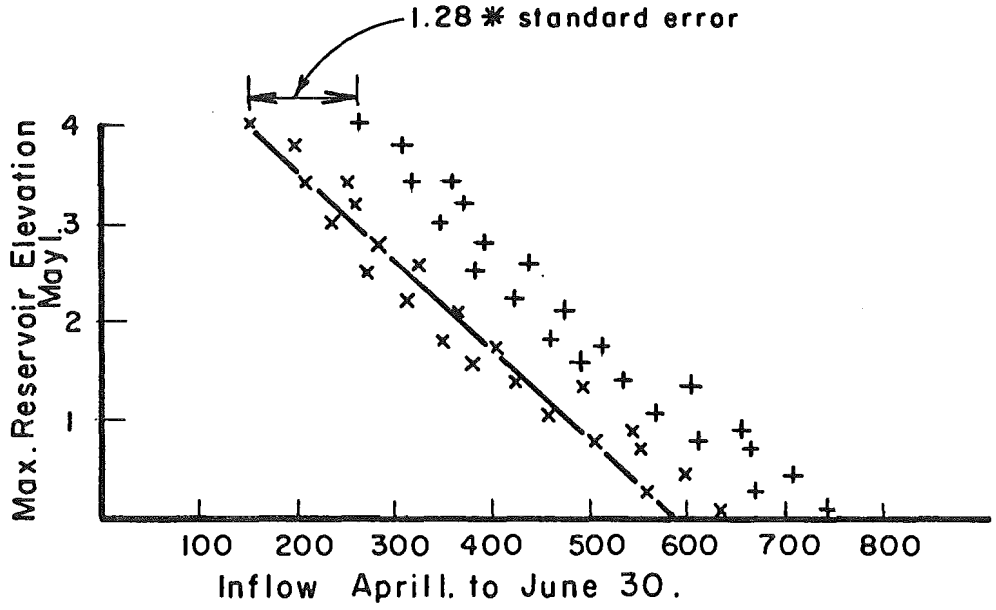
8.4.3 Target Elevations February-March

As the first forecast of seasonal inflow is not made until March 1 each year, it is necessary to set a level to which the reservoir should be drawn down by that time. Inspection of the historical lake levels showed that in recent years the March 1 elevation has averaged about 1 ft. above normal low water. The reservoir can then be drawn down further if the March-June forecast is for a high inflow as, in most years, the majority of the runoff occurs in May and June. However, a snow survey is done on February 1 and if this shows a very light snow covering in the valley, although no official forecast is issued, the lake is then held as high as possible for the next month. Accordingly, it was decided that, for the model, a target elevation of + 1.5 ft. (1121.3) would be used for February 1, and, at that time, if the forecast inflow



STEP 1

(One Such Computation per Year.)



STEP 2

(One Such Graph per Inflow Month.)

Procedure :

1. Plot '+' points from Step 1 .
2. Plot 'x' points - same elevation, but inflow reduced by 1.28 times standard error .
3. Do a linear regression on 'x' pts to get best line .
4. To use, enter graph with forecast inflow, read off target lake elevation. If reservoir is at this level, 90% chance of no flooding .

PROCEDURE for ESTABLISHING RULE CURVES for OKANAGAN LAKE

Figure 8.1

for the coming season were less than 200 kilo acre feet (kaf) the reservoir would be kept as high as possible. If the inflow were greater than 200 kaf then the reservoir would be drawn down to the March 1 target of + 1.0 ft. (1120.8) during February.

All target levels were used only if the reservoir would otherwise have reached higher elevations. At all times the minimum flows and downstream requirements were met irrespective of whether this meant that the reservoir was well below the target elevation.

8.5 GENERATION OF FORECASTS

If it were possible to predict the spring runoff accurately in advance, it would be a relatively simple matter to optimize the operation of the reservoir. However, there can be considerable discrepancies between the forecast and actual inflows, and it was necessary to devise some method of creating forecasts for the 50-year period of the study. (It is not possible to produce forecasts prior to 1948 based on present-day techniques, as the snow-course measurements, upon which the forecasting procedure relies very heavily, become too few and, prior to 1935, non-existent). The following paragraphs describe the method adopted to generate forecasts of Okanagan Lake inflows.

Forecasts for the last 23 years were generated using the techniques currently used by the Water Investigations Branch but including no hindsight data. In order to generate a forecast for any period of any year the following equation was used:

$$\text{Forecast for Period} = A + i\sigma$$

where A is the actual inflow to Okanagan Lake that would have occurred at the particular level of development being considered for the period of the forecast (i.e., the computed inflow for that period of that year adjusted for tributary storage, evaporation and consumptive use from the lake); σ is the standard error of the forecasts and i is a random normal deviate (i.e., a random number from a set with a mean of zero and a standard deviation of one). This gives a forecast of gross inflow to Okanagan Lake while the forecasts produced by the B.C.W.I.B. are of net inflow.

In order that the random number occurring for any forecast period did not have too great an influence on the results, each run of 50 years was repeated 10 times with different random numbers and the results printed are as percentages of the 10 runs thus generated. However, all runs with different conditions are comparable in that the random numbers used were identical in each case. (It is a property of any computer random number generator that, given the same "trigger" number, the computer will always produce the same set of random numbers). As a further constraint on the random numbers it was decided

that the sign of the random number should not change in any year. This constraint was added as it can be shown that if the March-June forecast is low, it is more likely that the April and May forecasts will be low rather than high.

8.6 BASIC OPERATION OF THE MODEL

8.6.1 General

The model is basically an accounting one. For each month, it computes the inflow to each of the sections by adjusting the natural inflow (which is given basic data) to account for withdrawals or upland reservoir storage changes appropriate to the conditions being modelled. Then it computes the minimum outflow from Okanagan Lake which would meet all the downstream demands appropriate to the condition being modelled and also the outflow required to meet the target rule. The larger of these outflows is used together with the adjusted inflows to compute the change in level in Okanagan Lake and hence the level at the end of the month. Despite its simple concept, the actual model with all its operating rules and accounting procedures is quite complex. A simplified flow chart is given in Figure 8.2 and the various operating rules are described below.

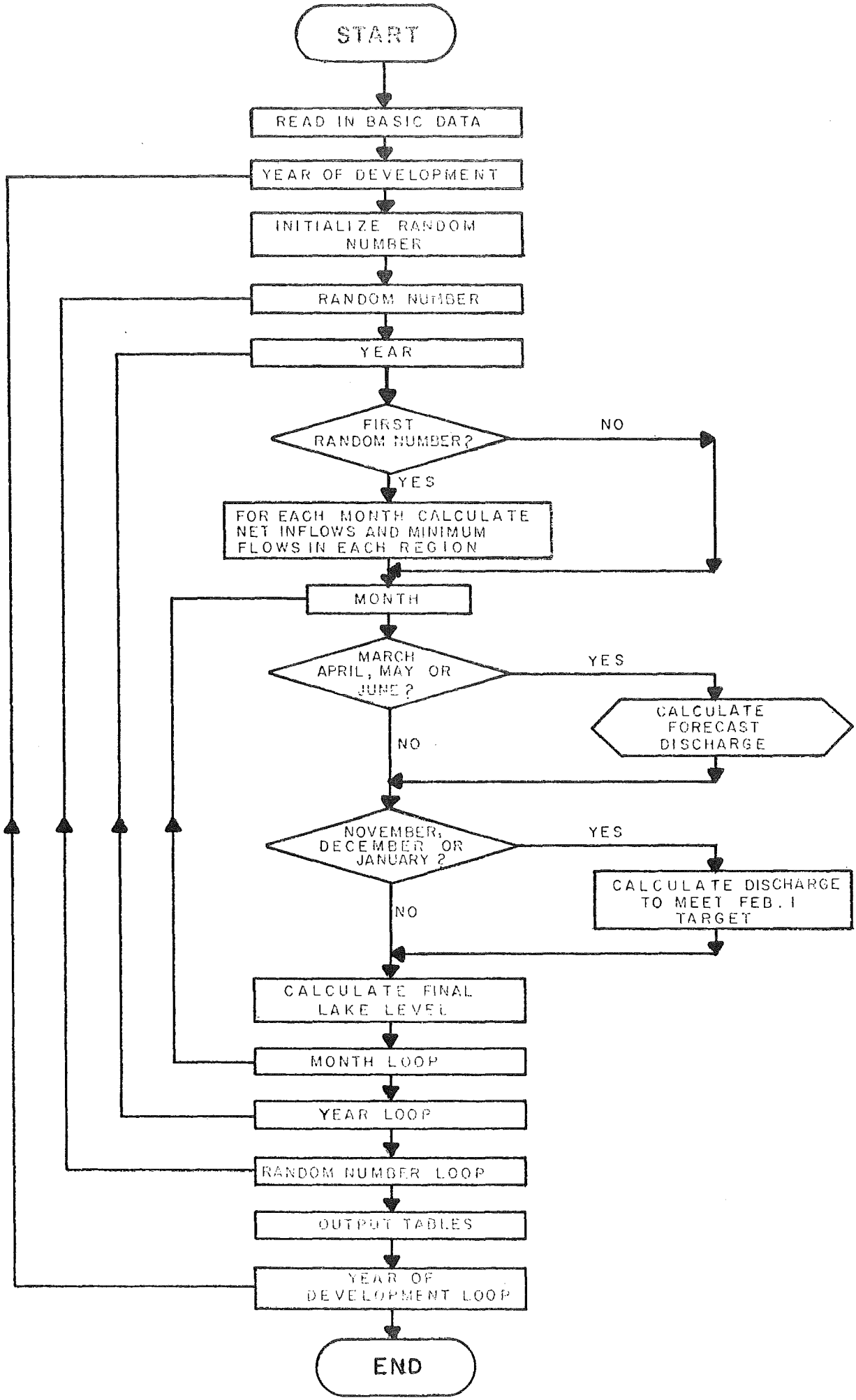
8.6.2 March-June Operation

During these months the reservoir is generally operated for flood control. Seasonal forecasts are made at the beginning of March, April and May of the anticipated inflows to Okanagan Lake to the end of the major spring inflow. For modelling purposes this was taken to be the end of June although, in practice, it is often mid-July before the "demands" exceed the supply. However, even if the lake is full on June 30, it is almost always possible to control lake in July.

As explained above, the previous year's operation brings the lake level to a predetermined March 1 level unless, due to lack of inflow, the reservoir is "naturally" below this level. The following steps are then undertaken.

(1) Using the forecast inflow a target elevation is set for April 1st, as described previously.

(2) Knowing the March 1st level, the target level for April 1st and assuming knowledge of the actual inflow in March, the release required to reach the April 1st target is calculated. (It was decided that the actual rather than the forecast March inflow would be used to compensate for the facts that in the model, the flow is only adjusted once per month and the target elevation, which is based on an uncertain forecast, is not changed during the month).



SIMPLIFIED FLOW CHART of MAINSTEM OPERATING MODEL Figure 8.2

(3) This discharge is then checked against the minimum flow required in the month - in March the minimum flow is generally controlled by the fisheries requirements plus the domestic and industrial requirements downstream while in April, May and June it is generally the minimum flow required in the river to meet irrigation and other downstream requirements. If the minimum flow is greater than the discharge required to meet the target elevation, then the discharge is set equal to the minimum flow.

(4) The discharge is then checked against the channel capacities in Regions 2, 3 and 4. The net inflow into each region is added to the discharge from Okanagan Lake in checking the capacities. If the channel capacity is exceeded at any point the discharge from Okanagan Lake is adjusted such that the maximum amount that avoids flooding at any point is released.

(5) Using the discharge calculated in steps 2, 3 or 4 above, the actual lake elevation at the start of the next month is computed.

(6) Steps 1 through 5 are repeated for April, May and June.

8.6.3 July-September Operation

During this period the reservoir is operated to conserve as much water as possible while satisfying the downstream requirements. These requirements include all withdrawals required for irrigation and other uses, required residual flows in the river and the minimum flow required to satisfy fishery requirements.

8.6.4 October-January Operation

The reservoir during this period is prepared for the forthcoming freshet. The difference between the October 1 lake level and the target elevation for February 1 plus the net inflows in these months gives a volume that has to be released in this period. Perfect knowledge of the net inflows is assumed as these are generally very small at this time of year and reservoir levels could, in practice, be adjusted by slight alterations to the discharges during each month. Once the discharge has been determined in this manner, the resulting flows are checked against the fishery requirements and channel capacity and adjusted if necessary.

8.6.5 February Operation

As discussed previously, indications of a very light snowpack are normally available at the beginning of February and if a much smaller than average runoff is anticipated the releases during February are restricted to those necessary to satisfy downstream demands and the fishery requirements. Otherwise the February releases from Okanagan Lake are set to reduce the lake level to the

March 1st target elevation of +1.0 ft. (1120.8) and, as always, checked against maximum and minimum flow restrictions.

8.7 CONDITIONS SIMULATED

8.7.1 General

More than 40 simulation runs were made using this model and this section briefly describes the various groups of runs made, the "rules" followed and the assumptions made. Comprehensive printouts of a few of these runs are given in Technical Supplement III.

8.7.2 Present Operating Conditions

As the model was to be used in the evaluation of alternatives, it was essential that, for comparative purposes, one run should simulate as closely as possible the present operating conditions. This was done in Run #0 and later updated in Run #33. This run satisfied all consumptive uses at all times, required a residual flow of 300 cubic feet per second (cfs) during the irrigation season but satisfied the sockeye fishery minimum flow requirements only when there was an excess of water. At other times the residual flow in the river was allowed to fall to 100 cfs in the period October through March.

8.7.3 Modified Operating Conditions

This group of runs (#1 through #9 and #34 through #38) involved no major structural or policy changes in the operation of the system. The principal change among the various runs concerned the residual flow assumed necessary to submerge the various intakes along the Okanagan River. Values of from 50 cfs to 300 cfs were simulated although it is doubtful if the lower figure would be sufficient to maintain Osoyoos Lake levels during the summer. The other variable in the runs was the salmon fishery flow requirement. Only in one run (#34) were both the maximum and minimum flows rigidly observed and in one other (#38) were they partially observed as the desired restriction to flows of less than 1000 cfs has a very marked effect on the lake levels in times of flood conditions. In many of the runs, however, the fishery minimum flow requirements were observed at all times. When the fishery flows were not considered the residual flow in the river was allowed to drop to 50 cfs.

8.7.4 Emergency Operations

In years in which the inflow is considerably less than normal, one method of conserving the available water would be to cut back on the amount released at Penticton below that theoretically required to satisfy demands and some runs

of the model (#10 through #15) simulated such "emergency" conditions. An emergency was defined as the failure to reach a predetermined level by the end of June. In practice this would be apparent some time in advance so, in the computer runs, emergency conditions were deemed to exist if the forecast made on May 1 indicated that the reservoir would not reach a predetermined level by July 1st. The actual lake level on July 1st was also checked and the emergency conditions said to exist if the reservoir were low. Emergency conditions were deemed to have ended if:

(a) the actual July 1st lake level were greater than the predetermined level;

(b) releases from Penticton were controlled by flood control measures rather than by downstream requirements;

(c) a forecast for the next July 1st showed that the reservoir would exceed the predetermined level.

If emergency conditions existed, then the flows from Penticton were cut back by a certain percentage. This blanket reduction in the release was made on the total release that would have otherwise been made and was not intended to represent a reduction in any specific use. In the model, however, the withdrawals from the river were not cut back so that the effect that appears in the results is that the residual flows in the river have decreased.

