Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE

ASSESSMENT OF THE HYDROLOGIC IMPACT OF OPHTHALMIA DAM

Report No. WS80

October 1991

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CONTENTS

Page No

EXECUTIVE SUMMARY 3

CHAPTER 1 - INTRODUCTION 5
1.1 General 5
1.2 Study Background 5
1.3 Study Objectives 6

CHAPTER 2 - STUDY APPROACH 7
2.1 Field Trip 7
2.2 Study Area 7
2.3 Study Philosophy 7
2.4 Detailed Methodology 8
2.5 External Consultant 9

CHAPTER 3 - CATCHMENT DESCRIPTION 10
3.1 Location 10
3.2 Topography 10
3.3 Land Use 10

CHAPTER 4 - AVAILABLE DATA 11
4.1 Rainfall Records 11
4.2 Streamflow Records 12
4.3 Satellite Imagery 13
4.4 Literature Review of Effects of Altered Hydrologic Regime on Riparian Forests 14

CHAPTER 5 - EXPLORATORY DATA ANALYSIS 15
5.1 Aim 15
5.2 Rainfall data 15
5.3 Groundwater Data 16

CHAPTER 6 - LONG TERM MODELLING - UPPER FORTESCUE CATCHMENT 17
6.1 General 17
6.2 Data Used 17
6.2.1 Streamflow 17
6.2.2 Rainfall 17
6.2.3 Evaporation 19
6.3 Model Calibration 19
6.4 Results of Long Term Modelling 20
6.5 Discussion 23
6.5.1 Comparison with other studies 23
6.5.2 Discussion of pre-dam and post-dam statistics 23

CHAPTER 7 - EVENT BASED MODELLING - TOTAL CATCHMENT 25
7.1 General 25
7.2 Approach 25
7.3 Catchment Schematisation 26
7.4 Catchment Rainfall Preparation 26

7.5 Source Areas 27
7.6 Catchment Wetness Index and Soil Moisture Deficit 27
7.7 Runoff Coefficient Analysis 27
7.8 Derivation of Routing Parameters 28
7.9 Estimates of Roy Hill Rating Curve 31
7.10 Derivation of Unit Hydrographs 32
7.11 FLOUT Model Calibration 33
7.12 Simulation of historic flood events 35
7.13 Results of Event Based Modelling 36
7.14 Discussion 37
7.15 Impact Assessment 38

CHAPTER 8 - FUTURE MONITORING OF CATCHMENT HYDROLOGY 41

CHAPTER 9 - CONCLUSIONS 42

ACKNOWLEDGEMENTS 43

REFERENCES 44

APPENDIX A
Rod Banyard - Personal Communication - Observation Bore Levels 46

APPENDIX B
Angus Davidson - Personal Communication - Observation Bore Levels 47

APPENDIX C
Rainfall Sites - Details of missing & accumulated record 48

APPENDIX D
Results of Event Based Modelling 50
Cross Section 5 - Double Channel One 50
Cross Section 7 - Seven Mile Bore, Marys Bore 51
Cross Section 8 - Ethel Creek 52
Cross Section 10 - Irwins Well 53
Cross Section 11 - Battle Hill 54
Cross Section 12 - Five Mile Bore 55

APPENDIX E
Backwater Analysis of Fortescue River 56
HEC-2 input data file 56
Example of HEC-2 result 60
Profile for Stream Cross Sections 21 - 1 65

FIGURES 66
List of Figures 66

EXECUTIVE SUMMARY

As part of the process of assessing the impact of Ophthalmia Dam on downstream floodplains, the Water Authority of Western Australia was requested to provide a comprehensive study of the hydrology of the Fortescue River catchment. The necessity for this study emerged following the publication of the preliminary rangeland study report by Payne and Mitchell (1990), which identified water stress in vegetation at several locations on the Fortescue River system.

The primary objective of this study was to assess the hydrologic and hydraulic impacts of Ophthalmia Dam on the Fortescue River floodplains through Ethel Creek and Roy Hill stations. It includes an assessment of the significance of variations in rainfall characteristics to changes in the flow regime of the Fortescue River floodplains downstream of Ophthalmia Dam. The results and conclusions of this study are intended to be used by the Department of Agriculture for their interpretation of the relative significance of possible causes of land degradation in the floodplains of the Fortescue River.

An integrated approach of modelling and statistical analysis has provided the best estimates of various measures of impact at specific locations on the Fortescue River floodplains. It was realised from the complexity of the catchment that an innovative methodology was required to meet the study objectives. The approach was selected after carefully considering the scope of the required output information required by the Department of Agriculture and the availability of hydrologic data. We believe that an approximate analysis based on a simpler approach would not adequately define the impacts experienced by the floodplains at the specific locations of interest. The adopted methodology is therefore considered valid and appropriate for the study objectives established for the project.

For the event based model, individual flood events were simulated using identical model inputs apart from the inclusion or exclusion of the dam. The reservoir routing component of the model is explicitly calculated by well established hydraulic principles. Therefore, the relative magnitudes of various measures of impact (flood volume, flood peak, and flood width) due to the dam, are more reliably estimated than the absolute magnitude of these variables. The results therefore achieved our objective of providing the best estimates of hydrologic impact on the floodplains due to the dam.

The conclusions of this study are:-

a) Comparing the post-dam average conditions (1982 to 1990) to the long term average conditions (1907 to 1990) on an event basis, the relative impact due to dam and climatic variations on streamflow volume reduction at specific cross sections in the floodplains downstream of Ophthalmia Dam are as follows:-

Cross Section No.	Impact due to dam	Impact due to climatic variations
5 (Double Channel One)	49%	51%
7 (Seven Mile Bore)	49%	51%
8 (Ethel Creek)	51%	49%
10 (Irwin's Well)	34%	66%
11 (Battle Hill)	33%	67%
12 (Five Mile Bore)	31%	69%

b) Analysis of rainfall data indicates that since construction of the dam, there has been a lack of large cyclone generated storm events. Although post-dam average annual rainfall totals were not significantly different from the pre-dam rainfall average, streamflow volumes were less in the post-dam period due to the lack of large storms. This is shown in the frequency plots of the width and flow variables which indicate that no large events (greater than about 5 year average recurrence interval) have occurred since dam construction.

c) The impact due to the dam for the small flow events (less than 5 year average recurrence interval) is significantly higher than for the larger events.

d) The dam has a larger impact on flows in the floodplains of the Fortescue River upstream of the Jiggalong confluence than the flows in the floodplains downstream of it. This is due to the addition of unregulated flow contribution from Jiggalong Creek to the Fortescue River downstream of Ethel Creek homestead.

e) To understand the hydrology of the catchment better and to manage the area in future, we recommend that the following actions be taken to obtain more hydrometric and meteorological data for the Fortescue River catchment.

   i) Re-establish Roy Hill gauging station and provide additional cross sectional surveys downstream of the station.

   ii) Investigate the relocation of Roy Hill gauging station to a more appropriate spot or the establishment of an additional station upstream of Roy Hill.

   iii) Improve the network of rainfall stations in the lower part of the catchment of the Fortescue River between Ophthalmia Dam and Roy Hill station by installing more rainfall stations.

   iv) Introduce an interim monitoring of flood behaviours in the floodplains downstream of the dam by installing peak stage indicators at surveyed cross sections.

CHAPTER 1 - INTRODUCTION

1.1 General

Ophthalmia Dam was constructed in 1981 by Mount Newman Mining Company Pty Ltd (MNM) on the Fortescue River just upstream of Ethel Gorge near the town of Newman (see Figure 1). The dam provides water for an artificial recharge system into a nearby aquifer with a borefield for town and mining water supply.

Recently, pastoralists on Roy Hill Station have claimed that the dam is having an adverse impact on the vegetation of the floodplain system from Ethel Gorge downstream to as far as the "Marshes" approximately 140 kilometres downstream of Ophthalmia Dam.

Various studies were initiated to investigate these claims including a study prepared for Mount Newman Mining Co. by Australian Groundwater Consultants (1989) and a study of land degradation on Ethel Creek and Roy Hill stations by Payne and Mitchell (1990).

1.2 Study Background

As part of the process of assessing the impact of Ophthalmia Dam on downstream floodplains, the Water Authority of Western Australia (WAWA) became involved as follows:

a) **February 1990**
WAWA was requested by the then Department of Resources Development (DRD) to review a study carried out by Australian Groundwater Consultants Pty Ltd (AGC) (1989) for MNM to assess the effects of Ophthalmia Dam.

b) **June 1990**
WAWA received a copy of the Western Australian Department of Agriculture's (WADA) preliminary report by Payne and Mitchell (1990). The report documented the results of a rangeland study into land degradation of the floodplains of the Fortescue River through Ethel Creek and Roy Hill stations.

c) **July 1990**
Following preparation of the preliminary report by Payne and Mitchell (1990), officers from DRD, WADA, EPA and WAWA concluded that a further and a more comprehensive hydrologic study was required to assist with:

   i) Assessment of the impact of Ophthalmia dam on the downstream flow regime, including the region of water stress affected vegetation on the floodplains through Ethel Creek and Roy Hill stations as identified by Payne and Mitchell (1990).

   ii) Development of a pastoral management policy for the floodplains and adjoining land of the Fortescue River aimed at stabilising floodplain processes that may be changing due to climatic and streamflow trends, and other impacts.

iii) Reassessment of the environmental monitoring requirements carried out by MNM.

d) **August 1990**
Study commenced after a study proposal with an estimate of costs was prepared and accepted by DRD and MNM.

The complexity of the proposed study was recognised as a concern early in the project during development of the methodology discussed in detail in Chapter 2. Innovation in the approach was required, with contributions from a progress review group meeting frequently during the project. Notes from meetings including details of financial contributions in support of the study are archived on Water Authority files.

e) **April 1991**
The study was completed and a draft report was submitted to all interested parties for comments.

f) **June 1991**
A meeting chaired by Dr David Bennett was held on the 5 June 1991 at the office of the Minister for Water Resources to discuss some of the concerns raised by the draft report. Representatives from WAWA, DRD, MNM, Mr Ramon Kennedy from Roy Hill Station and Dr Jim Davies from Gutteridge Haskins & Davey (GHD) attended the meeting. A further meeting was held on the 11 June 1991 at the Water Authority to discuss technical aspects of the comments on the draft report in more detail.

Following initial comments by Dr Davies on data accuracy and methodology, it was agreed that the Water Authority should discuss in more detail, the technical issues raised by him. This was done on the 13 and 18 June 1991. His written comments and all other written comments submitted on the draft report are archived on Water Authority files.

