Forecasting Springmelt Floods for the Rideau
River at Ottawa

by

© Mary-Jane Newman, B.Sc.

Copyright (1982) by Mary-Jane Newman

A thesis submitted to the Faculty of Graduate
Studies and Research in partial fulfilment of
the requirements for the degree of Master
of Arts
in Geography

Department of Geography
Carleton University
Ottawa, Ontario

July 1982

ABSTRACT

A system for forecasting springmelt flows for the Rideau River at Ottawa is developed. The forecast models take the form of multiple regression equations, the independent variables reflecting factors having a controlling influence on springmelt. Models are developed for long term, March 1, and short term forecasting. This allows for both a general indication of the likely flood risk and daily up-dating of forecasts once the flood wave begins. Duration of the rising limb is also predicted to give an estimate of the date of peak. The objective of producing more accurate forecasts than the current system used by the R.V.C.A. is achieved. The standard error for March 1 forecasts being reduced by 17 per cent. An operational procedure is developed incorporating the components of the system into a set of instructions such that the models can be applied in future years. The system is tested for the year 1981.

ACKNOWLEDGEMENTS

I would like to thank Dr. T.P. Wilkinson for the time he has given to the supervision of this thesis and for the valuable suggestions and comments made relating to data analysis and final thesis presentation. Dr. M.W. Smith who read the final draft of this thesis also deserves thanks. The cooperation of Mr. C. Craig of the Rideau Valley Conservation Authority in allowing access to information and data concerning their flood warning system is gratefully acknowledged. Also the staff of the Weather Office at Ottawa International Airport provided help in making available past meteorological data.

Thanks are also due to all those people, students and others, who have helped me during my stay in Ottawa; especially Janice Jeffs (long suffering room-mate) and the congregation of Mount Calvary Lutheran Church. Last, but by no means least, thank you to my parents without whom this venture would not have been possible. Without the support of all these people I would have given up long ago.

TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
Acknowledgements	iii
List of Figures	v
List of Tables	vi
List of Appendices	vii
List of Abbreviations	viii
 CHAPTER 1 Introduction	 1
 CHAPTER 2 The Rideau River Basin and Forecasting Techniques	 6
 CHAPTER 3 Long Term Forecasting	 21
 CHAPTER 4 Short Term Forecasting	 43
 CHAPTER 5 Operational Procedure for Springmelt Hydrograph Forecasting	 61
 CHAPTER 6 Summary and Conclusions	 79
 Bibliography	 84
 Appendices	 86

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1.1 Rideau River Basin	2
2.1 Snowmelt Hydrograph at Ottawa Gauge for 1977	8
2.2 Snowmelt Hydrograph at Smith's Falls Gauge for 1977	9
2.3 Snowmelt Hydrograph at Ottawa Gauge for 1956	10
2.4 Snowmelt Hydrograph at Ottawa Gauge for 1976	11
2.5 Long Range Forecasting Curve, R.V.C.A. Freehand Model and Acres Bivariate Model	15
3.1 Plot of Residuals, Initial Analysis, March 1 Forecast Model	30
3.2 Annual Peak Discharge 1950-1980 Showing Time Trend	32
3.3 Plot of Residuals, Analysis Including YEAR and YEAR2, March 1 Forecast Model	34
3.4 Plot of Residuals, Analysis Excluding YEAR, March 1 Forecast Model	36
3.5 Plot of Residuals, Analysis Excluding YEAR2, March 1 Forecast Model	37
3.6 Observed Against Predicted Peak Discharge at Ottawa, using Acres Bivariate Model	39
3.7 Observed Against Predicted Peak Discharge at Ottawa, using Multivariate Model	40
4.1 Observed Against Predicted Peak Discharge at Ottawa, using 5 Day Multivariate Model	51
4.2 Observed Against Predicted Peak Discharge at Ottawa, using 2 Day Multivariate Model	52
4.3 Observed Against Predicted Peak Discharge at Ottawa, using 1 Day Multivariate Model	53
4.4 Duration of Rising Limb of Hydrograph 1950-1980 showing Time Trend	55
4.5 Observed Against Predicted Duration of Rising Limb	58
5.1 Definition of Days on the Rising Limb	64
5.2 Observed Against Predicted Peak Discharge at Ottawa, using 5 Day Multivariate Model and Forecast Date of Peak (DURATN)	74
5.3 Observed Against Predicted Peak Discharge at Ottawa, using 2 Day Multivariate Model and Forecast Date of Peak (DURATN)	75
5.4 Observed Against Predicted Peak Discharge at Ottawa, using 1 Day Multivariate Model and Forecast Date of Peak (DURATN)	76
5.5 Snowmelt Hydrograph at Ottawa Gauge for 1981	77

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 March 1 Forecast Peak Discharge Categories	14
2.2 Thaw-Degree Day Index Developed by Acres (1979)	17
3.1 Variables Used in Multivariate March 1 Forecast Model	22
3.2 Pearson Product Moment Correlation Coefficients Between Variables used in March 1 Forecast Model	25
3.3 Comparison of Correlation Coefficients for Various Equations to Describe the Relationship between PEAKQ and WEQSP	28
3.4 Summary of Initial Multiple Regression Analysis for March 1 Forecast Model	29
3.5 Summary of Multiple Regression Analysis Including YEAR and YEAR2, March 1 Forecast Model	33
3.6 Comparison of Initial Multiple Regression Analysis and Analysis Including 'Time' Variables, March 1 Forecast Model	33
3.7 Summary of Multiple Regression Analysis Excluding YEAR and Excluding YEAR2, March 1 Forecast Model	35
3.8 Comparison of Residual PEAKQ for Acres Bivariate Model and Multivariate Model	38
3.9 Summary of Multiple Regression Analysis to Forecast Timing of the Flood Peak	41
4.1 Short Term Forecasting Requirements	44
4.2 Variables used in Short Term Forecasting Model	45
4.3 Summary of Multiple Regression Analysis for Short Term Forecasting, Data Lagged up to 12 Days	48
4.4 Short Term Forecasting Equations	49
4.5 Summary of Multiple Regression Analysis for Forecasting DURATN of Rising Limb of the Hydrograph	56
4.6 Summary of Multiple Regression Analysis to Forecast DURATN using Data on Various Days Prior to PEAKQ	59
5.1 Forecasts Which can be Made Available on Given Day of Rising Limb for Specified DURATN	67
5.2 Day of Rising Limb for Which Data is Required to Make Forecasts Given in Table 5.1	68
5.3 Mean Residuals for 5, 2 and 1 day and Mean of 5, 2 and 1 day Forecasts of PEAKQ	69
5.4 5, 2 and 1 day and Mean of 5, 2, and 1 Day Forecasts, with Residuals	73
5.5 Summary of 1981 Forecasts	77a

LIST OF APPENDICES

	<u>Page</u>
Appendix 1. Constant to convert daily mean discharge ($\text{m}^3\text{sec}^{-1}$) to runoff depth over Rideau Basin (mm)	86
Appendix 2. Summary tables for 5, 2 and 1 day forecast equations	87
Appendix 3. Summary table for DURATN forecasting equation	88
Appendix 4. Suggested means of recording March 1 forecast of PEAKQ	89
Appendix 5. Recording of data during the period from January 1 to date of flood peak	90
Appendix 6. Suggested means of recording short term forecasts	92
Appendix 7. Forecasting Procedure for 1981	93
Appendix 8. Forecast of DURATN on day R2 of rising limb for 1981	102
Appendix 9. Short term forecasts, calculation procedure, 1981	103
Appendix 10. Record of short term forecasts for 1981	105

LIST OF ABBREVIATIONS

Water equivalent of snowpack	WEQSP
Adjusted water equivalent of snowpack	Adjusted WEQSP
Minimum winter discharge	MINQ
Discharge on March 1	QMAR1
Snowdays	SNWDAYS
Degree days	DEGDAYS
Sunshine hours	SUNHRS
Rainfall	RAIN
Snowfall	SNWF
Total precipitation	TPREC
Year	YEAR
Year ²	YEAR2
Peak discharge	PEAKQ
Date	DATE
Minimum daily temperature	MINT
Maximum daily temperature	MAXT
Mean daily temperature	MEANT
Duration of rising limb	DURATN

CHAPTER 1

INTRODUCTION

1.1 Purpose of the Study

Forecasting of springmelt flooding in the Rideau River basin is presently the responsibility of the Rideau Valley Conservation Authority (R.V.C.A.) and an examination of their forecasting practices formed the starting point for this study. Details of the R.V.C.A. system will be discussed in Chapter 2. The purpose of this thesis can be briefly stated as being to develop a system for forecasting springmelt flows for the Rideau River at Ottawa to give more accurate forecasts than the present system.

Two time scales can be identified in the context of springmelt flood forecasting. Long term forecasting requires that an estimate be made of the peak flow, herein identified as maximum daily mean discharge in $\text{m}^3 \text{sec}^{-1}$, early in the melt season. March 1 is the date used by the R.V.C.A., and this thesis, on which to produce such a forecast. Short term forecasting allows for forecasts of daily mean discharge to be updated once stage levels begin to rise. The forecasting system developed in this thesis has the purpose of allowing long and short term forecasts to be made.

1.2 Definition - The Problem of and Need for Forecasting

Forecasting, which may be defined as a process by which a value is assigned to a particular variable for some future point in time, is a common practice in both the physical and social sciences. In hydrologic studies the need for forecasting peak flows or flood flows results from the need to have forewarning of the occurrence of flow levels of a magnitude sufficient to cause flood damage. This allows time for precautionary action to be taken to protect land and properties lying within the flood plain. Hydrologic forecasting involves the use of data available from previous time periods concerning flow characteristics and other independent variables which influence runoff. The nature of the relationship between the measured variables is determined and can be used to forecast the volume, magnitude and timing of the peak flow for future events from data available to the flood peak.

In the Rideau River watershed (Fig. 1.1) there are urbanised areas

within the flood plain. These include several areas in Ottawa; sections above and below Manotick; Osgoode Township; Kars, and Becketts Landing in Rideau Township; the Township of South Gower and the towns of Kemptville and Perth (R.V.C.A., 1980: 2). The potential for flood damage in these areas makes it necessary that flood warnings be issued which contain both the magnitude and timing of the flood peak so that protective measures can be implemented.

Many techniques are used in flood forecasting ranging from the relatively simple, such as flood frequency analysis, to highly complex watershed simulation models which are executed on computers. The method currently used for the Rideau River is fairly simple and involves a simple regression equation, a degree day index and precipitation, temperature and discharge data plotted daily during the springmelt period. Forecasts are partly made by extrapolating the river hydrograph. The particular shortcomings of the present system are identified in Chapter 2. The technique predominantly used in this thesis is that of multiple linear regression models.

1.3 Objectives

i) The primary objective of this thesis is to formulate a procedure for springmelt flood forecasting capable of providing more accurate forecasts than can be given using the present system. The accuracy of the two forecasting systems is compared statistically on the basis of the standard error of estimate, i.e., the sum of the squared residuals. Thus, a specific objective is that any new forecasting system gives a lower standard error of estimate than the R.V.C.A. system.

ii) A second objective is that the forecasting system be fairly simple to follow, not requiring the use of computer facilities, and that up-dated forecasts can be made quickly. A simulation procedure for forecasting the springmelt hydrograph would be highly complex and is best achieved using deterministic computer modelling. The final forecasting procedure developed here does not allow a simulation of the river hydrograph to be made. Once the flood wave has begun, forecasts are issued daily predicting a value for discharge should the peak occur on the day for which the forecast is being made, i.e., the predicted day of peak.

iii) The third objective in this study is to incorporate into the forecasting model those meteorological variables which have a controlling

influence on springmelt. This objective is applied to both the long term and short term forecasting models. The process of springmelt runoff is controlled by meteorological conditions. This is evident in this study on both the long term, seasonal, basis and on the short term, daily, basis. Seasonally, the primary determinant of springmelt runoff levels is the volume of water stored in the snowpack when melt begins. This is dependent upon the amount of precipitation during winter months. In years where the depth of snow lying at the commencement of the melt period is high, then it is to be expected that spring runoff levels will be high. On a short term basis, once the melt has begun, such factors as rainfall, temperature and insolation will determine the rate of ablation of the snowpack.

1.4 Scope and Limitations of the Study

The scope of this thesis is restricted to a specific watershed, i.e., the Rideau River at Ottawa, and the forecasting model cannot be directly applied to other basins nor to subbasins of the Rideau basin. Also the model applies only to springmelt flood forecasting and not to flooding resulting from heavy summer or fall rainfall. Flooding due to the latter events is uncommon. However, the methodology could be applied to snowmelt flood forecasting in other watersheds.

Theoretically it is possible to forecast flood discharges for the subcatchments within the Rideau basin. This could be expected to provide more accurate forecasts than when considering the basin as a whole. However, the data required to do this are not currently available so forecasts are made only for the Ottawa gauge.

The forecasting objective of this thesis places some limitations and constraints on the direction of data analysis. The emphasis of analysis is on development of a model which provides the most accurate forecasts of peak discharge levels. This excludes a detailed study of the physical processes operating during spring runoff. Although most of the variables used in the model have some relevance in terms of the melt process, there are instances where the variables providing the 'best' forecasting model cannot be obviously related to any physical process.

1.5 Methodology

i) Data acquisition

The data used in this study are available from published sources.

Meteorological data are taken from records kept for Ottawa International Airport and published by Environment Canada. Discharge data for the Rideau River are for the Ottawa gauge (Station number 02LA004) and are published by Water Survey of Canada. The R.V.C.A. provided the water equivalent of snowpack data measured at various stations operated by the Rideau Canal Office (Parks Canada) and by the R.V.C.A. Data for the years 1950 to 1980 are used to develop forecast models.

ii) Data Analysis

The statistical techniques required for data analysis are contained in the Statistical Package for the Social Sciences (SPSS), (1975). Multiple linear regression analysis is the technique used to develop various forecasting models and this technique is discussed in Chapter 2. Other analytical techniques include Pearson product-moment correlation coefficients and various graphical analyses of data.

iii) The Forecasting Model

An operational procedure is developed which incorporates the forecasting equations for different time periods into a comprehensive system which can be used for forecasting peak discharge in future years. Instructions are given regarding when to make forecasts, which forecasts should be made and the recording of the forecasts. The new forecasting equations are tested against the current model, where possible, to determine the degree of improvement in the forecasts made. The entire operational procedure is applied to the year 1981 which was not included in the data analysis.

1.6 Organization of Work

A description of the Rideau River basin and its snowmelt hydrology is provided in Chapter 2 of this thesis together with a summary of the current forecasting techniques used by the R.V.C.A. The development of a new model to produce forecasts on March 1 is described in Chapter 3. Chapter 4 examines the process by which short term forecasting models are produced. In Chapter 5 the new models are incorporated into an operational procedure which provides the basis for forecasting during the melt period. Throughout the thesis, comparison is made of the predictive accuracy of the R.V.C.A. system and the new forecasting models. The final chapter gives a summary of the research and suggestions as to areas of further study.

CHAPTER 2

THE RIDEAU RIVER BASIN AND FORECASTING TECHNIQUES

2.1 Character of the Rideau Basin

The Rideau River basin (Fig. 1.1) covers an area of $3,730 \text{ km}^2$ (at Hog's Back). Two types of flooding occur in the basin (R.V.C.A., 1980:2):

a) Flooding adjacent to the main river channels which occurs when river flows exceed channel carrying capacity.

b) Flooding around individual lakes or reservoirs due to overfilling.

This thesis is concerned with only the first of these two types of flooding. The areas of main channel flooding lie mainly within the Regional Municipality of Ottawa-Carleton and also in the Township of South Gower and the Towns of Kemptville and Perth.

Flood damage occurs only when flows at Ottawa are greater than $400 \text{ m}^3 \text{ sec}^{-1}$ and becomes significant at flows greater than $500 \text{ m}^3 \text{ sec}^{-1}$. The major flood events are in spring, being generated by rapid snowmelt and often accompanied by rainfall (Acres, 1979: 1). It is possible that floods may be generated by summer or fall rains; however, such floods are much less frequent and less severe than snowmelt floods. Ice jams on the Rideau and Jock Rivers can, at times, considerably increase flood levels above those associated with normal open water flow.

The Rideau basin can be divided into two major subbasins (Fig. 1.1), each having distinct flood response characteristics. The upper basin includes the area upstream of Poonamalie Lock near Smith's Falls; it covers 34 per cent of the basin area (Acres, 1979: 1) and is extensively covered by lakes. The Rideau Canal Office, Parks Canada, operates 4 reservoirs within the upper basin (Wolfe, Bobs, Upper and Lower Rideau Lakes). These and other water control structures are mostly connected with the operation of the Rideau Canal system.

A study by Acres Consulting Services Ltd. (1977) concluded that modest improvements in spring flood peak attenuation could be attained through modification of existing reservoir operation procedures. The Poonamalie control structure is the principal flow control point within the Rideau basin and is used to control the level of Upper and Lower Rideau Lakes and to regulate flow releases to downstream reaches of the Rideau River. One of Acres (1977) objectives in developing revised operating procedures for the late winter-spring period was to reduce

outflow at Poonamalie to zero during the springmelt peak. The potential for reducing flows at Ottawa is limited since the major cause of flooding in the lower Rideau basin is the relatively large area of uncontrolled flow downstream from Poonamalie (R.V.C.A., 1981: 5).

The lower subbasin, 66 per cent of the area, contains no natural lakes of any significance. Attenuation of the flood peak by lake storage is therefore much less than in the upper basin. This is demonstrated in Figs. 2.1 and 2.2 showing the springmelt hydrographs for 1977 at the Ottawa and Smith's Falls gauges. Whilst discharge is lower at Smith's Falls, the melt peak extends over a period of approximately 20 days compared with only 14 days at Ottawa.

2.2 Springmelt Hydrographs for the Rideau River

The springmelt hydrographs for the Rideau River at Ottawa are characterised by a steep rising limb followed by a sharp decline in discharge levels once peak discharge has occurred. The 2-year return period flood discharge is $335 \text{ m}^3 \text{ sec}^{-1}$ and the 100-year return period flood discharge is $650 \text{ m}^3 \text{ sec}^{-1}$ (at Ottawa). For the years 1950 to 1980, the mean peak daily mean discharge is $386 \text{ m}^3 \text{ sec}^{-1}$ and the mean number of days of the rising limb is 6 days, the range being between 1 and 13 days. The mean date for the occurrence of the springmelt peak is April 6, the earliest recorded peak is February 24, in 1981.