8.7.5 Importation of Water

(a) General

While proposals have been made to import water to the Okanagan from sources other than the Shuswap River, for the purposes of the computer simulations involving importation of water, it was assumed that water was diverted from the Shuswap River in the general locality of Enderby.

Two types of diversion from the Shuswap are possible; with and without storage. With no storage on the Shuswap, water could only be diverted when available. If there were sufficient storage on the Shuswap, diversions to the Okanagan could be made when required. This diversion with storage was never programmed for the computer although a few hand calculations were made.

(b) Diversion Rules

For the computer simulation, rules were required to determine both when to initiate and when to stop diversion and to determine the amount of water available for diversion from the Shuswap at any time.

Diversion was initiated when "emergency conditions" as defined above occurred and terminated when the lake level reached the "mean" level for any month. The mean level was taken as the average level over the 50 year simulation in run #8. Run #8 was chosen as the base since all the diversion runs were made with residual flows of 300 cfs and with minimum fishery flows satisfied.

After much discussion as to how much of the Shuswap flow should be considered as available for diversion, the following rule was adopted:

> "Diversion from the Shuswap River can only be made when the flow in any one month as measured at Enderby is in excess of the mean of the five lowest flows recorded for that month. At no time shall water be diverted that would cause the flow at Enderby to drop below this figure except in May, June and July when not less than 1500 cfs shall be left in the Shuswap."

In runs #16-25 this rule was applied to every month, but it was later agreed that, in general, it was probably unwise to allow for any diversion in December, January or February due to likely icing problems and that diversion in July and August would likely be difficult due to low flows. This was thought to provide the maximum reasonable flows to the Okanagan, but it should be emphasized that it was a rule devised only for the computer simulation. Having this rule it was a simple matter to construct a table showing the flows available for diversion for each month for the period of the study.

Some runs (#26 to #28, #39 and #41) were made assuming that diversion would only occur during the three month spring freshet while other runs (#29 to #31, #40 and #42) assumed that diversion could occur in seven months during the year.

(c) Diversion Capacity

Various diversion capacities were used in the simulations, with mean monthly capacities of 300 to 900 cfs being tried. The actual peak capacity would probably have to be somewhat larger to assure these mean monthly figures.

8.8 RESULTS

8.8.1 General

This section will only consider the results in a very general manner. The implications of the simulation are discussed elsewhere and the full output from a few runs are reproduced in Technical Supplement No. III. As all simulations satisfied all consumptive users, the only consistent measure of the effect of any simulation is its effect on Okanagan Lake and this is the only result presented in this section.

3.8.2 Layout of Results

To be readily assimilated and to cut down the volume of paper produced by the program, the majority of the output was presented in the form of frequency tables. The tables given are as follows:

(a) a frequency analysis of Okanagan Lake levels by months and by years in 0.5 ft. increments. The figures given are percentages of months over the 50 years of record and 10 random numbers. The figures under the heading "YEAR" are also as percentage of months.

(b) the maximum, minimum and mean elevations of the lake for the 50 year period of record by months.

(c) three tables containing frequency analyses of discharges from Okanagan Lake and SOLID Dam and discharges at Gauge 8NM-85 near Oliver. Again, the figures given are percentages of months over the 50 years of record and 10 random numbers. Each table is followed by the maximum, minimum and mean discharges in cfs for the 50 year period of record.

(d) for the runs in which run of the river diversions were included, a frequency analysis of diversions. In this case the percentages are of months in which diversion took place or would have taken place had sufficient water been available in the Shuswap. As in the other frequency tables, maximum, minimum and mean values for each month are given and these are of the months in which diversion was attempted.

(e) a table showing Okanagan Lake levels and discharges at Penticton for each month of the 50-year period of the study. The figures given are for the first random number loop only. It should be noted that the minimum flows always appear in this table, because, if the reservoir is low, the release from the lake is identical for all random numbers as the release is to satisfy downstream requirements rather than to meet flood control requirements and is independent of the forecast inflow.

N.B. All lake levels in this table refer to the end of the month.

(f) in the cases in which the run of the river diversion was operating, an additional line is given for each year in the table described in (e) above. This is blank if no diversion was attempted and shows the actual flows diverted (including zero if no water were available from the Shuswap).

(g) a table showing the flows in the Okanagan River at the Oliver gauge for each month of the 50-year period of the study. The figures given are for the first random number loop only.

8.8.3 Okanagan Lake Levels

Table 8.4 shows the minimum level reached by Okanagan Lake during the worst drought (1929-31) in the 50 year period simulated and also, because of the severity of this condition, the minimum level of the lake at the end of the 1926 drought is also given. All figures given in this table are for the simulation of the 1970 level of development. All computer runs also gave output for 1990 and 2020 levels of development but as the projections used were preliminary the results are now superceded.

Table 8.5 gives the same information for runs #37 to #42 which simulate the 2020 level of development under five different scenarios. For description and discussion of these scenarios see Technical Supplement III.

8.9 CONCLUSIONS

This model, developed to simulate the operation of the Okanagan mainstem system, proved to be a most powerful tool in the evalution of the various water management policies examined. Although the model was quite sophisticated internally, by keeping the output relatively simple and short it was found that evaluators from all the disciplines involved in the study were able to understand and use the results. This provided a common base from which all facets of the evaluation could be assessed and was the necessary link in the complicated process of reaching a consensus.

TABLE 8.4

EXTREME LOW OKANAGAN LAKE LEVELS AS CALCULATED BY COMPUTER SIMULATIONS

1970 LEVEL OF DEVELOPMENT

RUN #	IRRIGATION SEASON RESIDUAL FLOW (Cfs)	SALMON FISHERY FLOWS(?)		EMERGENCY CONDITIONS		DIVERSION		LOWEST LEVEL ATTAINED BY OKANAGAN LAKE**	
		Min.	Max.	L*	X*	CAPACITY	MONTHS OF DIVERSION	1929-31	1926
1	50	No	No	N/A	N/A	N/A	N/A	+0.6	+1.0
2	50	Yes	No	N/A	N/A	N/A	N/A	-1.6	+0.3
3	100	No	No	N/A	N/A	N/A	N/A	-0.6	+0.7
4	100	Yes	No	N/A	N/A	N/A	N/A	-2.0	+0.2
5	150	No	No	N/A	N/A	N/A	N/A	-2.0	+0.2
6	150	Yes	No	N/A	N/A	N/A	N/A	-2.5	0.0
7	200	Yes	No	N/A	N/A	N/A	N/A	-3.0	-0.2
8	300	Yes	No	N/A	N/A	N/A	N/A	-4.1	-1.5
9	300	Yes	No	N/A	N/A	N/A	N/A	-4.0	-1.2
10	300	Yes	No	N/A	N/A	N/A	N/A	-3.5	-1.2
11	300	Yes	No	1121.8	30	N/A	N/A	-2.4	-0.9
12	300	Yes	No	1121.8	50	N/A	N/A	-1.2	-0.4
13	300	Yes	No	1121.3	10	N/A	N/A	-3.7	-1.4
14	300	Yes	No	1121.3	30	N/A	N/A	-2.9	-0.9
15	300	Yes	No	1121.3	50	N/A	N/A	-2.0	-0.6
26	300	Yes	No	N/A	N/A	300	3	-2.6	-0.8
27	300	Yes	No	N/A	N/A	600	3	-1.1	-0.5
28	300	Yes	No	N/A	N/A	900	3	+0.4	-0.3
29	300	Yes	No	N/A	N/A	300	7	-1.6	-0.2
30	300	Yes	No	N/A	N/A	600	7	+0.3	+0.4
31	300	Yes	No	N/A	N/A	900	7	+0.5	+0.4
32	100	Yes	No	N/A	N/A	300	7	+0.3	+0.2
33	300	No	No	N/A	N/A	N/A	N/A	-3.2	-0.6
34	300	Yes	Yes***	N/A	N/A	N/A	N/A	-3.5	-1.8
35	300	Yes	Partly***	N/A	N/A	N/A	N/A	-4.4	-1.8
36	300	Yes	No	N/A	N/A	N/A	N/A	-4.5	-1.8

* Releases at Penticton reduced by x% when lake failed or was forecast to fail to read elevation L.

** Oft = 1119.8 ft. above mean sea level. Normal lowest lake elevation.

*** Maximum levels attained by Okanagan Lake:

Run #34 6.5 ft.
Run #35 5.3 ft.
Most other runs 4.9 ft. ± 0.1 ft.

TABLE 8.5

EXTREME LOW OKANAGAN LAKE LEVELS AS CALCULATED BY COMPUTER SIMULATION

2020 LEVELS OF DEVELOPMENT

RUN #	PROJECTION	IRRIGATION SEASON RESIDUAL FLOW	MINIMUM SALMON FISHERY FLOWS(?)	DIVERSION		LOWEST LEVEL ATTAINED BY OKANAGAN LAKE*	
				CAPACITY	MONTHS	1929-31	1926
37	1	300	No	N/A	N/A	-4.3	-1.6
	3	300	No	N/A	N/A	-3.8	-1.0
	5	300	No	N/A	N/A	-4.9	-2.1
38	1	100	Yes	N/A	N/A	-4.0	-1.2
	3	100	Yes	N/A	N/A	-3.5	-0.6
	5	100	Yes	N/A	N/A	-4.5	-1.7
39	1	300	No	500	3	-1.5	-0.3
	3	300	No	500	3	-1.3	-0.3
	5	300	No	500	3	-1.2	-0.7
40	1	300	No	500	7	-1.1	+0.5
	3	300	No	500	7	-0.5	-0.3
	5	300	No	500	7	-1.5	+0.1
41	1	100	Yes	500	3	-1.8	-0.6
	3	100	Yes	500	3	-1.3	-0.2
	5	100	Yes	500	3	-2.3	-1.0
42	1	100	Yes	500	7	-1.2	-0.1
	3	100	Yes	500	7	-0.7	+0.2
	5	100	Yes	500	7	-1.0	-0.1

* 0 ft. equivalent to 1119.8 feet above mean sea level. Normal lowest lake level.

CHAPTER 9

Budgeting Hydrologic Model

9.1 INTRODUCTION

This model, an elaborate and ambitious one, was developed in an attempt to simulate the main hydrologic processes in the Okanagan Basin on an areal and on a year-round basis. The aim was to provide a method for simulating runoff in the tributaries - to provide more accurate data for planning purposes than the other models could provide, to add to the understanding of hydrologic processes in the basin and to help in developing a model for forecasting runoff into both Okanagan Lake and the tributaries for operating purposes.

To deal with areal variation, which is considerable within the Okanagan Basin, the basin was broken down into 5-kilometer squares as an alternative to the more conventional breakdown into elevation bands. The squares were the same as those used by other agencies and described in Chapter 2. Separate hydrologic budgets were kept for each of the 383 squares used and the runoff was then routed to the tributaries and the mainstem system. Each square was assumed to behave as a unit; for example, it could be either completely snow-covered or free from snow but not partly covered, a necessary assumption to keep the number of computations feasible, but a reasonable one given the number of squares. Use of the squares allows the simulation of runoff in each tributary as well as in the whole basin. Also, by using the same squares and basic data bank as the other agencies, the option to eventually combine thebest features of all models is left open.

The model was designed to run on a year-round basis - a single 5-month period from November through March and daily for the remainder of the year. The winter was treated as a single period in order to take advantage of snow course data, a concept originally developed by Obedkoff (2). Snow courses measure accumulated winter precipitation and provide the only reliable precipitation data from high elevations from which the bulk of runoff originates. The main reason for trying to run on a year-round basis instead of the more normal seasonal basis was to obtain estimates of the soil moisture deficit throughout the valley at the beginning of the runoff season, a key variable for forecasting purposes. It was thought that the soil moisture deficit could be more easily estimated from a model than from direct measurements.

The simpler the model the easier it is to develop and the smaller the need for data to back it up. The aim of modelling is thus to develop the

simplest model with the smallest number of empirical parameters which will give adequate results. The first step was therefore to specify what would constitute adequate results. Ideally the model should be able to simulate runoff in all tributaries from meteorological data, thus providing data for planning purposes and also, by using meteorological forecasts, provide forecasts of runoff for operating purposes. It was recognized that this ideal was unlikely to be achieved but it was hoped to go as far towards it as possible. Also, in the course of development, simulation models can provide considerable insight into hydrologic processes and, by pointing up anomalies, suggest areas for further refinement, and show where additional data are needed and where gaps in knowledge exist.

Model building is very much an art, but an art which can be assisted by an efficient strategy. The strategy developed for the tributary models, including the EVOP procedure described in Chapter 3, was used for this model. Again, the emphasis was placed on arranging the program and the output to provide as much assistance as possible to the hydrologist - by making it easy to change parameters or equations in the model, and by providing output in a form which gave objective measures of the adequacy of any particular model and also allowed weaknesses to be diagnosed. In this way the hydrologist was able to interact with the model, use his experience and intuition to the full, benefit from insights provided by the model but not sub-consciously fool himself in his enthusiasm to obtain good results.

Using the above procedure a very full study was made in which more than 300 different combinations or parameters and equations were tried in a ruthless objective pursuit of the optimal model. In the end it was concluded that there is simply not sufficient understanding of basic hydrologic processes in mountainous areas and that there are too many unknown parameters to be able to use this type of model with confidence. The model considered 24 variables as unknowns, and thus it would be possible to arbitrarily fix quite a few of them and jiggle the remainder to produce acceptable results - a procedure which might work well most of the time since inaccuracies tend to cancel one another out but which leaves the possibility of very unpleasant surprises on occasions. A large number of the unknowns relate to the effect of elevation - how does precipitation vary with elevation? how does evaporation vary with elevation?, etc. These problems are not peculiar to British Columbia but they are critically important to an understanding of hydrology in British Columbia, where there is so little flat land. The model thus helped pinpoint a weak area where additional research is desperately needed in B.C.

Although the budgeting model was not completely successful in that it could not be made to run continuously from year to year and thus define the soil moisture deficit at the beginning of the runoff season, it has been possible to use the model (with hindsight) to simulate runoff throughout the basin in 1970, a near record dry year and in 1968, a near average year. These

data can be used for planning purposes. Also considerable insight into the hydrology of the basin has been gained which should be of value to future investigators, areas where additional research needs to be done have been identified and the model, together with its development procedure, provides a good base for continuing the search for better methods in hydrology.

9.2 INPUT DATA

9.2.1 General

Vast amounts of data were required for the model, particularly during the development phase. To handle these efficiently a data bank was established and data stored in the following categories:

(1) Physiographic data describing the basin - this was stored in the form of physical information about each of the 383 squares into which the basin was divided. These data did not change from one run to the next.

(2) Values of the parameters in the model. These were arranged such that they could easily be changed. Initial values were estimated from previous experience and these were refined by trial using the EVOP procedure during the development phase.

(3) Hydrologic data - meteorologic, snow survey and hydrometric data for the period November 1966 through October 1970, the base period used for development of the model. The hydrometric data were used for comparison with the computed runoff. To compute runoff data for any other period meteorologic and snow course data would be required for that period.

The main sources of data are given in Chapter 2 and the actual form of the input data is described in the following sub-sections.

9.2.2 Physiographic Data

For each of the 383 grid squares defining the Okanagan Basin in Canada, the following data are read in:

(a) The mean elevation above mean sea level.

(b) The latitude of the centre relative to an assumed datum.

(c) The area of lakes.

(d) The area of land within the Okanagan Basin.