1.3 Study Objectives

The objectives of this study are:-

a) to assess the hydrologic and hydraulic impacts of Ophthalmia Dam on the Fortescue River floodplains through Ethel Creek and Roy Hill stations.

b) to assess the significance of variations in rainfall characteristics to changes in the flow regime of the Fortescue River floodplains downstream of Ophthalmia Dam.

c) to provide the study results to the Department of Agriculture as a contribution to their rangeland study of floodplains of Ethel Creek and Roy Hill stations. The results will be used to help interpret the relative significance of Ophthalmia Dam, climatic variability and other causes to land degradation in the area.

CHAPTER 2 - STUDY APPROACH

The challenge of this study was to produce relevant specific hydrologic and hydraulic information at widely spaced locations on a large arid zone catchment, with the available rainfall and streamflow data. The specific requirements are set out in the objectives for the study (Chapters 1).

2.1 Field Trip

On the 28 and 29 August 1990, the two principal authors, Waugh and Ng, visited the study area and carried out a general reconnaissance of the catchment by light aircraft. It was then followed by a tour of the riverine floodplain areas by four wheel drive vehicle (with assistance from Mount Newman Mining Company). Arrangements were made to meet the owners of Roy Hill Station during the trip to discuss relevant aspects on site, however they were not available at that time. Useful discussions were held with them in Perth at various times during the course of the study.

Sites for cross-section surveys were identified during the trip and marked for survey by BHP Engineering surveyors (see Figure 2 for locations of cross-sections).

A record of the trip was obtained by still photography and video recorder.

2.2 Study Area

The study area is defined by the Fortescue River catchment upstream of Roy Hill gauging station as shown in Figure 2.

2.3 Study Philosophy

The main hydrologic issue of this study relates to climate and hydrologic variability of system inputs and outputs in both space and time, as a result of the large catchment size and its location in the arid region of Australia. It was realised from the complexity of the catchment that an innovative modelling approach would be required to meet the study objectives.

In terms of the supply of water to the floodplains of the Fortescue River downstream of Ophthalmia dam, the impacts experienced by the floodplains result from two specific causes.

a) Regulation of natural streamflows by the dam, in the upper catchment.
b) Climatic variability in the form of
   i) direct rainfall regime.
   ii) runoff generated on the catchment and routed through the floodplain system by the channel network.

Natural variations in rainfall can be evaluated by analysis of long term rainfall records. Similarly, for streamflow variations, analysis of long term flow data will indicate the hydrologic variability in the catchment as a result of rainfall variability.

The restriction in flow caused by the dam can be evaluated quite reliably by hydrologic/hydraulic simulation of the system for two scenarios, namely without the dam and with the dam in place.

In this study, an integrated strategy of statistical analysis, plus a two part computer modelling approach was adopted. Statistical analysis of raw rainfall data was used to assess any variations in direct rainfall on areas of specific interest. Periods before and after dam construction were isolated, analysed and compared.

The modelling strategy was developed after carefully considering the scope of the required output information and the availability of hydrologic data.

a) A lumped catchment model was applied in the upper catchment area to simulate the long term historic flow series using the long term rainfall records available in that region. A comparison of various periods of flow then reflects natural variability.

b) A separate distributed event model was then developed for the total catchment to Roy Hill gauging station, with output generated at a number of specific locations along the Fortescue River floodplains. This model has the capability of modelling explicitly, the behaviour of the dam during any flow event. Being able to deliberately include or exclude the dam within the model enabled its impact to be estimated at any node point for any selected historical storm event. The approach adopted for this study was to simulate a sufficient number of historic flow events to make a statistical interpretation of climatic and dam impacts. This was believed necessary because of the high areal variability of storm rainfalls in the region and the need to account for possible under and over estimation due to the widely spaced rainfall gauging network, especially in the major portion of the catchment downstream of Ophthalmia Dam and on the catchments of unregulated tributaries.

A comparison of selected pre-dam and post-dam periods at any particular location could then be estimated by a combined analysis of the results from both models.

This integrated approach was adopted to obtain the best estimates of the various measures of impact at widely spaced locations in a large catchment. It was selected on the basis of our engineering hydrology experience. We believe that an approximate analysis based on a simpler approach would not adequately define the impacts experienced by the floodplains at all specific locations of interest. The authors firmly believe that the methodology is valid and appropriate for the study objectives established for the project.

2.4 Detailed Methodology

a) Long Term Model:

The Sacramento model (Burnash et al., 1973) was used for this part of the study. It is a lumped catchment model that has been applied successfully to hydrologic studies by the Water Authority (Waugh, 1984) and others (Public Works Department of Western Australia, 1982). The model was first calibrated with data available from 1982 to 1990. It was then applied to the long term historic rainfall from 1907 to 1979 to derive the long term historic flows at Newman Bridge. These flows (comprising of estimated flows from 1907-1979 and observed flows from 1980-1990) provide information on the temporal variability of the long term hydrologic response of the catchment unaffected by Ophthalmia Dam. This gave a "control" data set against which downstream flow regime changes due to natural climatic variability can be compared. It also provides information on the antecedent storm conditions and runoff coefficient of flood events which then links with the event model of the whole catchment.

b) Event Model:

An event based model was used to model the entire catchment to Roy Hill station in greater detail than the lumped model. The flood routing model FLOUT by Price (1977), was selected for this application because of its ability to model channel flow and overbank flows based on measurable cross section properties. It is a quasi-distributed model with the ability to provide flow estimates at any node point in the catchment.

The model has the facility to include lateral inflow or outflow along the channel reach. This is believed to be a valuable model feature for this study because of the assumed importance of stream bed infiltration losses during flood events.

An important feature of the FLOUT model is its ability to explicitly model the hydrologic behaviour of a dam. The reservoir routing algorithm is based on established principles of hydraulics and the effect of a dam on any inflow hydrograph is always reliably predicted.

c) Statistical Analysis:

The two models above provided details of the hydrological impacts of the dam using a variety of large and small historic flow events. These results were analysed to assess the impact of the dam on the flows in the downstream floodplains.

Standard statistical techniques were applied to the rainfall data to describe its variability over the long periods for which data was available at several locations across the catchment. Statistical analysis was also applied to the event modelling outputs to summarise variations attributable to the dam alone.

2.5 External Consultant

Part of the process of modelling the flows through the complex floodplain system involved the routing of flood hydrographs from one reach to another. The estimation of routing parameters appropriate to the Fortescue channel system was developed in conjunction with Dr Bryson Bates, a flood routing specialist from CSIRO. Cross-section properties from site surveys were analysed to provide a firm basis for deriving the flood routing behaviour in the floodplain system. These parameter values were then incorporated in the event model. Dr Bates was also consulted on statistical analysis of the rainfall data.

CHAPTER 3 - CATCHMENT DESCRIPTION

3.1 Location

The study catchment is in the Pilbara region of the north west of Western Australia, approximately 350 kilometres directly inland from Port Hedland. To the south and east of the study area, are the catchment fringes on the Great Sandy Desert, and to the west, the boundary of the Ashburton River basin (Figure 1). It has a catchment area of 17,200 square kilometres to Roy Hill gauging station.

3.2 Topography

The catchment upstream of Ethel Gorge in the Ophthalmia Range has generally flat topography with elevated regions around the catchment divides, particularly the northern divide along the Ophthalmia Range. To the south and east granitic rocks predominate along the catchment divides and in the north and western quarters, shales, banded iron, basalts and dolomite define the catchment margins.

The remainder of the catchment downstream of Ethel Gorge is generally flatter, comprising a mixture of extensive sand plains, and broad floodplains along the main tributary streams. The catchment boundaries in this downstream section also consist of elevated rock outcrops of granite and shales.

The mainstream channels of the upper reaches of the Fortescue tend to be braided and generally broad and shallow (of order 150 metres by 2 to 3 metres). The floodplains in the region of the confluence of the Fortescue River, Jiggalong and Jimblebar Creeks are very wide and flat, with flood flows during significant events spreading up to 10 to 15 kilometres in width near Ethel Creek homestead.

3.3 Land Use

Vegetation throughout the catchment consists of spinifex grasses, scattered eucalypts and mulga, with more dense vegetation along the channels and levees of the main tributaries.

The study area has long been used for grazing of cattle and sheep on the Ethel Creek and Roy Hill stations. Some gold and copper mining took place during the 1930s and 1950s in the Jimblebar area (de la Hunty, 1969), however more recently major iron ore mining developments have been undertaken in the Ophthalmia Ranges, near the town of Newman. The Ophthalmia Dam was completed in December, 1981 as part of an aquifer recharge scheme for water supply to Newman and the mining development at nearby Mount Whaleback.

CHAPTER 4 - AVAILABLE DATA

4.1 Rainfall Records

The Fortescue River catchment upstream of Roy Hill station generally has a network of fifteen rainfall stations (Table 4.1). Although nine of them are located in the dam catchment (see Figure 3), their rainfall records are not as long as those from stations located outside the dam catchment. Sylvania, which began in 1950, has the longest record in the catchment upstream of the dam, but it has many years of missing record in the early period. More reliable daily rainfall records in the dam catchment were available when Newman P.O. and Prairie Downs rainfall stations were installed by the Bureau of Meteorology in 1965 and 1968 respectively.

TABLE 4.1
Fortescue River, Meteorological and Streamflow sites

Station No.	Station Name	Period of Record	Station Type and Operating Authority*
RAINFALL			
M004003	Balfour Downs	01/06/1907-	Daily Reader, CBM
M005003	Ethel Creek	01/01/1907-	Daily Reader, CBM
M005023	Roy Hill	01/08/1900-	Daily Reader, CBM
M007062	Mundiwindi	01/01/1916 - 30/11/1981	Daily Reader, CBM
M007079	Sylvania	01/01/1950-	Daily Reader, CBM
M007083	Turee Creek	01/01/1920-	Daily Reader, CBM
M007151	Newman P.O.	01/01/1965-	Daily Reader, CBM
M007153	Prairie Downs	01/01/1968-	Daily Reader, CBM
M007191	Capricorn Road House	01/03/1975-	Daily Reader, CBM
M013003	Jiggalong	01/01/1913-	Daily Reader, CBM
M505023	Roy Hill	20/09/1973 - 01/10/1986	Pluviograph, WAWA
M507005	Newman Bridge	10/02/1980-	Pluviograph, WAWA
M507007	South Giles	15/01/1980-	Pluviograph, WAWA
M507008	East Giles	16/01/1980-	Pluviograph, WAWA
M507009	Southern Fortescue	31/01/1980-	Pluviograph, WAWA
STREAMFLOW			
S708008	Roy Hill, Fortescue River	18/09/1973 - 30/09/1986	Stage Record only, WAWA
S708011	Newman Bridge, Fortescue River	09/01/1980-	Streamflow, WAWA
S708012	Ophthalmia Dam, Fortescue River	17/12/1981-	Dam level, WAWA
EVAPORATION			
E11	E11 Mount Newman Meteorological Station	09/09/1981-	Daily Evaporation Pan, MNM

Most of the rainfall stations located upstream of the dam (Newman Bridge, South Giles, East Giles, and Southern Fortescue) are operated by the Water Authority. They are pluviograph type stations installed in 1980 when Ophthalmia dam was under construction. The data from the pluviograph stations are mostly of good quality.