Two examples of springmelt hydrographs are given in Figs. 2.3 (1956) and 2.4 (1976) to illustrate the variations in hydrograph response to the melt processes and meteorological conditions. The hydrographs show obvious differences which are due to the prevailing meteorological conditions for the particular year. Fig. 2.3, 1956, shows a hydrograph having multiple peaks. The rapid rise in discharge levels from $20 \text{ m}^3 \text{ sec}^{-1}$ on April 4 to $350 \text{ m}^3 \text{ sec}^{-1}$ on April 5 was in response to the rainfall of 7 mm on April 4 and also to the rise in maximum daily temperature between April 2 and 4 from 4°C to 12°C . Although temperatures remained similar for the next 10 days, discharge levels dropped rapidly. On April 15 and 16 there was a significant rainfall event (approximately 60 mm), which led to a subsequent rise in discharge levels to give a second but lower peak on April 17. The response of the hydrograph to rainfall is seen within 1 day of the rainfall event. A similar pattern is repeated on April 28 when river levels began to rise in response to rainfall on

FIG.2.1 SNOWMELT HYDROGRAPH AT OTTAWA
GAUGE FOR 1977.

FIG.2.2 SNOWMELT HYDROGRAPH AT SMITHS FALLS
GAUGE FOR 1977.

DISCHARGE
 $\text{M}^3 \text{SEC}^{-1}$

FIG.2.3 SNOWMELT HYDROGRAPH AT OTTAWA
GAUGE FOR 1956.

April 27, 28 and 29. It is now

published here as a

FIG.2.4 SNOWMELT HYDROGRAPH AT OTTAWA
GAUGE FOR 1976.

April 27, 28 and 29. It is suggested that the hydrograph response exhibited here, particularly on April 17, is due to the melting effect of rainfall on the snowpack and to the direct contribution of rainfall to channel runoff, rather than to melting due to rising temperatures.

The river hydrograph for 1976, in contrast to that for 1956, shows only one peak. The rising limb is longer and more gradual, being a response to the increase in temperature from below 0°C on March 16, to 13°C on March 20. There were three rainfall events during this period which obviously aided the melt process but it is probable that rising temperatures were mainly responsible for the release of water from the snowpack. After March 28, discharge levels began to fall, indicating that the peak had passed. However, on April 1 there was a slight increase in discharge in response to a total rainfall of 31 mm on March 31 and April 1. This caused the falling limb to be delayed and again emphasises the role of precipitation in controlling springmelt runoff.

These examples identify the nature of springmelt hydrographs for the Rideau River and the role of short term meteorological conditions in controlling the character of the hydrograph. Specifically, the effect of maximum daily temperature and rainfall are considered. These and other meteorological variables are incorporated in the forecasting models developed in this study. The possible range in hydrograph response is also seen in these examples, 1956 having multiple peaks and 1976 a single peak. The nonconformity in hydrograph response in different years makes forecasting more difficult.

2.3 The Current Springmelt Flood Forecasting System

In 1980, the R.V.C.A. published its Flood Warning System which describes the procedure currently in use. The following description is drawn from this document (R.V.C.A., 1980) and from a 1979 report by Acres Consulting Services Ltd. carried out for the R.V.C.A. which reviewed the existing R.V.C.A. forecasting techniques and made recommendations for improvement. Some of these recommendations are incorporated into the current R.V.C.A. system.

i) Long Term Forecast

On March 1 a forecast is made to allow assessment of the potential flood risk. At this stage only the range or category of the flood peak

is indicated. Table 2.1 gives the categories used. No indication of the timing of the flood peak is given. The estimate of the flood peak is made using the regression line in Fig. 2.5. The regression line and freehand line relate water equivalent of the snowpack on March 1 to peak daily mean discharge at Ottawa. The least squares regression line was calculated by Acres (1979: 19) and will be referred to in this thesis as the 'Acres bivariate model'. The R.V.C.A. freehand fit curve will be referred to as the 'R.V.C.A. freehand model'. The Acres bivariate model is now used by the R.V.C.A. and has a correlation coefficient of 0.84 and a standard error of +25 to -20 percent.

Acres (1979: 31) suggest that regression equations could also be developed relating the forecast flood peak to the average water equivalent of the snowpack at forecast time, t , river discharge at time t , and/or before time t to give some indication of soil moisture conditions. Such regression equations have not yet been developed.

ii) Short Term Forecasting

As flood levels begin to rise, flood peak and time to peak forecasts are made at more frequent intervals. Several weeks prior to the peak, daily forecasts are produced. The short term forecasts consist of a 6 day and a 1-2 day forecast of peak discharge. The main tool used in making these forecasts is the Acres bivariate model (Fig. 2.5), using a value of the water equivalent of the snowpack adjusted for days since March 1 rather than the March 1 value. This is obtained by adding accumulated rainfall and subtracting runoff over the basin. In addition, the observed flows up to the forecast time are recorded graphically together with plots of precipitation and temperature. By extrapolating the hydrograph (usually by eye), forecasts can be made for the required forecast period. This is combined with an intuitive deterministic estimate of the effects of recent and forecast meteorological conditions.

Acres (1979: 27) propose that an autoregressive, integrated moving average time series model be developed to replace this intuitive extrapolation of the hydrograph. This has the advantage of being wholly objective and forecasts will not vary between operators, the intuitive element in the procedure having been eliminated.

The time to peak forecasts are made using a thaw-degree day index developed by Acres (1979: 8). This index relates the number of thaw-

Table 2.1. March 1 Forecast Peak Discharge Categories

<u>Category No.</u>	<u>Peak Discharge Range m³ sec⁻¹</u>	<u>Conditions</u>
1	Below 400	No flood damage
2	400-500	Slight flood damage
3	Above 500	Flood damage becomes significant

Source: R.V.C.A. (1980: 6).

FIG.2.5 LONG RANGE FORECASTING CURVE.

SOURCE: ACRES (1979)

degree days, observed + forecast, to the probability that the peak will have occurred by the end of the temperature forecast period (24 hours). The thaw-degree index is given in Table 2.2.

As a means of improving the short term forecasting procedure, Acres (1979: 32) also suggest that use could be made of regression equations. These would relate forecast discharge and time to peak discharge to variables such as measured water equivalent of the snowpack, precipitation, temperature, streamflow and ground temperature for various periods of time. A set of equations could be developed for various specific forecast times.

Other recommendations made by Acres (1979) for the improvement of the springmelt forecasting system relate to the use of deterministic computer modelling which is beyond the scope of this thesis.

The procedure for issuing flood warnings to the relevant authorities is described in the R.V.C.A. Flood Warning System (1980).

iii) Shortcomings of the Current R.V.C.A. System

Three basic shortcomings can be identified in the current R.V.C.A. system:

1) The long term forecast of peak discharge is made using only one variable, water equivalent of the snowpack on March 1. It is suggested that the inclusion of additional variables, reflecting aspects of the snowmelt process, will improve the accuracy of the forecasts. This is achieved in this thesis through the development of multiple regression models.

2) The Acres bivariate model (Fig. 2.5) is used as the main forecasting tool in both long and short term forecasting. This assumes that the water equivalent of the snowpack is equally important in estimating discharge values on a long and short term basis. Thus there is no means of including, in a quantitative manner, those variables which become important in determining short term variations in springmelt runoff.

3) There is an element of subjectivity in the R.V.C.A. System which is apparent in short term forecasting when extrapolating hydrographs by eye and making intuitive estimates of the effects of meteorological conditions on runoff. Different forecasters are likely to produce different estimates of discharge using this method. A more objective model would remove this element of subjectivity.

Table 2.2. Thaw Degree Day Index Developed by Acres (1979)

	Observed + Forecast Thaw Degree Days				
	18	25	32	39	46
Per cent probability that peak will have occurred by end of temperature forecast period (24 hrs.)	2	17	50	84	98

Method of calculation: data base 1971 to 1978.

Average thaw-degree ($^{\circ}\text{C}$) days prior to flood peak = 32°C days

Standard deviation = 7°C days

= 2 days.

(The standard deviation in terms of days was obtained by dividing the standard deviation in degree days by the weighted average daily temperature ($^{\circ}\text{C}$) derived from all thaw periods).

Source: Acres (1979: 21).

2.4 Hydrologic Forecasting

i) Types of Hydrologic Models

Hydrologic forecasting can take many forms with a wide variety of techniques being available. Three groups of models can be identified (Gregory and Walling, 1973: 226):

- 1) Physical models.
- 2) Analogue models.
- 3) Digital models.

Digital models which are associated with the use of computers, allowing the processing of large quantities of data, can be further divided into a) deterministic physically based models, b) stochastic models and, c) parametric models. An example of a digital parametric model is the multiple regression model used in this thesis involving the development and analysis of relationships between numerically defined characteristics of basin processes.

Forecasting models may also be grouped according to the extent to which they attempt to represent actual processes operating within the watershed. Black box models attempt no process explanation whilst white box models attempt complete modelling of basin processes. Grey box models use variables known to be important in process terms to represent the internal functioning of the basin.

The models developed in this thesis using multiple regression analysis are within the parametric and grey box group of models, being classified as multivariate forecasting models.

ii) Multiple Regression Analysis

The specific objectives of developing a new forecasting system are outlined in Chapter 1, section 1.3 and the shortcomings of the R.V.C.A. system are identified in section 2.3. It is felt that multiple regression analysis provides the best means of developing a new model which both fulfills these objectives and overcomes the problems of the R.V.C.A. system.

The statistical technique of multiple regression analysis allows the relationship between a dependent variable and several independent variables to be examined. In this study the dependent variable is peak daily mean discharge and the independent variables are those which influence springmelt runoff. The multiple regression model is expressed as an

equation of the general form:

$$Y' = A + B_1X_1 + B_2X_2 + \dots + B_iX_i$$

where Y' is the estimated value for Y (peak discharge in this instance), A is the Y intercept, B_i are the regression coefficients and X_i are the independent variables (e.g., water equivalent of the snowpack, snowfall, etc.). The coefficients A and B are those values which minimise the sum of the squared residuals, $\Sigma(Y-Y')^2$. This means that the correlation between the actual Y values and the estimated Y' values is maximised, while the correlation between the independent variables and the residual values ($Y-Y'$) is reduced to zero (Kim and Kohout, 1975: 330).

There are two basic uses of multiple regression techniques these being as a descriptive tool and as an inferential tool. As a descriptive tool the technique can be used to summarise and decompose the linear dependence of one variable on others. Used inferentially, the relationships in the population are evaluated from an examination of sample data. In hydrology and fluvial geomorphology, multiple regression techniques have been used descriptively to examine the relationship between suspended sediment concentration and various controlling factors, for instance Guy (1964), and by Foster (1978) to model storm period solute behaviour. Other hydrologic studies have used multiple regression equations to predict various characteristics of basin runoff, such as the mean annual flood (Wong, 1963); flood frequency (Nash and Shaw, 1966); streamflow characteristics (Thomas and Benson, 1970) and annual runoff (Busby, 1964).

Cohen (198?) uses a multivariate model, in the form of an Auto-regressive Integrated Moving Averages time series model, to forecast runoff from the Sentinel Glacier in British Columbia. Amongst the variables included in this model are precipitation, temperature, melting degree days, relative humidity and sunshine hours. Milton and Hannan (1982) analyse the role of various climatological factors contributing to spring discharge in three subbasins of the Red River using a stepwise linear regression program. The independent (climatological) variables include antecedent and winter precipitation, a winter severity index, springmelt degree days and an index of springmelt duration. The model was tested using March 1 data to assess the possibility of its use as a forecasting model. These two studies use multivariate techniques and

climatological variables in the forecasting of melt runoff and are therefore similar to the approach used in this thesis.

CHAPTER 3

LONG TERM FORECASTING

3.1 Aims of Producing a New March 1 Forecast Model

As stated in the R.V.C.A. Flood Warning System (1981: 6), the aim on this date is to generate a mean discharge value for the day of the expected flood wave peak. This predicted value can then be related to the three flood damage categories given in Table 2.1. This provides a first approximation of likely flood risk. The model developed in this thesis is an attempt to improve upon the accuracy of the existing R.V.C.A. forecasts. Eight variables, additional to the water equivalent of the snowpack on March 1 used by the R.V.C.A., which would appear to be important in determining the amount of water available as potential runoff, are included (Table 3.1, #2-9). It is to be expected that a more accurate forecast will be made if variables reflecting the processes operating within the system under consideration are incorporated into the model. The selection of variables is discussed in Section 3.2. The statistical basis for selecting the 'best' model is the standard error term, the final model being that with the lowest standard error. This is discussed fully in section 3.4.

In this chapter the selection of the additional variables, the development of the multivariate long term forecasting model and the selection of the final model are discussed. The forecasts obtained using the multivariate model are then compared with those produced using the Acres bivariate model which is currently used by the R.V.C.A.

3.2 Selection of Variables

The variables used in the development of a new March 1 forecast model are listed in Table 3.1 together with the operational definitions and abbreviations used in the text. The long range forecast attempts only to indicate the peak daily mean discharge. Thus, the variables used in the forecasting model reflect various aspects of the mass or water equivalent of the snowpack and basin moisture conditions. These conditions are dependent upon preceding meteorological conditions and will determine the availability of water for runoff once melt begins. The variables can be grouped according to the following snowpack and basin characteristics.

Table 3.1. Variables Used in Multivariate March 1 Forecast Model

<u>Variable</u>	<u>Abbreviation used in text</u>	<u>Operational definition</u>
1. Water equivalent of snowpack on March 1	WEQSP	Mean of readings at R.V.C.A. and Rideau Canal stations
2. Minimum winter discharge ($\text{m}^3\text{sec}^{-1}$)	MINQ	Minimum daily mean discharge at Ottawa in January and February
3. Discharge on March 1 ($\text{m}^3\text{sec}^{-1}$)	QMAR1	Daily mean discharge on March 1 at Ottawa
4. Snowdays (days)	SNWDAYS	Number of days with snowfall in January and February
5. Degree days ($^{\circ}\text{C}$)	DEGDAY	Cumulated degree days above 0°C since January 1
6. Sunshine hours (hours)	SUNHRS	Cumulated hours of bright sunshine since January 1
7. Rainfall (mm)	RAIN	Cumulated rainfall since January 1
8. Snowfall (cm)	SNWF	Cumulated snowfall since January 1
9. Total precipitation (mm)	TPREC	Total precipitation (snow reduced to water content) since January 1
10. Year	YEAR	Sequence in the series 1950-1980
11. Year ²	YEAR2	Sequence in the series 1950-1980 squared
12. Peak discharge ($\text{m}^3\text{sec}^{-1}$)	PEAKQ	Maximum daily mean discharge during springmelt, at Ottawa

a) Condition of the snowpack

WEQSP

SNWF

TPREC

DEGDAYS

b) Storminess of the winter

SNWDAYS

SNWF

c) Degree of melting

SUNHRS

DEGDAYS

RAIN

d) Basin moisture conditions

MINQ

QMARI

The water equivalent of the snowpack on March 1 is the independent variable used in the R.V.C.A. by eye regression and in Acres bivariate model. The location of the snow depth stations from which these data are obtained varies considerably between 1950 and 1981. Therefore, Thiessen polygon weights, which express the area closer to a station than to any other station were calculated as a proportion of the total basin area. The value of WEQSP for the basin is obtained by applying the Thiessen weight to the reading for each station and summing the values obtained. This should be more accurate than using the arithmetic mean value; however, the difference between the arithmetic and area-weighted means is not significant. In addition to WEQSP, river discharge on March 1 is suggested by Acres (1979: 31) as being indicative of basin soil moisture conditions.

The variables WEQSP, SNWF, TPREC and DEGDAYS all reflect the condition of the snowpack in some way. SNWF and TPREC represent the amount of input to the snowpack over the period January 1 to March 1. DEGDAYS indicates the ripening of the snowpack. The balance of additions to and losses from the snowpack is measured by WEQSP.

The storminess of the winter is measured by the variables SNWF and SNWDAYS. These reflect the severity of the winter. Prior to the beginning of the actual melt period, it is likely that there will be some losses from the snowpack due to melt. The variables SUNHRS, DEGDAYS and

RAIN are included since these will influence the amount of melt.

Minimum winter discharge (MINQ) and discharge on March 1 (QMAR1) reflect overall basin moisture conditions which may affect the magnitude of PEAKQ. MINQ gives an indication of the levels of baseflow during the winter months and QMAR1 is a surrogate for the moisture conditions on March 1. The extent to which these conditions remain in effect during the springmelt period however is not considered.

3.3 Correlation Analysis

Pearson product-moment correlation coefficients are computed using SPSS (1975) for the variables used in forecasting peak discharge (Table 3.2). Although no causal relationship can necessarily be implied from a correlation coefficient, the degree of association between two variables is indicated which is necessary and sufficient for forecasting purposes. Often causal links can be identified and these are discussed as appropriate.

Peak discharge is most highly correlated with WEQSP, the correlation coefficient (r), of 0.74 giving an r^2 (coefficient of determination), value of 0.55. Thus, 55 per cent of the variance in PEAKQ values can be statistically 'explained' by the values of WEQSP. Other variables which are significantly correlated with PEAKQ are (Table 3.2): SNWDAYS ($r = 0.52$); MINQ ($r = 0.34$); TPREC ($r = 0.34$); and SNWF ($r = 0.31$). This suggests that these variables may be important in a multiple regression equation used to forecast PEAKQ values.

In causal terms, SNWDAYS, TPREC and SNWF are all indicators of the amount of moisture being input into the system as potential runoff. The greater these values are, the higher the amount of runoff, as measured by PEAKQ, is likely to be. The positive correlation between MINQ and PEAKQ may be due to higher baseflow, (as measured by MINQ), caused by greater saturation of the basin which will add to the PEAKQ level. This explanation assumes that the high baseflow conditions persist during the melt period. No attempt is made to test this assumption because of the forecast rather than process explanation objectives of this thesis.