(e) The value of Danard's constant P_{mH} for the winter period November through March and also November through February. This was used in the calculation of winter precipitation.

(f) The proportion of the square in each of the tributary sub-basins to which it contributes.

Also for each of the meteorological stations and snow courses used in the model the station elevation and latitude are given.

9.2.3 Model Parameters

In attempting to get reasonable agreement between the model and the "recorded" natural flows it was desirable to be able to adjust several parameters very easily and quickly. Two cards at the beginning of the program are used for this. The parameters read in included:

(a) Two factors for varying the initial soil deficit.
(b) Five factors used to change the amounts, distribution or rate of evaporation.
(c) Two factors affecting the snowmelt pattern.
(d) Three factors for varying runoff characteristics.
(e) Four factors for varying the assumed soil and groundwater behaviour.
(f) A factor for varying the precipitation/elevation relationship.

9.2.4 Hydrologic Data Used in Model Development

For the summer periods (March through October) the following meteorologic data were read in on a daily basis.

(a) Maximum and minimum temperatures at Penticton A, Kelowna A, Vernon Coldstream Ranch, Joe Rich Creek, McCulloch, and (in 1970 only) Brenda Mines and Mt. Kobau.

(b) Precipitation at the same stations.

(c) Evaporation and maximum air temperature at Summerland (the only long-term evaporation station).

For the winter periods (November-through February or November through March at the option of the program user) the following data were read in:

(a) Total precipitation during the period for all meteorologic stations in the basin for which records existed.

(b) All March 1 and April 1 snow course records.

(c) Daily maximum temperatures at the stations listed above. These were used for estimating the winter melt at the snow courses.

For comparison purposes daily natural inflows to Okanagan Lake for a study period (November 1966 through October 1970) were estimated from available records.

9.3 MODEL COMPONENTS

9.3.1 General

The model is designed to operate year round. This is achieved in two stages with the winter accumulation period (four or five months at the user's option) treated as a block and the remainder of the year treated on a daily basis. Separate hydrologic "budgets" for snowpack and soil moisture are kept for each square and a large part of the model consists of equations to transfer water from one budget to another and eventually to runoff input. The runoff input is then aggregated into either the tributary sub-basin or to the basin as a whole and is routed through storage. This section describes the assumptions about the processes which occur and gives details of the best equations developed to model them. Values of the constants which were either tested or derived as a result of deliberate trial are shown with an asterisk. The model proved to be extremely sensitive to some and these are shown with a double asterisk.

9.3.2 Precipitation

(a) Winter - The majority of the runoff in the Okanagan Basin results from the melting of snow which has accumulated, during the previous winter. The accumulated amount of snow is thus the most important input to the model.

Precipitation is measured on a daily basis throughout the year at meteorological stations but, with few exceptions, these are all located in the populated valley bottom and not at the higher elevations which receive the most snow. The snow on the ground is measured at snow courses which are mainly located at high elevations on February 1, March 1, April 1, May 1, May 15 and June 1 and these give information about the total amount of precipitation which has fallen in the accumulation season less that which fell as rain and that which has already melted. With the scarcity of basic data, it was important to use all that was available from both the meteorologic stations and the snow courses. Since this could only be done on a seasonal basis it was necessary to treat the winter period as one "block."

Both types of data had to be converted to a common base. This involves determining a standard accumulation period and adjusting the snow course data to account for snow which had already melted. An examination of past records showed that temperatures usually dropped rapidly below freezing about November 1. This date was therefore adopted as the beginning of the accumulation period. Since good snow course data is available for both March 1 and April 1, the option to use either date as the end of the accumulation period was left open. Precipitation at the meteorological stations was totalled for the accumulation period. The snow course data were adjusted for melt by adding on an amount equal to .04* inches times the total degree days above 42° based on maximum temperatures during the winter period, the number of degree days being computed after lapsing temperatures

at 4°*F per thousand feet from the recorded values at the stations listed in Section 9.2.4. As a result of these computations a set of compatible point estimates of total winter precipitation at both high and low elevations was obtained.

Extensive studies were next made to find relationships between the total winter precipitation and physiographic variables for later use to estimate values of winter precipitation for each of the squares. Eventually the following equation was found to be best:

$$P_{ij} = a_j + b_j P_{mHi} + C_j E_i/(6.5 - E_i) \qquad (9.3.1)$$

where

P_{ij} = total precipitation during the accumulation period;
P_{mHi} = the factor developed by Danard(5) to account for the upward transport of water vapour in a mountainous area. Danard's monthly figures were aggregated for the period;
E_i = elevation in thousands of feet (of either a station or a square)

} for year j and point or square i

a, b and c = constants determined by linear regression for any particular year.

The constants were determined by regression from the adjusted total precipitation values. Usually correlation coefficients (r^2) were greater than 0.9 and standard errors less than 3". This equation is then used with the appropriate physiographic parameters to compute the total winter precipitation on each square.

Summer - Summer precipitation proved extremely difficult to model, partly because of the lack of high elevation data and partly because of the scattered pattern of summer rains. In summer, rains mostly result from local storms rather than the widespread frontal storms of winter. After extensive analyses of available data, mainly on a monthly basis, the following formula was selected.

$$P_{ij} = P_{m,j}(0.48* + 0.52*L_i/L_m)\ (a + (1-a)E_i/E_m) \qquad (9.3.2)$$

where

P_{ij} = daily precipitation on square i on day j;
P_{mj} = mean daily precipitation at base stations on day j;
L = latitude;
E = elevation;
a = a constant = 0.3*

i = index of square
j = index of day
m = mean

The constant "a" was one of the parameters arranged to be easily changed in attempts to close in on the "best" value. Values between 0 and 0.7 were tried - but it was almost impossible to be sure of the best value.

Daily precipitation on each square is computed from the above formula. If the mean temperature at the square is below 32°F the precipitation is added to the snowpack budget. If above 32°F it is added as water input to the soil moisture budget.

9.3.3 Evaporation

Most of the precipitation which falls on the Okanagan Basin is "lost" through evaporation and transpiration (an annual average of about 19 out of 22 inches). Evaporation, used here in the sense of evapotranspiration, is a complex phenomenon about which little is known particularly under conditions other than agricultural crop land, where it has been extensively studied. For this model the concepts of potential evaporation - where the water supply is not limiting, and actual evaporation - which depends on both the potential evaporation and the available soil moisture are used. The approach is first to compute potential evaporation on each square, and then, from this and the available soil moisture, compute the actual evaporation. Considerable efforts were devoted to attempting to model evaporation accurately, since it is such a large item in the hydrologic budget. However, after intensive studies, consultations with eminent authorities in the field and attempts to use the model as a research tool, it has been concluded that the state of knowledge is such, and there are so many interrelationships that the unknowns can only be resolved with additional field measurement. The following paragraphs describe the methods, assumptions and equations used in the final model. These may appear somewhat simplistic but they are the best available at this time.

(a) Potential evaporation

Potential evaporation was estimated for each square for each day from the following equation:

$$PE_{ij} = PE_{mj} - a(T_{mj} - T_{ij}) \qquad (9.3.3)$$

where

PE_{ij} = potential evaporation on square i, day j

PE_{mj} = lake evaporation on day j computed as pan evaporation recorded at Summerland CDA times 0.7;

T_{ij} = max. temperature on square i, day j;

T_{mj} = max. temperature at Summerland, day j;

a = an "elevation effect" constant (.004*).

When the ground was snow covered it was assumed that evaporation could still take place - since the trees would be growing and transpiring, but at a reduced rate. This is a much debated but unresolved point among experts, and illustrates the type of deficiency in basic knowledge which plagues hydrologic modelling. The following equation was used:

$$SPE_{ij} = k(PE_{ij} - 0.13\ M_{ij}) \qquad (9.3.4)$$

where

SPE_{ij} = potential evaporation from square i, day j when the square is snow covered;

PE_{ij} = potential evaporation from square i, day j;

M_{ij} = melt on square i, day j;

k = a constant (0.4**)

The figure of 0.13 above is the approximate ratio of the latent heat of melting to the latent heat of evaporation.

(b) Actual Evaporation

Actual evaporation depends on many inter-related factors but these are usually summarised in the potential evaporation - the "driving force" - and the "soil moisture" which characterises the "ability to respond." After many trials, a two layer soil moisture model was adopted primarily to account for the phenomenon that, after rainfall, evaporation is at a high rate even though most of the soil may be quite dry. The top layer is assumed to be quite thin (0.25* inches). The following equations are used:

$$AE_{ij} = PE_{ij} \quad \text{if } PE_{ij} \leq SMU_{ij} \tag{9.3.5}$$

or

$$AE_{ij} = SMU_{ij} + (PE_{ij} - SMU_{ij})K^{Dij} \quad \text{if } PE_{ij} > SMU_{ij} \tag{9.3.6}$$

where

AE_{ij} = actual evaporation from square i, day j;

PE_{ij} = potential evaporation from square i, day j;

SMU_{ij} = soil moisture in upper layer of square i, beginning of day j;

D_{ij} = soil moisture deficit in lower layer of square i, beginning of day j;

K = a depletion constant (0.7*).

9.3.4 Budgets

Separate "budgets" are kept for the snowpack and for the two soil moisture layers for each square, on a seasonal basis in winter and daily for the remainder of the year.

(a) Snowpack

The snowpack at the end of the winter accumulation period is computed for each square as described in Section 9.3.1. Thereafter a running budget is maintained for each day:

$$SP_{i,j+1} = SP_{i,j} + P_{i,j} \tag{9.3.7}$$

if $T_{ij} \leq 32°F$.

or

$$SP_{i,j+1} = SP_{i,j} - M_{ij} \qquad (9.3.8)$$

where

$M_{ij} = k(T_{ij} - 32)$ if $T_{i,j} > 32°F.$

where

$SP_{i,j+1}$ = snowpack on square i, day j+1;

$SP_{i,j}$ = snowpack on square i, day j;

$P_{i,j}$ = precipitation on square i, day j (see section 9.3.2);

$T_{i,j}$ = mean temperature on square i, day j;

M_{ij} = melt on square i, day j (cannot exceed $SP_{i,j}$)

k = a melt constant (0.04*)

(b) Soil Moisture Upper Layer

This layer is assumed to be full (0.25* inches) at the beginning of the daily accounting period. Daily accounts are kept with the following equations:

$$SMU_{i,j+1} = SMU_{i,j} + P_{i,j} + M_{i,j} - PE_{i,j} \qquad (9.3.9)$$

subject to

$P_{i,j} + M_{i,j} \leq k$

$P_{i,j} = 0$ if $T_{i,j} \leq 32°F.$

$0.25 \geq SMU_{i,j} \geq 0$

where

$SMU_{i,j}$ = soil moisture in upper layer
$P_{i,j}$ = precipitation
$T_{i,j}$ = mean temperature;

} on square i, day j;

k = a constant (0.3* inches) defining the maximum daily infiltration into the soil.

When the rate of infiltration K (0.3*) is exceeded, the excess (or $P_{i,j} + M_{i,j} - 0.3$) goes to the surface runoff account. When the upper layer is full (0.25*) the excess goes to the lower soil moisture layer and the upper layer is maintained at its full level for that day.

(c) Soil Moisture Lower Layer

The lower layer contains all the soil moisture storage with the exception of the top 0.25* inches. The model was set up to model soil moisture on either a continuing year round basis or to be initialised at the beginning of November at the user's choice.

A continuous budget is maintained on a daily basis during the summer period using the following equations:

$$SM_{i,j+1} = SM_{i,j} + E_{i,j} - AE_{i,j} - GWR_{i,j} \qquad (9.3.10)$$

where

$$GWR_{i,j} = G_{max} \cdot K^{D}{}_{i,j} \qquad (9.3.11)$$

subject to $SM_{i,j} \leq$ Soil Capacity (10* inches)

where

$SM_{i,j}$ = soil moisture in lower layer;
$E_{i,j}$ = Excess from soil moisture upper layer;
$AE_{i,j}$ = Actual evaporation from equation 9.3.6;
$GWR_{i,j}$ = Ground water recharge;'
$D_{i,j}$ = Soil Deficit = Capacity - SM_{ij}
G_{max} = Maximum rate of groundwater recharge (0.3* inches)
K = A constant (0.7* inches)

) for square i day j

The equation for groundwater recharge is based on the assumption that when the soil was saturated water would go to groundwater at its maximum rate but that as the soil dries the amount going to groundwater rapidly diminishes. When the soil moisture capacity is reached the excess inflow is transferred to the surface flow account.

For the winter period the total seasonal melt is computed as .04* times the number of degree days above 42°F based on maximum temperatures for the square in question, subject to not exceeding the total snowfall on the square. This total is then divided by the number of days to obtain the average daily melt. This is then run through the soil moisture budget on a daily basis in the same way as described above for the summer period.

9.3.5 Runoff

In hydrology an enormous amount of effort has been devoted to modelling the runoff process and there are many models in existence. Many deal with short-term events and only model part of the process, an example being the unit hydrograph approach where water which infiltrates into the ground is simply considered "lost" from the short-term point of view. For this study a model which accounted for all the runoff was considered essential. To cover the wide range of response, runoff has to be split into 2 or 3 components which are treated separately. There has been much argument about the relative merits of 2 and 3 component models, the former considering only surface runoff and groundwater while the latter also considers interflow. In favour of the two component model are simplicity, doubt

about whether interflow actually exists, the fact that proponents of 3 components suggest that with snowmelt only interflow and groundwater runoff occur (2 components), the facts that 2 components provide adequate accuracy and that the model has been used before (Caseco Consultants). These were persuasive and a two component model was adopted. Daily input to runoff is obtained as the excess from the soil moisture budgets for the squares. This is distributed between the two runoff accounts (surface and groundwater) and aggregated to give the total input to each account for either a complete tributary or the total basin. These inputs are routed through storage and then combined to give the total daily runoff. The process is described in more detail below.

(a) Groundwater Runoff

The input to groundwater is obtained from the lower soil moisture budget as described in section 9.3.4. To account for the fact that part of the basin is underlain by almost impermeable rock it is assumed that only a fraction of the calculated input actually goes to groundwater, the remainder being "diverted" to surface runoff. The groundwater input was routed through storage using the following equation:

$$GRO_j = K \cdot GRO_{(j-1)} + (1-K)\, GWR_{(j-m)} \qquad (9.3.12)$$

where

$$GWR_{j-m} = f \cdot \sum_i GWR_{i,j-m} \qquad (9.3.13)$$

GRO_j = groundwater runoff on day j;

GWR_{j-m} = basin groundwater recharge on day j-m;

$GWR_{i,j-m}$ = groundwater water recharge on day j-m, square i;

K = recession constant (.98*);

m = groundwater lag (10* days);

f = ground factor (0.5*)

(b) Surface Runoff

Input to the surface runoff account came from three"sources".

(i) excess input to the soil over and above the infiltration rate (section 9.3.4(b));

(ii) excess to the soil moisture over and above its capactity (section 9.3.4(c));

(iii) water "transferred" from the groundwater account (a) above.

The inputs were again aggregated for either a sub-basin or the whole basin and routed through storage using:

$$RO_j = c \cdot RO_{j-1} + (1-c)w_j \qquad (9.3.14)$$

where

RO_j = surface runoff on day j;

w_j = input to surface runoff day j;

c = a recession constant (0.7*)

(c) Total Runoff

The total runoff on any day is obtained by simply adding the two components. To obtain the net runoff it is necessary to subtract evaporation from the lakes. This is done with the following equation:

$$LE_{i,j} = PE_{i,j} * (1 - \frac{X}{2} + j * \frac{X}{m}) \qquad (9.3.15)$$

where

$LE_{i,j}$ = is the lake evaporation on square i on day j;

$PE_{i,j}$ = is the potential evaporation as calculated for square i on day j;

m = is the number of days in the summer period;

and

X is an "evaporation distribution" constant (0.4*).