The rainfall stations located in other parts of the region (Ethel Creek, Roy Hill, Balfour Downs, Mundiwindi, Turee Creek and Jiggalong) are more sparsely spread out. They are operated by the Bureau of Meteorology and most have long term records commencing from the early 1900s. The rainfall data from the Bureau's station are of reasonable quality. There were period of missing and accumulated records but these can be filled in or adjusted using data from adjacent stations (see Appendix C).

4.2 Streamflow Records

There are two streamflow gauging stations in the study catchment (Newman Bridge and Roy Hill) and a level recorder at Ophthalmia Dam (see Figure 3). The Newman Bridge gauging station is located upstream of Ophthalmia Dam with records available from January 1980.

The accuracy of the data at Newman Bridge was discussed in great detail with Dr Jim Davies on the 13 June 1990. The rating curve was scrutinised with the Water Authority hydrographers responsible for the gauging station. Particular reference was made to the hydrographer's comments and notes logged in the station history file.

The rating curve is reasonably well defined throughout the flow range except for portion from 220 m^3/s to 1050 m^3/s which was interpolated. The rating curve segment in the high flow range (about 1100 m^3/s to 1600 m^3/s) is drawn slightly above the four metering points from cyclones Dean and Enid. This means that the rating curve could tend to underestimate the high flows. In view of the rating curve at the high flow end being based on meterings carried out by Mount Newman staff under instructions from Water Authority hydrographers and under circumstances new to them, the hydrographer's assessment of rating curve accuracy for high flows is "greater than 7% " (ref. station history file 708011). However, we consider that the accuracy of the rating curve in the high flow region is within 20%. This would have a small effect on the accuracy of data recorded since cyclone Dean because they fall within the lower and better defined portion of the rating curve (accuracy probably less than 10%). Overall the data recorded at Newman Bridge are regarded as good quality and satisfactory for model calibration.

The Roy Hill gauging station was installed in conjunction with two other stations at Bunje Well (708 007) and Goodiadarrie (708006). Their purpose was to determine the contributions of flow to the Lower Fortescue River to gain a general understanding of the hydrological characteristics at the Gregory Gorge dam site.

The Roy Hill gauging station was closed after the cessation of Commonwealth funds precipitated a review of existing hydrometric network. It's continued operation was no longer justified after it was found that there was no flow contribution from the catchment upstream of Goodiadarrie Hills. The priority for rating this station then was considered low, although the Water Authority hydrographers believe that it can be rated in spite of known backwater effects.

The Roy Hill gauging station had records of river stage heights from September 1973 to September 1986. This station was only metered once for a low flow of about 4 m^3/s. During its period of operation, the station had very good record recovery with little record loss.

A rating curve is required to convert river stage heights to flows. In the absence of a rating curve provided normally by discharge measurements over a wide range of flows, an alternative hydraulic analytical approach was used to derive a rating curve for Roy Hill gauging station. Its derivation is discussed in detail in Chapter 7.

A lack of discharge measurements at this gauging station means that the accuracy of the analytical rating curve is lower than that for the Newman Bridge gauging station. It is expected that it would be within 25% to 30% in terms of peak discharges, however the record is regarded as of good quality with respect to timing of the hydrographs derived from its application.

The recorder at Ophthalmia Dam has been in operation since December 1981. It provides a record of dam water levels which were used in the reservoir routing part of the flood model. In the event model, the observed dam level at the commencement of the modelled storm event was used when available.

4.3 Satellite Imagery

The following LANDSAT images were obtained for the study.

1:250,000 prints on loan from MNM:

30 November 1972,
4 September 1980,
15 August 1985,
30 September 1988,
11 September 1989.

Purchased from the Department of Land Administration (DOLA), Remote Sensing Centre for the following dates:

Digital data tapes:

10 February 1980 (cyclone Dean),
28 February 1980 (cyclone Enid),
27 July 1984.

1:100,000 prints:

22 April 1980,
15 June 1980,
12 July 1980.

This imagery, combined with aerial photographs, was used for catchment subdivision, definition of flow paths, interpretation of landform and general catchment morphology.

4.4 Literature Review of Effects of Altered Hydrologic Regime on Riparian Forests

Potential sources of moisture for riparian forests include (Reily and Johnson, 1982):

a) overbank flooding;
b) groundwater; and
c) precipitation.

The relative importance of these sources is unknown. In dry climates, overbank flooding may assist forest abundance and tree growth by saturating the rooting zone and raising the water levels of shallow, unconfined aquifers. The timing, frequency and size of these floods can be crucial in preventing drought stress and promoting regeneration.

A number of researchers have described the decline of riparian forests downstream from dams (e.g., Reily and Johnson, 1982; Harris et al., 1987; Kondolf et al., 1987; Bren, 1988; Rood and Heinze-Milne, 1989; Rood and Mahoney, 1990). This decline may be the result of altered seasonal streamflow patterns (high- and low-flow regimes), changes in channel morphology and pattern, and the retention of suspended silt, sediment, and nutrients behind the dam wall. Potential impacts include:

a) reduced forest abundance;
b) reduced plant vigour;
c) reduced seedling abundance;
d) absence of seedlings;
e) fewer saplings; and
f) changes in species composition and diversity;

Harris et al. (1987) state that these impacts are poorly understood and that government agencies have little scientific information on which to base their decisions. Furthermore, the development of a general model for predicting the impacts of dams on downstream riparian forests has proved elusive owing to the differences in species composition, geomorphic setting and hydrologic setting from site to site (Kondolf et al., 1987), as well as the dynamic response of vegetation to natural and artificial events such as droughts and dam releases.

CHAPTER 5 - EXPLORATORY DATA ANALYSIS

5.1 Aim

The aim of this phase was to analyse the available meteorological data and present relevant statistics and comments on the meteorological conditions on the Fortescue River catchment before and after the construction of Ophthalmia dam.

5.2 Rainfall data

The rainfall investigation consisted of statistical analysis of recorded data from twelve rainfall stations. Data used were from long term daily read rainfall stations such as at Roy Hill, Ethel Creek, Balfour Downs plus more recent stations (mainly pluviographs) such as Newman Bridge and those operated by the Water Authority. Figure 4 shows the periods of available record for the rainfall stations used in the study.

The general climatic trend indicating a more or less steady rise or fall was obtained by the method of moving averages. A seven year moving average was chosen in this case as an indicator of general trends. However, greater or lesser smoothing could be obtained by using a longer or shorter averaging period, the choice is somewhat arbitrary (taking the whole period, of course, gives the long term mean).

It is considered that annual statistics for reporting rainfall should be based on an appropriate "water year". In this region from October to September would be suitable, because this avoids the possibility of splitting a wet season across two years. This effect is negligible on the mean and the seven year moving average over long periods of record.

Figures 6 & 7 shows the plots of annual rainfall totals (calculated on the basis of a calendar year), the mean and the moving averages for twelve rainfall stations. In the post-dam period, the stations (Newman P.O., Prairie Downs, Capricorn Road House, South Giles, East Giles and Southern Fortescue) in the upper Fortescue catchment area had slightly above average rainfall. In the rest of the catchment, the stations (Ethel Creek, Roy Hill, Mundiwindi, Sylvania, and Jiggalong) except Balfour Downs (which has above average rainfall) had below average rainfall in the post-dam period.

The annual rainfall totals give no indication of the temporal distribution of rainfall through the year. Different temporal patterns can result in vastly different streamflow response. It is therefore more appropriate to examine characteristics of short duration rainfalls of relevance to flow generation. In this case statistical analysis of <u>daily</u> rainfall totals is a more appropriate indicator of the variability of climatic inputs to the system.

The mean, median, maximum, minimum, 25 and 75 percentiles were calculated from a sample of all non zero daily rainfall totals in each calendar month extracted from the rainfall record. Figures 8 to 11 show the relevant statistics, in a form described as box plots, for stations at Roy Hill, Ethel Creek, Newman P.O. and Jiggalong. The raw rainfall data were used. Box plots were drawn for pre-dam (all raindays before December 1981) and post-dam (all raindays after December 1981).

In terms of direct rainfall impacts on vegetation stress in the region near Ethel Creek homestead, the analysis of Ethel Creek daily rainfalls provides some useful insights. The box plots for this station show a downward shift in mean values from the pre-dam to the post-dam period in most months of the year. All maximum values for each month are higher in the pre-dam period than in the post-dam period, although this is partly due to the longer period of pre-dam record. Also of hydrological significance is a comparison of the average number of raindays per month for the two periods. The data indicates a distinct reduction from the pre-dam to post-dam periods for most of the wet season months. When combined with a reduced mean rainfall for the raindays, this indicates a reduction in the number of significant storm events during the post-dam years.

In terms of maximum rainfall value, the box plots for the other three stations indicate a trend similar to Ethel Creek. There appears to be marginally more raindays per month for Newman P.O. in the post-dam period than for the other three station. This is confirmed by the mean rainfall of other stations in the upper Fortescue area being slightly above average.

The significance of the rainfall regime in the catchment outside the areas of vegetation stress needs to be examined in terms of runoff generated as a result of these rainfalls flowing through the floodplains from upstream areas. Chapters 6 and 7 discuss the runoff response of the catchment on both the long term and event basis.

5.3 Groundwater Data

A brief examination of standing water levels at three observation bores located outside the influence of the groundwater extraction in the Newman area was undertaken (see Figure 12). The behaviour of water levels in this area is believed to reflect recent climatic trends in terms of rainfall inputs over the region. No reliable long term groundwater levels were available for areas of the study catchment down-stream of Ethel Gorge.

Comments by Mr Rod Banyard (Water Authority of WA) and Mr Angus Davidson (Geological Survey of Western Australia) on the data from three bores at locations shown on Figure 13 are included in Appendix A & B. The main points from their comments are shown below:-

a) The behaviour of the water levels in the bores is consistent with the climatic conditions and may not be affected by the construction of Ophthalmia Dam.

b) The low rainfall period since 1984 could account for the relatively low water levels measured in the bores.

c) The changes noted are close to natural variation and are influenced by the dry period.

CHAPTER 6 - LONG TERM MODELLING - UPPER FORTESCUE CATCHMENT

6.1 General

The aim of this work is to derive an extended record of the estimated historical streamflows over the period 1907 to 1979. Streamflow over the extended period then indicates the historic variations in catchment response corresponding to natural climatic variability. It provides a more rational basis for estimating the magnitude of effects due to natural variability, as opposed to an intuitive assessment based only on a measure assumed to be relevant to flow generation, e.g. assuming that a higher annual rainfall total means a higher annual streamflow yield.