Other relationships where causal links can be identified are: WEQSP significantly and positively correlated with SNWDAYS ($r = 0.51$), TPREC ($r = 0.52$), and SNWF ($r = 0.48$) (Table 3.2). These relationships are to be expected since the greater the amount of precipitation, the greater

Table 3.2. Pearson Product-Moment Correlation Coefficients Between Variables
used in March 1 Forecast Model

	PEAKQ	WEQSP	SUNHRS	RAIN	DEGDAY	SNWDAYS	QMAR1	MINQ	TPREC	SNWF
PEAKQ	—	<u>0.74</u>	-0.28	-0.10	-0.12	<u>0.52</u>	-0.04	<u>0.34</u>	<u>0.34</u>	<u>0.31</u>
WEQSP		—	<u>-0.34</u>	-0.06	-0.30	<u>0.51</u>	0.02	0.19	<u>0.52</u>	<u>0.48</u>
SUNHRS			—	0.15	-0.11	<u>-0.47</u>	-0.22	-0.24	-0.62	<u>-0.51</u>
RAIN				—	0.24	-0.16	-0.10	0.19	0.33	<u>-0.34</u>
DEGDAY					—	-0.10	0.13	0.02	0.22	0.09
SNWDAYS						—	0.22	0.03	<u>0.60</u>	<u>0.66</u>
QMAR1							—	0.24	0.11	0.23
MINQ								—	0.00	-0.07
TPREC									—	<u>0.89</u>
SNWF										—

Significant at 99%

Significant at 95%

will be the amount of water stored in the snowpack. As expected, SUNHRS and WEQSP are inversely related ($r = -0.34$). The greater the amount of insolation as represented by SUNHRS, the more water will be lost from the snowpack due to melt.

All of the remaining significant correlations (Table 3.2) are between meteorological variables. For example, SUNHRS is negatively correlated with SNWDAYS, TPREC and SNWF (i.e., cloudy days).

3.4 The Development of a Long Term Forecasting Model

i) Statistical Basis for Model Development

The multiple regression technique is used in this study to develop a forecasting equation using those independent variables which give the 'best' forecasts. In statistical terms the 'best' regression model can be selected on the basis of the coefficient of determination (R^2), R being the multiple correlation coefficient, and on the basis of the standard error associated with a specific equation. R^2 is the proportion of the variance in the dependent variable which is statistically explained by the independent variables. The standard error is the standard deviation of the actual PEAKQ (Y) values from the predicted PEAKQ (Y') values and is the variance about the regression line:

$$\text{Standard Error} = \frac{\sum (Y - Y')^2}{N - 2}$$

where N is the number of observations.

Thus, it is desirable that R^2 should be high and the standard error be low. In choosing the 'best' equation a low standard error term forms the basis for selection as suggested by Hann (1970: 210). Confidence levels may be attached to the regression equation; 68 per cent of observations will be within ± 1 standard error and 95 per cent within ± 2 standard errors of the predicted values*. The equation with the smallest standard error will have the narrowest confidence limits and, on average, predicted values will be closest to observed values. Initially as independent variables (B_2 to B_i) are included, R^2 increases and the standard error decreases. As yet more variables are added to a multiple regression equation, the standard error may increase. This indicates that the additional variables do not contribute significantly to the regression

* actually 1.96 (King, 1979:71)

and may be omitted (Hann, 1970: 210).

The level of confidence attached to the regression equations developed in this study is the 68 per cent confidence level, equivalent to ± 1 standard error. Although it is more usual to use the 95 per cent confidence level, ± 2 standard errors, the 68 per cent level has been used since Acres (1979: 14) adopt this level as the desired accuracy for the forecasts of peak discharge. Therefore direct comparison between the accuracy of forecasts produced by the R.V.C.A. system and by the models developed in this thesis is possible.

One of the obvious assumptions of multiple linear regression analysis is that a linear relationship exists between the dependent and independent variables. If the relationship is not linear, then the variables should be transformed in an appropriate manner to achieve such a relationship. In this study, individual variables were not tested for linearity except in the case of the relationship between PEAKQ and WEQSP, which is most important in 'explaining' variations in PEAKQ. Regression equations were computed for this relationship using various transformations and functions of WEQSP (Table 3.3). However, r values for these transformations are not significantly greater than that obtained when fitting a raw data regression line to warrant transforming the data, although the Acres bivariate model uses a power curve to describe this relationship. Further assessment of the linearity of data is possible when the residual plots from the multiple regression analyses are examined. An abnormality in the data is usually apparent as an identifiable pattern in such plots. This will be seen in section 3.4 iii) when additional variables are added to the model to remove a non-linear trend in the data.

Should the data used in a regression analysis be non-linear, and no transformations performed, then the effect will be to produce a model which is less accurate (i.e., having a greater standard error) in its predictive ability than possibly could be achieved. As the equation representing the relationship will not provide the best possible fit to the data, the scatter of points about the regression line will be greater than if transformed data are used. Thus, r will underestimate the strength of the relationship (Bennett, 1977). The standard error will be higher and forecasts will either over or underestimate the observed Y values by an amount greater than would be achieved had the data been increased. Therefore it may be possible to improve the accuracy of the

Table 3.3. Comparison of Correlation Coefficients for Various Equations to Describe the Relationship Between PEAKQ and WEQSP

<u>Relationship</u>	<u>Equation</u>	<u>r</u>	<u>r²</u>
1. Straight line $y = a + bx$	$PEAKQ = 2.16 \cdot WEQSP + 177.39$	0.72	0.52
2. Exponential curve $y = ae^{bx}$ $\ln y = \ln a + bx$	$PEAKQ = 181.12e^{0.01 \cdot WEQSP}$	0.69	0.48
3. Power curve $y = ax^b$ $\ln y = b \ln x + \ln a$	$PEAKQ = 34.23 \cdot WEQSP^{0.52}$	0.73	0.53
4. Logarithmic curve $y = a + b \ln x$	$PEAKQ = -286.8 + 150.85 \ln WEQSP$	0.72	0.52

models developed in this study if any non-linear data were transformed.

The multiple regression analyses use the subprogram 'Regression' of SPSS. A forward (stepwise) inclusion of the variables enters variables in single steps. The variable 'explaining' the greatest amount of variance in the dependent variable is entered first in the equation, the variable which explains the greatest amount of variance in conjunction with the first is entered second, and so on. Several versions of the regression analysis were executed with modifications being made where suggested by the output data. Only the initial analysis and the final model are discussed below.

ii) Initial Analysis

The initial analysis included variables 1-9 listed in Table 3.1 and the results are summarised in Table 3.4.

Table 3.4. Summary of Initial Multiple Regression Analysis,
March 1 Forecast Model

<u>Variable</u>	<u>R²</u>	<u>Standard Error (m³sec⁻¹)</u>
WEQSP	0.547	82.8
MINQ	0.590	80.2
SNWDAYS	0.625	78.1
QMAR1	0.652	76.8
TPREC	0.665	76.9
DEGDAYS	0.700	74.4
RAIN	0.713	74.4
SNWF	0.726	74.3
SUNHRS	0.745	73.4

It is clear that WEQSP explains the greatest proportion of the variance in discharge values (54.7 per cent) and that the explanation of variance added by the remaining eight variables is 19.8 per cent.

iii) Search for Additional Variables

A useful analysis in the development of any regression model is the examination of residuals. The pattern exhibited by residual plots is useful in indicating that the assumptions implicitly required in the use of a multiple linear regression model are fulfilled, and in indicating those aspects which may require modification.

The plot of standardised residuals against time (Fig. 3.1), reveals a slightly arched pattern about the time axis. This pattern suggests

FIG.3.1 PLOT OF RESIDUALS, INITIAL ANALYSIS, MARCH 1
FORECAST MODEL.

that a time trend exists in the data (peak discharge values), and that a linear and quadratic term in time should be included in the model (Draper and Smith, 1966: 89). An ideal plot would be a uniform band of residuals about the time axis which occurs when there is no long term time trend influencing the data.

In order to confirm whether or not a time trend exists in the data, the peak discharge values are plotted against time and the trend line and 5 year moving averages calculated (Fig. 3.2). The trend line indicates a general increase in peak discharge values over the years 1950 to 1980. The plot of 5 year moving averages shows a group of high values between 1950 and 1962, low values between 1963 and 1968, followed by higher values until 1978. The downward trend, apparent in the years 1979 and 1980 may represent the beginning of a second trough in the plot.

The variables added to the model to represent the observed time trend are linear sequence number (YEAR), and the quadratic form, year squared (YEAR2) where 1950 is Year 1 and 1980 Year 31. As it is the position of the observation within the data series which appears to have some influence on PEAKQ rather than the actual year, it is felt that this would be an appropriate measure of 'time'. Year and year squared are used to provide both a linear and quadratic function of time as indicated by Draper and Smith (1966: 89). Gregory (1968: 223) gives an example of using year as sequence number in a regression line for annual rainfall at Bidston for 1901 to 1930. The data are then made symmetrical about the mean such that year 15 becomes 0, year 1, -14 and year 30, +15. It seems that in this case the sequence number, as opposed to actual year, was used to simplify the computations and not directly to represent a time trend in the data. Draper and Smith (1966: 137) state that either the sequence number on the symmetrical data may be used to remove a linear time trend in regression analysis.

iv) The Effect of the 'Time' Variable on the Regression Model

A subsequent regression analysis included the variables YEAR and YEAR2 with those already used in the analysis. The R^2 and standard error values, given in Table 3.5 and Table 3.6 compare the results of this analysis with the initial analysis (Table 3.4).

FIG.3.2 ANNUAL PEAK DISCHARGE 1950-1980 SHOWING
TIME TREND.

Table 3.5. Summary of Multiple Regression Analysis including YEAR and YEAR2, March 1 Forecast Model

<u>Variable</u>	<u>R²</u>	<u>Standard Error (m³ sec⁻¹)</u>
WEQSP	0.547	82.8
MINQ	0.590	80.2
SNWDAYS	0.625	78.1
YEAR2	0.664	75.5
YEAR	0.768	63.9
TPREC	0.796	61.2
DEGDAYS	0.810	60.4
QMAR1	0.825	59.5
RAIN	0.839	58.3
SUNHRS	0.840	59.7

Table 3.6. Comparison of Initial Multiple Regression Analysis and Analysis Including 'Time' Variables, March 1 Forecast Model

	<u>Minimum Standard Error (m³ sec⁻¹)</u>	<u>Corresponding R² value</u>
Initial Analysis	73.4 at step 9	0.745
Analysis including time variables	58.3 at step 9	0.839

Incorporating the linear and quadratic functions of time into the model results in significant improvement by reducing the standard error term, which is the basis for selection of the 'best' model in this thesis, by 22 per cent. The variable SUNHRS is added after the minimum standard error is reached, thus it, together with SNWF, which does not contribute significantly to the 'explanation' to be entered in the equation, is omitted from the final forecasting equation.

The plot of standardized residuals against time (Fig. 3.3) reveals a more even distribution of points about the time axis than was apparent in the initial analysis. This provides evidence that the time trend is substantially reduced through the addition of these variables.

As a check on whether both YEAR and YEAR2 need be included in the model, two further equations were developed excluding YEAR and excluding YEAR2. The results of these changes on the R² and standard error terms are shown in Table 3.7.

Table 3.7. Summary of Results

FIG.3.3 PLOT OF RESIDUALS, ANALYSIS INCLUDING YEAR
AND YEAR2, MARCH 1 FORECAST MODEL.

Table 3.7. Summary of Multiple Regression Analysis Excluding YEAR and Excluding YEAR2, March 1 Forecast Model

	<u>Minimum Standard Error ($\text{m}^3 \text{sec}^{-1}$)</u>	<u>Corresponding R^2 Value</u>
Including YEAR and YEAR2	58.3 at step 9	0.839
Excluding YEAR	69.1 at step 9	0.774
Excluding YEAR2	72.2 at step 8	0.741

Examination of Table 3.7 shows that the regression having both YEAR and YEAR2 gives the lowest standard error term. The residual plots for these two equations (Figs. 3.4 and 3.5) retain the slightly arched pattern apparent in the initial residual plot. This indicates that the time trend is not as effectively reduced as in the model containing both YEAR and YEAR2. This model will be used as the long term forecasting equation. The forecasting equation may then be written as:

$$\begin{aligned} \text{PEAKQ} = & 2.26.\text{WEQSP} + 0.85.\text{MINQ} + 9.20.\text{SNWDAYS} + 0.67.\text{YEAR2} - 21.23. \\ & \text{YEAR} - 1.03.\text{TPREC} + 1.28.\text{DEGDAYS} - 0.29.\text{QMAR1} - 1.09.\text{RAIN} \\ & + 134.61. \end{aligned}$$

The application of this equation is discussed in Chapter 5.

v) Comparison of the Accuracy of Forecasts Produced by the Multivariate and Bivariate Models

To compare the accuracy of the PEAKQ values predicted on March 1 by the multivariate model developed here with those predicted by the Acres bivariate model (now used by R.V.C.A.), the residual discharges are calculated as a percentage of the observed PEAKQ for the years 1950 to 1980 (Table 3.8). The average residual for the bivariate model is 19.9 per cent compared with 13.2 per cent for the multivariate model. This provides some evidence that the latter model gives predictions of PEAKQ which are closer to the observed PEAKQ values.

A further indication of the accuracy or reliability of the forecasting equations can be deduced from the standard error associated with the equation. The standard error calculated for the Acres bivariate model is $70.2 \text{ m}^3 \text{sec}^{-1}$ compared with $58.3 \text{ m}^3 \text{sec}^{-1}$ for the multivariate model. This represents an improvement of 17 per cent in the standard error term.

In Figs. 3.6 and 3.7, the observed PEAKQ values are plotted against

FIG.3.4 PLOT OF RESIDUALS, ANALYSIS EXCLUDING YEAR,
MARCH 1 FORECAST MODEL.

FIG.3.5 PLOT OF RESIDUALS, ANALYSIS EXCLUDING YEAR2,
MARCH 1 FORECAST MODEL.

Table 3.8. Comparison of Residual PEAKQ for Acres Bivariate Model and Multivariate Model

Year	Residual Discharge ($\text{m}^3 \text{sec}^{-1}$)		Residual Discharge, % of Observed Discharge	
	Bivariate Model	Multivariate Model	Bivariate Model	Multivariate Model
1950	163 *	22	36	5
1951	59 *	18	14	4
1952	8	-81 **	2	21
1953	-	-	-	-
1954	63 *	27 *	16	7
1955	33	-24 **	7	5
1956	90	81	26	23
1957	11	-10	8	8
1958	-88	-55	29	18
1959	-49	-2	12	0.5
1960	-1	20	0.2	4
1961	-88	46	46	24
1962	-94 **	21	29	7
1963	31	62 *	7	14
1964	-68	-53	62	49
1965	-160	-102	111	71
1966	0	-33	0	15
1967	-75	3	24	1
1968	58	41	16	11
1969	-96 **	-48	29	15
1970	-28	-28	6	6
1971	-45 **	48	9	10
1972	82 *	40 *	15	8
1973	42	48 *	9	11
1974	16	-18 **	4	4
1975	21	-19 **	5	5
1976	90 *	30	15	5
1977	62	7	13	1
1978	39	31	8	6
1979	-101 **	-113 **	25	28
1980	208	43	54	11
1981	-	-	-	-
Mean	68	39	19.9	13.2

* Flood peak category under predicted.

** Flood peak category over predicted.

FIG.3.6 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA ,USING ACRES BIVARIATE MODEL.

FIG.3.7 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA , USING MULTIVARIATE MODEL .

the predicted values for both forecasting models. The line of agreement represents the situation where observed and predicted values are equal. The plotted points in Fig. 3.7 generally lie closer to this line than do the points in Fig. 3.6. This shows that the multivariate model produces predicted values which are closer to the observed values than the values produced by the bivariate model. The 68 per cent confidence limits are also shown on Figs. 3.6 and 3.7 and it is obvious that these limits are narrower for the multivariate model.

The accuracy of the multivariate and bivariate models may also be considered in terms of predicting the flood damage category within which PEAKQ will fall. It is found that both models give an inaccurate forecast of PEAKQ category in 9 out of 30 years, i.e., in 30 out of 100 years the forecast and observed PEAKQ category will disagree. Years where the models under-predict the flood peak are of particular concern. Such predictions are made for eight years using the Acres bivariate model, with residuals ranging from 9 to 54 per cent. Four predictions under-estimate the flood peak category when using the multivariate model, the residuals being between 7 and 14 per cent. The multivariate model produces 6 forecasts having a residual >20 per cent of observed discharge as compared to 11 such forecasts using the bivariate model. This again reflects the increased accuracy of the multivariate model.

3.5 Forecasting the Timing of the Flood Peak

Some indication of the likely date of peak discharge would be useful in the long term forecasting procedure. Therefore a multiple regression model is also developed to forecast the timing of the flood peak using data available on March 1. The variables used are those given in Table 3.1 and a summary of the regression analysis is given in Table 3.9.

Table 3.9. Summary of Multiple Regression Analysis to Forecast Timing of The Flood Peak

<u>Variable</u>	<u>R²</u>	<u>Standard Error (days)</u>
WEQSP	0.203	11.44
DEGDAYS	0.354	10.48
RAIN	0.388	10.40
SNWDAYS	0.427	10.26
SUNHRS	0.444	10.31
MINQ	0.464	10.34
QMAR1	0.486	10.36
TPREC	0.487	10.59
SNWF	0.512	10.58

The minimum standard error for this model is ± 10.26 days (i.e., 10 days). Thus, the forecasting of timing of the peak flow using March 1 date does not produce an estimate of the date of the flood peak which would be of practical use. For this reason a forecast of the timing of PEAKQ is excluded from the long term forecasting procedure. This problem is addressed in the context of the short forecasting procedure and an estimate of the timing of the flood peak is made at this time.

3.6 Summary

A new multivariate model to be used on March 1 to forecast discharge for the peak flood day is developed. The model uses variables additional to the WEQSP, which is used in the Acres bivariate model. These additional variables are felt to reflect various aspects of snowpack conditions and the melt process and thus influence the PEAKQ values. Linear and quadratic time variables are also incorporated in the model since it is demonstrated that a time trend exists in the data. The inclusion of these variables significantly reduces the standard error associated with the multiple regression equation.

Comparison of the standard error term and the residuals of both models indicates that the multivariate model has a greater predictive accuracy than the Acres bivariate model. It is hoped that use of the multivariate model to predict springmelt peak discharge for future years will lead to more accurate forecasts than if the bivariate model were used.