This equation has the effect of reducing the theoretical small lake evaporation at the beginning of the season and increasing it in the latter part of the year. This allows for the fact that Okanagan Lake and the other main lakes are considerably larger than the lakes for which the use of small lake evaporation figures are intended and take a long time to warm up.

It is likely that a large body of water such as Okanagan Lake loses an appreciable volume of water during the winter through evaporation due to the warmth retained in the lake water (36). 5* inches were allowed for this.

9.4 OUTPUT FROM THE MODEL

Great care was taken with the program output to ensure that it met the objectives of providing information that would help the hydrologist assess the latest model, diagnose its weaknesses and learn from it, but without submerging the whole office in paper. It was found that with the large number of parameters involved it was not possible to use the computer interactively as had been done with the tributary model described in Chapter 3 without putting too much stress on the operator. The batch process was used and the EVOP squares to assess the results and optimize the parameters were plotted by hand. This allowed time for analysis of the output and due deliberation about what to do next.

The parameters in the model were broken down into two groups - those which affect the volume of runoff and those which affect its timing. With the EVOP procedure it was possible to check that there was little interaction between the two sets. Monthly, seasonal and annual totals of the differences between computed

and recorded flows served as indices for the parameters affecting runoff volume while coefficient of variation type indicators, together with a visual comparison between computed and recorded hydrographs and between mass curves of computed and recorded flows provided indicators of the adequacies of the parameters which affected timing. With the EVOP procedure it was possible to use as many of the indicators as desired and find the direction of change most likely to bring improvement.

At the beginning of each run basic information about the run was printed out.This included the time at which the computation was made, the period of record being investigated, values of the parameters being tried and notes to permit the method of calculation to be identified. In addition any or all of the following outputs could be selected for any run:

(1) A geographical plot of the area in each square within a sub-basin. An example is shown in Figure 9.1.

(2) A geographic plot of the area of lakes and swamps within each square of any particular sub-basin.

(3) A hydrograph of computed and recorded runoff plotted on a three-day basis with the normal printer plot output. This provided a visual assessment of any particular run.

(4) Plotted mass curves of computed and recorded flows, again on a three-day basis with the printer plot. This, together with the hydrographs, gave an indication of the accuracy of the modelling of runoff timing.

(5) A detailed day-by-day budget of the main components of runoff for any tributary or for the main basin. An example is given in Table 9.1. This provided detailed information to track down any anomalies.

(6) A table of all the input meteorological data - temperature precipitation and evaporation. This permitted easy checking for errors in the input.

(7) Printout of monthly total recorded and computed flows and the differences between them and also totals for the summer season, the winter season as a whole and for the whole year.

(8) Error indicators for each month of the year in the following form:

$$\left(\frac{\sum d^2}{n}\right)^{1/2}$$

where

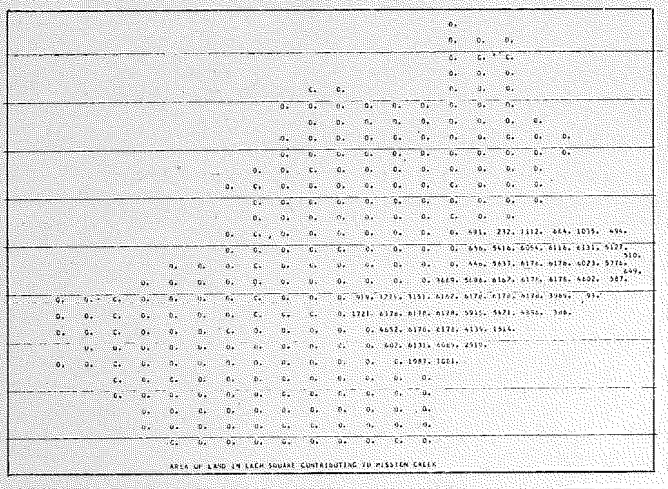
d = difference between computed and recorded daily flow;

n = number of days.

TABLE 9.1

COMPARISON OF COMPUTED AND RECORDED RUNOFF FOR: WHOLE SUB-BASIN NORTH OF PENTICTON

DAY	VOLUME (AF) GOING TO GROUNDWATER RECHARGE (GWR)	VOLUME(AF) OF ROUTED SURFACE WATER RUN-OFF (SWRO)	VOLUME (AF) OF ROUTED GROUNDWATER RUNOFF (GWRO)	TOTAL RUNOFF (SWRO+GWRO + LAKE PRE-CIP.) (TOTRO)	VOLUME (AF) LOST THROUGH LAKE EVAPO-RATION (EVAP)	NET VIRGIN RUNOFF (TOTRO-EVAP.) (NVRO)	CUMUL-ATIVE "NVRO" (RECRO)	RECORDED RUNOFF (CUMVRO)	CUMUL-ATIVE "RECRO" (CUMRRO)	"RECRO" MINUS "NVRO" (DIFF)	CUMUL-ATIVE "DIFF" (CUMDIFF)
JUNE 1970											
1	1745	5803	953	6756	2657	4099	2360	126129	134691	-1739	8561
2	1552	7080	997	8077	3183	4894	3202	131023	137893	-1692	6869
3	1374	7825	1034	8921	3173	5748	6569	136771	144462	821	7690
4	1204	7042	1070	8112	3144	4968	8254	141739	152716	3286	10976
5	1045	6114	1100	7214	3031	4183	2303	145922	155019	-1880	9096
6	955	5806	1127	6933	2109	4825	2303	150747	157322	-2522	6574
7	876	5324	1150	6567	2086	4481	2303	155229	159625	-2178	4396
8	844	4931	1171	7774	2183	5591	-224	160819	159401	-5815	-1419
9	823	4342	1189	6987	1377	5610	-75	166429	159326	-5685	-7104
10	799	3281	1203	4484	1864	2620	3293	169049	162619	673	-6430
11	718	2513	1214	3738	2287	1451	6662	170499	169281	5211	-1219
12	641	2126	1221	4008	2924	1083	5819	171582	175100	4736	3517
13	624	2037	1224	3880	501	3379	-76	174961	175024	-3455	62
14	609	1926	1223	4006	1716	2290	-916	177252	174108	-3206	-3144
15	591	1782	1220	3302	741	2561	767	179812	174875	-1794	-4938
16	564	1692	1214	2907	1992	914	4085	180727	178960	3171	-1768
17	524	1649	1208	2868	1759	1108	717	181835	179677	-391	-2159
18	460	1532	1200	2733	2730	3	3194	181838	182871	3191	1032
19	406	1446	1193	2639	2640	-2	3354	181836	186225	3356	4388
20	357	1453	1185	2638	2850	-212	2647	181624	188872	2859	7247
21	349	1462	1176	2938	1059	1879	965	183502	189837	-914	6334
22	309	1306	1165	2471	3231	-760	1807	182742	191644	2567	8901
23	274	1224	1154	2378	3006	-628	125	182115	191769	753	9653
24	250	1101	1143	2244	2539	-295	-719	181820	191050	-424	9229
25	232	958	1132	2090	2490	-400	-709	181420	190341	-309	8920
26	224	919	1121	2401	1069	1332	985	182752	191326	-347	8573
27	211	851	1109	2341	2133	209	143	182961	191469	-66	8507
28	206	713	1096	2057	965	1092	983	184052	192452	-109	8398
29	193	557	1082	1639	1752	-113	-705	183939	191747	-592	7807
30	176	457	1068	1525	2569	-1044	-2272	182895	189475	-1228	6578
TOTALS	19132	85252	34342	126625	65760	60866	57144			-3722	



AREA OF LAND IN EACH SQUARE CONTRIBUTING TO MISSION CREEK

EXAMPLE OF COMPUTER PRINT-OUT
(Reduced)

COMPUTER PRINT-OUT DATA WITH GRID SQUARES AND BASIN WATER-SHED BOUNDARY SUPERIMPOSED FOR ILLUSTRATION PURPOSES.

AREA OF LAND IN EACH SQUARE CONTRIBUTING TO MISSION CREEK

Figure 9.1

(9) The current balance in any account for all the squares at any time printed out in the format of the Okanagan Basin. Typical examples were the soil moisture at the beginning of the runoff season and the date of which the snowpack was depleted on each square. An example is given in Figure 9.2. This allowed the hydrologist to assess the effects of regional variability, one of the key features of this particular model.

9.5 RESULTS AND CONCLUSIONS

The model was developed to meet two main aims:

(a) As a research tool to increase the understanding of hydrologic processes in the Okanagan Basin;

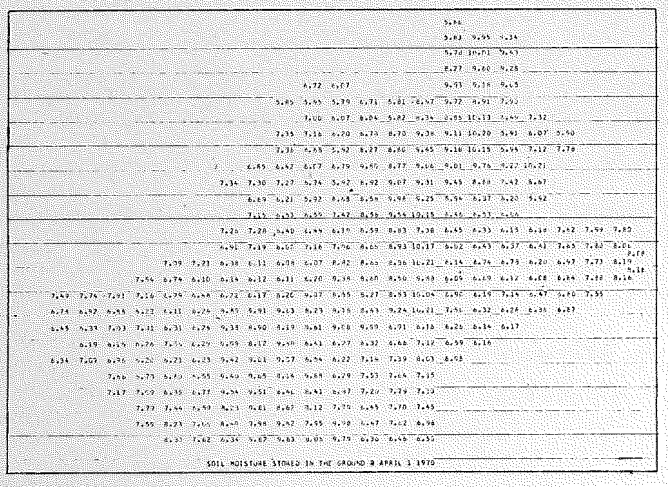
(b) To provide a method for forecasting flows in the tributary basins and the inflows to Okanagan Lake.

The model was designed "around the user," results were presented in a way that facilitated their interpretation, and the model was arranged such that equations or values of parameters could be changed readily. As a research tool the model was highly successful. It allowed assumptions to be tried and assessed, it allowed sensitive and insensitive variables to be identified, it allowed interactions to be checked, and with the EVOP plotting procedure it allowed any particular sub-model to be quickly pushed to its limit. However, instead of helping to find the right answer, in some cases the model results showed that present understanding and the available data are simply inadequate to provide results of the desired accuracy. This was interesting from an academic point of view and useful for guiding future research, but disappointing from the practical point of view.

As a forecasting tool the model falls short, although not by much, for the reason outlined - basic knowledge is lacking. This was disappointing but not surprising considering that runoff, which averages about 3 inches annually, is the residual from the processes of precipitation and evaporation, which average in the order of 20 inches annually. Under less severe circumstances, say where runoff averages 10 inches annually (and, because the climate is more moist, evaporation and soil moisture would not be so critical) the model would almost certainly work. Also, given some more knowledge, which could be obtained from a local research and measurement program, the model could probably be made to work even for an area as difficult, hydrologically, as the Okanagan.

From the studies made with the model the following conclusions were reached:

(1) There is not sufficient understanding of hydrologic processes nor sufficient data to allow development of the budgeting model to a level where it can be used as an operational tool.



EXAMPLE OF COMPUTER PRINT-OUT
(Reduced)

| | | |

(2) Although presently inadequate a complete understanding of the hydrologic processes is not necessary. The model is a highly efficient research tool. If a few of the more sensitive parameters could be "fixed" this would reduce the number of "floating unknowns" to manageable proportions, and allow the model to close in on the best values for them.

(3) The parameters which affect the timing of runoff are largely independent of those that affect the volume. A few runs showed that the timing parameters could be adjusted to match computed and recorded flows provided the total volume were correct. Consequently most of the effort was devoted to trying to model the volume correctly.

(4) The model can be run to reproduce flows of record throughout the basin with reasonable accuracy by adjusting the soil moisture deficit at the beginning of the runoff season and making some minor changes in other parameters. This information should be useful for planning purposes.

(5) Of the various hydrologic processes, evaporation is the least understood and most difficult to model. The model proved highly sensitive to assumptions about:

(a) the variation of potential evaporation with elevation;

(b) the modelling of actual evaporation (including transpiration) given the potential evaporation and the available soil moisture;

(c) the modelling of evaporation (including transpiration) from a snow covered surface.

If these could be modelled accurately then the model could almost certainly be developed to run on a year round basis in which case it could be used for forecasting.

(6) As a partial alternative to (5) above, if the available soil moisture could be sampled say on March 1 and April 1 and generalised to the basin as a whole, the model could be used for forecasting procedures.

(7) Results were not very sensitive to several variables including the soil storage capacity, the variation of summer precipitation with elevation and the snowmelt rate.

(8) It might be possible to improve the estimates of winter precipitation by assigning mean values to all the squares and using the STAMPEDE program (see Chapter 6) to compute and distribute "deviations" to correct the values for a particular year.

CHAPTER 10

Forecasting Water Budget Model

10.1 INTRODUCTION

The model described in this chapter, while developed in the Department of Civil Engineering, University of British Columbia, during the period of the Okanagan Study, was not formally a part of the Study. The methodology for the model was originally developed for use on the Fraser River and then adapted for use in the Okanagan Basin, all the work being funded by the British Columbia Disaster Relief Fund. The model is presently used by the BCWIB as a component of the "tool kit" used for preparing inflow forecasts to the Okanagan Lake basin.

The purposes for developing the model were twofold. The first was to develop an understanding of the hydrological behavior of the Okanagan watershed, particularly to identify the areas which do and do not contribute to runoff under given input conditions. The second purpose was to use the fully developed method as a forecasting tool so that the several lake storages could be operated to minimize flood risks and to assist in the regulation of lake outflows and levels. With the help of such forecasts better use may be made of the available runoff for such competing purposes as irrigation, fisheries, domestic, industrial and recreational use.

The method was developed so that all identifiable components of the hydrologic process are represented in a physically realistic manner. All coefficients used in the calculations are maintained as true constants and are not varied either during a given calculation year or from year to year. This constancy of coefficients is considered essential for the method to be useful in the forecasting mode, as well as being desirable in the simulator mode. Great effort has been made to keep the method simple, with the minimum of coefficients necessary to describe adequately the total runoff process.

The following sections briefly describe the model and results are given of the reconstitutions of the recorded flows in some recent years. The forecasting method is illustrated and estimates are given of the relability of forecasting inflow volumes.

10.2 DATA INPUT

The following data were required for any year for which a model simulation was required:

(1) Snow water equivalents from selected snow courses for March 1 and all subsequent measurements.

(2) Daily maximum and minimum temperatures at Penticton, Kelowna, Vernon Coldstream Ranch, Joe Rich Creek and McCulloch meteorological stations.

(3) Daily precipitation at the above stations.

(4) Monthly evaporation data from the Class A pan at Summerland.

(5) Daily Okanagan Lake levels and flows in the Okanagan River at Penticton. (Okanagan Lake levels are liable to error as the result of wind set-up, but these errors tend to average out over a two or three day period).

(6) Upland reservoir storage volumes for March 1.

(7) An estimate of the soil moisture deficit at March 1.

The lake data are used to compute net lake inflow and the remaining data is used to calculate snowmelt and rain input and to partition this total input into evaporation, groundwater and runoff.

10.3 OUTLINE OF THE MODEL

This model operates on elevation bands rather than the grid system used for the models described in Chapters 5, 6, 7 and 9. The water balance calculations are made on a daily basis on each elevation band.