Runoff coefficients from events before 1973 (no pluviograph available) are then available for use in the event based modelling which is discussed in detail in the next chapter.

The Sacramento model by Burnash et al. (1973) was selected for this study. It is a lumped daily catchment simulation model, which provides daily flows from daily rainfall inputs, transformed by passage through various conceptual stores subject to infiltration and transpiration losses. The model parameters governing the movement of water through the various stores are selectively adjusted to reproduce the observed daily, monthly and annual flows as closely as possible.

6.2 Data Used

6.2.1 Streamflow

The streamflow record at Newman Bridge gauging station was used to calibrate the Sacramento Model parameters over the 1980 to 1989 period. Daily streamflow values were used in the model and they were extracted as daily totals at 0900 hrs to correspond with the totals for rainfall data.

6.2.2 Rainfall

The upper Fortescue catchment at the Newman Bridge gauging station has an area of 2670 km^2. It is located in a region subject to localised thunder storms and cyclonic events. These occur primarily in the summer months, January to April. Except for very large storm events, rainfall can be localised and the use of rainfall data from a single site may not be representative of the spatial variability of rainfall over the catchment. The use of multiple rainfall sites to represent the catchment rainfall is therefore preferable.

The Thiessen weighting method, which is a standard hydrologic technique, was used to calculate catchment rainfalls. It assumes that rainfall depth recorded at a station is applied uniformly out to a point equidistant to the next station in any direction. The derived catchment rainfall was used for both the short term and event based modelling.

Details of operating periods as well as missing and accumulated records are described in tabular form in Appendix C.

Correlation of monthly rainfall data from adjacent rainfall stations was used to extend data back to 1907. Correlations obtained were considered quite reasonable with most of the relationships able to explain about 80% of the variance between sites and a minimum of just over 60% was explained by the adopted relationships in two cases. These regressions were applied to fill in missing daily record etc., details of which are shown in Table 6.1.

TABLE 6.1
Catchment Rainfall - Station Correlations and filling in of Missing record

Station No.	Station used to fill in missing record	Multiplier	r^2
M004003 Balfour Downs (06/1907-) Daily Reader, CBM	M005003 Ethel Creek M005023 Roy Hill	0.767 0.746	0.6418 0.6222
M005003 Ethel Creek (01/1907-) Daily Reader, CBM	M005023 Roy Hill M505023 Roy Hill (-Pluvio) M013003 Jiggalong	0.932 1.032 0.919	0.7942 0.7936 0.6992
M005023 Roy Hill (08/1900-) Daily Reader, CBM	M005003 Ethel Creek M505023 Roy Hill (-Pluvio) M004003 Balfour Downs	1.073 1.102 1.341	0.7942 0.7042 0.6222
M007062 Mundiwindi (01/1916-11/1981) Daily Reader, CBM	M007079 Sylvania M007191 Capricorn R.H M007151 Newman P.O. (-"completed record")	1.157 1.0855 1.037	0.8530 0.7871 0.7608
M007079 Sylvania (01/1950-) Daily Reader, CBM	M007062 Mundiwindi M007191 Capricorn R.H M007151 Newman P.O. (-"completed record")	0.864 1.079 0.916	0.8530 0.7636 0.7571
M007151 Newman P.O. (12/1965-) Daily Reader, CBM	M007062 Mundiwindi M005003 Ethel Creek M005023 Roy Hill	0.965 0.945 1.228	0.7608 0.6562 0.5934
M007153 Prairie Downs (01/1968-) Daily Reader, CBM	M507009 Sth Fortescue M507007 South Giles M007083 Turee Creek M007151 Newman P.O. (-"completed record")	1.255 1.346 0.839 0.899	0.8618 0.8393 0.6745 0.6204
M007191 Capricorn Road House (03/1975-) Daily Reader, CBM	M007151 Newman P.O. M007079 Sylvania M007151 Newman P.O. (-"completed record")	0.944 0.927 0.944	0.8473 0.7636 0.8473
M013003 Jiggalong (01/1913-) Daily Reader, CBM	M007191 Capricorn R.H M005003 Ethel Creek M007062 Mundiwindi	0.978 0.919 0.921	0.7237 0.6992 0.6973
M507007 South Giles (15/01/1980-) Pluviograph, WAWA	M007153 Prairie Downs M007151 Newman P.O. (-"completed record")	1.020 1.055	0.8393 0.7875
M507008 East Giles (16/01/1980-) Pluviograph, WAWA	M007151 Newman P.O. (-"completed record")	0.871	0.8848
M507009 Southern Fortescue (31/01/1980-) Pluviograph, WAWA	M007151 Newman P.O. (-"completed record")	0.774	0.8686

Of the twelve sites available, only six were used in the catchment rainfall analysis. However, all sites were used in the regression analysis. Figure 3 shows the location and distribution of the sites used for estimating the catchment rainfall.

Long term rainfall sites such as Ethel Creek, Roy Hill, etc. are mainly located outside the upper Fortescue catchment area. The derivation of catchment rainfall for the upper Fortescue for the early 1900s, was therefore based mainly on rainfall sites located outside the catchment. Catchment rainfall in the early 1900s therefore may be of lower quality. Significant storm events however, were usually widely distributed and the use of rainfall sites outside the catchment was regarded as valuable for these cases.

6.2.3 Evaporation

Evaporation data were also required by the Sacramento model, as mean daily evaporation for each month of the year. This was obtained by averaging the raw data provided by Mount Newman Mining Company (1990) at Site E11, see Table 6.2. Figure 5 shows details of averaging the mean daily evaporation for each month.

Table 6.2
Mt Newman Mining Co., E11 Met Stn Pan Evaporation (mm)

Mean Daily Evaporation

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981									9.08	11.20	12.39	13.85
1982	10.76	12.33	10.11	8.12	5.94	4.21	4.41	6.44	8.03	11.01	11.35	12.83
1983	13.38	11.22	10.36	7.07	5.55							
1984								4.54	7.27	10.56	12.39	10.84
1985	12.92	10.50	9.47	6.02	4.58	3.93	4.10	5.45	7.75	9.89	10.86	13.28
1986	9.99	9.87	10.74	7.44	5.64	4.70	4.50	5.22	7.43	12.01	14.47	16.50
1987	14.17	10.27	9.35	9.37	4.13	2.75	3.69	5.61	8.46	10.50	12.44	11.08
1988	13.49	12.00	11.36	6.05	3.14	3.38	4.46	5.68	7.59	10.88	10.89	11.11
1989	9.30	10.97	10.15	7.63	4.23		3.66	4.24	8.25	11.47	11.57	14.10
1990	10.89	9.89	9.84	8.04	6.38	4.69	4.44	5.25				
Mean	11.86	10.88	10.17	7.47	4.95	3.94	4.18	5.30	7.98	10.94	12.04	12.95

6.3 Model Calibration

The calibration of the model required the fitting of a number of parameters until observed events were simulated as best as possible. The daily flows recorded at Newman Bridge between 1980 and 1990 were used as calibration period.

Greatest emphasis was put on calibrating the two cyclone events in January and February 1980. They therefore had the greatest impact on the selection of the final set of parameter values. The priority was to conserve the annual water balance. Once this was achieved, fine tuning was carried out using monthly and then daily flows. The comparisons of the predicted and observed hydrographs are shown in Figures 14 & 15.

There were minor differences in the timing of some of the predicted hydrographs, but they were considered acceptable. Some recessions of the simulated data showed a small delay, however compared to the peak values, these delays were considered insignificant. The set of parameters that provided the best fit is shown in Table 6.3.

The overall model calibration was within 11% of the observed runoff over a 10 year period.

Table 6.3
Final Input File to Sacramento Model

```
SACRAMENTO MODELLING - NWMAN.INP                                 title  (a60)
 1  1980    1  1990                        start and end month and year
 1                                         month to start the water year
  2670.0                                          catchment area(km2)
  N   Y   N      Y Evfil? Flfil? Daily? Mthly? Yrly?   run       (3x,a1)
708011                                 modelled flow station number (a6)
DDRAIN.DAT                                rainfall data input file (a30)
                                    evaporation input file (if reqd) (a30)
DDFLOW.DAT                            recd flow input file (if reqd) (a30)
FLOW.OUT                                 simulated flow output file (a30)
WBAL.OUT                                 water balance output file (a30)
  0.00223        0.770        174.000             RACON1  RAEXP1  RACON2
  1.330         55.0           40.0               RAEXP2   RAINT   UZTWM
 13.0           75.0           30.0                UZFWM   LZTWM   LZFSM
 25.0            0.70           0.15               LZFPM     UZK    LZSK
  0.100          0.0            0.0                 LZPK   UZTWC   UZFWC
  0.0            0.0            0.0                LZTWC   LZFSC   LZFPC
 40.0            2.0            0.035              ZPERC    REXP   PCTIM
  0.020          0.010          0.20               ADIMP   SARVA   PFREE
  0.200          0.50           0.500              RSERV    SIDE   SSOUT
11.86 10.88 10.17  7.47
 4.95  3.94  4.18  5.30
 7.98 10.94 12.04 12.95              monthly mean daily evaps (if reqd)
 1.2   1.2   1.2   1.2
 1.2   1.2   1.2   1.2
 1.2   1.2   1.2   1.2                        monthly evaporation factors
  2     2                         no. unitgraph and last flow ordinates
.1500 .8500                                         unitgraph ordinates
.000  .000                                          last flow ordinates
1.20                                                 Rainfall weighting
```

6.4 Results of Long Term Modelling

After the model had been calibrated, the long term flow simulation at Newman Bridge was reasonably straightforward. The model was run using the adopted set of parameters and the Thiessen's weighted catchment rainfall derived for the period 1907 to 1989. The results of the estimated monthly flows at Newman Bridge are shown plotted in Figure 16.

By multiplying the flows at Newman Bridge by the ratio of Ophthalmia Dam catchment area (4228 km^2) to Newman Bridge catchment area (2861 km^2), a value of 1.48, the estimated inflows to Ophthalmia Dam were calculated. Table 6.4 and Figure 17 show the estimated annual flows at the dam and their comparison with results from previous studies by Tahal (1980 & 1981) and GHD (1985 & 1986).

The estimated long term flows provided a basis for comparison of flows for various historical periods for long term and short term analyses.