CHAPTER 4

SHORT TERM FORECASTING

4.1 Background to Short Term Forecasting

The process of short term forecasting is intended to be implemented almost as soon as there is an indication that river levels are rising towards a flood peak. The peak typically occurs around 6 days after the beginning of a rise, but the rise may last from 1 to 13 days. At present the R.V.C.A. produces a 6 day and 1-2 day forecast of PEAKQ. The desired accuracies of these forecasts are given in Table 4.1. The techniques used to produce these forecasts have been discussed in Chapter 2 and include the bivariate regression model (Fig. 2.5), visual data plots and weather forecasts and a degree day index to forecast the likelihood that PEAKQ will occur within 24 hours. Acres (1979) suggest various means of improving the short term forecasting techniques, these being; time-series analysis, regression equations and deterministic computer modelling. The use of regression equations would relate forecast discharge, peak discharge and time to peak, to variables such as measured water equivalent of the snowpack, precipitation, temperature, streamflow and ground temperature for various specific forecast times.

In this thesis regression equations similar to those suggested by Acres are developed with the intention of producing forecasts of PEAKQ for time periods comparable to those used by the R.V.C.A. A multivariate model is also derived to forecast the duration of the rising limb (DURATN) of the hydrograph from the time stage levels begin to rise. This is comparable to a time to peak forecast. An indication of the likely date of the peak is needed not only from the practical perspective of issuing flood warnings, but also in this thesis, as a means of determining when to begin and when to terminate short term forecasting of PEAKQ. Chapter 5 describes in detail the implementation of the short term forecasting system.

This chapter discusses the selection of variables for short term forecasting, development of the forecasting equations and selection of the final forecasting models.

Table 4.1: Short Term Forecasting Requirements

Desired Accuracy - Standard Error

(i.e. 68 per cent level of confidence)

Type of Forecast	Time of Forecast	Forecast Period (Days)	Time to Peak (hrs.)	Level Accuracy (m)	Corresponding Discharge Accuracy (per cent)
6 days	March to early May	6	± 12	± 0.30	± 20
24/48 Hours	As above	1-2	± 6	± 0.15	± 10

Source: R.V.C.A. (1980:7)

Table 4.2. Variables Used in Short Term Forecasting Model

<u>Variable</u>	<u>Abbreviation used in Text</u>	<u>Operational Definition</u>
1. Adjusted water equivalent of snowpack (mm)	Adjusted WEQSP	March 1 value + daily precipitation - daily runoff
2. Sunshine hours	SUNHRS	Hours of bright sunshine on forecast day
3. Snowfall (cm)	SNWF	Snowfall on forecast day
4. Rainfall (mm)	RAIN	Rainfall on forecast day
5. Total precipitation (mm)	TPREC	Total precipitation on forecast day
6. Maximum daily temperature ($^{\circ}\text{C}$)	MAXT	Maximum temperature on forecast day
7. Minimum daily temperature ($^{\circ}\text{C}$)	MINT	Minimum temperature on forecast day
8. Mean daily temperature ($^{\circ}\text{C}$)	MEANT	Mean temperature on forecast day
9. Degree days ($^{\circ}\text{C}$)	DEGDAYS	Number of degree days above 0°C since January 1
10. Date (days)	DATE	Number of days after January 1 that forecast is made
11. Discharge ($\text{m}^3\text{sec}^{-1}$)	DISCH	Daily mean discharge at Ottawa on forecast day
12. Year	YEAR	Sequence in the series 1950-1980
13. Year ²	YEAR2	Sequence in the series 1950-1980 squared
14. Peak discharge ($\text{m}^3\text{sec}^{-1}$)	PEAKQ	Maximum daily mean discharge during springmelt at Ottawa
15. Duration of rising limb of hydrograph (days)	DURATN	Number of days of rising limb measured from day R0 to day of PEAKQ

4.2 Variables Used in Short Term Forecasting

A list of the variables used in the short term forecasting procedure is given in Table 4.2. These variables are generally similar to those used in making long term forecasts. The adjusted WEQSP is used rather than the March 1 value since it is felt that when forecasting on a short term basis, it is the amount of water available in the period antecedent to the flood peak which will be important in determining discharge values. This variable is calculated by taking the area (Theissen polygon) weighted WEQSP on March 1 for each year, adding to it total daily precipitation as measured at Ottawa International Airport, and subtracting runoff from the basin on a daily basis. Daily mean discharge ($\text{m}^3 \text{sec}^{-1}$), measured at Ottawa, is converted to runoff (mm) by applying a factor of 0.02254. The derivation of this factor is given in Appendix 1. Through these calculations it is possible to determine the adjusted WEQSP for any day prior to the flood peak.

The variable DATE is included in this analysis as it is possible that the timing of the peak within the melt season may to some extent determine the magnitude of the peak. It may be argued that early peaks are likely to be of greater magnitude since there will be less opportunity for potential runoff to be lost gradually from the snowpack. Therefore more water remains to contribute directly to the flood wave. The variable DEGDAYS, which is measured cumulatively up to the forecast day, indicates the likely extent of melting of the snowpack and consequent loss of water prior to the flood wave. It has been demonstrated in developing the March 1 forecast model that a complex time trend exists in the flood peak data. This suggests that the variables YEAR and YEAR2 be included in a short term, as well as in a long term forecasting model since it is the flood peak which is being forecast.

All of the data used in the short term forecasting model are lagged by various time periods. That is, for example, a 2 day forecast would use data measured 2 days prior to the peak. This is based on the assumption that there will be a time delay between the occurrence of the meteorological conditions which control the release

of water from the snowpack and/or basin response to rainfall, and the arrival of this water in the river channel at the discharge station. In the search for an appropriate lag, the data were lagged on a daily incremental basis from 1 to 12 days prior to the peak for each of the 31 years in the analysis. Data were not lagged for periods greater than 12 days since there was no further improvement in the standard error term for the forecast equations.

4.3 Development of the Short Term Forecast Model

As with the long term forecast model, multiple regression equations are developed using the SPSS subprogram 'Regression'. The basis for selection of the 'best' model is again the standard error term, as explained in Chapter 3.

A summary of the regression analysis, using all the variables listed in Table 4.2, and with data lagged up to 12 days is given in Table 4.3.

It is evident that the 'best' model uses data lagged by 5 days, the standard error being lowest. Considering the fact that the standard error for the long term forecasting equation is $58.3 \text{ m}^3 \text{ sec}^{-1}$, it is perhaps surprising that the standard error for the short term forecasts is not lower. It would be expected that, when using variables measured close to the flood peak, which represent recent events, values predicted by the multiple regression equations would be more in agreement with observed values than when using March 1 data.

4.4 The Final Short Term Forecasting Equations

The equations selected for use in the short term forecasting model are the 1, 2 and 5 day equations. A 1 and 2 day forecast corresponds with the R.V.C.A. 1-2 day forecast. The 5 day forecast is chosen as it gives the lowest standard error of all the equations considered. It is intended that this replace the 6 day forecast produced by the R.V.C.A. Table 4.4 gives the three final equations.

The standard error term increases, though not consistently, when the data are lagged by periods of greater than 5 days. It would seem that the 5 day lag period is of significance in predicting PEAKQ. This may represent the time taken for water added to the basin, by

Table 4.3: Summary of Multiple Regression Analysis for Short Term Forecasting, data lagged up to 12 days.

Forecast Period of Lag of Data	Minimum Standard Error ($\text{m}^3\text{sec}^{-1}$)	Step in Which Minimum Standard Error Achieved	R^2
1	54.5	6	0.883
2	62.0	8	0.862
3	67.3	6	0.822
4	67.7	7	0.828
5	49.3	8	0.913
6	80.4	8	0.808
7	58.4	5	0.860
8	67.1	10	0.854
9	84.0	7	0.728
10	73.0	9	0.818
11	89.0	5	0.677
12	81.1	8	0.764

Table 4.4: Short Term Forecasting Equations

1 Day Forecast:

$$\text{PEAKQ} = 0.72.\text{DISCH} - 0.93.\text{DEGDAYS} + 3.00.\text{DATE} - 5.31.\text{SUNHRS} + 3.90.\text{MAXT} \\ + 33.09.\text{SNWF} - 33.82$$

2 Day Forecast:

$$\text{PEAKQ} = 0.57.\text{DISCH} - 0.84.\text{DEGDAYS} + 2.93.\text{DATE} + 2.14.\text{RAIN} + 0.32.\text{YEAR}^2 \\ - 9.47.\text{YEAR} + 0.48.\text{Adjusted WEQSP} - 3.64.\text{SUNHRS} + 55.60$$

5 Day Forecast:

$$\text{PEAKQ} = 1.49.\text{Adjusted WEQSP} + 0.19.\text{DISCH} - 0.35.\text{DEGDAYS} - 25.79.\text{RAIN} \\ + 21.70.\text{TPREC} + 0.63.\text{YEAR}^2 - 18.23.\text{YEAR} - 3.66.\text{SUNHRS} + 303.04$$

melt or rainfall, to reach the main channel at the Ottawa gauge and thus be reflected in the discharge readings.

In terms of the process of snowmelt, the temperature variables can be expected to be significant in determining runoff. However, they are not present in the final 5 day equation. Presumably DEGDAYS and SUNHRS provide a more adequate indicator of the controlling influences on snowmelt hydrology in the basin. Similarly, RAIN, which tends to induce melting and contribute directly to runoff, is included in the model. MAXT is entered only on the 1 day equation although it contributes only 0.6 per cent to the R^2 statistic (Appendix 2).

A further point of interest when considering the variables present in the three final equations is that for the 1 and 2 day forecasts DISCH 'explains' a large proportion of the variance in PEAKQ values. This is shown by the R^2 values of 0.79 and 0.70 respectively for step 1 on these equations (Appendix 2). It is obvious that stream discharge 1-2 days from the time of the forecast, will be largely determined by discharge on the forecast day. Adjusted WEQSP is absent from the 1 day forecasting equation and 'explains' only 0.6 per cent of the variation in PEAKQ when entered on the 2 day model

(Appendix 2). However it is of primary importance in the 5 day forecast, contributing 51.6 per cent to the 'explanation' of PEAKQ in contrast to 15 per cent by DISCH. It may be hypothesised that at 5 days prior to the flood peak, the volume of water stored in the snowpack is the most important factor in predicting the actual peak discharge. As the lag between forecast time and occurrence of PEAKQ decreases, the predicted peak is more dependent upon current river discharge. By this stage most of the stored water will have been released from the snowpack and is in the river channel, or in movement towards the channel.

Other multiple regression models of 5, 2 and 1 day forecasts of PEAKQ included the forecast DURATN (i.e. forecast day of the flood peak), amongst the independent variables. Only on the 5 day model is the standard error reduced (by $2 \text{ m}^3 \text{ sec}^{-1}$), by including DURATN. Since the reduction in the standard error of the 5 day model is insignificant, the forecast variable DURATN is excluded from the model used to forecast PEAKQ.

4.5 Accuracy of the 5, 2 and 1 Day Forecasting Models

It is not possible to make a comparison between the accuracy of the 5, 2 and 1 day forecasts produced by the multivariate models developed in this thesis and the short term forecasts made by the R.V.C.A. This is because no records are available of the short term forecasts issued daily by the R.V.C.A. Also the R.V.C.A. forecasting system does not take the form of a forecasting equation and so would be more difficult to apply to historical data.

The predicted peak discharges for the 5, 2 and 1 day forecasts are plotted against the observed discharges for the 1950 to 1980 data in Figs. 4.1, 4.2 and 4.3. There is greatest agreement between observed and predicted discharges for the 5 day forecasting model which has the lowest standard error. The greatest deviation of points from the line of agreement is seen in Fig. 4.2 (2 day forecasting model) where the standard error is $\pm 62.0 \text{ m}^3 \text{ sec}^{-1}$. These figures allow some assessment of the predictive accuracy of the 5, 2 and 1 day models to be made.

FIG.4.1 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA, USING 5 DAY MULTIVARIATE MODEL.

FIG.4.2 OBSERVED AGAINST PREDICTED DISCHARGE PEAK
AT OTTAWA, USING 2 DAY MULTIVARIATE MODEL.

FIG.4.3 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA, USING 1 DAY MULTIVARIATE MODEL.

4.6 Forecasting Duration of the Rising Limb of the Springmelt Flood Hydrograph

i) Definition of the Rising Limb

Through examination of springmelt hydrographs for the years 1950 to 1980, the following definition of the rising limb was developed for use in this study. Daily mean discharge on the first day of a rise (R1) must be at least $15 \text{ m}^3 \text{ sec}^{-1}$ greater than the previous day (R0). On day two (R2) the increase in discharge from R1 must be at least 50 per cent of the increase between R0 and R1. Discharge levels must continue to rise on day R3. The mean duration (DURATN) is 6 days, though some rising limbs have been as short as 1 day and as long as 13 days. DURATN is measured from day R0.

ii) The Forecasting Equation

From the definition of the rising limb it is clear that on day R2, the likelihood of a rising limb occurring is fairly well established. It thus seems reasonable to use data obtained on this day to produce a forecast of the duration of the rising limb. Applying this procedure to the years for which data are available shows that in only 2 years, 1956 and 1957, where DURATN is 1 and 2 days respectively, would the peak have occurred before a forecast was issued, i.e. some 6 to 7 years in one hundred years. For the majority of cases a forecast of DURATN on R2 should allow a forecast of PEAKQ to be made before the peak occurs.

As with the short term forecasting equations for PEAKQ, a multiple regression model is developed to forecast rising limb duration. The variables used are those given in Table 4.2 with DURATN being the dependent variable. Inclusion of the 'time' variables (YEAR and YEAR2) can be justified on the basis of Fig. 4.4 showing DURATN for the years 1950 to 1980. The trend line indicates a general increase in DURATN whilst the 5 year moving averages suggests successive irregular cycles with 1978 possibly marking the beginning of a fourth cycle. Table 4.5 summarises the results of this multiple regression analysis.

FIG.4.4 DURATION OF RISING LIMB OF HYDROGRAPH
1950-1980 SHOWING TIME TREND.

Table 4.5: Summary of Multiple Regression Analysis for Forecasting DURATN of Rising Limb of the Hydrograph

Variable	Standard Error (Days)	R^2
AWEQSP	2.42	0.354
MAXT	1.96	0.590
MEANT	1.87	0.641
YEAR	1.86	0.659
DISCH	1.85	0.675
SNWF	1.87	0.683
SUNHRS	1.90	0.687
RAIN	1.93	0.691
TPREC	1.87	0.724
DEGDAY	1.88	0.735
DATE	1.92	0.739
YEAR 2	1.96	0.743
MINT	2.02	0.744

Taking the minimum standard error as the decision criterion for the inclusion of variables, the forecasting equation can be written as:

$$\text{DURATN} = 0.04.\text{Adjusted WEQSP} - 0.68.\text{MAXT} + 0.44.\text{MEANT} + 0.04.\text{YEAR} \\ - 0.004.\text{DISCH} + 5.68$$

The standard error for this equation is ± 1.85 days. However for forecasting purposes this is given as ± 2 days.

Some process explanation of these terms is possible. The variables present in the forecasting equation, apart from YEAR, can be expected to have some controlling influence on DURATN when the process of snowmelt is considered. Adjusted WEQSP is positively correlated with DURATN ($r = 0.59$, Appendix 3). The greater the

volume of water stored in the basin, the longer it is likely to be before storage is totally depleted, thus, generally the time taken to reach PEAKQ will also be increased. Both MAXT and MEANT are negatively correlated with DURATN ($r = -0.52$ and -0.42 respectively, Appendix 3): warmer temperatures will induce more rapid melt and consequently the increase in discharge levels will be at a faster rate than when temperatures are lower.

iii) Accuracy of Forecasting DURATN Using Multivariate Model and Comparison with R.V.C.A. System

The observed against predicted DURATN of the rising limb with 68 per cent confidence limits (± 2 days) about the line of agreement are plotted in Fig. 4.5. The majority of data points fall within the 68 per cent confidence limits.

The R.V.C.A. does not produce a forecast of DURATN as such, although through hydrograph extrapolation and taking account of recent and forecast meteorological conditions some estimate of the time of the flood peak is made. A probability statement concerning the occurrence of the flood peak by the end of the temperature forecast period (24 hours) is also issued using the observed forecast thaw degree days (Table 2.2). For example if thaw degree days equal 32, there is a 50 percent probability that PEAKQ will occur in the next 24 hours. This assumes that the temperature forecasts are accurate. The standard deviation associated with this index is ± 2 days, the same as the standard error associated with the multiple regression model developed here which depends only on measured, not on forecast data.

It is not possible to compare directly the predicted time of flood peak given by the multivariate model with that given by the R.V.C.A. system. This is because no records are available of the time to peak forecasts issued by the R.V.C.A. These would be needed to make a direct comparison. In terms of the standard error and standard deviation, the two methods would seem to be of comparable accuracy, both have an error term of ± 2 days. However one advantage of the multivariate model is that it does not depend on forecast but on measured data.

FIG.4.5 OBSERVED AGAINST PREDICTED DURATION OF
RISING LIMB.

The fact that DEGDAYS does not enter into the multivariate model indicates that it is not as important as other variables (i.e., Adjusted WEQSP, MAXT, MEANT, YEAR and DISCH) is determining DURATN of the rising limb. DEGDAYS adds only 1 per cent to the R^2 statistic (Appendix 3), MAXT and MEANT are substituted for DEGDAYS as the index of temperature affecting the rate of rise of the flood wave.

iv) Additional Equations to Forecast DURATN

Multiple regression equations were also developed to forecast DURATN from data measured on various days prior to PEAKQ using historical data. The 'best' model in terms of the standard error, 1 day (Table 4.6) is achieved using data measured 6 days prior to peak.

Table 4.6: Summary of Multiple Regression Analyses to Forecast DURATN Using Data on Various Days Prior to PEAKQ

Number of Days Before PEAKQ Data Obtained	Standard Error (Days)	Step Minimum Standard Error Achieved	R^2
3	1.49	9	0.747
4	1.52	9	0.735
5	1.71	7	0.668
6	1.10	10	0.861
7	1.40	4	0.775

Attempts were made to identify the day 6 days prior to forecast DURATN (i.e. day of PEAKQ), to utilise this 'best' forecast of DURATN model. However, using data for 6 days prior to forecast DURATN did not produce any improvement in the standard error over forecasting DURATN on day 2 of the rising limb. Given that when the forecasting system is in operation, the day 6 days prior to peak discharge will not be known, it appears that this 'best' forecasting model for DURATN cannot be incorporated into the forecasting system.