Subdivision of the valley into 500 foot elevation bands was found adequate and, because of the sparseness of meteorological data, the area within each elevation band has not been subdivided. The areal distribution of snowcover is derived from the snowcourse data and is upgraded during the progress of the runoff season. Precipitation is calculated from five stations and areal and elevation distribution factors have been derived from historic data and reconstitution of historical runoff.

Selected snow course measurements are fitted to a semi-logarithmic precipitation/elevation relationship and are used to provide an estimate of the total amount of snow in each elevation band on March 1 of each year. Daily snow-melt is calculated for each elevation band using average daily temperatures and an average lapse rate. The use of average daily temperatures for calculating snowmelt has been found to be an excellent index and in good agreement with snowpillow and melt-catchbasin studies made on Mount Seymour (37). Precipitation during the snowmelt season is partitioned between rain and snow using a temperature index for each elevation band. Rain is added to the melt to yield a total daily precipitation plus melt input.

A percentage of the watershed is considered to be impermeable so that the precipitation on this area all runs off. This impermeable area is considered to increase as a function of the soil moisture status of the watershed varying from low values of 1 to 2% and reaching a maximum value of some 10 to 15% of each band

area as rainfall and snowmelt reduce the soil moisture deficit to zero. The remainder of the catchment is subject to a water balance analysis involving allowance for soil moisture deficit, evapotranspiration and percolation to groundwater. The residual precipitation from the water balance calculation contributes to fast runoff. The impermeable area runoff and the net water balance runoff is then routed to the stream system using a unit hydrograph method.

Allowance is made for upland reservoir storage which controls about 20 per cent of the runoff above 4000 feet. A running total of the water going to storage indicates when the upland reservoirs are full and this storage provides water for much of the consumptive use in the latter part of the irrigation season.

An accounting procedure is carried out in the model so that the total snowmelt and rain is partitioned between the soil moisture, evapotranspiration and runoff. Knowing the initial snowpack, an account of residual snowpack in each elevation band is made and areal depletion of snowcover is calculated. This is an important feature of the model because snowmelt is very much a function of snow-covered area. In this manner, the model is self-checking by calculating a total water balance continuously. Comparison can readily be made between the calculated and the measured snowcover. This approach makes it possible to show how much of the runoff is coming from each elevation band and how much is being lost to soil moisture and hence to evapotranspiration.

The calculated stream runoff is corrected to allow for evaporation from Okanagan Lake and precipitation on the lake. This corrected value, referred to as net lake inflow, is combined with data on the controlled lake outflows to predict Okanagan Lake level. The daily lake evaporation is obtained by redistributing the published estimates of monthly lake evaporation at Summerland CDA meteorological station on a daily basis. This is done by using the ratio of the maximum daily temperature to the monthly cumulative maximum temperatures. These daily values are treated as a measure of potential evapotranspiration at lake level. From data published by Blaney (38), and, more recently, by Ferguson as described in Chapter 6 of this Supplement, these values of evapotranspiration are decreased as a function of the lapse rate. In addition, the evapotranspiration rate is assumed to diminish exponentially as a function of the soil moisture deficit. It is interesting to note that by lapsing the potential evapotranspiration proportionally with maximum daily temperatures above a base of 32°F., a similar seasonal effect to that suggested in Chapter 6 is produced.

The final form of the model resulted from experience and experimentation with various preliminary forms. Throughout the development two basic rules were observed, firstly that the model should be kept as simple as possible, yet physically as realistic as possible, and secondly, that any coefficients used must be constant throughout the season and even from year to year. The model was calibrated by adjusting the various coefficients from their originally "guestimated" values until as good a fit as possible between the calculated and recorded inflows

was achieved. Considerable use was made of graphical displays of both calculated and recorded inflow hydrographs produced by the computer line printer.

This visual-graphic approach is powerful because it enables the hydrologist to handle complex data at a glance. Other approaches, such as residual variance and other statistical measures do not always reveal the location of the misfit; they cannot easily distinguish between a rather general error as opposed to a large local error, although this is easily seen by visual inspection.

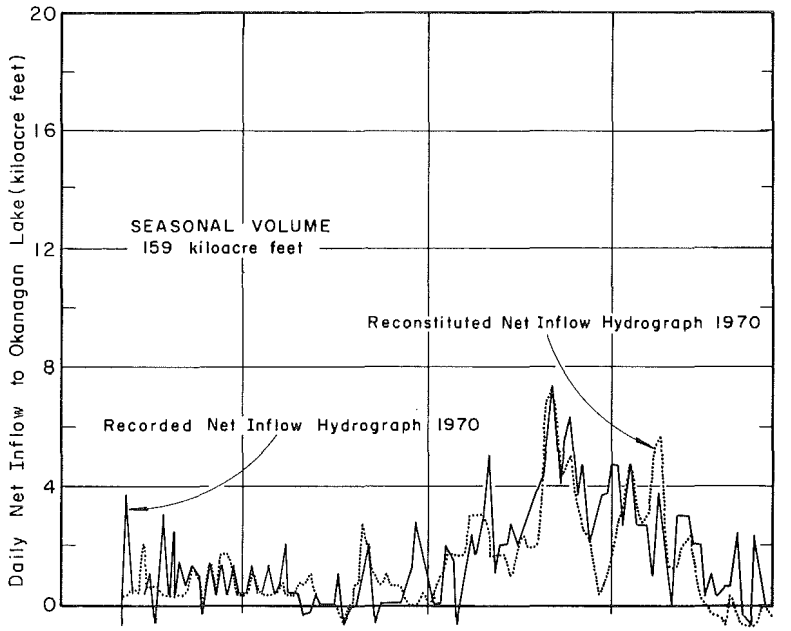
One factor which has to be estimated each year is the soil moisture deficit which describes the state of the soil in the catchment at the commencement of runoff. This factor can be partially estimated from melt occurring before March 1 and, to a lesser extent, from rain during the previous Fall. Better definition of this important factor can only be achieved, at present, after analysis of the first part of the melt season, and therefore it currently represents a source of uncertainty in any forecast during the early part of the runoff season. The model has recently been operated on an annual cycle to generate a water balance account during the winter period. This procedure has allowed earlier definition of the soil moisture status of the watershed. It may prove possible to achieve a better definition of this factor after further study and analysis.

10.4 RESULTS

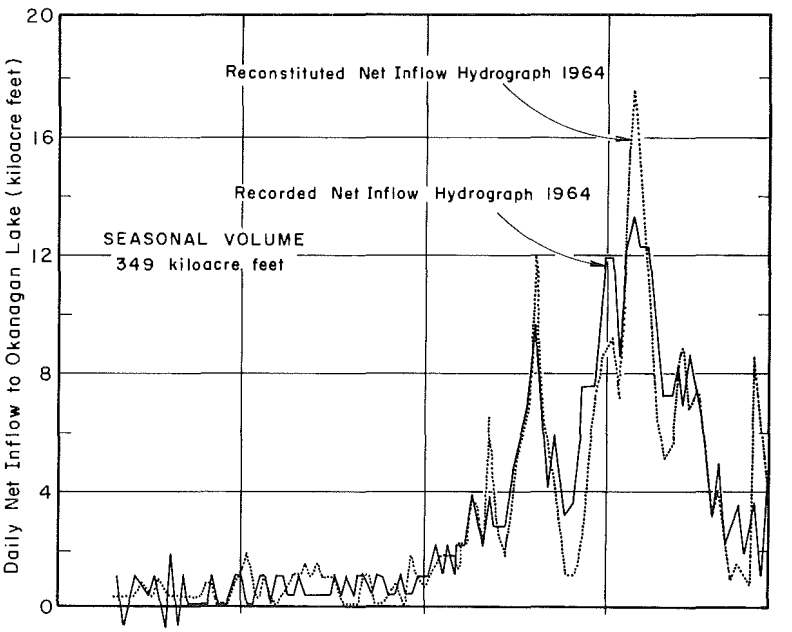
10.4.1 Reconstitution

Figures 10.1, 10.2 and 10.3 show plots of the recorded and model reconstituted inflow hydrographs for 1970 (a low inflow year), 1964 (an average inflow year) and 1948 (a high inflow year) respectively. Additional output, an example of which is given in Table 10.1, indicates the distribution of the total input to each elevation band amongst evapotranspiration, soil moisture and groundwater recharge with the residual allocated to fast runoff. The analysis also shows what percentage of runoff originates from winter snowpack (March 1) as opposed to spring snow and rain. In an average year 87 percent of the total runoff arises from the catchment areas above 3000 feet. Of the total precipitation only some 30 percent eventually runs off as fast runoff, while a further 14 percent emerges as long-term groundwater base flow. The remaining 56 percent is lost as evaporation. Furthermore, it appears that on average 50 percent of the runoff can be accounted for by March 1 data, whereas the remaining 50 percent arises from later events. In an extreme year these figures can be as low as 35 percent for March 1 data, leaving 65 percent from later events. The land surface runoff is further controlled by upland reservoir storage and the Okanagan Lake water balance to yield the model output, that is, the net inflow quantity to Okanagan Lake.

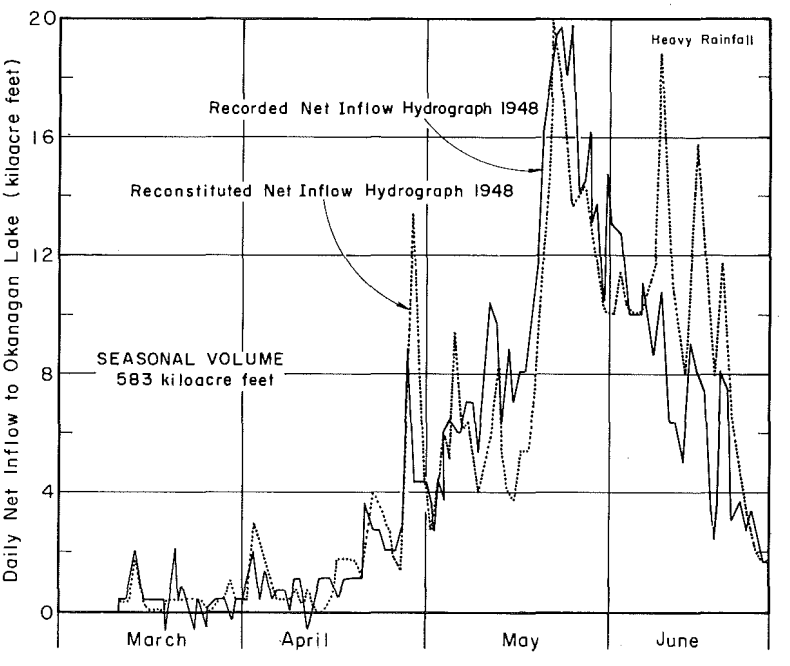
The detailed information contained in the water balance account is not easy to grasp and consequently an attempt has been made to illustrate the major features



RECONSTITUTION OF 1970 SEASONAL RUNOFF. Figure 10.1



RECONSTITUTION OF 1964 SEASONAL RUNOFF. Figure 10.2



RECONSTITUTION OF 1948 SEASONAL RUNOFF Figure 10.3

TABLE 10.1

AVERAGE BAND AREA WATER BALANCE FROM MARCH TO JULY 1964

ELEV. RANGE (ft.)	AREA (sq. mi.)	MARCH 1 SNOWPACK WATER EQ. (ins)	JULY 1 SNOWPACK WATER EQ. (ins)	ADDITIONAL SNOWFALL (ins)	ADDITIONAL RAINFALL (ins)	GROUND WATER (ins)	SOIL MOISTURE (ins)	ACTUAL ET. (ins)	POTENTIAL ET. (ins)	MELT RUNOFF (ins)	RAINFALL RUNOFF (ins)	SURFACE RUNOFF (ins)
> 6000	28	24.0	15.6	9.8	3.5	8.0	1.3	6.0	6.0	4.0	2.4	6.4
5500-6000	68	17.0	1.8	7.4	3.5	8.5	1.8	6.9	6.9	6.1	2.8	8.9
5000-5500	134	12.0	0	5.7	3.7	6.0	1.8	7.6	7.8	4.1	1.9	6.0
4500-5000	225	8.6	0	4.2	3.7	4.2	1.8	8.3	8.7	1.6	0.6	2.2
4000-4500	202	6.1	0	3.1	4.0	2.1	1.9	8.7	9.2	0.3	0.3	0.6
3500-4000	141	4.4	0	2.1	4.3	0.3	1.9	8.6	10.5	0	0	0
3000-3500	121	3.1	0	1.5	4.4	0	1.7	7.4	11.5	0	0	0
2500-3000	101	2.2	0	1.1	4.6	0	1.5	6.4	12.5	0	0	0
2000-2500	100	1.6	0	0.7	4.8	0	1.5	5.6	13.5	0	0	0
1500-2000	135	1.1	0	0.4	5.0	0	1.4	5.1	14.5	0	0	0
1000-1500	113	0.6	0	0.2	5.0	0	1.4	4.4	15.5	0	0	0

of the budget in graphical form. Figure 10.4 shows the variation in total snowpack from March 1 onwards plotted against cumulative net lake inflow for twelve individual years. Figure 10.5 gives the same plot but with nine of the years removed to emphasize the difference in the slopes of the plotted lines for the dry, average and wet years 1970, 1964 and 1948 respectively. Figure 10.6 indicates an idealized and simplified version of the previous two figures and can be used, given the correct scales, as a reasonably reliable index of the final lake inflow if historic records are inserted. In practise, as can be seen in Figure 10.5 the lines for various individual years cross over and the number of crossovers is an indication of the inherent forecast error. The fact that there are fewer crossovers as the season progresses indicates that the uncertainty about the final volume is diminishing and, as can be seen from Figure 10.5, by May 1 the final outcome is likely to be much more deterministic than a month earlier.

When forecasting for the current year, it is of help to the forecaster to superimpose the latest data for the current season on Figure 10.5. Such a plot shows the possible routes which the season may yet follow. The figures might be considered to represent a series of stages and states in a dynamic programming regime. The various routes form one state to a range of future states would each have a statistical probability, so that there would be a most probable outcome as well as various more extreme outcomes.

10.4.2 Forecasting

Simulations in which hydrographs reconstituting the recorded net lake inflows acceptably well, were produced for the nine year period 1962 to 1970 with all coefficients maintained constant throughout. This ability of the model to monitor the hydrologic state of the watershed throughout the runoff season allows some confidence in the parametric interrelationships developed. The model can therefore be used to test different weather sequences during the runoff period and to determine the hydrologic impact that they would have at any given time and from any given state of the watershed during the runoff period. An operational forecasting method can then be used which will give three levels of forecast - an average or most probable volume, an extreme high volume and an extreme low volume of lake inflow. The following paragraphs give three examples of the use of the model as a forecasting tool.