Table 6.4
Results of Long Term Modelling and Comparison with other studies

Year (1)	Modelled Flow @ Newman Br (2)	Est Flow (TCM) @ Ophthalmia Dam WAWA (3)=(2)*1.48	Tahal (4)	GHD (5)	Thiessen Wgt Catchment Rainfall(mm) (6)
1907	1505.9	2225.4			139.2
1908	11344.7	16765.3			225.2
1909	88196.0	130336.5			294.3
1910	1307.6	1932.4			121.2
1911	1848.7	2732.0			93.1
1912	55041.2	81340.2			299.7
1913	1250.4	1847.8			64.0
1914	1083.4	1601.1			187.9
1915	4293.2	6344.5			219.1
1916	11652.4	17220.0			313.0
1917	29613.8	43763.4			412.1
1918	34163.0	50486.3			231.8
1919	1718.4	2539.5			201.6
1920	1650.0	2438.4	9882.0	14400.0	193.8
1921	937.5	1385.4	9579.0	9100.0	188.3
1922	1323.0	1955.1	1090.0	14100.0	224.5
1923	12054.4	17814.1	16313.0	23200.0	236.6
1924	0.0	0.0	0.0	600.0	47.5
1925	4055.2	5992.8	21021.0	30200.0	285.5
1926	4777.9	7060.8	16062.0	4400.0	155.9
1927	5285.9	7811.5	62500.0	19800.0	277.9
1928	0.0	0.0	1012.0	1500.0	116.4
1929	1655.4	2446.4	1875.0	6600.0	173.2
1930	23709.4	35037.9	56303.0	23000.0	360.6
1931	71033.2	104973.2	97937.0	89600.0	456.6
1932	7788.4	11509.7	13111.0	11700.0	160.8
1933	161.5	238.7	3812.0	7200.0	196.9
1934	26208.5	38731.1	55249.0	81300.0	353.2
1935	0.0	0.0	131.0	700.0	89.7
1936	0.0	0.0	247.0	2600.0	101.4
1937	1550.9	2291.9	8601.0	4800.0	154.2
1938	35902.7	53057.2	20850.0	74100.0	312.9
1939	12408.1	18336.8	18058.0	12100.0	244.6
1940	1728.3	2554.1	1495.0	6700.0	112.2
1941	4051.6	5987.5	13391.0	9400.0	221.2
1942	142543.7	210651.8	216490.0	312200.0	682.4
1943	2994.7	4425.6	9609.0	12200.0	185.2
1944	0.0	0.0	54.0	100.0	24.0
1945	113476.2	167695.7	90013.0	102900.0	213.4
1946	2941.8	4347.4	62957.0	8800.0	190.8
1947	12173.6	17990.2	81841.0	119100.0	379.2
1948	49775.7	73558.8	34914.0	39900.0	261.5
1949	5846.7	8640.3	7188.0	10400.0	254.0
1950	0.0	0.0	888.0	1800.0	87.7
1951	1845.1	2726.7	7476.0	1700.0	123.9
1952	30327.3	44817.8	9556.0	13200.0	196.3
1953	3274.5	4839.1	16204.0	4900.0	171.0
1954	33736.6	49856.1	24785.0	31800.0	283.8
1955	84434.8	124778.2	61639.0	99700.0	539.2
1956	0.0	0.0	167.0	1000.0	119.9
1957	0.0	0.0	714.0	2800.0	129.3
1958	4559.4	6737.9	6336.0	4800.0	190.6
1959	0.0	0.0	488.0	3200.0	120.0

TCM = thousands of cubic metres

Table 6.4 cont'd
Results of Long Term Modelling and Comparison with other studies

Year (1)	Modelled Flow @ Newman Br (2)	Estimated Flow (TCM) @ Ophthalmia Dam WAWA (3)=(2)*1.48	Tahal (4)	GHD (5)	Thiessen Wgt Catchment Rainfall(mm) (6)	
1960	116619.7	172341.2	122867.0	169400.0	426.9	
1961	487.8	720.9	18263.0	7800.0	142.5	
1962	0.0	0.0	3363.0	500.0	92.6	
1963	1567.2	2316.0	16168.0	14300.0	252.9	
1964	829.5	1225.8	13474.0	3000.0	137.9	
1965	9479.3	14008.6	8954.0	15500.0	204.6	
1966	122650.4	181253.4	105844.0	80700.0	353.2	
1967	9010.9	13316.4	3119.0	30200.0	251.2	
1968	17214.1	25439.1	34745.0	20800.0	310.3	
1969	1481.9	2190.0	3935.0	5600.0	112.0	
1970	19136.3	28279.7	5308.0	13900.0	160.4	
1971	63103.1	93254.1	213906.0	159000.0	350.7	
1972	81.3	120.1	1131.0	3700.0	122.9	
1973	48293.1	71367.8	76497.0	97400.0	439.5	
1974	1416.9	2093.9	2163.0	30800.0	274.3	
1975	2251.7	3327.6	8743.0	17900.0	264.9	
1976	1738.1	2568.6	24236.0	5000.0	156.9	
1977	0.0	0.0	191.0	6100.0	121.7	
1978	52507.9	77596.4	32583.0	43800.0	353.9	
1979	10687.9	15794.6	9637.0	66100.0	320.7	
1980	102947.5	152136.3	155480.0	145800.0	470.4	
1981	8827.2	13044.9		19100.0	204.9	-dam Dec81
1982	29919.5	44215.2		45000.0	400.2	
1983	3423.4	5059.1		7900.0	215.2	
1984	7485.4	11062.0		20100.0	273.8	
1985	31860.7	47083.9			256.3	
1986	29135.1	43056.0			180.9	
1987	18630.1	27531.7			254.8	
1988	20932.4	30934.0			364.6	
1989	54.3	80.2			189.5	
1907-1989 Mean:	20229.0	29894.4			232.3	
1920-1980 Mean:	21077.3	31148.2	31482.7	35326.2	231.7	
1920-1984 Mean:	20544.2	30360.3		34569.2	234.3	
1960-1989 Mean:	24392.4	36047.2			255.4	
POST DAM 1982-1989 Mean:	17680.1	26127.8			266.9	
PRE DAM 1907-1981 Mean:	20500.8	30296.2			228.6	

TCM = thousands of cubic metres

6.5 Discussion

6.5.1 Comparison with other studies

Comparison of the flows over the common period i.e. from 1920 to 1980, indicated that

a) there is good agreement with Tahal's estimate of average annual flow and the estimate of 31.1 million cubic metres (MCM) derived in this study.

b) GHD's flow of 35.3 MCM was 13% higher, however only 4 years of observed flow data was available for that study. In view of that, long term flows were estimated to be within 20% (GHD, 1985).

c) The average catchment rainfall was found to be 232 mm. This figure was reasonably consistent whether it was calculated from 1907 or from 1920.

6.5.2 Discussion of pre-dam and post-dam statistics

For comparison purposes, we assumed the pre-dam period to be from 1907 to 1981 and the post-dam period to be from 1982 to 1989. It must be recognised that the selection of the pre-dam period of 75 years is over nine times longer than the post dam period, and therefore provides a good sample of the rainfall and runoff variability exhibited by the catchment in response to climatic inputs driving the streamflow system. This is a standard hydrologic technique for assessment of yield potential of a particular dam site. Its specific purpose is to take account of streamflow variability from year to year usually carried out as a precursor to reservoir simulation (eg GHD, 1985).

Statistics relating to flow volumes over various periods were used as the basis for estimating the effects of climatic variation to the Fortescue catchment downstream of the Newman Bridge gauging station. Table 6.4 lists the mean annual streamflow volumes for the total pre-dam and post-dam period. Mean annual flows are listed for other periods for comparisons with earlier studies and for use with the event based model results covered in Chapter 7. The estimated flows at Ophthalmia Dam ranked in order of size of annual total volume are shown in Table 6.5.

Table 6.4 indicates that the ratio of mean annual post-dam flow to long-term mean annual flow is 17680/20229 or a ratio of 0.87. This indicates a natural shift due to climatic variability alone of about 13% reduction in flow volumes. The corresponding ratio for comparison of the post-dam period with the period 1960-89 is 0.72. This reflects the higher average flows in the period between 1960 and 1981, and this is acknowledged in the application of appropriate scaling factors to event modelling results in Chapter 7.

Table 6.5
Ranked Calculated Flow at Ophthalmia Dam

Rank	Year	Calc Flow at Ophthalmia Dam TCM	Rain mm	Period*	Rank	Year	Calc Flow at Ophthalmia Dam TCM	Rain mm	Period*
1	1942	210.7	682.4		43	1915	6.3	219.1	
2	1966	181.3	353.2		44	1925	6.0	285.5	
3	1960	172.3	426.9		45	1941	6.0	221.2	
4	1945	167.7	213.4		46	1983	5.1	215.2	post
5	1980	152.1	470.4	pre	47	1953	4.8	171.0	
6	1909	130.3	294.3		48	1943	4.4	185.2	
7	1955	124.8	539.2		49	1946	4.3	190.8	
8	1931	105.0	456.6		50	1975	3.3	264.9	pre
9	1971	93.3	350.7		51	1911	2.7	93.1	
10	1912	81.3	299.7		52	1951	2.7	123.9	
11	1978	77.6	353.9	pre	53	1976	2.6	156.9	pre
12	1948	73.6	261.5		54	1940	2.6	112.2	
13	1973	71.4	439.5	pre	55	1919	2.5	201.6	
14	1938	53.1	312.9		56	1929	2.4	173.2	
15	1918	50.5	231.8		57	1920	2.4	193.8	
16	1954	49.9	283.8		58	1963	2.3	252.9	
17	1985	47.1	256.3	post	59	1937	2.3	154.2	
18	1952	44.8	196.3		60	1907	2.2	139.2	
19	1982	44.2	400.2	post	61	1969	2.2	112.0	
20	1917	43.8	412.1		62	1974	2.1	274.3	pre
21	1986	43.1	180.9	post	63	1922	2.0	224.5	
22	1934	38.7	353.2		64	1910	1.9	121.2	
23	1930	35.0	360.6		65	1913	1.8	64.0	
24	1988	30.9	364.6	post	66	1914	1.6	187.9	
25	1970	28.3	160.4		67	1921	1.4	188.3	
26	1987	27.5	254.8	post	68	1964	1.2	137.9	
27	1968	25.4	310.3		69	1961	0.7	142.5	
28	1939	18.3	244.6		70	1933	0.2	196.9	
29	1947	18.0	379.2		71	1972	0.1	122.9	
30	1923	17.8	236.6		72	1989	0.1	189.5	post
31	1916	17.2	313.0		73	1950	0.0	87.7	
32	1908	16.8	225.2		74	1977	0.0	121.7	pre
33	1979	15.8	320.7	pre	75	1959	0.0	120.0	
34	1965	14.0	204.6		76	1957	0.0	129.3	
35	1967	13.3	251.2		77	1956	0.0	119.9	
36	1981	13.0	204.9	pre	78	1936	0.0	101.4	
37	1932	11.5	160.8		79	1935	0.0	89.7	
38	1984	11.1	273.8	post	80	1924	0.0	47.5	
39	1949	8.6	254.0		81	1928	0.0	116.4	
40	1927	7.8	277.9		82	1962	0.0	92.6	
41	1926	7.1	155.9		83	1944	0.0	24.0	
42	1958	6.7	190.6						

* "pre" => pre-dam years ie 1973-1981
"post" => post-dam years ie 1982-1989

CHAPTER 7 - EVENT BASED MODELLING - TOTAL CATCHMENT

7.1 General

A quasi-distributed model, FLOUT by Price (1977) was used for modelling historic flood events. FLOUT has the capability of modelling streamflow at any specified node point within the catchment. It uses a deterministic approach to simulate a historic flood with rainfall data. This requires assessment of the rainfall data that caused the flood event and the antecedent conditions prevailing at that time.