4.7 Summary

In developing a short term forecasting model it is the intention to produce equations to correspond with the forecasting time periods used by the R.V.C.A. whilst maintaining the objective of selecting the model with the lowest standard error. Perhaps the most surprising outcome in the development of these forecasting equations is that even when using data obtained only 1 day prior to PEAKQ, the standard error in prediction of PEAKQ is only 6.4 per cent lower than would be achieved with the multivariate long term forecast model. A model is also presented to forecast the duration of the rising limb once the second day (R2) of the rise is identified. This allows an estimate of the date of PEAKQ to be made.

It is not possible to compare the accuracy of the short term models developed in this thesis with the R.V.C.A. system since records of the short term forecasts made are not available. However, Figs. 4.1 4.2 and 4.3 show the extent of agreement between predicted and observed peak discharges for the 5, 2 and 1 day models. The closest agreement between predicted and observed discharge values is achieved using the 5 day forecast. In the next chapter, the incorporation of these forecasting equations into an operational procedure, allowing the development of a comprehensive forecasting system, will be discussed.

CHAPTER 5

OPERATIONAL PROCEDURE FOR SPRINGMELT HYDROGRAPH FORECASTING

The multivariate models described in Chapters 3 and 4 provide the means of forecasting characteristics of the flood wave, namely peak discharge and duration of the rising limb. These components are required in order to issue a flood warning containing both the magnitude and timing of the peak flow. This chapter establishes the procedure for using the multivariate models as a forecasting system and considers such aspects as when to begin forecasting and determining both the start of the rising limb and when PEAKQ has been reached. The operational procedure is represented by a series of flow charts giving directions based on various decision criteria. This procedure will be tested using years for which data are available.

5.1 Forecasting on March 1

The multivariate model for forecasting on this date is described in Chapter 3. PEAKQ is forecast using the following equation:

$$\text{PEAKQ} = 2.26.\text{WEQSP} + 0.85.\text{MINQ} + 9.20.\text{SNWDAYS} + 0.67.\text{YEAR}^2 - 21.23.\text{YEAR} \\ - 1.03.\text{TPREC} + 1.28.\text{DEGDAY} - 0.29.\text{QMAR1} - 1.09.\text{RAIN} + 134.61$$

The data required to make the long term forecast are the values of these variables as measured on March 1. It is suggested that the calculation procedure be recorded as in Appendix 4. This will ensure that a record is kept of the March 1 forecast produced each year. The forecast value of PEAKQ should be categorised according to the values given in Table 2.1 as is R.V.C.A. current practice for public distribution.

5.2 Short Term Forecasting

i) Data Records

The multivariate models to be used in the short term forecasting procedure are developed in Chapter 4. Since some of the variables used in these models are derived from cumulative data, it is essential to maintain continuous records for these variables from January 1

throughout the melt period. When forecasts are to be made the values will be readily available, removing the need for further calculations. A suitable means of recording the necessary variables for short term forecasting is given in Appendix 5.

ii) Decision to Begin Short Term Forecasting

The first stage in the short term forecasting procedure is to provide a forecast of the duration of the rising limb of the flood hydrograph. As stated in Chapter 4, this forecast uses data obtained on day 2 of the rising limb. Thus the initial step is to determine whether the rising limb has begun; this is based on the definition of the rising limb given in Chapter 4. The process of determining whether day 2 of the rising limb has been reached, can be represented as follows:

Q_{R1} is daily mean discharge $\text{m}^3 \text{ sec}^{-1}$, on the day which is the anticipated first day of rising limb (R1).

Q_{R2} is daily mean discharge $\text{m}^3 \text{ sec}^{-1}$, on the day which is the anticipated second day of rising limb (R2).

$$\text{DURATN} = 0.04.\text{Adjusted WEQSP} - 0.68.\text{MAXT} + 0.44.\text{MEANT} + 0.04.\text{YEAR} \\ - 0.004.\text{DISCH} + 5.68$$

The decision as to when short term forecasting should begin is always determined by whether or not a rising limb can be identified. Even when the rising limb begins prior to March 1, (the date for long term forecasts), the short term forecasting procedure should begin when indicated.

iii) Production of 5, 2 and 1 day PEAKQ Forecasts

The procedure outlined below gives directions for producing a 5, 2 and 1 day forecast under the assumption that PEAKQ will occur on the forecast day of peak (i.e. DURATN).

DURATN is the number of days of rise to PEAKQ from day 0 (R0) of the rising limb (Fig. 5.1). Rx is the current day of the rising limb.

5 day PEAKQ Forecast:

$$\text{PEAKQ} = 1.49.\text{Adjusted WEQSP} + 0.19.\text{DISCH} - 0.35.\text{DEGDAYS} - 25.79.\text{RAIN} \\ + 21.70.\text{TPREC} + 0.63.\text{YEAR}^2 - 18.23.\text{YEAR} - 3.66.\text{SUNHRS} + 303.4$$

To produce 2 day PEAKQ Forecast:

Substitute 2 for 5 in above diagram.

$$\text{PEAKQ} = 0.57.\text{DISCH} - 0.84.\text{DEGDAYS} + 2.93.\text{DATE} + 2.14.\text{RAIN} + 0.32.\text{YEAR}^2 \\ - 9.47.\text{YEAR} + 0.48.\text{Adjusted WEQSP} - 3.64.\text{SUNHRS} + 55.60$$

To produce 1 day PEAKQ Forecast:

Substitute 1 for 5 in above diagram.

$$\text{PEAKQ} = 1.72.\text{DISCH} - 0.93.\text{DEGDAYS} + 3.0.\text{DATE} - 5.31.\text{SUNHRS} + 3.9.\text{MAXT} + 33.09$$

FIG.5.1 DEFINITION OF DAYS ON THE RISING LIMB.

From the confidence limits (68 per cent), attached to the standard error (± 2 days), for the DURATN forecast, it is clear that there is a 16 per cent probability that PEAKQ will occur either earlier or later than ($\text{DURATN} \pm 2$ days). This poses a problem to the forecasting procedure. If forecasts are given only for those days within the ($\text{DURATN} \pm 2$ day) time period, in 16 out of 100 years the peak may have occurred prior to the day ($\text{DURATN} - 2$) with no PEAKQ forecast being made for this day. One solution would be to produce 5, 2 and 1 day PEAKQ forecasts for each day of the rising limb following R2. Since 95 per cent of observations will fall within ± 2 standard errors of DURATN (i.e. ± 4 days), in only 5 out of 200 years will PEAKQ occur prior to day ($\text{DURATN} - 4$). Thus, an acceptable solution would be to produce forecasts for days beginning with ($\text{DURATN} - 4$).

The general forecasting procedure is given below in terms of the modified DURATN, nDURATN where n is the number of days prior to, or later than the forecast peak day, identified by DURATN, for which a forecast is required ($-4 < n < 4$), and y is the forecast period (5, 2 or 1 days).

Rx is current day of rising limb.

y is forecast period (i.e. 5, 2 or 1 days).

$nDURATN$ is forecast $DURATN + (n)$ (i.e. $n = -4, -3, -1, 0, +1, +2, +3$, or $+4$), where n is number of days prior to or later than forecast peak day for which a forecast is required, i.e. ± 2 standard errors.

It is apparent that the forecasting procedure becomes fairly complex when forecasts for days ($DURATN - 4$) to ($DURATN + 4$) and three forecast periods are considered. Table 5.1 has been constructed to summarise which forecasts should be made given the forecast $DURATN$ on any day of the rising limb for days ($DURATN \pm 4$). The day of the rising limb for which data are needed in order to make the forecasts listed in Table 5.1 is given in Table 5.2. An example of the use of these tables is given below:

A rising limb has been identified: day R2.

Forecast $DURATN = 8$ days, i.e. forecast duration of rising limb from R0. Say forecast of peak discharge is required for the lower 95 per cent confidence limit of forecast $DURATN$, i.e. $n = -4$, then, day $nDURATN$ is $DURATN + (n) = 8 + (-4) = 4$, i.e. day R4 of rising limb. Suppose current day of rising limb, Rx, is 3.

In cell 4($nDURATN$), 3(Rx) of Table 5.1 the numbers 5, 2 and 1 are given. This indicates that a 5, 2 and 1 day forecast of PEAKQ can be made. The corresponding cell in Table 5.2 shows that data on days R-1, R2 and R3 of the rising limb are required to make these forecasts. It should be noted that the 5 and 2 day forecasts using data on R-1 and R2 will have been available on day R2 for $nDURATN$ of 4.

To avoid duplication of forecasts a record should be kept of the day on which the forecast is made, the forecast period and the data used. Only those forecasts for which data were not available on an earlier date should be made. Appendix 6 gives a suggested means of recording the forecasts made. The use of data prior to the current day to produce the 5 day forecast, as is needed in the example above, is justified as the standard error is lower for the 5 day than for the 2 or 1 day forecast.

iv) Use of Degree Day Index in the Forecasting Procedure

Although it is proposed that PEAKQ forecasts be made only for

Table 5.1. Forecasts which can be made available on given day of rising limb for specified nDURATN

Day of rise Rx	nDURATN														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	x	x	5,2,1	5,2	5	5	5	-	-	-	-	-	-	-	-
3	x	x	x	5,2,1	5,2	5	5	5	-	-	-	-	-	-	-
4	x	x	x	x	5,2,1	5,2	5	5	5	-	-	-	-	-	-
5	x	x	x	x	x	5,2,1	5,2	5	5	5	-	-	-	-	-
6	x	x	x	x	x	x	5,2,1	5,2	5	5	5	-	-	-	-
7	x	x	x	x	x	x	x	5,2,1	5,2	5	5	5	-	-	-
8	x	x	x	x	x	x	x	x	5,2,1	5,2	5	5	5	-	-
9	x	x	x	x	x	x	x	x	x	5,2,1	5,2	5	5	5	-
10	x	x	x	x	x	x	x	x	x	x	5,2,1	5,2	5	5	5
11	x	x	x	x	x	x	x	x	x	x	x	5,2,1	5,2	5	5
12	x	x	x	x	x	x	x	x	x	x	x	x	5,2,1	5,2	5
13	x	x	x	x	x	x	x	x	x	x	x	x	x	5,2,1	5,2
14	x	x	x	x	x	x	x	x	x	x	x	x	x	x	5,2,1
15	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

x Indicates that on this day it is too late to forecast for this nDURATN

- Indicates that no forecast can yet be made as data required does not exist.

The numbers given refer to the forecast period, i.e., 5, 2 or 1 day forecast.

Table 5.2 Day of rising limb for which data is required to make forecasts given in
Table 5.1

Day of Rise Rx	nDURATN														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	x	x	-2,1,2	-1,2	0	1	2	-	-	-	-	-	-	-	-
3	x	x	x	-1,2,3	0,3	1	2	3	-	-	-	-	-	-	-
4	x	x	x	x	0,3,4	1,4	2	3	4	-	-	-	-	-	-
5	x	x	x	x	x	1,4,5	2,5	3	4	5	-	-	-	-	-
6	x	x	x	x	x	x	2,5,6	3,6	4	5	6	-	-	-	-
7	x	x	x	x	x	x	x	3,6,7	4,7	5	6	7	-	-	-
8	x	x	x	x	x	x	x	x	4,7,8	5,8	6	7	8	-	-
9	x	x	x	x	x	x	x	x	x	5,8,9	6,9	7	8	9	-
10	x	x	x	x	x	x	x	x	x	6,9,10	7,10	8	8	9	10
11	x	x	x	x	x	x	x	x	x	x	7,10,11	8,11	8,11	9	10
12	x	x	x	x	x	x	x	x	x	x	x	8,11,12	8,11,12	9,12	10
13	x	x	x	x	x	x	x	x	x	x	x	x	x	9,12,13	10,13
14	x	x	x	x	x	x	x	x	x	x	x	x	x	x	10,13,14
15	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

x Indicates that on this day it is too late to forecast for this nDURATN

- Indicates that no forecast can yet be made as data required does not exist.

The numbers given refer to the day of the rising limb (Rx) for which data is needed to make the forecasts given in Table 5.1.

days between and including days ($\text{DURATN} \pm 4$), a further guide as to when forecasting should begin is through the use of the degree day index developed by Acres (1979:20). Using this index (Table 2.2), it is possible to attach a probability statement to the occurrence of PEAKQ within the temperature forecast period (24 hours). If the observed + forecast thaw-degree days suggest that there is a high probability that the peak will occur within the next 24 hours, a 5, 2 and 1 day PEAKQ forecast should be made, regardless of whether day ($\text{DURATN} - 4$) has been reached. Provision for such action is provided in the procedure outlined above.

v) The Use of the 5, 2 and 1 day Forecasts

On any day within the days ($\text{DURATN} \pm 4$) time period for which it is possible to make forecasts, at least one of a 5, 2 and 1 day forecast of PEAKQ will be available, and on many occasions all three (Table 5.1). In order to make use of the three forecasts it is suggested that the mean of the three forecasts be taken as the PEAKQ forecast for that day, even though the standard error is lower on the 5 day forecast. This practice is suggested from a comparison of the residual discharges for the 5, 2 and 1 day and mean of the 5, 2 and 1 day forecasts for 1950 to 1980. The lowest mean residual, both actual and as a percentage of observed discharge, and the lowest standard deviation of the residuals, is obtained when taking the mean of the forecasts (Table 5.3).

Table 5.3: Mean Residuals for 5, 2 and 1 day and Mean of 5, 2 and 1 day Forecasts of PEAKQ

Forecast	Mean Residual as % of Observed Discharge	Mean Residual $\text{m}^3\text{sec}^{-1}$	Standard Deviation of Residuals $\text{m}^3\text{sec}^{-1}$	Standard Error of Forecasting Equation $\text{m}^3\text{sec}^{-1}$
5 day	± 18.3	± 63	94.0	± 49.3
2 day	± 16.9	± 52	76.3	± 62.0
1 day	± 13.5	± 53	76.0	± 54.6
Mean of 5, 2 and 1 day , i.e. 5 day + 2 day + 1 day forecast $\div 3$	± 11.6	± 41	64.6	

When issuing a 5 day forecast obviously only the 5 day forecast can be used and for a 2 day forecast the mean of the 5 and 2 day forecast should be used. An exception to this rule would be where the discharge levels have already exceeded the levels of one or two of the forecasts but not that of the third. In such cases the mean of the two highest or the highest forecast should be taken as the PEAKQ forecast.

vi) Comparison of Forecast and Observed Daily Mean Discharge Levels

Once the forecasting procedure is underway, the forecast and observed daily mean discharge must be compared. This will allow the flood wave peak to be identified and the accuracy of the forecasts to be assessed. The flow chart below provides a framework for comparing forecast and observed discharge levels.

If Rx has a
forecast PEAKQ.

Rx is day of rising limb.

Q_{Rx} is daily mean discharge ($m^3 sec^{-1}$) on day Rx.

On a given day of the rising limb for which a forecast of PEAKQ is available, this value should be compared with the observed daily mean discharge for this day (Q_{Rx}). If Q_{Rx} is less than the forecast for Rx, then it is assumed that the peak has not occurred. Comparison must also be made between Q_{Rx} and Q_{Rx-1} , since even though Q_{Rx} does not exceed the forecast PEAKQ, the peak may still have been reached. If the peak has not occurred the process is repeated for day Rx+1. When Q_{Rx} is less than Q_{Rx-1} then it is likely that PEAKQ has passed and the falling limb of the hydrograph reached. Forecasting should terminate at this point but should be resumed if there is a subsequent rise in river levels.

5.3 Testing of the Short Term Forecasting Procedure

i) Testing for 1950 to 1980

Since it is impracticable, within the scope of this thesis, to work through the forecasting procedure for each year, producing 5, 2 and 1 day forecasts for the days from day (DURATN - 4) until day of PEAKQ, the procedure is tested using only the main forecasts. That is, making a 5, 2 and 1 day forecast of PEAKQ for the forecast day of the peak, i.e. for DURATN only. This method will obviously produce less accurate forecasts since it omits the process of giving forecasts for days prior to, and after DURATN, and the checking for whether PEAKQ has occurred.

The standard deviation for these forecasts is greater than the standard error associated with the 5, 2 and 1 day forecasting equations (Table 5.3). This is because the equations are developed using data 5, 2 and 1 days before the actual peak, whereas data for the testing procedure are based on forecast DURATN which has a standard error of ± 2 days. When applying the full operational procedure to a given year, the accuracy of the forecasts should improve. By beginning forecasts for day (DURATN - 4) and checking observed and forecast discharge values, it is probable that the actual peak can be detected and forecasts made accordingly.

The 5, 2 and 1 day forecasts of PEAKQ made for the day of the

peak, as forecast by DURATN, for the years 1950 to 1980 are given in Table 5.4. The residuals and standard deviations of these forecasts are also given. In all cases the standard deviation is greater than the standard error for the forecasting equations and is highest for the 5 day forecasts which has the lowest standard error on the forecasting equation. Figs. 5.2, 5.3 and 5.4 demonstrate graphically the deviation of observed from predicted PEAKQ values. As stated in section 5.3 v), the lowest residuals are obtained when using the mean of the 5, 2 and 1 day forecasts as the forecast for PEAKQ (Table 5.4).

ii) Testing of the Operational Procedure for a Single Year, 1981.

The complete operational procedure for giving short term forecasts of PEAKQ is followed for the year 1981 which is not included in the data base from which the models are developed. The hydrograph and meteorological data for 1981 are plotted in Fig. 5.5. Precise details of the procedure and the various forecasts made are given in Appendix 7. This begins with the identification of the rising limb, forecasting DURATN on day R2 and then providing a series of short term forecasts beginning with the day closest to day (DURATN - 4). Obviously much of the detailed description will normally not be given and is included to aid in the understanding of the forecasting procedure. The year 1981 is somewhat unusual as it is the only year on record where PEAKQ has occurred before March 1, thus development of a long term forecast is not appropriate. Short term forecasting should always begin once conditions for the identification of the rising limb have been met, regardless of whether March 1 has passed.