The first example is based on 1964 conditions when the March 1 snowpack was considered to be average with a total volume of 709 thousand acre feet (kaf) and a March 1 to July 1 recorded runoff of 349 kaf. The plot of the recorded net inflow for 1964 is shown on Figure 10.7 as the heavy line. To obtain an upper bound of future net lake inflow the 1964 snowpack was subjected to the temperature and precipitation recorded in 1948 - a moderately warm but very wet summer. Switching to the 1948 summer on April 1 gave a March 1 to July 1 runoff volume of 757 kaf which is over twice the actual 1964 runoff. Switching to 1948 one month later on May 1 gave a March 1 to July 1 runoff volume of 523 kaf so that the month of April alone

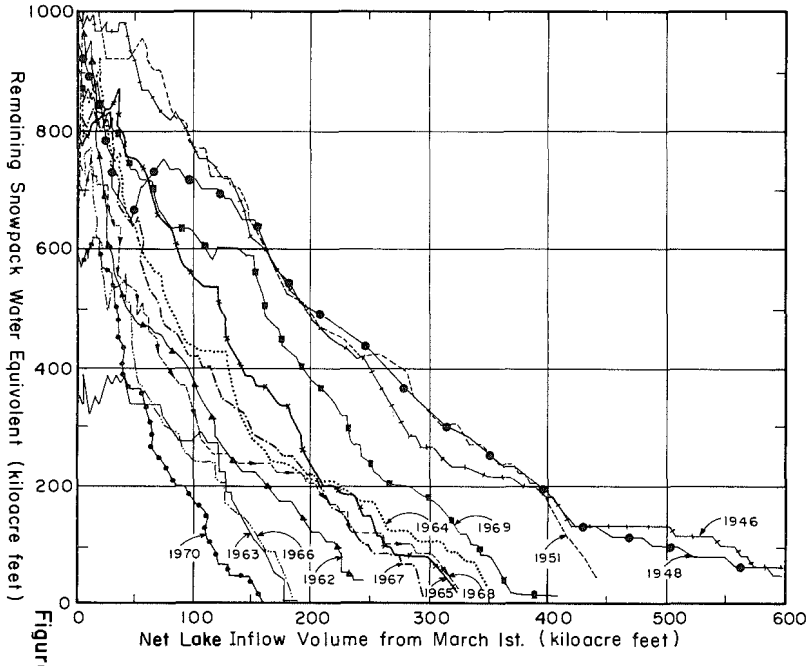


Figure 10.4

TYPICAL CURVES OF NET LAKE INFLOW
AS A FUNCTION OF SNOWPACK DEPLETION.

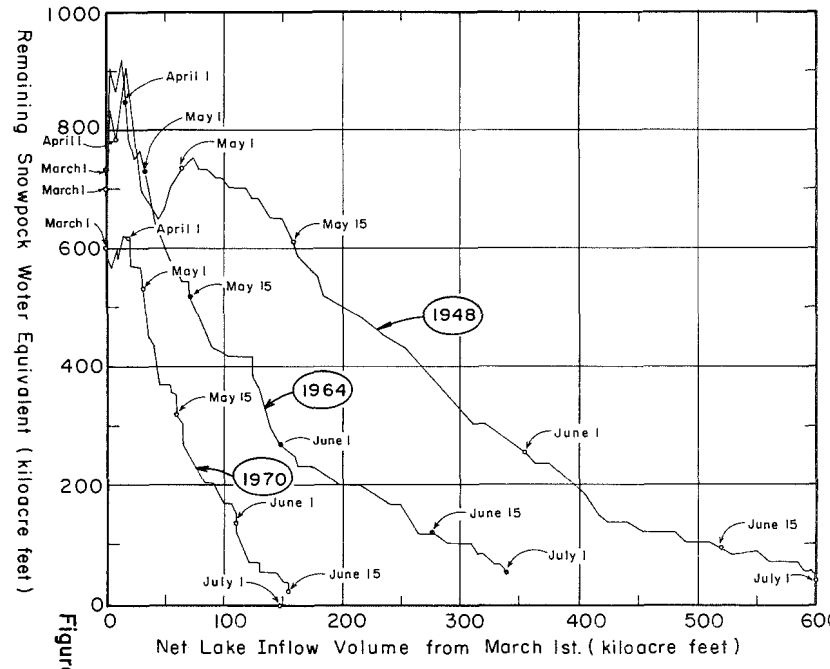


Figure 10.5

NET LAKE INFLOW AS A FUNCTION OF SNOWPACK
DEPLETION FOR 1948, 1964 AND 1970.

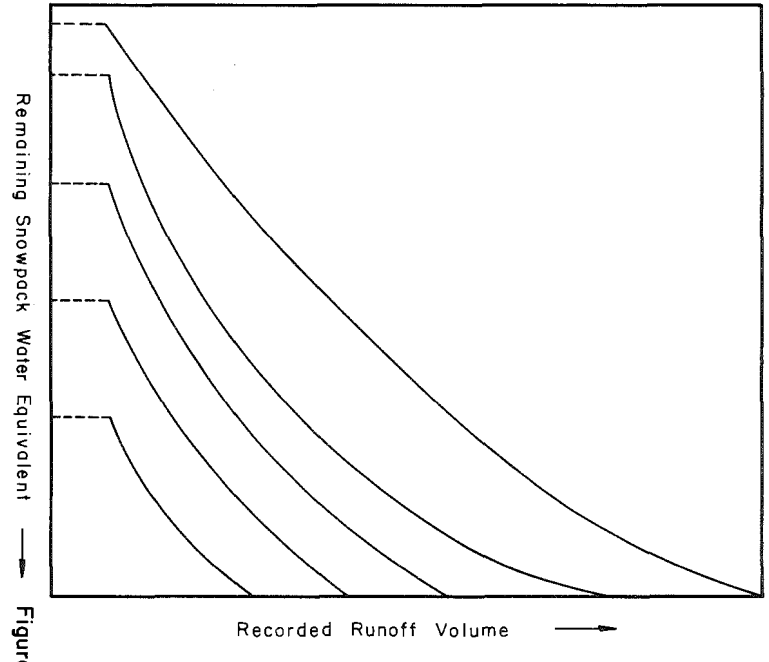


Figure 10.6

IDEALIZED CURVES OF NET LAKE INFLOW
S A [illegible] TION [illegible] NOWI[illegible] DEPL[illegible] N.

could account for an additional 230 kaf. Similarly, to get a lower bound the 1964 snowpack was subjected to the recorded meteorlogical data for 1970, a warm and very dry year. Switching to the 1970 summer on April 1 result in a March 1 to July 1 net lake inflow of only 309 kaf. If switching were delayed by a month the runoff is further reduced to 263 kaf. These upper and lower bounds are illustrated in Figure 10.7.

The second example is considered to be a "high bound" year. 1946 probably had the maximum recorded snowpack, although the snow course data were sparse. The actual March 1 to July 1 runoff was 563 kaf. Applying 1948 summer from April 1 gave a runoff of 878 kaf while if 1946 summer continued to May 1 and the 1948 summer was then applied, the runoff was only 675 kaf. Again the large contribution due to April is seen, namely a difference of over 200 kaf. Subjecting 1946 to the 1970 summer might indicate a minimum expected runoff for the year. Switching to 1970 on April 1 gave 432 kaf for the March 1 to July 1 volume, while delaying the switch to May 1 gave 401 kaf. The upper extreme of 878 kaf shows much more variability than does the lower extreme of 432 kaf.

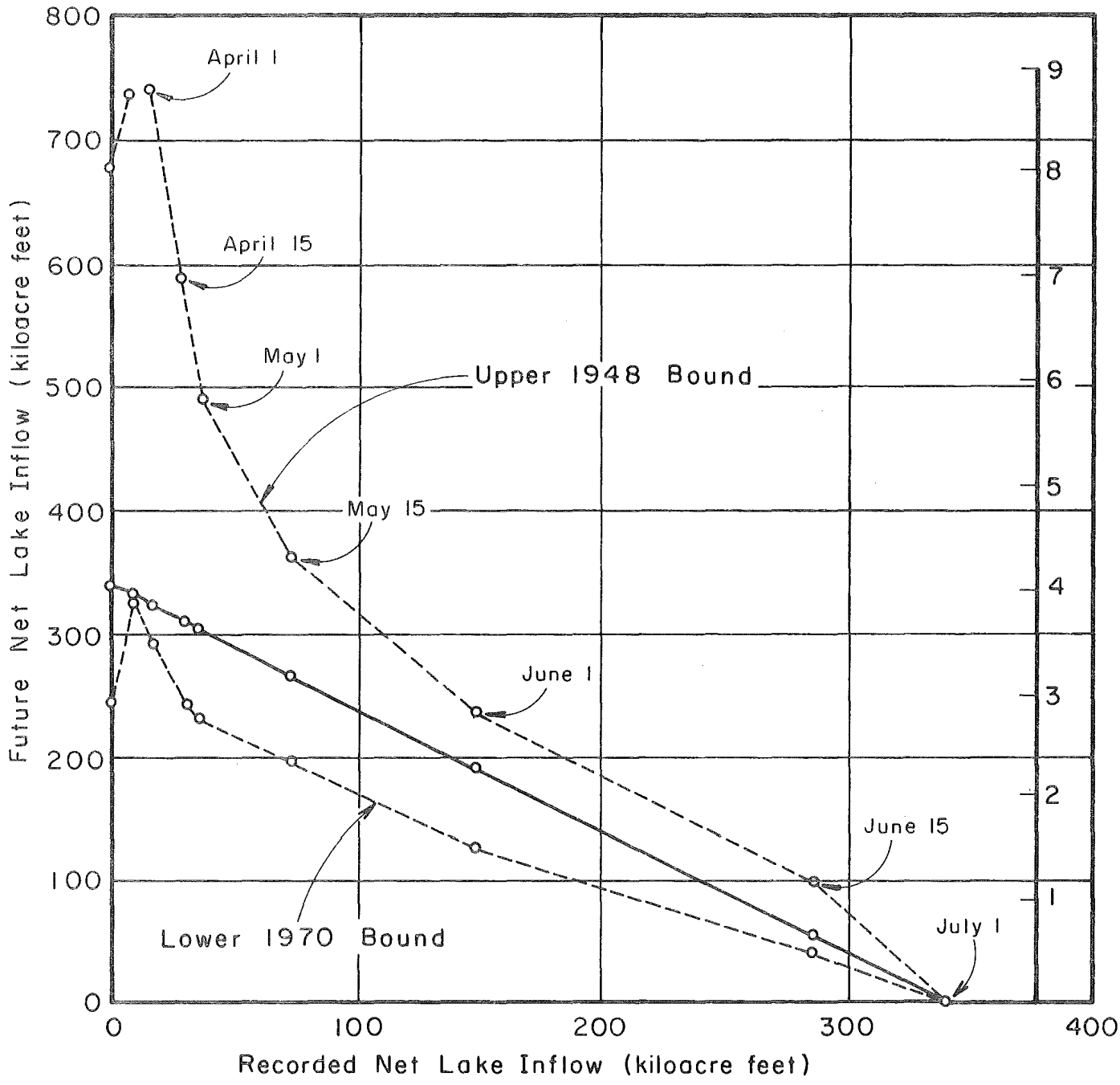
The third example is a "low bound" year based on 1963 which had the minimum recorded March 1 snowpack. The actual 1963 runoff volume, March 1 to July 1, was 188 kaf. Giving 1963 the 1948 summer from April 1 increased the runoff volume to 485 kaf, while delaying the 1948 summer to May 1 gave a runoff volume of 341 kaf. Again the significance of April's weather is apparent. To produce a low extreme, 1963 is given 1970 summer from April 1 and May 1 respectively and gave runoff volumes of 130 kaf and 158 kaf. The low value of 130 kaf might be compared with the worst low flow sequence of record, namely 1929, 1930 and 1931 when the inflows were 130, 151 and 125 kaf for March 1 to July 1.

Table 10.2 tabulates most of these figures for easy reference.

TABLE 10.2

RECORDED AND SIMULATED HIGH AND LOW BOUND RUNOFFS

Snowpack (year)	Recorded Runoff kaf	Simulated Volume of March 1-July 1 Net Lake Inflow			
		1970 (dry) weather from:		1948 (wet) weather from:	
		April 1 kaf	May 1 kaf	April 1 kaf	May 1 kaf
1963 (low)	188	130	158	485	341
1964 (average)	349	309	263	757	523
1946 (high)	563	432	401	878	675



ILLUSTRATIVE FORECASTS OF THE FUTURE NET LAKE INFLOWS PLOTTED AGAINST RECORDED NET LAKE INFLOW. (Extreme values and actual values are shown for 1964).

Figure 10.7

10.5 SUMMARY AND CONCLUSIONS

The forecasting study demonstrates that any forecast of volume inflow for Okanagan Lake will necessarily contain uncertainty arising from the unknown pattern of melt and precipitation during the melt season. The study has tried to determine the magnitude of the uncertainty, or "inherent error of forecast," based on certain probabilities of extreme events, although the exact possibilities are not considered to be well defined as yet. The study shows that there is a large inherent error of forecast for seasonal volume inflows to Okanagan Lake if the forecast is based on March 1 data.

The weather pattern after March 1 can, in extreme conditions, increase the runoff by over 100 percent or decrease the runoff by some 30 to 40 percent. These extremes have a recurrence interval of about one in 100 years. These large inherent forecast errors can be given bounds and can be recognized as the true uncertainties under which the system is being operated. The uncertainty of forecast decreases appreciably as the melt season progresses and the outcome of the operation of the system can be more certain. The forecasts can be used in conjunction with some lake operating scheme such as that proposed in the following Chapter to minimize the damage resulting from either floods or droughts.

The computer model achieves a water balance through the season and indicates how much water is going to fast runoff,groundwater base flow, soil moisture and eventual evapotranspiration, and lake storage. The calculations show that the runoff from summer rain is very much a function of the residual snowpack. Rain on snow results in runoff, whereas rain on soil usually gives a small or zero runoff contribution.

The initial soil moisture deficit can be estimated by running the model through the winter period. This estimate of soil moisture deficit can then be upgraded after the first few weeks of early runoff data are available. The variability of soil moisture deficit is from 41 kaf to 219 kaf for the region above 4000 feet. Below 4000 feet there is a huge deficit which is generally never satisfied. Certainly the catchment below 4000 feet contributes only small amounts to basin runoff and this contribution appears to come from areas which are effectively impervious and not subject to a water balance.

Another problem area at present is a systematic over-production from late melt-season rain. This error may be due to over-estimates of rain by the currently used meteorological stations. Such an error may be either in amount or in areal distribution. It can be corrected by a fairly constant decrease of rain, either in amount or contributing area. The reconstitutions illustrated show a small error for seasonal volumes because the seasonal volumes are brought more into line by adjusting the initial soil moisture deficit, the average adjustment being 101 kaf. Therefore a better estimate of volume error is given by the unexplained variation in the initial soil moisture deficit.

For forecasting, Figures 10.4 and 10.6 showing snowpack depletion versus cumulative lake inflow, are valuable aids. As previously stated the reliability of forecast depends partly on how many times the various yearly lines cross each other. In a perfectly deterministic situation the lines would never cross, as in Figure 10.6. In practice the crossing of lines is most frequent in the early part of the season and the number of crossings decreases considerably even after 50 kaf has flowed into the lake. Superimposing the current year's forecast on such a diagram gives a good visual indication of the probable range of inflows.

CHAPTER 11

Operation of Okanagan Lake

11.1 INTRODUCTION

Water levels in Okanagan Lake are controlled by operating the gates on the dam at the downstream end of the lake. Decisions about how much to open the gates are made by the Director B.C.W.I.B., Water Resources Service, Victoria. These decisions are usually of a routine nature (such as the amount of water to release for irrigation needs downstream) except during the period of freshet runoff when it is necessary to balance the risk of releasing too much water, and perhaps wasting it in a low runoff year, against the risk of having the lake too full and not being able to release enough water to avoid flooding in a high runoff year. Decisions are made mainly on the basis of experience and judgement and on information about the current level of the lake and the latest forecasts of inflow to the lake. The operators have a good "track record" and actual operations have been close to optimal in recent years. However forecasts are never perfect and decision making under uncertainty is always an uncomfortable process. Most of the models described in previous chapters have the objective of improving the understanding of the Okanagan Basin hydrology which should result in better forecasts. This, in turn, should allow the Okanagan system to be operated as effectively and with as much assurance as possible.