The model allows basic behaviour of the catchment to be simulated for several inputs, constraints or assumptions, e.g. flood behaviour at a specific point of interest with and without the dam in place. This enabled the impact of the dam to be assessed in the areas of concern under a variety of historic meteorological conditions, rainfall intensities and spatial distributions of rainfall.

Post-processing of the estimated hydrographs enabled flood widths and volumes to be available for further analysis. The derived flow/duration or flooded width/duration information, or other statistics provided the basis for understanding the important floodplain processes and the significance of the hydrologic effects of the dam on the water available for vegetation.

The model allows for inclusion of stream bed infiltration and other channel losses during the simulation of a flood event. This feature is believed to represent an important process in this region. The "loss" of flood water by infiltration into the stream bed and banks of the floodplain is the mechanism by which floodplain vegetation receives a water supply for survival. The trees and shrubs of these floodplain areas have adapted to a regime of periodic flooding (Payne and Mitchell, 1990).

7.2 Approach

The approach adopted to model the Fortescue River catchment involves the following processes:-

a) Catchment schematisation
b) Catchment rainfall preparation
c) Runoff coefficient analysis
d) Derivation of routing parameters
e) Estimates of Roy Hill rating curve
f) Model calibration
g) Historic floods simulation

7.3 Catchment Schematisation

The sub-division of the catchment into smaller sub-areas (see Figure 18) provided a structured sequence for the FLOUT model to carry out the following computations:-

a) Reservoir routing
b) Rainfall/runoff generation
c) Channel routing
d) Lateral inflow or outflow (transmission losses) estimation

The subdivision of the catchment was based on detailed study of satellite photographs of the catchment. We also had detailed discussions with Alan Payne on vegetation types and the runoff behaviour of specific areas in the catchment. Topographic maps with scales of 1:100,000 and 1:250,000 and satellite imageries were used to define the watershed boundaries. The methods used to schematise the catchment were as follows:-

a) draw the boundary of the catchment to Roy Hill on the 1:100,000 topographic maps.
b) transfer a) to a clear film copy of the 1:250,000 topographic maps.
c) lay b) over the satellite imagery of the Fortescue catchment and draw sub-catchment boundaries.

The satellite imageries provided valuable information on streamlines, flowpaths of historic floods, and detailed geographic features that were not available on a topographic map. They helped define more precisely the watershed boundaries for areas where there was a lack of contour definition on topographic maps. The entire catchment was divided into 40 sub-areas as shown in Figure 19.

The schematised layout of the catchment is shown in Figure 20. The 5 major branches of the catchment are:-

a) Upper Fortescue
b) Caramulla
c) Jimblebar
d) Jiggalong
e) Lower Fortescue

7.4 Catchment Rainfall Preparation

The major input required by FLOUT was the rainfall on each sub-area. Thus it was necessary to prepare daily rainfall data. Details of the adopted procedure were described earlier in the section on long-term modelling. Again a Thiessen weighting was used.

Unlike the Sacramento model, the FLOUT model was run with a three-hourly time step. This meant the daily rainfall had to be converted to three-hourly data. The temporal patterns from four pluviographs operating within the catchment were used to distribute the total daily rainfall for each event to three-hourly values. The daily rainfall totals were always preserved on an event by event basis.

The logic in selecting the most appropriate pluviograph is outlined below.

a) Select the pluviograph nearest the sub-area in question.
b) If more than one nearby pluviograph is available, then select the one which best matches the sub-area rainfall total.

Figure 21 shows the pluviograph locations. Pluviograph 505023 (Roy Hill) was used as a temporal pattern for all sub-areas located north of the dashed line. For those, south of the line, it was attempted to use one of the other three (507007, 507008, or 507009), depending upon their relative rainfall totals.

7.5 Source Areas

From our site visit and discussions with Alan Payne, we considered that the spinifex sand plains within the catchment would contribute little or no runoff (see Figure 19). The rest of the area in the catchment was modelled as runoff producing (source) areas. The total area covered by the sand plains is about 4,300 km^2, which is about 25% of the total catchment area. These included the areas:-

a) west of Warrawanda Creek, and just south of Ophthalmia Dam
b) west of Fortescue River between Ethel Gorge and Roy Hill
c) bounded by Fortescue River, Jimblebar Creek and Ophthalmia Range
d) bounded by Jimblebar Creek, Caramulla Creek and Ophthalmia Range
e) bounded by Caramulla Creek, Ophthalmia Range and Lower Jiggalong Creek
f) bounded by Kondy Creek and Pickering Creek.

7.6 Catchment Wetness Index and Soil Moisture Deficit

To model an event more accurately, FLOUT recognises and accounts for the wetness of the catchment prior to and during the process of the storm event. Two parameters, the initial catchment wetness index (CWI) and soil moisture deficit (SMD) specify the antecedent conditions. The wetness index objectively distributes the losses during the storm with recognition of the changing state of the catchment. If a storm occurs on an initially wet catchment, FLOUT would model the event to have runoff almost immediately. If however, the storm were to occur on a initially dry catchment, runoff would be delayed until the catchment is wetted up in the later stages of the storm.

Rather than establishing separate CWI and SMD values for each of the 40 sub-areas, a more regional approach was adopted. The catchment was divided into five regions (see Figure 21). Then daily CWI and SMD values were computed for a typical sub-area within each of these regions. Each sub-area was assigned the values of the typical sub-area within the same region.

7.7 Runoff Coefficient Analysis

The catchment's response to rainfall relies on the runoff coefficient. This coefficient varies on an event by event basis. Both rainfall and streamflow are necessary to compute this parameter. Figure 22 shows the available periods of flow record. There were four possible cases:

Case 1: Flow record at Newman Bridge only (1986-1989)
Case 2: Flow record at both Newman Bridge and Roy Hill (1980 - 1986)
Case 3: Flow record at Roy Hill only (1973-1980)
Case 4: No flow record, although long term modelling results gave estimates of flow at Newman Bridge (1960-1973).

For purposes of determining the runoff coefficients, the catchment was divided into three regions:

a) "Upper Fortescue", with a runoff coefficient of "RU",
b) "Range", with a runoff coefficient of "RR", and
c) "Plain", with a runoff coefficient of "RP".

It was assumed that the runoff coefficient of the range areas was 50% greater than those of the plain areas. The calculation procedures for the four cases were as follows:

Case 1: RU=Newman flow/Upper Fort. rain
RR=RU
RP=RR/1.5

Case 2: RU=Newman Flow/Upper Fort. rain
RP=(Roy Hill flow-Newman flow)/(1.5*Range rain+Plain rain)
RR=1.5*RP

Case 3: RP=Roy Hill flow/(1.5*Range rain+Plain rain)
RR=1.5*RP
RU=RR

Case 4: As for (1) above.

Table 7.3 indicates that the small events produce about 10% runoff and larger events about 25% runoff. The remainder, 90% and 75% respectively is regarded by the model as "losses", which comprise infiltration, transpiration and evaporation from open water surfaces. These amounts of water form a significant part of the water balance of the catchment. These "losses" do not appear explicitly in our rainfall runoff model, which deals only with the net runoff, but they are an important aspect in terms of water supply to catchment vegetation.

7.8 Derivation of Routing Parameters

Two variables are required as functions of discharge for the flood routing component of the FLOUT program:

a) the convection or kinematic wave speed c(Q); and
b) the attenuation parameter $\alpha(Q)$.

These variables describe the hydraulic characteristics of the river channel and its floodplain.

The kinematic wave speed describes the variation of the average speed of travel of a flood wave with discharge under the condition that there is no attenuation of the wave. It is defined by the Kleitz-Seddon Law

$$c(Q) = dQ/dA \tag{1}$$

where A is the cross sectional area of flow. In this study, the wave speed between two surveyed cross sections was assumed to be equal to the simple mean of the c(Q) values at the cross sections.

The attenuation parameter describes the variation with discharge of the attenuation of the flood wave peak due to temporary storage in the channel and floodplain. It is defined by

$$\alpha(Q) = \frac{L}{2BS} \tag{2}$$

where L is the reach length, B is the mean top width of the water surface, and S is slope. A convenient way to express the attenuation parameter is $\alpha(Q)/L$. This form reduces $\alpha(Q)$ to a manageable magnitude and allows the comparison of $\alpha(Q)$ values obtained from two or more reaches.

Application of equations (1) and (2) to a natural channel reach requires the specification of the A-Q and B-Q relationships at the reach ends. The A-Q and B-Q data were obtained by computing the water surface profiles from Roy Hill gauging station to the dam using the 21 surveyed cross sections. The HEC2 backwater program (U.S. Army Corp of Engineers, 1981) was used to model the hydraulic characteristics of the channel flows.

Two types of regression models were fitted to log transformed A-Q and B-Q data obtained from the computed water surface profiles. The first was the polynomial of degree n [P(n)] defined by

$$Y=\sum_{r=0}^{n} a_r.(\log Q)^r \tag{3}$$

where Y denotes either log A or log B, a_r denotes the r^{th} model parameter, and n = 0, ..., 3. This is consistent with Richards' (1973, 1976) approach of fitting polynomials to log transformed, at-a-station hydraulic geometry data. The second type was a piecewise linear model of order m [PLM(m)]:

$$Y=b_1+b_2(\log Q)+\sum_{i=1}^{m-1} b_{i+2}(\log Q-b_{i+(m+1)})X_i \tag{4}$$

where m is the number of phases (or segments) used to partition the ordered log Q data (m = 1, ..., 4), and X_i is an indicator variable defined by

$$X_i = \begin{cases} 1 & \text{if } \log Q > b_{i+(m+1)} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Notice that the polynomial and piecewise linear models are equivalent for n = m = 1.

Fitting the PLM(2) to log transformed, at-a-station hydraulic geometry data is described in detail by Bates (1990). He found that the PLM(2) was superior to the P(1) and P(2) models in that it often produced smaller residual variances for discharges below bankfull. Clearly, higher degree polynomials or higher order piecewise linear models may be required to fit the A-Q and B-Q data for discharges in excess of bankfull, particularly for reaches with wide floodplains.