Comparison of the observed and forecast PEAKQ values for 1981 show that the final forecast, the mean of the 5, 2 and 1 day forecasts, overestimates the flood peak by 20 per cent. The 'best' forecast is given using the 2 day model, having a residual of only 6 per cent, (Table 5.5). The DURATN forecast underestimates the actual DURATN of the rising limb by 3 days, which is outside the 68 per cent confidence limits associated with the DURATN forecasting equation. Since the observed PEAKQ does not exceed the forecast PEAKQ, the decision to terminate

Table 5.4. 5,2,1 and Mean of 5,2, and 1 day forecasts with residuals

Year	5 day Forecast				2 day Forecast				1 day Forecast				Mean of 5,2,1 day Forecast			
	Actual		Fore-		Fore-		Fore-		Fore-		Fore-		Fore-		Fore-	
	PEAKQ	Residual	PEAKQ	Residual	PEAKQ	Residual	PEAKQ	Residual	PEAKQ	Residual	PEAKQ	Residual	PEAKQ	Residual	PEAKQ	Residual
	3 m sec	-1 m sec	3 m sec	-1 m sec	3 m sec	-1 m sec	3 m sec	-1 m sec	3 m sec	-1 m sec	3 m sec	-1 m sec	3 m sec	-1 m sec	3 m sec	-1 m sec
1950	447	55	392	12	415	32	354	8	354	93	387	60	387	60	387	13
1951	419	74	345	18	423	-4	416	1	416	3	395	24	395	24	395	6
1952	379	-27	406	7	455	-76	405	17	405	-26	422	-43	422	-43	422	11
1953	331	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1954	405	62	343	15	407	-2	424	0.4	424	-19	391	14	391	14	391	3
1955	493	30	463	6	487	6	588	1	588	-95	513	-20	513	-20	513	4
1956	351	35	316	10	354	-3	373	1	373	-22	348	3	348	3	348	0.8
1957	133	-68	201	51	169	-36	173	21	173	-40	181	-48	181	-48	181	36
1958	306	-5	311	2	355	-49	338	14	338	-32	335	-29	335	-29	335	9
1959	413	4	409	1	450	-37	444	8	444	-31	434	-21	434	-21	434	5
1960	813	305	508	38	589	224	569	38	569	244	555	258	555	258	555	32
1961	193	-109	302	56	173	20	182	12	182	11	219	-26	219	-26	219	13
1962	323	31	292	10	297	26	273	9	273	50	287	36	287	36	287	11
1963	442	32	410	7	487	-45	439	10	439	3	445	-3	445	-3	445	0.6
1964	109	29	80	27	69	40	76	58	76	33	75	34	75	34	75	31
1965	144	-47	191	33	227	-123	166	54	166	-22	195	-51	195	-51	195	35
1966	215	32	183	15	260	-45	232	17	232	-17	225	-10	225	-10	225	5
1967	311	72	239	23	305	6	360	2	360	-49	301	10	301	10	301	3
1968	377	47	330	12	295	82	276	28	276	101	300	77	300	77	300	20
1969	328	-242	569	74	338	-10	359	3	359	-31	422	-94	422	-94	422	29
1970	442	-35	477	8	433	9	422	2	422	20	444	-2	444	-2	444	0.4
1971	496	-18	514	4	472	24	454	5	454	42	480	16	480	16	480	3
1972	535	35	500	7	538	-3	485	1	485	50	508	27	508	27	508	5
1973	447	-165	612	37	497	-50	445	10	445	2	518	-71	518	-71	518	16
1974	396	42	354	11	431	-35	425	8	425	-29	403	-7	403	-7	403	2
1975	394	19	375	5	327	67	303	20	303	91	335	59	335	59	335	15
1976	583	60	523	10	653	-70	673	11	673	-90	616	-33	616	-33	616	6
1977	467	36	431	8	309	158	300	51	300	167	347	120	347	120	347	26
1978	487	-53	540	11	556	-69	408	12	408	79	501	-14	501	-14	501	3
1979	403	-99	502	25	338	176	333	44	333	70	391	12	391	12	391	3
1980	385	-25	410	6	353	32	405	9	405	-20	389	-5	389	-5	389	1
Mean Residual		±63		±18.3		±52		±16.9		±53		±41		±13.5		±11.6
standard error of Forecast model m ³ sec ⁻¹		±49.3				±62.0				±54.6						
Standard deviation of residuals		94.0				76.3				76.0						64.6

FIG.5.2 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA, USING 5 DAY MULTIVARIATE MODEL
AND FORECAST DATE OF PEAK (DURATN).

FIG.5.3 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA, USING 2 DAY MULTIVARIATE MODEL
AND FORECAST DATE OF PEAK (DURATN).

FIG.5.4 OBSERVED AGAINST PREDICTED PEAK DISCHARGE
AT OTTAWA, USING 1 DAY MULTIVARIATE MODEL
AND FORECAST DATE OF PEAK (DURATN).

FIG.5.5 SNOWMELT HYDROGRAPH AT OTTAWA
GAUGE FOR 1981.

Table 5.5 Summary of 1981 Forecasts

Summary of forecast accuracy

Forecast DURATN 5 days

Observed DURATN 8 days

Residual +3 days

	Forecast			
	5 day	2 day	1 day	Mean 5,2,1
Forecast PEAKQ for DURATN 8 days	403	406	758	522
Actual PEAKQ $435 \text{ m}^3 \text{ sec}^{-1}$				
Residual PEAKQ $\text{m}^3 \text{ sec}^{-1}$	32	29	-323	-87
Residual PEAKQ as % of observed	7	6	74	20

Summary of Forecasts Made

Day and Date of Rising Limb Fore- cast made for	Corres- ponding value of n	5 day forecast		2 day forecast		1 day forecast		Mean forecast $\text{m}^3 \text{ sec}^{-1}$
		Data used R_x	$\text{m}^3 \text{ sec}^{-1}$	Data Used R_x	$\text{m}^3 \text{ sec}^{-1}$	Data used R_x	$\text{m}^3 \text{ sec}^{-1}$	
3 14.2.81	-2	-2	371	1	210	2	246	276
3 19.2.81	-2	-2	409	1	241	2	356	335
4 20.2.81	-1	-1	403	2	287	3	456	382
5 21.2.81	0	0	417	3	335	4	568	440
6 22.2.81	1	1	419	4	393	5	705	506
7 23.2.81	2	2	405	5	406	6	750	520
8 24.2.81	3	3	403	6	406	7	758	522
9 25.2.81	4	4	383	7	445	8	819	549

forecasting is based upon the observed decrease in daily mean discharge on February 25. In other years the decision may be based on the fact that the PEAKQ forecast has been exceeded.

Further examination of the forecast and observed PEAKQ values for 1981 (Table 5.5) reveals several areas where an intuitive approach may be applied in the forecasting procedure. The 5 and 2 day forecasts of PEAKQ give residuals of only 32 and $29 \text{ m}^3 \text{ sec}^{-1}$ respectively for the day R8 which is the day of the actual PEAKQ. However the 1 day forecast over estimates the peak by $323 \text{ m}^3 \text{ sec}^{-1}$. This may be a result of applying the forecast model when discharge levels are rising rapidly and the forecast values will continue to increase as the flood wave proceeds. This poses a significant problem to the forecasting procedure in terms of when to terminate forecasting. Where it is apparent to the forecaster from observed flow records that the 1 day forecast produces a mean forecast which is a significant over estimate of PEAKQ, then the mean of the 5 and 2 day forecasts should be issued. In 1981 the 1 day forecast of $758 \text{ m}^3 \text{ sec}^{-1}$ for R8 is unrealistic when seen in terms of observed flows just prior to R8. Discharge on R7 is $395 \text{ m}^3 \text{ sec}^{-1}$ and even though 19 mm of rain fell on day R7 a rise in discharge to $758 \text{ m}^3 \text{ sec}^{-1}$ on R8 is not credible. Thus the 1 day forecast should be eliminated and the mean of the 5 and 2 day forecasts issued ($404 \text{ m}^3 \text{ sec}^{-1}$). This indicates that there is scope for intuition and experience in modifying the forecasting procedure.

The predicted PEAKQ for day DURATN (i.e. R5) is $440 \text{ m}^3 \text{ sec}^{-1}$ when using the mean of the 5, 2 and 1 day forecasts. This is only $5 \text{ m}^3 \text{ sec}^{-1}$ greater than the observed PEAKQ which occurred on day R8. It could be suggested that the peak discharge forecasting procedure works best when forecasting PEAKQ for the specific day forecast DURATN only. If so, this PEAKQ forecast should be retained and issued as the forecast for days following DURATN if the peak has not occurred.

During the 1981 springmelt period river levels were increased as a result of ice jams and the actual peak river levels occurred on February 21 (Craig, pers. comm.). This is the day forecast for peak discharge by the DURATN forecast model. When applying the operational procedure it is the telemetred river level data which is used on a day to day basis whereas in testing the procedure the corrected discharge data

has been used. If the forecasting system had been used in 1981 the DURATN forecast would have identified the correct day of maximum river levels. Forecasting would have been terminated on day R5 because river levels and thus discharge (determined through the rating curve) would be identified as having decreased.

Although the 1 day forecast for the day DURATN (R5, February 21) is much larger ($568 \text{ m}^3 \text{ sec}^{-1}$) than the 2 day forecast ($335 \text{ m}^3 \text{ sec}^{-1}$), it should be noted (Fig. 5.5) that there was almost 20 mm of rainfall on February 20. Experience and intuition would have suggested therefore that the 1 day forecast should be included in the computation of the final forecast (i.e. mean of 5,2 and 1 day forecasts) i.e. $440 \text{ m}^3 \text{ sec}^{-1}$ for day R5.

5.4 Summary

An operational procedure for giving short term forecasts of PEAKQ has been established; this allows PEAKQ forecasts to be continually up-dated. Identification of the rising limb is the first step in the procedure and this is followed by a forecast of DURATN (the number of days to peak) on the second day of the rise (day R2). Forecasts of PEAKQ are then made using the 5,2 and 1 day models for days beginning with DURATN - 4. This is the limit of the 95 per cent confidence limits of forecast DURATN. The final forecast to be issued is usually the mean of the 5,2 and 1 day forecasts. Throughout the forecasting process the observed and forecast daily mean discharge values are compared to determine whether or not the peak has occurred.

The procedure is tested for the years 1950 to 1980 using only the main forecast of DURATN. That is, forecasts are not made for days prior to or following DURATN as would be the case when using the system for a given year. For the year 1981 the full operational procedure is followed in detail as an example of how to apply the system. The residual for the final forecast made is 20 per cent of the observed discharge. The year 1981 was an atypical year in that the flood peak occurred at an earlier date than for any year on record.

CHAPTER 6

SUMMARY AND CONCLUSIONS

1. A forecasting system is developed for the Rideau River (Ottawa gauge), to be applied during the springmelt period. The system comprises a long term estimate of peak discharge, made on March 1, short term estimates of peak discharge which allow forecasts to be updated and a forecast of the duration of the rising limb. The components of the system, which are based on multiple regression analyses, produce forecasts of greater accuracy than the existing procedures.
2. A specific objective in the development of this new forecasting system was that the accuracy of the forecasts, as measured by the residual differences between observed and forecast values, be minimised and be less than those given by the R.V.C.A. system. In developing both the long and short term models the decision basis for selection of the 'best' model was the standard error term, rather than the coefficient of determination. This represents the situation where forecast and observed values are closest.

For the long term model, a standard error of $58.3 \text{ m}^3 \text{ sec}^{-1}$ is achieved as compared with $70.2 \text{ m}^3 \text{ sec}^{-1}$ for the Acres bivariate model. This is an average improvement of 17 per cent in the forecast. Thus the objective of a more accurate prediction of peak discharge values is achieved.

It is not possible to compare the accuracy of the short term models in a similar way, as no records are available of the daily forecasts made by the R.V.C.A. Short term forecasts of peak discharge are produced in this thesis for 5, 2 and 1 day periods. The standard errors associated with the 5, 2 and 1 day models are 49.3, 62.0 and $54.6 \text{ m}^3 \text{ sec}^{-1}$ respectively. Surprisingly, using data for 1 day prior to the actual peak reduces the standard error of the forecasts of peak discharge by only $3.7 \text{ m}^3 \text{ sec}^{-1}$ compared with the long term forecast which uses data on March 1.

The 5 day model gives the lowest standard error ($49.3 \text{ m}^3 \text{ sec}^{-1}$). This suggests that a significant lag period (5 days) occurs between

the meteorological conditions leading to release of water from the snowpack, and/or precipitation events, and the time at which this water reaches the point of river discharge measurement (Ottawa).

3. The forecasting system developed also requires that a forecast of the duration of the rising limb be given. This is made using a multiple regression equation which has a standard error of ± 2 days. In the forecasting procedure, this forecast is used in association with a cumulative thaw-degree day index (Acres, 1979: 20) which shows that the flood peak occurs on average when 32 degree days have been accumulated with a standard deviation of ± 7 degree days or ± 2 days.

When considering that the mean duration of the rising limb is 6 days, a standard error of ± 2 days could produce a significantly inaccurate forecast of the date of the peak. For this reason, in the actual forecasting procedure, forecasts are begun on the day four days prior to the predicted peak day which is the earliest day of the 95 per cent confidence limits on the estimated duration. This makes it less likely that the day of the peak will pass without forecasts having been made for that day. The system developed allows for careful monitoring of flood wave development and appropriate forecasting action. The estimation of the date of the flood peak is an obvious aspect of the forecasting system which warrants further investigation to allow more accurate forecasts to be made.

4. As stated in Chapter 2, there is an element of subjectivity in the current system used by the R.V.C.A. Specifically, this occurs where hydrographs are extrapolated by eye and where the effects of recent and forecast meteorological conditions on discharge levels are estimated intuitively. Forecasts made under such circumstances are likely to differ between forecasters, with presumably the more experienced operator producing the most accurate forecasts. The forecasting system produced in this thesis is based wholly on quantitative techniques which eliminate this element of subjectivity as far as is practical.

It can be argued however, that even where quantitative techniques form the basis for making forecasts, the experienced operator, having a good knowledge of the basin hydrology may in some instances detect that forecasts made are not likely to be

accurate and may choose to abort the procedure. No procedure is developed for such circumstances as this is seen to relate more to emergency planning.

5. Most of the variables present in the forecast models are meteorologically based and are those which would be expected to influence the snowmelt process in some way. Although a detailed examination of the physical process of snowmelt was beyond the scope of this study, due to its forecasting objectives, the initial selection of variables for both the long and short term models was based on an identification of those factors likely to influence snowmelt. The stepwise inclusion of variables in the multivariate predictive equations was analysed in process terms for appropriate direct and inverse relationships.

There are three variables in the models which are not included for this reason but because they help remove time trends, both linear and cyclic, in the flood peak data. The variables of sequence year and its squared value (YEAR and YEAR2) are included to account for a time trend which is apparent in the data. These appear in both long, short term and DURATN forecasting models. Sequence as a seasonal trend (DATE), is used in the short term 2 and 1 day models and can be seen as reflecting changing conditions through the melt season. This may be explained in part in process terms; possibly later peaks being lower due to the increased opportunity for previous loss of water from the snowpack.

The variables selected for use in the multiple regression models are then, initially chosen for their controlling influence on the melt process. However, variables are not rejected if their role in determining peak discharge cannot be identified. This reflects the primarily forecasting objective of this thesis of minimising the standard error of the forecast models.

6. The operational procedure for applying the forecast models described in Chapter 5, gives full details and a worked example of how to use the system (Appendix 7). Suggested means of recording

the forecasts are also given (Appendices 4, 5 and 6). It is anticipated that the time involved in making forecasts will be minimal since only the substitution of the current data into the equations is necessary. This fulfills the objective of producing a fairly simple system, not requiring complex computer facilities, which also enables forecasts to be up-dated quickly.

7. An area for further investigation within the topic of this thesis is that of classifying peak discharges according to the meteorological and runoff characteristics for that year. This would involve identifying those years which have similar weather patterns during the melt period and similar hydrograph characteristics (i.e. DURATN and PEAKQ). Should it be found that particular meteorological occurrences tend to correlate with hydrographs of a certain character, then it may be possible to establish classes of relationships for different types of year for which forecasts are being made. A statement could then be made concerning the likely character of the springmelt hydrograph for that year and this could lead to further improvements in the forecasts.

One such improvement could be applied to the selection of which of the 5, 2 and 1 day forecasts to issue as the most probable peak discharge during the short term forecasting period. In Chapter 5, it was stated that the mean of the 5, 2 and 1 day forecasts should be used as this combined forecast gives, on average, lower residuals than the 5, 2 and 1 day forecasts used separately when applied to the 1950 to 1980 data. This requires examination of the data in more detail, which is beyond the scope of this study. However, for the year 1981 it was found that the 2 day forecast was most accurate in predicting PEAKQ.

8. It can be expected that a more accurate forecast for peak discharge at Ottawa could be obtained if forecasts were made separately for the subbasins of the Rideau River basin. In order to develop such a forecasting system an adequate data coverage would be required at the subbasin level. Since these data do not exist at present it is not possible to develop a subbasin forecasting

system in this thesis. If such models were developed without sufficient data coverage then the accuracy of the forecasts made is not likely to be any greater than where forecasts are made for the basin as a whole.

BIBLIOGRAPHY

- Acres Consulting Services Ltd. (1977). Study of the Operation of The Rideau-Cataragui System. Carried out for Rideau Canal, Parks Canada, Department of Indian and Northern Affairs. Niagara Falls, Ontario.
- Acres Consulting Services Ltd. (1979). Spring Flood Level Forecasting for the Rideau River. Carried out for the Rideau Valley Conservation Authority. Niagara Falls, Ontario.
- Bennett, D. (1977). "The effects of data transformations on the principal components solution", Area, 9(2), pp. 146-152.
- Busby, M.W. (1964). "Relation of annual runoff to meteorological factors", U.S. Geol. Survey Prof. Paper, 501C.
- Cohen, P. (198?). Forecasting Glacier Runoff. Carried out for Environment Canada, Computing and Applied Statistics Directorate, Project No. T421, Ottawa, Canada.
- Craig, C. (1982). Personal Communication.
- Draper, N.R. and H. Smith. (1966). Applied Regression Analysis. New York: John Wiley and Sons.
- Environment Canada, Atmospheric Environment (1950-1981). Monthly Meteorological Summary at Ottawa International Airport.
- Foster, I.D.L. (1978). "A multivariate model of storm period solute behaviour", Journal of Hydrology, 39, pp. 339-353.
- Gregory, K.J. and D.E. Walling (1973). Drainage Basin Form and Process. London: Edward Arnold.
- Gregory, S. (1968). Statistical Methods and the Geographer. 2nd Edition. London: Longman.
- Guy, H.P. (1964). "An analysis of some storm-period variables affecting stream sediment transport", U.S. Geol. Survey Prof. Paper, 462E.
- Hann, C.T. (1977). Statistical Methods in Hydrology. Ames, Iowa: The Iowa State University Press.
- Kim, J-O. and F.J. Kohout (1975). Multiple regression analysis: Sub-program regression. In Nie, N.H. et al. (1975). Statistical Package for the Social Sciences, 2nd Edition. New York: McGraw-Hill.
- King, L.J. (1969). Statistical Analysis in Geography. Prentice-Hall.
- Milton, D. and T. Hannan (1982), "Flooding in some sub-basins of the Red River Valley of the North". In St. Onge, D.A. and G. Rivard (Eds.) (1982). Abstracts of papers presented at the Annual Meeting 1982, Canadian Association of Geographers. University of Ottawa, Ottawa, Ontario.
- Nash, J.E. and B.L. Shaw (1966). Flood frequency as a function of catchment characteristics. In River Flood Hydrology. London: Institution of Civil Engineers.