Improved hydrologic forecasting would obviously help the operators but forecasts can never be 100% accurate, nor is it always necessary that they should be. For example, if the lake is unusually low at the beginning of the runoff season and all the snow courses are indicating near record low readings then the course of action is clear - conserve as much water as possible; and in this situation even perfect forecasts are of limited help. This chapter describes a research study made at the University of British Columbia, about decision-making. It began with the aim of defining just how accurate forecasts need be but soon had to be broadened to consider the whole process of decision-making. It was found that formal decision theory provides many useful insights into the decision process but that it is rarely used - largely for lack of a few "bridges" between theory and practice. The Okanagan Lake decision problem contains most of the elements of decision making under uncertainty and in a rather pure form. Thus it provided a good opportunity to begin developing the necessary bridges. This has now been done and a computer program has been developed to aid in making decisions about how much water to release at any time during the freshet period. The study is still in the research phase and it will take some time before it can be validated by experience. Preliminary results, however, are promising. The underlying concepts and the model are described in the following sections.

11.2 DECISION THEORY

11.2.1 General

Where there is uncertainty, it is necessary to consider both the probabilities of the various possible outcomes and the relative desirability of each. Decision theory or Bayesian decision theory simply provides a way of separating out the probabilities and their consequences, thus allowing each to be assessed separately, and then combining them in a rational way. The relative desirability of the consequences have eventually to be expressed in the form of a single valued utility curve. Probabilities are assessed in the light of the latest available information at the time of the decision. Decision theory states that at any given time one should choose the action which maximizes the expected utility, which is defined as the sum of the utility of each possible outcome multiplied by its probability of occurrence. Mathematically:

$$E(u) = \sum_i P_i \cdot u_i$$

where

$E(u)$ = expected utility

P_i = probability of outcome i

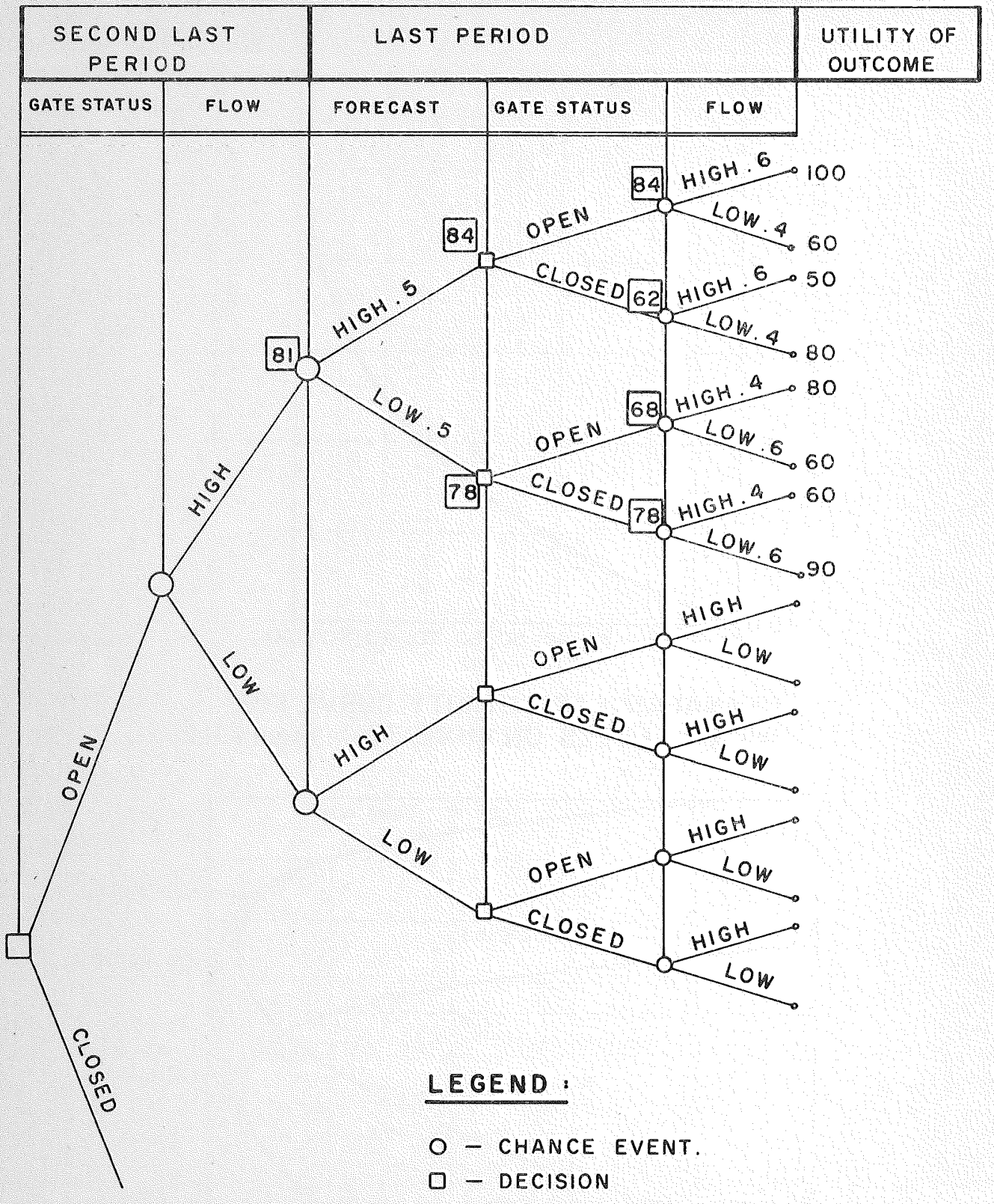
u_i = utility of outcome i

The decision process can be structured in the form of a decision tree such as that illustrated in Figure 11.1. Utilities are assigned to the tips of the tree and probabilities to the branches. There are two types of junction - chance events and decision events. To find the best overall course of action one simply works through the tree from right to left assigning expected utilities to the chance events and selecting the branch with the highest utility and assigning that value to the decision events. In this way a complete decision policy can be made out.

In the very simple example shown in Figure 11.1, if the first forecast is high then the gates should be opened; if the next one is low then the gates should be closed and so on.

11.2.2 Utilities

Figure 11.2 shows the utility curve for water levels in Okanagan Lake at the end of June (the end of the freshet season) which was supplied by the Water Investigations Branch in Victoria in February 1973. It should be emphasized that this was simply their assessment at the time of the relative desirability of levels in Okanagan Lake and was supplied for purposes of the research study. It does not represent government policy. The part of the curve above the four feet (reservoir full) level was obtained by asking questions of the form, "What is the highest certain level that you would settle for instead of the 50-50 chance of having the

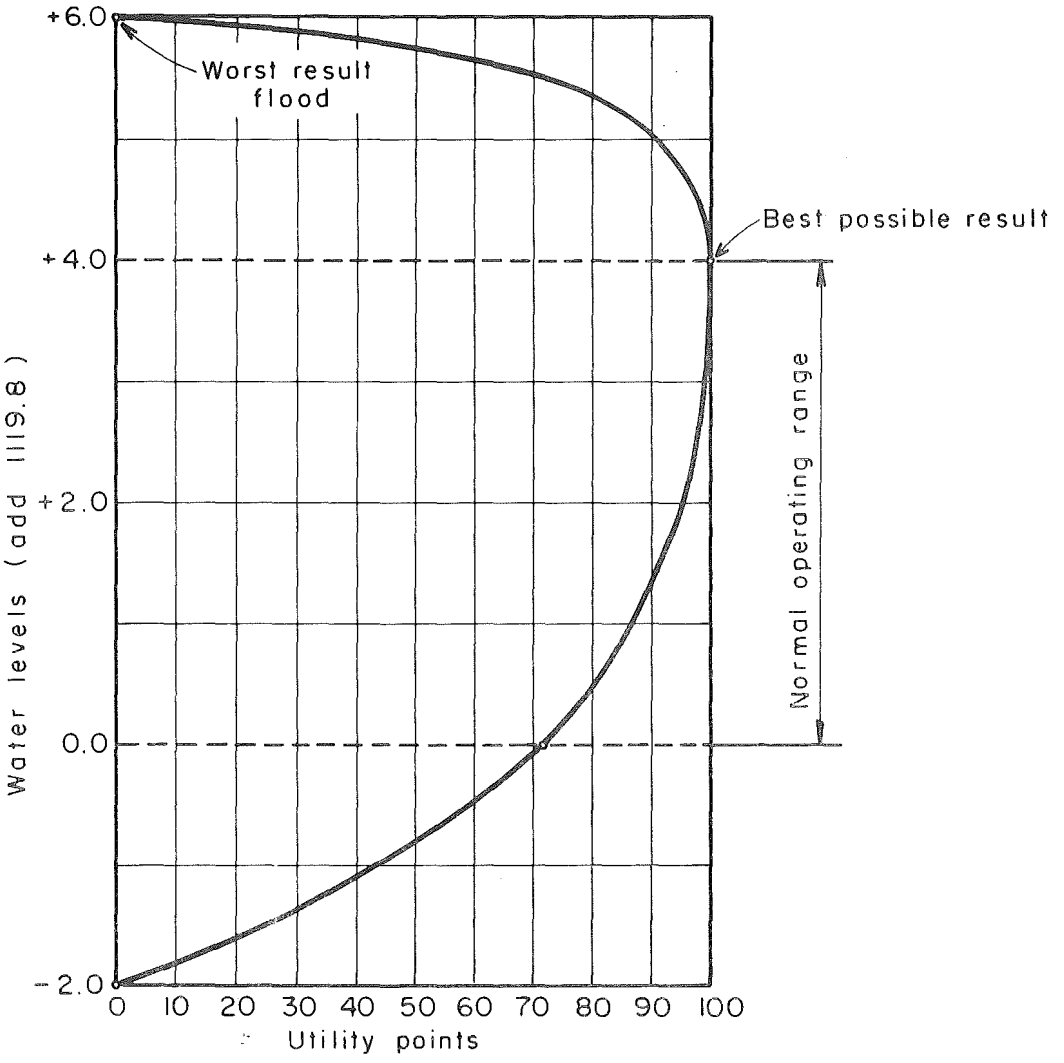


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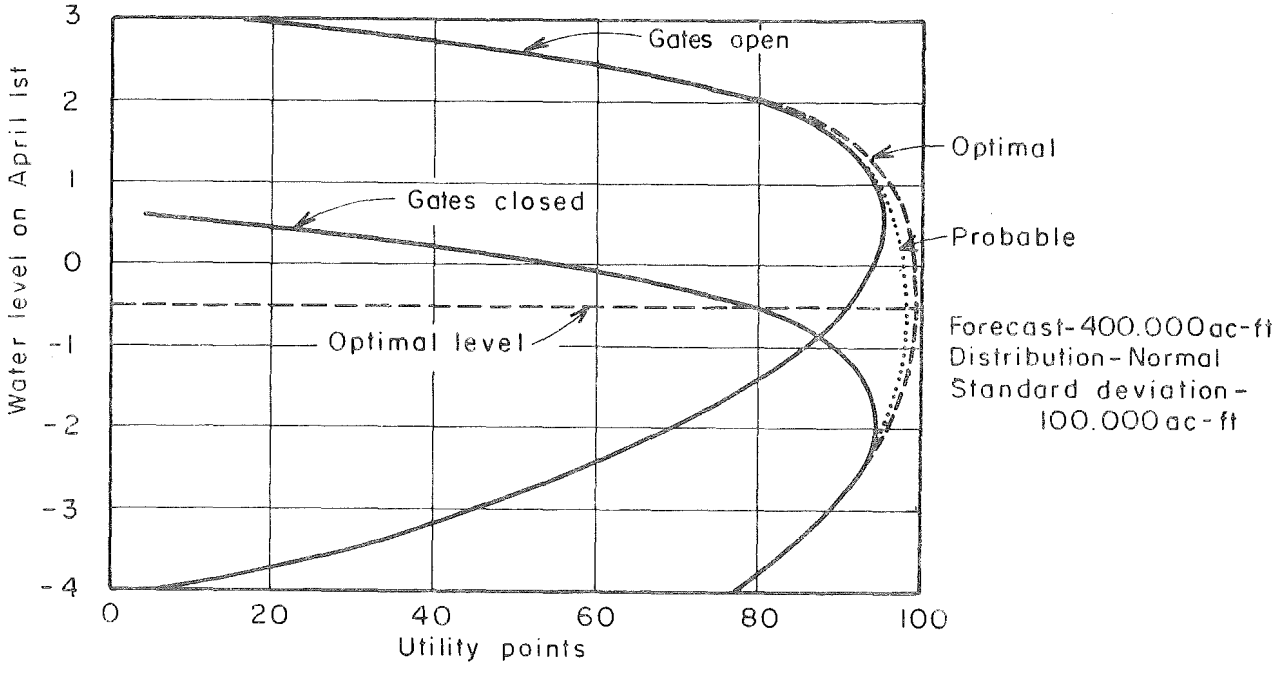
- ○ — CHANCE EVENT.
- □ — DECISION
- .4 — PROBABILITY
- [78] — EXPECTED UTILITY

} Only shown for top branch

ILLUSTRATION OF DECISION TREE . Figure II.1



OKANAGAN LAKE UTILITY CURVE FOR WATER LEVELS ON JUNE 30th. Figure 11.2



OKANAGAN LAKE ILLUSTRATION OF EXPECTED UTILITY CURVES ON APRIL 1st. Figure 11.3

reservoir just full (the best possible outcome) or 2 feet above the full level (the worst possible outcome)?" This level was plotted against 50 points on the utility scale. Then the 75-25 chance of the reservoir being full or 3 feet over, plotted against 75 points on the utility scale and so on. The utilities of levels below the full level were obtained by asking questions of the form, "What low level would be just as bad as being 1 foot, etc., above the full level?" - and assigning the same utility to the low level as the high level. Ideally, the utility curve should encapsulate all the decision makers' knowledge and experience about the effects of having high and low levels in Okanagan Lake.

11.2.3 Probabilities

At any given time a probability distribution of the inflows to Okanagan Lake up to the end of June can be prepared on the basis of hydrologic knowledge available at that time. The state of the art is such that the distribution cannot be defined with any great precision; the most that can be said is that, on the basis of past experience, the distribution should probably have a shape similar to a normal curve defined either by a probable value and a variance or by a probable value together with an upper and lower bound. The probability distribution of inflows can be transformed into a probability distribution of water levels using either the method derived by Russell and Caselton (39) or from simple relationships derived from past records provided that assumptions are made about the way in which the gates will be operated throughout the season.

The art of forecasting, however, falls very far short of being able to specify all the conditional probabilities that would be necessary for a decision tree similar to that shown in Figure 11.1 at a realistic level of detail and covering the whole freshet season.

11.2.4 Bridge Between Theory and Practice

As pointed out in the previous section, hydrologic understanding is just not sufficient to permit definition of the conditional probabilities that would be required for a decision tree such as shown in Figure 11.1. Also, even if they could be defined and if a realistic number of probability intervals were to be used instead of the simple high and low shown in the illustrative example, the decision tree would become so complex that even modern computers would have difficulty in handling it. Thus decision theory in pure form is not appropriate to the Okanagan decision problem on two counts: (1) probability data are not available in the detail required; and (2) even if they were the whole decision tree process would be too complex and cumbersome to be practical. A new approach was therefore required.