Tables 7.1 and 7.2 report the residual variances for the model/data set combinations. Clearly, the PLM(m) is superior to the P(n) model in every case. Furthermore, examination of plots of the data and the fitted curves shows that the turning points of the P(3) model are frequently located within the range of the discharge data. Perusal of the available evidence suggested that these points did not have any physical significance and that they were merely a consequence of fitting polynomials to the data. Similar problems with the fitting of polynomials to log transformed at-a-station hydraulic geometry data have been reported by Bates (1990). Consequently, the PLM(m) was used to describe the A-Q and B-Q data for the study catchment.

The computation of c(Q) from a log piecewise linear A-Q relation is reasonably straightforward. By taking the inverse transformation of (4), and differentiating the resulting equation with respect to discharge, it can be shown that

$$\frac{dA}{dQ} = \left(b_2 + \sum_{i=1}^{m-1} b_{i+2} X_i\right) 10^{\left(b_1 - \sum_{i=1}^{m-1} b_{i+2} b_{i+(m+1)} X_i\right)} Q^{\left(b_2 + \sum_{i=1}^{m-1} b_{i+2} X_i - 1\right)} \tag{6}$$

So the kinematic wave speed at a cross section is given by

$$c(Q) = \frac{1}{dA/dQ} \tag{7}$$

Table 7.1
Residual Variances - Area vs Discharge

CROSS SECTION	RESIDUAL VARIANCE P(1)	P(2)	P(3)	PLM(2)	PLM(3)	PLM(4)
1	0.00121338	0.00089571	0.00034935	0.00059106	0.00026529	
2	0.00190342	0.00151282	0.00114757	0.00091363	NA	
3	0.00070864	0.00045489	0.00045758	0.00039179	NA	
4	0.00507978	0.00239679	0.00242274	0.00202257	0.00224879	
5	0.00569554	0.00574875	0.00437084	NA	0.00286897	
6	0.00483323	0.00221473	0.00126158	0.00152570	0.00141598	0.00100758
7	0.03781897	0.02474412	0.02132230	0.01771891	0.01805124	
8	0.14694560	0.15249173	0.15124278	0.16146640	NA	
9	0.00121338	0.00089571	0.00034935	0.00059106	0.00026404	
10	0.01122780	0.01012923	0.00991011	0.00916805	NA	
11	0.01014688	0.00589227	0.00557715	0.00579752	0.00617674	0.00488207
12	0.07541357	0.05579867	0.05850530	0.04184450	0.03545059	
13	0.01864101	0.00236851	0.00245213	0.00149789	0.00150450	
14	0.01053246	0.00996706	0.00345991	NA	0.00074516	
15	0.03221433	0.00530267	0.00482544	0.00116600	0.00006528	
16	0.00256711	0.00100059	0.00103675	0.00094150	0.00093345	
17	0.00433211	0.00384849	0.00374421	0.00372600	0.00413990	
18	0.02231142	0.00979496	0.00893204	0.00731283	0.00199756	0.00006172
19	0.02797312	0.01127144	0.00981624	NA	0.00045203	
20						
21	0.03626775	0.03153012	0.01022050	NA	0.00311326	0.00139795

NA - Not Applicable

Table 7.2
Residual Variance - Flood Width vs Discharge

CROSS SECTION	RESIDUAL VARIANCE P(1)	P(2)	P(3)	PLM(2)	PLM(3)	PLM(4)
1	0.00599941	0.00097649	0.00061908	0.00049163	0.00045935	
2	0.00569253	0.00036853	0.00032605	NA	0.00017272	
3	0.00311042	0.00048237	0.00048249	0.00026109	0.00028058	
4	0.01763630	0.01487767	0.00813991	NA	0.00304773	
5	0.04475947	0.04294282	0.01922275	NA	0.00217701	
6	0.03704446	0.00746492	0.00783362	NA	NA	0.00074833
7	0.23766926	0.15878059	0.16463848	NA	NA	0.09663325
8	0.05487101	0.05565082	0.05655900	NA	NA	
9	0.05299118	0.04780535	0.04966962	0.04669577	0.05106908	
10	0.01704798	0.00835789	0.00735593	NA	0.00539782	
11	0.07700944	0.01816944	0.01905757	NA	0.00266539	0.00044933
12	0.09612500	0.09616023	0.10027715	0.09895820	0.10633411	
13	0.04217630	0.02114848	0.01521762	NA	0.00709568	0.00694349
14	0.04431541	0.04208686	0.01902822	NA	0.00118824	0.00053746
15	0.11611230	0.07238400	0.06402423	NA	0.03834644	0.00403354
16	0.00640246	0.00256287	0.00235077	0.00200449	NA	
17	0.01871994	0.01249465	0.00981898	0.00984707	0.00529535	
18	0.12528550	0.05490600	0.05757747	NA	0.00038764	0.00055968
19	0.10467468	0.03404680	0.03572520	NA	0.00113511	
20						
21	0.12734185	0.13315839	0.00235316	NA	0.00726245	0.00666291

NA - Not Applicable

7.9 Estimates of Roy Hill Rating Curve

Cross sections of the Fortescue River from Ethel Gorge to Roy Hill station were surveyed for the purpose of hydraulic modelling of the Fortescue River system. The calculation of hydraulic backwater profiles provided the basic information required for calculation of routing parameters required by FLOUT. They also provided the relationship of flooded width with discharge, which is essential for assessing the flooding regime of historic flows at the Fortescue River floodplains.

A standard rating curve was not available at the Roy Hill gauging station because of a lack of meterings and the complication of backwater effects. It was gauged only once in 1978 at a very low flow of about 4 m^3/s. An alternative approach involving hydraulic backwater modelling was used to derive an approximate rating curve. The hydraulic characteristics of the channel upstream and downstream of the Roy Hill gauging station were modelled using the HEC2 backwater program. Cross section surveys were carried out at a much closer interval than those surveyed elsewhere in the catchment particularly for this backwater modelling exercise.

The cross-section furthest downstream was created using cross-sections 19 and 20 combined with appropriate spot levels from the ROY HILL 1:50,000 map Sheet Number 2852 1. This cross-section was established as a boundary condition for the backwater calculations through the gauging station and sections upstream. Cross-section No. 21 (CS21) was set up approximately 5 kilometres down stream of the gauging station. This was to minimise sensitivity of calculated stage at the gauging station to downstream starting levels.

The starting water level is calculated by the slope area method. It incorporates an automatic adjustment of depth until the computed flow is within 1% of the starting flow. The water surface elevation thus determined is used as the starting water surface level for subsequent surface water profile computations (HEC2, 1981).

It has been suggested that survey of additional cross-sections downstream of the gauging station could improve the accuracy of the rating curve. Any improvement in accuracy in the calculation of hydraulic characteristics downstream, however, is considered unlikely to significantly affect the conditions calculated at the gauging station.

A sensitivity analysis was carried out to determine the effect of changes in calculated depths due to variations in Mannings roughness coefficient (n). The maximum effect of 10% change was found for flows less than 100 m^3/s. For larger flows the effect was less significant, less than 2% for combined channel and floodplain flow. The selection of appropriate Manning's n values depends largely on the engineer's interpretation of site conditions combined with practical experience in river channel hydraulics.

Deriving a rating curve using this alternative approach is based on established hydraulic principles reinforced by the experience of the principal authors in this particular field. This alternative approach to derivation of a rating curve is considered to be not as accurate as that obtained at Newman Bridge gauging station, but is approximately within 25%. The derived rating curve is shown in Figure 23.

7.10 Derivation of Unit Hydrographs

FLOUT uses a unit hydrograph which is a simple linear model to derive the flood hydrograph from excess rainfall hyetograph. For the upper Fortescue catchment where pluviographs and flows were available, the actual unit hydrograph was derived and used in the model.

For the rest of the catchment that is not gauged, the synthetic unit hydrograph approach was used to estimate unit hydrograph. Two types of synthetic unit hydrograph approaches were used:-

- Type A: FLOUT standard synthetic unit hydrograph.
- Type B: synthetic unit hydrograph based on upper Fortescue unit hydrograph shape.

The FLOUT standard synthetic unit hydrograph is based on a simple triangular shape which can be described using the following relationship:-

$$T_B = 2.52\ T_p$$

$$\text{and} \qquad Q_p = \frac{2.20}{T_p} \tag{8}$$

where T_p is the time to peak of the 10mm unit hydrograph (hr)
T_B is the time base of the unit hydrograph (hr)
Q_p is the peak flow of the unit hydrograph ($m^3/s/100km^2$)

The synthetic unit hydrograph which fitted the shape of the upper Fortescue unit hydrograph was based on the following relationship:-

$$T_B = 1.40\ T_p$$

$$\text{and} \qquad Q_p = \frac{3.97}{T_p} \tag{9}$$

Both types were used in the calibration process. The type B synthetic unit hydrograph was used mainly for calibrating the very large events. For smaller events, type A was more appropriate. Table 7.3 shows the results of the calibration parameters derived for the two groups of events.

For the large events, the calibration parameters did not vary greatly. The average transmission loss derived was about 2.4E-6 $m^3/s/m$ reach. For smaller events, the derived parameters showed more scatter. The transmission loss that was adopted was 1.0E-6 $m^3/s/m$ reach. The transmission loss rate forms part of the total loss of water from the system during a storm event. It is another parameter that was used to calibrate the model.

7.11 FLOUT Model Calibration

The calibration of the FLOUT model involved adjustment of a set of model parameters. The objective was to reproduce observed hydrographs at Roy Hill gauging station so that flood peaks and volumes were matched.

To calibrate the model it was necessary to isolate several historical events. Useful events were only those for which both rainfall and flow data were available. Since Roy Hill flow data were available from 1973 to 1986 all the calibration events had to be limited to this period.

The selection of events to be modelled was initially based on the Newman Bridge catchment having runoff greater than or equal to 0.2 mm. However, some events were found to have significant rainfalls in other parts of the catchment. Selection of other significant events was based on manually perusing rainfall records at several stations over the entire catchment. This meant that regional rather than just local storms could be selected. Choosing these events was somewhat subjective, but a total of 68 events were finally adopted (see Table 7.4). Of these events, 16 were used for calibration.

Determining the FLOUT model parameters was a trial and error process. Table 7.3 shows the values which gave the best hydrograph fit at Roy Hill for each event. It was seen that there were two distinct sets of parameters. One of these was appropriate for only the very large storm events (ie. cyclones such as Dean and Enid). Another set was found appropriate for the small to large events.

Comparison of estimated hydrographs with observed for three events, 19 April 1976, 31 January 1980 and 17 February 1980 are shown in Figure 24.