Nie, N.H. et al. (1975). Statistical Package for the Social Sciences. 2nd Edition. New York: McGraw Hill.

Rideau Valley Conservation Authority (1980). Flood Warning System. Manotick, Ontario.

Thomas, D.M. and M.A. Benson (1970). "Generalisation of streamflow characteristics from drainage basin characteristics", U.S. Geol. Survey Water Supply Paper, 1975.

Water Survey of Canada. Historical Streamflow Summary and Surface Water Data. Ontario.

Wong, S.T. (1963). "A multivariate statistical model for predicting mean annual flood in New England", Ann. Ass. Amer. Geog. 53, pp. 298-311.

Appendix 1. Constant to Convert Daily Mean Discharge ($\text{m}^3 \text{sec}^{-1}$) to Runoff
Depth over Rideau Basin (mm).

$$\text{Basin Area} = 3833 \text{ km}^2$$

$$\text{Factor} = \frac{\text{Discharge}}{\text{Area}}$$

$$\text{Area} = 3833 \times 10^{12} \text{ mm}^2$$

$$\text{Discharge } \text{m}^3 \text{sec}^{-1} = 86400 \times 10^9 \text{ mm/day}$$

$$\text{Factor} = \frac{86400 \times 10^9}{3833 \times 10^{12}} = 0.02254$$

Daily mean discharge at Ottawa is multiplied by 0.02254 to calculate average depth of runoff over basin (mm).

APPENDIX 2. SUMMARY TABLES FOR 5, 2 AND 1 DAY FORECASTING EQUATIONS.

5 DAY

SUMMARY TABLE					
VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B
WEQSP	.71819	.51579	.51579	.71819	1.488163
DISCH	.81355	.66186	.14607	.71239	.1916177
DEGDAY	.85318	.72792	.06606	-.18577	-.3527091
RAIN	.86558	.74923	.02131	-.27619	-25.79590
TPREC	.89759	.80567	.05644	.13882	21.70559
CASE2	.91340	.83431	.02864	.22149	.6333883
CASE	.95202	.90635	.07204	.15894	-18.23146
SUNHRS	.95549	.91296	.00661	-.03666	-3.656861
(CONSTANT)					303.0437

2 DAY

SUMMARY TABLE					
VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B
DISCH	.83948	.70472	.70472	.83948	.5679730
DEGDAY	.86291	.74461	.03989	-.17777	-.8430461
DATE	.88087	.77593	.03133	.39177	2.926491
RAIN	.90522	.81942	.04348	.10609	2.137684
CASE2	.91067	.82932	.00990	.22149	.3258999
CASE	.92105	.84833	.01901	.15894	-9.466072
WEQSP	.92446	.85463	.00630	.65542	.4817530
SUNHRS	.92857	.86224	.00760	-.09685	-3.638979
(CONSTANT)					55.59996

1 DAY

SUMMARY TABLE					
VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B
DISCH	.89076	.79346	.79346	.89076	.7211122
DEGDAY	.90764	.82382	.03036	-.19110	-.9319493
DATE	.92764	.86051	.03669	.39177	3.004928
SUNHRS	.93328	.87100	.01049	.33838	-5.306109
MAXT	.93643	.87690	.00590	.28868	3.905892
SNWF	.93974	.88312	.00622	.05157	33.09020
(CONSTANT)					-33.81723

CASE = YEAR
CASE2 = YEAR2

APPENDIX 3. SUMMARY TABLE FOR DURATN FORECASTING EQUATION.

FINAL MODEL

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B
AWERSP	.59483	.35382	.35382	.59483	.3734341E-01
MAXT	.76795	.58974	.23592	-.52108	-.6817637
MEANT	.80075	.64119	.05145	-.42000	.4421127
CASE	.81213	.65956	.01836	.15118	.4471694E-01
DISCH	.82160	.67503	.01548	.12884	-.4590055E-02
(CONSTANT)					5.684676

CASE = YEAR
CASE2 = YEAR2

INITIAL ANALYSIS

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B
	.59483	.35382	.35382	.59483	.3271415E-01
AWERSP	.76795	.58974	.23592	-.52108	-.5607535
MAXT	.80075	.64119	.05145	-.42000	.2089076
MEANT	.81213	.65956	.01836	.15118	.1514784
CASE	.82160	.67503	.01548	.12884	-.1397400E-02
DISCH	.82627	.68272	.00768	.16612	-.3413886
SNWF	.82875	.68682	.00410	-.17436	-.5379555E-01
SUNHRS	.83152	.69143	.00461	-.33583	-.5207358
RAIN	.85106	.72430	.03287	-.23155	.4631980
TPREC	.85737	.73508	.01078	-.25322	.1144656E-01
DEGDAY	.85989	.73940	.00432	.18916	-.2638073E-01
DATE	.86195	.74295	.00355	.13181	-.2843938E-02
CASE2	.86252	.74394	.00099	-.30007	.7731253E-01
MINT					6.316563
(CONSTANT)					

Appendix 4. Suggested Means of Recording March 1 Forecast of PEAKQ

Calendar			+		+		+		-
Year	WEQSP	x2.26	MINQ	x0.85	SNWDAYS	x 9.20	YEAR2	x0.67	YEAR
									x21.23

	-		+		-		-
TPREC	DEGDAYS	QMAR1	RAIN				
TPREC	x1.03	DEGDAYS	x 1.28	QMAR1	x0.29	RAIN	x1.09 +134.6

PEAKQ	ACTUAL	
forecast	PEAKQ	RESIDUAL
$\text{m}^3\text{sec}^{-1}$	$\text{m}^3\text{sec}^{-1}$	$\text{m}^3\text{sec}^{-1}$

Appendix 5. Recording of data during the period from January 1 to
date of flood peak

Date		February 1981							
		11		12		13		14	
		*	**	*	**	*	**	*	**
Daily Mean Discharge at Ottawa ($\text{m}^3\text{sec}^{-1}$)	(1)	26.5		68.2		101.0		66.0	
Max. daily temp. $^{\circ}\text{C}$	(2)	9.1		-12.8		-6.0		-2.0	
Min. daily temp. $^{\circ}\text{C}$	(3)	-12.8		-18.4		16.3		-8.8	
Mean daily temp. $^{\circ}\text{C}$	(4)	-1.9		-15.6		-11.2		-5.4	
Degree days above 0°C	(5)	9.1	21.8	0	21.8	0	21.8	0	21.8
Daily rainfall (mm)	(6)	13.4	25.0		25.0		25.0		25.0
Daily snowfall (cm)	(7)	3.6	50.0		50.0	0.4	50.4		50.4
Daily total precipi- tation (mm)	(8)	17.0	70.4		70.4	0.4	70.8		70.8
Hours of bright sunshine	(9)	0.0	187.7	8.6	196.3	6.3	202.6	5.7	208.2
No. of days with snowfall	(10)		12		13		13		14
Water equivalent of snowpack on March 1 (mm)	(11)		Data		not		available		
Daily runoff ($Q \times 0.02254$) (mm)	(12)		Data		not		available		
Adjusted water equivalent of snowpack (WEQSP + TPREC - runoff) (mm)	(13)		Data		not		available		

*daily record

**cumulative totals for, Degree days, Rainfall, Snowfall, Total
Precipitation, Days with snowfall, hours of bright sunshine.

All meteorological data is for Ottawa International Airport.

Appendix 5 cont'd.

February 1981

	15		16		17		18		19	
	*	**	*	**	*	**	*	**	*	**
(1)	53.6		54.0		71.0		150.0		208.0	
(2)	1.0		7.7		6.1		7.7		6.2	
(3)	-9.4		-0.2		3.2		3.0		3.0	
(4)	-4.2		3.8		4.7		5.4		4.6	
(5)	1.0	22.8	7.7	30.5	6.1	36.6	7.7	44.3	6.2	50.2
(6)		25.0	0.2	25.2		25.2	0.4	25.6	8.6	34.2
(7)		50.4		50.4		50.4		50.4		50.4
(8)		70.8	0.2	71.0		71.0	0.4	71.4	8.6	80.0
(9)	6.1	214.3	1.6	215.9	0.9	216.8	0.0	216.8	0.0	216.8
(10)		14		14		14		14		14
(11)			39.93							
(12)			1.22		1.60		3.40		4.69	
(13)			39.93		39.71		47.91		44.51	
<hr/>										
	20		21		22		23		24	
	*	**	*	**	*	**	*	**	*	**
(1)	273.0		356.0		380.0		395.0		435.0	
(2)	8.1		7.8		12.0		8.4		6.7	
(3)	3.6		4.5		4.3		3.5		2.1	
(4)	5.9		6.2		8.2		6.0		4.4	
(5)	8.1	58.6	7.8	66.4	12.0	78.4	8.4	86.8	6.7	93.5
(6)	17.3	51.5	0.6	52.1		52.1	18.4	70.5	5.4	75.9
(7)		50.4		50.4		50.4		50.4		50.4
(8)	17.3	97.3	0.6	97.9		97.9	18.4	116.3	5.4	121.7
(9)	0.0	216.8	0.0	216.8	1.6	218.4	0.8	219.2	0.0	219.2
(10)		14		14		14		14		14
(11)										
(12)	6.15		8.02		8.56		8.90		9.80	
(13)	41.02		35.07		29.05		20.49		29.99	

Appendix 6. Suggested Means of Recording Short Term Forecasts

Day and Date of Rising Limb Forecast Made	Day and Date of Rising Limb Forecast Made For	Type of Forecast (e.g., 5, 2 or 1 day)	Forecast PEAKQ ($\text{m}^3\text{sec}^{-1}$)	Observed Daily Q_{Rx} ($\text{m}^3\text{sec}^{-1}$)	Comments
--	--	---	--	--	----------

Summary of Forecasts Made.

Day and Date of Rising Limb Forecast Made for	Corresponding value of n	5 day forecast Data used to make forecast (Rx).	2 day forecast Data used to make forecast (Rx).
--	--------------------------------	--	--

1-day forecast Data used to make forecast (Rx).	Mean Forecast ($\text{m}^3 \text{ sec}^{-1}$)	Actual Discharge	Residual
---	---	---------------------	----------

Appendix 7. Forecasting Procedure for 1981

DATA: The data used to make the forecasts is recorded in Appendix 5, the river hydrograph and meteorological data are plotted in Fig. 5.5.

LONG TERM FORECAST: No March 1 forecast issued as peak discharge occurred February 24.

SHORT TERM FORECASTS:

Terminology

The day within the period forecast duration ± 2 standard errors, i.e. (DURATN + (n)), is known as n DURATN, where n is either -4, -3, -2, -1, 0, 1, 2, 3, or 4 and is the day within the 95 per cent confidence limits of DURATN.

This modified DURATN is the day for which a forecast is required, e.g. forecast DURATN is 8, day within the confidence limits of DURATN for which a forecast is required is $n = -3$, then modified DURATN, i.e., nDURATN is given by (DURATN + (-3)) = 8 + (-3) = 5 = nDURATN. This is the value to read in the columns of Table 5.1 and Table 5.2

Forecasts

First indication that discharge levels are rising is on February 12 (Fig. 5.4). Use decision criteria for identification of rising limb.

$$\text{February 11} \quad Q_{Rx} = 26.5 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{February 12} \quad Q_{Rx+1} = 68.2 \text{ m}^3 \text{ sec}^{-1}$$

$$\begin{aligned} Q_{Rx+1} - Q_{Rx} &= 68.2 - 26.5 \text{ m}^3 \text{ sec}^{-1} \\ &= 41.7 \text{ m}^3 \text{ sec}^{-1}, > 15 \text{ m}^3 \text{ sec}^{-1} \end{aligned}$$

$$\text{February 13} \quad Q_{Rx+2} = 101 \text{ m}^3 \text{ sec}^{-1}$$

$$\begin{aligned} Q_{Rx+2} - Q_{Rx+1} &= 101 - 68.2 \text{ m}^3 \text{ sec}^{-1} \\ &= 32.8 \text{ m}^3 \text{ sec}^{-1} > 0.5(Q_{Rx+1} - Q_{Rx}) \end{aligned}$$

Therefore February 13 becomes day R2 and DURATN forecast made using Appendix 8, and data on R2.

Forecast DURATN is 5 days ± 4 days (2 standard errors), therefore forecast date of PEAKQ is February 16.

Use Tables 5.1 and 5.2 to determine which forecasts of PEAKQ should be made and the data required, beginning with day (DURATN-4).

$$1) \text{ DURATN} = 5 \quad n = -4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (-4) = 1$$

-4 DURATN = 1, corresponds to day R1 of rising limb. This day has passed, $\therefore$ no forecasts can be made for this day.

2) DURATN = 5 $n = -3$

$$nDURATN = (DURATN + (n)) = 5 + (-3) = 2$$

-3 DURATN = 2, corresponds to day R2 of rising limb, this is the current day, $\therefore$ no forecasts can be made for this day.

3) DURATN = 5 $n = -2$

$$nDURATN = (DURATN + (n)) = 5 + (-2) = 3$$

-2 DURATN = 3, corresponds to day R3 of rising limb, this day has not passed, $\therefore$ forecasts can be made.

Using Table 5.1, on day 2 of rising limb (i.e., $R_x = 2$), for $nDURATN = 3$ a 5, 2 and 1 day forecast can be made for R3. Using Table 5.2, data on days R-2, R1 and R2 is required to make these forecasts. The calculations for the forecasts are recorded in Appendix 9(1) forecasts are recorded in Appendix 10(1).

February 14 (R3)

Need to compare the forecast of PEAKQ for $nDURATN = 3$, (R3), with observed Q_{R3}

$$\text{On R3 } Q = 66 \text{ m}^3 \text{sec}^{-1}$$

$$\text{Forecast PEAKQ} = 270 \text{ m}^3 \text{sec}^{-1}$$

$$Q_{R3} < \text{PEAKQ} \therefore \text{assume PEAKQ has not occurred.}$$

$Q_{R3} < Q_{R2}$, rising limb has not continued, stop forecasting procedure until rising limb is again identified.

Redefine Rising Limb:

$$\text{February 16. } Q_{Rx} = 54.0 \text{ m}^3 \text{sec}^{-1}$$

$$\text{February 17. } Q_{Rx+1} = 71.0 \text{ m}^3 \text{sec}^{-1}$$

$$\begin{aligned} Q_{Rx+1} - Q_{Rx} &= 71.0 - 54.0 \text{ m}^3 \text{sec}^{-1} \\ &= 17 \text{ m}^3 \text{sec}^{-1}, > 15 \text{ m}^3 \text{sec}^{-1} \end{aligned}$$

$$\text{February 18. } Q_{Rx+2} = 150 \text{ m}^3 \text{sec}^{-1}$$

$$\begin{aligned} Q_{Rx+2} - Q_{Rx+1} &= 150 - 71 \text{ m}^3 \text{sec}^{-1} \\ &= 79 \text{ m}^3 \text{sec}^{-1}, > 0.5(Q_{Rx+2} - Q_{Rx+1}) \end{aligned}$$

Therefore February 18 becomes day R2 and DURATN forecast is made using Appendix 8, and data on R2

Forecast DURATN is 5 days $\pm$ 4 days (2 standard errors), therefore forecast date of PEAKQ is February 21.

Use Tables 5.1 and 5.2 to determine which forecasts of PEAKQ should be made and the data required, beginning with day (DURATN -4)

$$1) \text{ DURATN} = 5 \quad n = -4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (-4) = 1$$

-4 DURATN = 1, corresponds to day R1 of rising limb. This day has passed, $\therefore$ no forecasts can be made for this day.

$$2) \text{ DURATN} = 5 \quad n = -3$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (-3) = 2$$

-3 DURATN = 2, corresponds to day R2 of rising limb, this is the current day, $\therefore$ no forecasts can be made for this day.

$$3) \text{ DURATN} = 5 \quad n = -2$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (-2) = 3$$

-2 DURATN = 3, corresponds to day R3 of rising limb, this day has not passed, $\therefore$ forecasts can be made.

Using Table 5.1 on day 2 of rising limb (i.e., $R_x = 2$), for $n\text{DURATN} = 3$ a 5, 2 and 1 day forecast can be made for R3. Using Table 5.2 data on days R-2, R1 and R2 is required to make these forecasts. The calculations for the forecasts are recorded in Appendix 9 (2) and the forecasts recorded in Appendix 10(2).

$$4) \text{ DURATN} = 5 \quad n = -1$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (-1) = 4$$

-1 DURATN = 4, corresponds to day R4 of rising limb, this day has not passed, $\therefore$ forecasts can be made.

Using Table 5.1 on day 2 of rising limb (i.e. $R_x = 2$), for $n\text{DURATN} = 4$ a 5 and 2 day forecast can be made for R4. Using Table 5.2 data on days R-1 and R2 is required to make these forecasts. The calculations for the forecasts are recorded in Appendix 9 (3) and the forecasts recorded in Appendix 10(3).

$$5) \text{ DURATN} = 5 \quad n = 0$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (0) = 5$$

0 DURATN = 5, corresponds to day R5 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 on day 2 of rising limb (i.e. $R_x = 2$), for $n\text{DURATN} = 5$ a 5 day forecast can be made for R5. Using Table 5.2 data on day R0 is required to make this forecast. The calculations for the forecast are

recorded in Appendix 9(4) and the forecast recorded in Appendix 10(4).

6) DURATN = 5 n = +1

$$nDURATN = (DURATN + (n)) = 5 + (+1) = 6$$

+1 DURATN = 6, corresponds to day R6 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 on day 2 of rising limb (i.e. Rx = 2), for nDURATN = 6 a 5 day forecast can be made for R6. Using Table 5.2 data on day R1 is required to make this forecast. The calculation for the forecast is recorded in Appendix 9(5) and the forecast recorded in Appendix 10(5).