Standing at any point in the theoretical full decision tree and looking forward, the decision maker faces two sources of uncertainty - what the flows and

future forecasts will be (the chance boxes in the tree) and, since he does not know these, what he himself will do (the decision boxes in the tree). However, he does have a probability distribution of what the total inflows during the remainder of the season will be. He also has only limited freedom of action since discharges cannot be reduced below the specified minimum nor can they be increased above the maximum that the channel will take. By making appropriate assumptions about future behavior it is possible to bound the expected utilities and, by assuming a range of present levels, it is possible to plot these in a way which can be used to guide action.

Expected utilities are computed for a range of present levels for each of the following conditions:

(1) Minimum releases for the remainder of the season.

(2) Maximum releases for the remainder of the season.

(3) "Optimal" releases. This is a theoretical condition which assumes that the operator behaves in the best possible way, i.e., he makes releases such that the reservoir ends as close to the desired level as is possible with the flow that actually occurs.

Normally the actual expected utility will be better than that obtained from (1) and (2) above, and lower than that obtained from (3). By interpolating between the three curves (which are illustrated in Figure 11.3) the operator can decide on the level at which the reservoir ought to be and then decide on the best action. By making a minor adjustment to the three assumptions above, as described in the following section, the output can be arranged to provide guidance on how much water to release during the coming decision period. Skill and judgement are still required in the interpolation process but it is a rather simpler skill than that presently required to deal with all the probabilities, consequences, uncertainties and intangibles at the same time.

11.3 COMPUTER PROGRAM

11.3.1 Present Development

A computer program has been developed to make the computations outlined in the previous section and, if desired, to plot the results in a form which can be used to decide what is best to do. The program uses as input:

(1) the utility curve shown in Figure 11.2 (the ordinates can be modified as required.)

(2) Forecasts of inflow to the reservoir during the remainder of the season in any of the following forms:

  (a) a normal distribution given the mean and the variance;
  (b) probable, high and low values - and fits a "skew" normal curve;
  (c) vectors of forecasts and cumulative probabilities of being exceeded.

(3) Relationships between forecast inflows at various dates and the maximum increases in water level (set equal to zero if there is a decrease) which would occur between that date and the end of June for both minimum and maximum discharges during the remainder of the season.

The program computes expected utilities for a range of present water levels for each of the following three conditions:

(a) minimum discharge during next week; maximum discharge thereafter;

(b) minimum discharge next week and for the remainder of the season;

(c) minimum discharge next week and optimal discharge thereafter.

One week is taken as the decision period, i.e., the decision can be updated every week.

For any given present level and any particular operating condition, the program takes the first forecast (together with its probability of occurrence) from (2) above; converts the forecast value to an increase in level using the relationship defined in (3) above; adds it to the present level and looks up the corresponding utility from (1) above; and then multiplies the utility by the probability of occurrence of the forecast value obtained from (2) above. This process is repeated for each forecast at each of the probability intervals and the products of the probabilities and the utilities are summed to give the expected utility. This is then repeated for the next assumed present level and so forth. The output comes in the form of the curves illustrated in Figure 11.3 and, by interpolating between the curves, the level which has the maximum utility can be estimated.

It will be recalled that all the expected utility curves are based on the assumption of minimum discharge during the next decision period. If, however, maximum releases were to be made during this period, that would be equivalent to lowering all three curves together with the interpolated one by four inches, or alternatively raising the origin of the level scale in Figure 11.4 by 4 inches. Four inches on Okanagan Lake corresponds to the volume which could be released during one week and thus represents the operator's flexibility within any one decision period.

If the optimal level as indicated on the interpolated curve is at or below the present level only the minimum required amount of water should be released during the coming period. If it is x inches above the present level then the discharge during the next time period should be x/4 times the maximum, but, of course, it cannot exceed the maximum allowable even if x is greater than four inches. The interpolated expected utility curve can thus be used for defining the best discharge to make during the coming decision period.

11.3.2 Possible Extensions

The computer program described in the previous section is designed to accept forecast information together with the basic utility curve and provide output in a form to assist decision making about the operation of Okanagan Lake. The program could obviously be adapated to other similar situations. For those cases where long-range forecasts are not available, as would be the case with most reservoirs where the runoff results from rain and not from snowmelt, the procedure could be used together with the probability distribution derived from past records to develop rule curves. Such rule curves should more closely balance risks and gains than those devised by most present-day conventional procedures.

11.4 ACCURACY OF FORECASTS

For operating the Okanagan system, the desired accuracy of forecasts can best be specified in terms of upper and lower bounds. Table 11.1 lists upper and lower bounds for forecasts for various reservoir water levels at various times of the year. There are three possible conditions:

(1) If the forecast upper and lower bounds in any year fall within the bounds indicated in Table 11.1, then it should be possible to ensure just filling the reservoir to the desired full level by the end of June. This assumes that knowledge about future inflows increases at least as fast as the operator's flexibility decreases, a reasonable assumption in the light of operating experience with Okanagan Lake.

(2) If the forecast upper and lower bounds both fall above the upper bound indicated in Table 11.1, then a flood is inevitable - but the course of action is clear, i.e., release water at the maximum feasible rate. Similarly, if the forecast bounds both fall below the bounds in Table 11.1, then filling the reservoir will be impossible, but again the course of action is clear - reduce discharges to the minimum possible.

(3) If the forecast upper and lower bounds straddle one of the bounds shown in Table 11.1, then there is still uncertainty about what to do and the decision model can be brought into play.

With conditions (1) and (2) above, improved forecasts will not help but in case of (3) it would be helpful if the forecast could be improved to the point that the upper and lower bounds would either both stay inside or both stay outside the bounds indicated in Table 11.1. The upper bounds in the table were obtained by computing the inflow which would result in the reservoir reaching but not exceeding its full level if releases were made at the maximum rate from the date in question. The lower bound was obtained by computing the inflow which would just fill the reservoir by the end of June with releases held to their minimum value.

TABLE 11.1

FORECAST BOUNDS
(thousands of acre feet)

OKANAGAN LAKE LEVEL / DATE	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Feb. 1	550	508	466	424	382	339	297	255	213	171	129	87	45
	942	900	858	816	774	732	689	647	605	563	521	479	437
Feb. 11	547	505	463	421	379	336	294	252	210	168	126	84	42
	913	871	829	787	745	703	660	618	576	534	492	450	408
Feb. 21	544	502	460	418	376	333	291	249	207	165	123	81	39
	884	842	800	758	716	674	632	590	548	506	464	421	379
Mar. 3	541	499	457	415	373	330	288	246	204	162	120	78	36
	855	813	771	729	687	645	603	560	518	477	435	392	350
Mar. 13	538	496	454	412	370	327	285	243	201	159	117	75	33
	826	784	742	700	658	615	573	531	489	447	405	363	321
Mar. 23	535	493	451	409	367	324	282	240	198	156	114	72	30
	797	755	713	671	629	587	544	502	460	418	376	334	292
Apr. 2	532	490	448	406	364	321	279	237	195	153	111	69	27
	767	725	683	641	599	557	514	472	430	388	346	304	262
Apr. 12	529	487	445	403	361	318	276	234	192	150	108	66	24
	738	696	654	612	570	528	486	443	401	359	317	275	233
Apr. 22	526	484	442	400	358	315	273	231	189	147	105	63	21
	709	667	625	583	541	499	457	414	372	330	288	246	204
May 2	523	481	439	397	355	312	270	228	186	144	102	60	18
	680	638	596	554	512	470	428	385	343	301	259	217	175
May 12	520	478	436	394	352	309	267	225	183	141	99	57	15
	651	609	567	525	483	441	399	356	314	272	230	188	146
May 22	517	475	433	391	349	306	264	222	180	138	96	54	12
	622	580	538	496	454	412	370	327	285	243	201	159	117
June 1	514	472	430	388	346	303	261	219	177	135	93	51	9
	592	550	508	466	424	382	340	297	255	213	171	129	87
June 11	511	469	427	385	343	300	258	216	174	132	90	48	6
	563	521	479	437	395	353	311	268	226	184	142	100	58
June 21	508	466	424	382	340	297	255	213	171	129	87	45	3
	534	492	450	408	366	334	282	239	197	155	113	71	29

Upper bound assumes releases of 1470 cfs/day (i.e. 70% channel design capacity).

Lower bound assumes releases of 150 cfs/day to June 30.

11.5 CONCLUSION

A computer program to aid in deciding about how to operate Okanagan Lake during the freshet season is presented in this chapter. To make this practicable it has been necessary to develop a bridge between decision theory and practice. Although results are promising the model represents a radical departure from previous policies and as such should be used with caution until validated by experience. A useful by-product has been the table specifying forecast bounds beyond which it is not necessary to try improving forecast procedures.

CHAPTER 12

Summary and Conclusions

12.1 GENERAL

Hydrology and hydrologic modelling are rapidly developing sciences and each new study seems to raise almost as many questions as it answers. The water quantity component of the Okanagan Basin Study was no exception. This chapter attempts a brief assessment of the various models - the contributions they make to hydrology, the questions they raise and the way in which they were developed; suggests the need for a field measurement program to fill gaps in basic knowledge which were identified; and puts forward a framework (which was conceived in the course of the studies) for co-ordinating the work of the various agencies and providing a solid base for future advances.

12.2 ASSESSMENT OF MODELS

The operation models developed for both the tributaries and the mainstem had clearly defined objectives, were relatively straight-forward, encountered few problems and served their purpose well. The most noteworthy facet was probably the form in which the results of the mainstem model were presented, a form which had a large influence on the successful comparison and evaluation of the water quantity management alternatives. The monthly time base adopted for both models resulted in some lack of sensitivity. In the mainstem model this did not matter for the Okanagan Lake but it meant that it would not have been meaningful to model Osoyoos Lake which responds very rapidly to changes in the flow regime. In the tributary model, mean monthly flows do not accurately reflect the hydrology of most creeks. Further development in tributary modelling should include the simulation of weekly flows during the freshet, the inclusion of return flows and,where significant, the effects of lake evaporation.

The "research" models (Grid Square, AES and Basin Characteristic) all add to hydrologic knowledge but since they all attempt to model mean values the results are difficult to assess. In water management, one is usually more concerned with extreme events, low and high flows, droughts and floods than mean values. As a result, there are no "acid tests" for these models. They appear to be good and to add to knowledge but, as yet, the results are not directly used. The results from these types of models are used as a contribution to the background knowledge of hydrologists. For example, all the knowledge and understanding available at the time were used in the preparation of runoff estimates which were used as input to the tributary operation model, as described in Chapter 4. However, an objective method for assessing this type of research model is badly needed. A possible further development of these models is described in the following section.

Hydrologic simulation models such as the budgeting and forecasting models are subject to the same difficulty of assessment. Usually there are enough parameters which can be adjusted to match computed and recorded flows during a single season and it is often difficult to say whether the processes are being modelled accurately or whether errors are simply compensating one another. If, however, a model can be operated over several successive years without any adjustment of parameters then one can be confident about its adequacy. Alternatively the use of a model for real time forecasting provides a harsh and effective test of its adequacy and accuracy, but it may take several years to accumulate data for the necessary comparisons between predicted and actual runoff values and for the model to be trusted by the operators. The EVOP procedure, used first with the tributary flow model and later in the budgeting model, represents an important step towards greater objectivity in hydrology and is a procedure which allows full use of the hydrologist's experience and judgement.

Sometimes the results of research are negative. With the EVOP procedure it was established that there is not sufficient data or basic understanding to support the budgeting model for use as a forecasting tool although it can be used to reconstitute recorded flows. The model would probably be adequate for a less extreme environment where the runoff is a larger proportion of the precipitation. The shortcomings could be classed as "medium scale" - e.g., how does evaporation vary with elevation, and similar questions that could probably be answered from a research program tailored to the needs of the Okanagan.

The decision model approaches the problem of forecasting from the opposite end, the user's end, and provides a method for making the best use of available information. It also specifies limits of accuracy beyond which it is not necessary to go. These limits are beyond what is now obtainable, but they do provide useful bounds beyond which it is unprofitable to try to improve the forecasts. This model represents a fairly radical innovation which seems promising but which will have to be tested in practice. The concepts are being extended to other more complex decision problems and the model thus represents a minor breakthrough into a new area of research and development.

12.3 CO-ORDINATION AND FUTURE WORK

Sincere attempts at co-operation were made throughout the study. A common data base was used and information was freely exchanged between groups. However, the approaches were so diverse that there was little opportunity for real co-ordination between groups even those within the same agency. As a result there are many loose ends which have not been resolved, such as the fact that AES corrected all meteorological data by a substantial amount to allow for undercatch, something which no one else did. This wide dispersion of effort is appropriate to a pioneering study and it provides a good wide base for future advances. However, it will not be appropriate in the next phase of work for which much closer co-ordination will be necessary.

To advance the work the most effective next step would be to set up a field measurement program in the Okanagan to fill in some of the gaps in knowledge which were identified in the budgeting model studies; in particular how do summer precipitation, evaporation and soil moisture vary with elevation? Existing instruments are unsuitable for this purpose since they are either expensive or need to be tended daily. Cheap, simple, robust instruments that can be widely distributed but only need to be read, say, once a month are required. The instrumentation part of the field program would thus be largely experimental in the early stages. Rain gauges and "flower pot" size lysimeters that can be weighed on a portable scale are presently being tried at U.B.C.and it appears that development of suitable instruments for the suggested field program need present no insuperable problems.

Information from the field program could be most effectively used in conjunction with additional trial runs of the budgeting model and the EVOP procedure. However, all the various types of hydrologic information from all the participating agencies can only be used to full advantage if there is a common framework to help bridge gaps which could not be bridged before. Parts of the models described in this supplement can be integrated to provide the necessary framework. The key concepts are the following:

(a) Adoption of a common data reference system. This has already been achieved with the grid square system. (The squares can be further subdivided as necessary).

(b) Use of long-term averages for characterizing the hydrologic processes in the basin. This involves using all the available skills and knowledge to estimate long-term average values of key hydrologic variables such as annual and monthly values of precipitation, evaporation and runoff and the March 1 and April 1 snowpack and soil moisture deficits for each square. This data bank would be the main "repository" of hydrologic knowledge about the Okanagan Basin and would be updated from time to time as more information became available about any of the processes from any source for any particular section of the Basin. (It is possible to relate almost any information whatever to long-term averages by a pro-rating procedure and thus almost no data need to be wasted). The data bank could eventually be expanded to include the same information for extreme dry and wet years.

(c) Use of deviations from the average as the link between all the knowledge encapsulated in (b) above and the simulation model. A simulation model, similar to that described in Chapter 9 could be used as the main tool for computing discharge in any part of the basin in any year. The link between the individual year in question and the long-term average data stored under (b) above would be made by expressing all parameters in terms of deviations from their long-term value. For this purpose the "STAMPEDE" program as used by the AES would provide the actual computational tool.

The water quantity models developed for the Okanagan Study together with the above framework provide a good base for further study and development, the type of study which Barbara Ward and Rene Dubos recommend in their book, "Only One Earth",

written for the Stockholm Conference:

> "The first step towards devising a strategy for planet earth is for the nations to accept a collective responsibility for discovering more - much more - about the natural system and how it is affected by man's activities and vice versa. It implies a quite new readiness to take research where it is needed; it means the fullest co-operation in converting knowledge into action."

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