7) DURATN = 5 n = +2

$$nDURATN = (DURATN + (n)) = 5 + (+2) = 7$$

+2 DURATN = 7, corresponds to day R7 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 on day 2 of rising limb (i.e. Rx = 2), for nDURATN = 7 a 5 day forecast can be made for R7. Using Table 5.2 data on day R2 is required to make this forecast. The calculation for the forecast is recorded in Appendix 9(6) and the forecast recorded in Appendix 10(6).

On day R2 of the rising limb, forecasts have been made up to day R7.

However as only 5 day forecasts are available for R5, 6 and 7, the PEAKQ forecast will be updated once 2 and 1 day forecasts can be made. Forecasts are recorded in Appendix 10.

February 19 (R3)

Need to compare forecast PEAKQ for DURATN = 3 (R3) with observed Q_{R3}

$$Q_{R3} = 208 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 335 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R3} < \text{forecast PEAKQ} \therefore$ assume PEAKQ has not occurred

$Q_{R3} > Q_{R2}$ rising limb has continued $\therefore$ PEAKQ has not occurred.

1) DURATN = 5 n = -1

$$nDURATN = (DURATN + (n)) = 5 + (-1) = 4$$

-1 DURATN = 4, corresponds to day R4 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 on day 3 of rising limb (i.e., Rx = 3), for nDURATN = 4, a 1 day forecast can be made for R4. Using Table 5.2 data on day R3 is required to make this forecast. The calculation for the forecast is recorded in Appendix 9(7) and the forecast recorded in Appendix 10(7).

2) DURATN = 5 n = 0

$$nDURATN = (DURATN + (n)) = 5 + (0) = 5$$

0 DURATN = 5, corresponds to day R5 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 a 2 day forecast can be made for R5. Using Table 5.2 data on day R3 is required to make this forecast. The calculation for the forecast is recorded in Appendix 9(8) and the forecast recorded in Appendix 10(8).

3) DURATN = 5 $n = +1$

$$nDURATN = (DURATN + (n)) = 5 + (+1) = 6$$

+1 DURATN = 6 corresponds to day R6 of rising limb.

Using Table 5.1 no additional forecasts can yet be made for R6.

4) DURATN = 5 $n = +2$

$$nDURATN = (DURATN + (n)) = 5 + (+2) = 7$$

+2 DURATN = 7, corresponds to day R7 of rising limb.

Using Table 5.1 no additional forecast can yet be made for R7.

5) DURATN = 5 $n = +3$

$$nDURATN = (DURATN + (n)) = 5 + (+3) = 8$$

+3 DURATN = 8 corresponds to day R8 of rising limb, this day has not passed, $\therefore$ forecasts can be made.

Using Table 5.1 a 5 day forecast can be made for R8. Using Table 5.2 data on day R3 is required to make this forecast. The calculations for the forecast are recorded in Appendix 9 (9) and the forecast recorded in Appendix 10(9).

February 20 (R4)

Need to compare forecast PEAKQ for $nDURATN = 4$ (R4) with observed Q_{R4}

$$Q_{R4} = 273 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 335 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R4} < \text{forecast PEAKQ}$ $\therefore$ assume PEAKQ has not occurred.

$Q_{R4} > Q_{R3}$ rising limb has continued $\therefore$ PEAKQ has not occurred.

1) DURATN = 5 $n = 0$

$$nDURATN = (DURATN + (n)) = 5 + (0) = 5$$

0 DURATN = 5, corresponds to day R5 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 a 1 day forecast can be made for R5. Using Table 5.2 data on day R4 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9 (10) and the forecast recorded in Appendix 10(10).

$$2) \text{ DURATN} = 5 \quad n = +1$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+1) = 6$$

+1 DURATN = 6, corresponds to day R6 of rising limb, this day has not passed $\therefore$ forecasts can be made.

Using Table 5.1 a 2 day forecast can be made for R6. Using Table 5.2 data on day R4 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9(11) and the forecast recorded in Appendix 10 (11).

$$3) \text{ DURATN} = 5 \quad n = +2$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+2) = 7$$

+2 DURATN = 7, corresponds to day R7 of rising limb.

Using Table 5.1 no additional forecasts can yet be made for R7.

$$4) \text{ DURATN} = 5 \quad n = +3$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+3) = 8$$

+3 DURATN = 8, corresponds to day R8 of rising limb.

Using Table 5.1 no additional forecasts can yet be made for R8.

$$5) \text{ DURATN} = 5 \quad n = +4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+4) = 9$$

+4 DURATN = 9, corresponds to day R9 of rising limb.

Using Table 5.1 a 5 day forecast can be made for R9. Using Table 5.2 data on day R4 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9 (12) and the forecast recorded in Appendix 10 (12).
February 21 (R5)

Need to compare forecast PEAKQ for $n\text{DURATN} = 5$ (R5) with observed Q_{R5}

$$Q_{R5} = 356 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 440 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R5} < \text{forecast PEAKQ}$ $\therefore$ assume PEAKQ has not occurred.

$Q_{R5} > Q_{R4}$ rising limb has continued $\therefore$ PEAKQ has not occurred.

$$1) \text{ DURATN} = 5 \quad n = +1$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+1) = 6$$

+1 DURATN = 6, corresponds to day R6 of rising limb.

Using Table 5.1 a 1 day forecast can be made for R6. Using Table 5.2 data on day R5 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9(13) and the forecast recorded in Appendix 10(13).

$$2) \text{ DURATN} = 5 \quad n = +2$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+2) = 7$$

+2 DURATN = 7, corresponds to day R7 of rising limb.

Using Table 5.1 a 2 day forecast can be made for R7. Using Table 5.2 data on day R5 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9(14) and the forecast recorded in Appendix 10(14).

$$3) \text{ DURATN} = 5 \quad n = +3$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+3) = 8$$

+3 DURATN = 8, corresponds to day R8 of rising limb.

Using Table 5.1, no additional forecasts can yet be made for R8.

$$4) \text{ DURATN} = 5 \quad n = +4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+4) = 9$$

+4 DURATN = 9, corresponds to day R9 of rising limb.

Using Table 5.1 no additional forecasts can yet be made for R9. Forecasts are not made for days beyond R9 since this represents the forecast (DURATN +4) days. Therefore R9 is the limit of DURATN +2 standard errors and in only 5 out of 200 years will PEAKQ fall outside this limit.

February 22 (R6)

Need to compare forecast PEAKQ for $n\text{DURATN} = 6$ (R6) with observed Q_{R6} .

$$Q_{R6} = 380 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 506 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R6} < \text{forecast PEAKQ}$ ∴ assume PEAKQ has not occurred.

$Q_{R6} > Q_{R5}$ rising limb has continued ∴ PEAKQ has not occurred.

$$1) \text{ DURATN} = 5 \quad n = +2$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+2) = 7$$

+2 DURATN = 7, corresponds to day R7 of rising limb.

Using Table 5.1 a 1 day forecast can be made for R7. Using Table 5.2 data on day R6 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9(15) and the forecast recorded in Appendix 10(15).

$$2) \text{ DURATN} = 5 \quad n = +3$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+3) = 8$$

+3 DURATN = 8, corresponds to day R8 of rising limb.

Using Table 5.1 a 2 day forecast can be made for R8. Using Table 5.2 data on day R6 is required to make this forecast. The calculation for

this forecast is recorded in Appendix 9 (16) and the forecast recorded in Appendix 10 (16).

$$3) \text{ DURATN} = 5 \quad n = +4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+4) = 9$$

+4 DURATN = 9, corresponds to day R9 of rising limb.

Using Table 5.1 no additional forecasts can yet be made for R9.

February 23 (R7)

Need to compare forecast PEAKQ for $n\text{DURATN} = 7$ (R7), with observed Q_{R7}

$$Q_{R7} = 395 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 520 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R7} < \text{forecast PEAKQ}$ ∴ assume PEAKQ has not occurred.

$Q_{R7} > Q_{R6}$ rising limb has continued ∴ PEAKQ has not occurred.

$$1) \text{ DURATN} = 5 \quad n = +3$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+3) = 8$$

+3 DURATN = 8, corresponds to day R8 of rising limb.

Using Table 5.1 a 1 day forecast can be made for R8. Using Table 5.2 data on day R7 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9 (17) and the forecast recorded in Appendix 10 (17).

$$2) \text{ DURATN} = 5 \quad n = +4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+4) = 9$$

+4 DURATN = 9, corresponds to day R9 of rising limb.

Using Table 5.1 a 2 day forecast can be made for R9. Using Table 5.2 data on day R7 is required to make this forecast. The calculation for this forecast is recorded in Appendix 9 (18) and the forecast recorded in Appendix 10 (18).

February 24 (R8)

Need to compare forecast PEAKQ for $n\text{DURATN} = 8$ (R8), with observed Q_{R8}

$$Q_{R8} = 435 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 522 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R7} < \text{forecast PEAKQ}$ ∴ assume PEAKQ has not occurred.

$Q_{R7} > Q_{R6}$ rising limb has continued ∴ PEAKQ has not occurred.

$$1) \text{ DURATN} = 5 \quad n = +4$$

$$n\text{DURATN} = (\text{DURATN} + (n)) = 5 + (+4) = 9$$

+4 DURATN = 9, corresponds to day R9 of rising limb.

Using Table 5.1 a 1 day forecast can be made for R9. Using Table 5.2 data on R8 is required to make this forecast. The calculation for the forecast is recorded in Appendix 9 (19) and the forecast recorded in Appendix 10 (19).

February 25 (R9)

Need to compare forecast PEAKQ for nDURATN = 9 (R9), with observed Q_{R9}

$$Q_{R9} = 411 \text{ m}^3 \text{ sec}^{-1}$$

$$\text{Forecast PEAKQ} = 549 \text{ m}^3 \text{ sec}^{-1}$$

$Q_{R9} < \text{forecast PEAKQ}$ ∴ assume PEAKQ has not occurred.

However, $Q_{R9} < Q_{R8}$ ∴ PEAKQ has occurred and falling limb of hydrograph reached.

Terminate forecasting procedure.

Note: The number in brackets following the reference to Appendix 9 and 10 corresponds with the forecast number in these Appendices.

Appendix 8. Forecast of DURATN on day R2 of rising limb for 1981

			-		+		+		-
AWEQSP	AWEQSP	MAXT	MAXT	MEANT	MEANT	YEAR	YEAR	DISCH	DISCH
	x0.04		x0.68		x0.44		x0.04		x0.004
44.51	1.78	-6.0	-4.08	-16.3	-7.17	32	1.28	101	0.43

+
5.68 DURATN DATE
 5.25 13.2.81
 _ 5 days

Forecast date of PEAKQ is February 16

			-		+		+		-
AWEQSP	AWEQSP	MAXT	MAXT	MEANT	MEANT	YEAR	YEAR	DISCH	DISCH
	x0.04		x0.68		x0.44		x0.04		x0.004
37.31	1.49	7.7	5.24	5.4	2.38	32	1.28	150	0.6

+
5.68 DURATN DATE
 4.99 18.2.81
 _ 5 days

The forecast day of PEAKQ is 21.2.81.

Adjusted WEQSP is represented as AWEQSP.

Appendix 9. Short Term Forecasts, Calculation Procedure, 1981 (5 day Forecast)

Forecast #	Day and date of rising limb forecast made for	AWEQSP x1.49	DISCH	+ DISCH x0.19	DEGDAY	- DEGDAY x0.35	RAIN	- RAIN x25.79	TPREC	+ TPREC x21.70	YEAR2	+ YEAR2 x0.063	YEAR	- YEAR x18.23	SUNHRS	- SUNHRS x3.66	+ 303.04	PEAKQ m ³ sec ⁻¹
1	3 14.2.81 18.51	27.58	15.1	2.87	20.2	7.07	0	0	0	0	1024	645.12	32	583.36	4.7	17.20		371
2	3 19.2.81 42.63	63.52	66	12.54	30.9	10.82	0	0	0	0	1024	645.12	32	583.36	5.7	20.86		409
3	4 20.2.81 41.14	61.30	53.6	10.18	30.9	10.82	0	0	0	0	1024	645.12	32	583.36	6.1	22.33		403
4	5 21.2.81 39.93	59.50	54.0	10.26	31.9	11.17	0.2	5.16	0.2	4.34	1024	645.12	32	583.36	1.6	5.86		417
5	6 22.2.81 38.91	57.98	71.0	13.49	39.6	13.86	0	0	0	0	1024	645.12	32	583.36	0.9	3.29		419
6	7 23.2.81 37.31	55.59	.50	2.56	45.7	16.00	0.4	10.32	0.4	8.68	1024	645.12	32	583.36	9	0		405
9	8 24.2.81 34.33	51.15	208	39.52	50.20	17.57	8.6	221.79	8.6	186.62	1024	645.12	32	583.36	9	0		403
12	9 25.2.81 38.2	56.98	273	51.87	56.4	19.74	17.3	446.17	17.3	375.41	1024	645.12	32	583.36	9	0		383

Adjusted WEQSP is represented as AWEQSP

Short term forecasts, calculation procedure, 1981 (2 day forecast)

Forecast #	Day and date of rising limb forecast made for	DISCH x0.57	DEGDAY	- DEGDAY x0.84	DATE	+ DATE x2.93	RAIN	+ RAIN x2.14	YEAR2	+ YEAR2 x0.32	YEAR	- YEAR x9.47	AWEQSP	+ AWEQSP x0.48	SUNHRS	- SUNHRS x3.68	+ 55.60	PEAKQ m ³ sec ⁻¹
1	3 14.2.81 68.2	38.87	30.9	25.96	43	125.99	0	0	1024	327.68	32	303.04	46.05	22.10	8.6	31.65		210
2	3 19.2.81 71	40.47	39.6	33.26	47	137.71	0	0	1024	327.68	32	303.04	38.91	18.68	0.9	3.31		241
3	4 20.2.81 150	85.50	45.7	38.39	48	140.64	0.4	0.86	1024	327.68	32	303.04	37.31	17.91	0	0		287
8	5 21.2.81 208	118.56	50.2	42.17	49	143.57	8.6	8.40	1024	327.68	32	303.04	34.33	16.48	0	0		335
11	6 22.2.81 273	155.61	56.4	47.38	51	149.43	17.3	37.02	1024	327.68	32	303.04	38.24	18.36	0	0		393
14	7 23.2.81 356	202.92	64.5	54.18	52	152.36	0.6	1.28	1024	327.68	32	303.04	49.39	23.71	0	0		406
16	8 24.2.81 380	216.60	72.3	60.73	53	155.29	0	0	1024	327.68	32	303.04	41.97	20.15	1.6	5.89		406
18	9 25.2.81 395	225.15	84.3	70.81	54	158.22	18.4	39.38	1024	327.68	32	303.04	33.40	16.03	0.8	2.94		445

Appendix 9 cont'd.

Short term forecasts, calculation procedure, 1981 (1 day forecast)

Forecast#	Day and Date of Rising Limb forecast made for DISCH	DISCH x1.72	DEG DAYS x0.93	- DEG DAYS	+ DATE x3.0	- SUNHRS x5.31	+ MAXT x3.9	+ SNWF x33.09	-33.82	PEAKQ m ³ sec ⁻¹
1	3 14.2.81 101	173.72	30.9	28.74	44 132	6.3 33.45	-6.0 -23.40	0.4 13.24		246
2	3 19.2.81 150	258	45.7	42.5	48 144	0 0	7.7 30.03	0 0		356
7	4 20.2.81 208	357.76	50.20	46.69	49 147	0 0	6.2 32.92	0 0		456
10	5 21.2.81 273	469.56	56.4	52.45	51 153	0 0	8.1 31.59	0 0		568
13	6 22.2.81 356	612.32	64.5	59.99	52 156	0 0	7.8 30.42	0 0		705
15	7 23.2.81 380	653.6	72.3	67.24	53 159	1.6 8.5	12.0 46.8	0 0		750
17	8 24.2.81 395	679.4	84.3	78.40	54 162	0.8 4.25	8.4 32.76	0 0		758
19	9 25.2.81 435	748.2	92.7	86.21	55 165	0 0	6.7 26.13	0 0		819

Forecast Appendix 10. Record of Short term forecasts made for 1981

#	Day and Date of Rising Limb Fore- cast made	Day and Date of Rising Limb Fore- cast made for	Type of Forecast	Forecast PEAKQ m^3sec^{-1}	Observed daily mean discharge $Q_{Rx} m^3sec^{-1}$	Comments
1	2 13.2.81	3 14.2.81	Mean of 5,2,1	276	66 14.2	
2	2 18.2.81	3 19.2.81	Mean of 5,2,1	335	208 19.2	
3	2 18.2.81	4 20.2.81	Mean of 5,2	345		1 day not available
4	2 18.2.81	5 21.2.81	5 day	417		2,1 day not available
5	2 18.2.81	6 22.2.81	5 day	419		2,1 day not available
6	2 18.2.81	7 23.2.81	5 day	405		2,1 day not available
7	3 19.2.81	4 20.2.81	Mean of 5,2,1	382	273 20.2	Replaces forecast of 345 made 18.2.81
8	3 19.2.81	5 21.2.81	Mean of 5,2	376		Replaces forecast of 417 made 18.2.81
9	3 19.2.81	8 24.2.81	5 day	403		2,1 day not available
10	4 20.2.81	5 21.2.81	Mean of 5,2,1	440	356 21.2	Replaces forecast of 376 made 19.2.81
11	4 20.2.81	6 22.2.81	Mean of 5,2	406		Replaces forecast of 419 made 18.2.81
12	4 20.2.81	9 25.2.81	5 day	383		2,1 day not available
13	5 21.2.81	6 22.2.81	Mean of 5,2,1	506	380 22.2	Replaces forecast of 406 made 20.2.81
14	5 21.2.81	7 23.2.81	Mean of 5,2	405		Replaces forecast of 405 made 18.2.81
15	6 22.2.81	7 23.2.81	Mean of 5,2,1	520	395 23.2	Replaces forecast of 405 made 21.2.81
16	6 22.2.81	8 24.2.81	Mean of 5,2	404		Replaces forecast of 403 made 19.2.81
17	7 23.2.81	8 24.2.81	Mean of 5,2,1	522	435 24.2	Replaces forecast of 404 made 22.2.81
18	7 23.2.81	9 25.2.81	Mean of 5,2	414		Replaces forecast of 383 made 20.2.81
19	8 24.2.81	9 25.2.81	Mean of 5,2,1	549	411 25.2	Replaces forecast of 414 made on 23.2.81
	9 25.2.81	Forecasting procedure terminated				