Figures 25 & 26 shows the rainfall and flow distribution for the 16 calibration events, on five different regions in the catchment. The spatial variability of rainfall on the catchment can influence the size and timing of the floods in the Fortescue River and Jiggalong Creek system. This is relevant to small events caused by localised thunderstorm, where rainfall distribution is usually patchy.

Table 7.3
Model Calibration Parameters

LARGE EVENTS							
EVENT	RANGE RUNOFF COEFF. %	TIME TO PEAK FACTORS (Synthetic UH based on upper Fortescue UH)					Transmission loss 10^{-6} x $m^3/s/km$
		Branch 1	Branch 2	Branch 3	Branch 4	Branch 5	
19APR80*	7.9	4.0	7.0	7.0	6.0	2.0	-2.9
31JAN80*	18.2	4.0	7.0	7.0	5.0	0.7	-2.8
17FEB80*	46.2	4.0	7.0	7.0	6.0	1.6	-3.2
12MAR79*	22.4	4.0	7.0	7.0	5.0	2.2	-3.0
31JAN78*	49.8	5.0	7.0	7.0	5.0	2.0	-2.0
21MAR75*	18.8	3.2	5.6	5.6	4.0	3.0	-0.3
Mean	27.2	4.0	6.8	6.8	5.2	1.9	-2.4
Adopted parameters		4.0	7.0	7.0	5.0	2.0	-3.0

SMALL EVENTS							
EVENT	RANGE RUNOFF COEFF. %	TIME TO PEAK FACTORS (Standard Synthetic UH Available in FLOUT)					Transmission loss 10^{-6} x $m^3/s/km$
		Branch 1	Branch 2	Branch 3	Branch 4	Branch 5	
23FEB82	13.7	2.0	0.8	0.8	0.8	0.8	0.0
17FEB82	4.2	2.5	2.5	2.5	2.5	1.5	-1.0
25MAR77*	3.9	2.0	2.0	2.0	2.0	1.0	-1.0
05APR83	14.7	2.0	3.0	3.0	3.0	2.0	0.0
19MAY84	4.1	1.5	0.8	0.8	1.0	1.5	0.0
26APR84	9.2	0.5	0.5	0.5	1.0	3.0	-1.0
03AUG78*	2.0	3.0	4.0	4.0	1.0	0.5	0.0
17DEC75*	16.2	2.0	1.5	1.5	1.8	1.5	0.0
19APR76*	9.5	3.0	3.5	3.5	3.5	1.0	0.0
30MAR78*	4.9	1.5	1.5	1.5	1.8	2.5	-1.0
Mean	8.2	2.0	2.0	2.0	1.8	1.5	-0.4
Adopted parameters		2.0	2.0	2.0	1.8	1.5	-1.0

* Indicates a pre-dam event, ie pre December 1981.

7.12 Simulation of historic flood events

After the FLOUT model was calibrated, it was applied to 52 historic events (see Table 7.4). Although 68 events were selected (16 being for calibration), they were not the only significant events occurring between 1960 and 1990. It was found that several events were unable to be modelled by FLOUT with the adopted model parameters. This was usually attributable to observed rainfalls not being representative of effective rainfalls, in terms of either temporal or areal distribution or in magnitude. Such events were therefore excluded from the analysis. This is sometimes a feature of model calibration in any hydrologic study where additional data would be useful.

Although Table 7.4 includes an event on the 13 January 1990, the rainfall data was not available for all stations (see Figure 4). Catchment rainfall was derived by correlation with other stations for this event. The results are therefore not as reliable as other modelled events with observed data.

Table 7.4
List of Modelled Events

Event No	Event Start Date	Calibr Event?	Flow @ NewmanBr?	Event No	Event Start Date	Calibr Event?	Flow @ NewmanBr?
1	11-Jan-60			35	17-Dec-75	yes	
2	29-Jan-60			36	19-Apr-76	yes	
3	06-Feb-60			37	25-Mar-77	yes	
4	11-Feb-60			38	31-Jan-78	yes	
5	10-Feb-61			39	18-Feb-78		
6	14-Apr-61		no	40	30-Mar-78	yes	
7	08-Jan-63			41	03-Aug-78	yes	
8	30-Jan-63			42	09-Feb-79		
9	01-Jun-63		no	43	01-Mar-79		
10	15-Feb-64		no	44	12-Mar-79	yes	
11	26-Apr-64		no	45	31-Jan-80	yes	
12	10-Mar-65			46	17-Feb-80	yes	
13	01-Jan-66			47	19-Apr-80	yes	
14	25-Apr-66			48	12-Jun-80		
15	15-Jan-67			49	14-Feb-81		
16	14-Dec-67			50	17-Feb-82	yes	
17	31-Jan-68			51	23-Feb-82	yes	
18	04-Mar-68			52	29-Mar-83		
19	13-Mar-68		no	53	05-Apr-83	yes	
20	05-May-68		no	54	26-Apr-84	yes	
21	09-Jun-68		no	55	19-May-84	yes	
22	16-Jun-68			56	18-Jul-84		
23	18-Feb-69			57	06-Feb-85		
24	04-May-70			58	14-Feb-86		
25	26-Jan-71		no	59	15-Jan-87		
26	02-Feb-71			60	05-Feb-87		
27	30-May-71			61	26-Feb-87		no
28	20-Jan-73			62	30-Apr-87		
29	30-Jan-73		no	63	20-Dec-87		no
30	18-Mar-73			64	31-Jan-88		no
31	05-Aug-73			65	27-Mar-88		
32	21-Jan-74		no	66	09-May-88		
33	21-Mar-75	yes		67	20-May-88		
34	08-Dec-75			68	13-Jan-90		

The dam water level at the start of the modelled event governs the amount of runoff from the upper Fortescue River catchment, that would be retained by the dam. A near empty dam at the start of the event, therefore would have a greater capacity to retain floodwater than a dam that is nearly full. Thus, to model the event accurately, we used the recorded dam water level if it was available. Otherwise, calculated monthly median dam levels based on historic levels shown in Figure 27 were used. The maximum effect of the dam on downstream flows would be when the dam is almost empty. Under the near empty condition, the maximum amount of water that would be retained by the dam would be about 31 MCM.

7.13 Results of Event Based Modelling

Results from the model are shown in Appendix D. Plots of hydrographs at upstream and downstream of Jiggalong confluence for the ten largest modelled events are shown in Figures 28 & 29. For post-dam events only, bar graphs showing the relative magnitudes of the variables are shown in Figures 30 to 35.

The number of events simulated provides a population from which the effects of the dam on downstream flows can be statistically expressed. Individual results of flood peak, flood volume and flood width should not be taken in isolation for evaluating impact as the overall impact may not be represented.

Because of the large amount of information generated, post-processing of the data was necessary to help with the interpretation of results. The aim of the post processing was to present results in the simplest graphical and tabular form.

The main post-processing operation was to analyse the frequency of flood events and changes due to the dam. The annual maxima of variables such as flood peaks, flood widths, and flood volumes were used for the frequency plots. Frequency analysis is commonly used for design of many engineering structures such as dams, bridges, culverts and flood control structures.

The frequency analyses were carried out on 5 different computed variables. They are:-

a) Maximum Flood Width
b) 12-hour Flood Width
c) 24-hour Flood Width
d) Peak Flow
e) Flow Volume

These variables were extracted from the results for 6 different points of interest in the Fortescue River system. They are:-

Cross Section No		Name
5	-	Double Channel One
7	-	Seven Mile Bore, Marys Bore
8	-	Ethel Creek
10	-	Irwins Well
11	-	Battle Hill
12	-	Five Mile Bore

The analyses were confined to two main groups of events:-

a) All modelled events (1960-1989)
b) Post-dam events (1982-1989)

Results of all modelled events are shown in frequency plots in Figures 36 to 41. Each frequency plot of a particular variable consists of two curves; the top curve (full line) is the frequency curve if the dam is not present and the bottom curve (dashed line) is the frequency curve if the dam is in place. The difference between the two curves indicates the relative impact of the dam on that particular variable. The post-dam events are highlighted by plotting the events with symbols on the curves. A triangle indicates if the dam is not present and a diamond indicates if the dam is present.

Due to the amount of information available from the plots in Figures 36 to 41, a set of graphs summarising the general statistics was produced. Figure 42 shows the plots of the average effects of the dam for the 5 parameters at 6 cross sections for different flood sizes. The average effects were computed as average percentage difference (shown as bar graphs) and average absolute difference (shown as line graphs) between the "with dam" and without dam" scenarios.

7.14 Discussion

Generally, the plots in Figure 42 show the same trend for flood width, flood peak and flood volume. The dam has the most impact on the more frequent events (or smaller floods). For less frequent events (larger floods) the impact is less. The impact of the dam on all the selected indicators decreases with distance downstream of the dam towards Roy Hill. This is also intuitively what is expected.

The frequency plots of the width and flow variables show that no large events (greater than about 5 year average recurrence interval, (ARI)) have occurred since the dam was constructed. This can be attributed to the climatic variations discussed in Chapter 5.

Flood Volume

The percentage impact of the dam on flood volumes is greatest for the more frequent events, with ARI less than 5 years. For the larger flood events, with ARI greater than 5 years, the percentage impact is less. The impact is also greater on the Fortescue River upstream of the Jiggalong confluence. Once the Fortescue River receives the Jiggalong flows, the effect of the dam is smaller. This effect is indicated by a shift in the average percentage difference in the flood volume bar graph for the cross sections downstream of the Jiggalong confluence, i.e. CS 10, 11 & 12.

In absolute terms, the impact of the dam on flood volume relates directly to the size of the flood and the empty space in the dam prior to the flood. The maximum effect of the dam on flood volume however, does not exceed the dam capacity of about 31 MCM. This is also intuitively correct.

Flood Peak

A similar trend is also found for flood peaks. The percentage impact of the dam on flood peak is greatest for the more frequent events (small floods). The effect of the Jiggalong contribution in decreasing the overall impact on flood peaks is clearly indicated by the decrease in absolute difference for the less frequent events (larger floods).

Flood Width

In percentage terms, the results for flood width are similar to those for flood volume and flood peaks (i.e. percentage impact is greatest for the more frequent floods). In absolute terms however, the trend relative to the magnitude of the flood or the cross section location is not so obvious. This behaviour is explained by the variation of the river cross sections along the Fortescue River system. The cross section profile and the slope of the river channel generally define the hydraulic characteristics of the river such as bankfull capacity and the width of flow on the floodplain. The increase in percentage difference in flood width for CS 7 for the larger events is likely to be due to the larger bankfull capacity of the CS 7 relative to the other cross sections (see Figures 43 to 47).

The results above indicate the impact of the dam relative to the magnitude of the floods. Another way of expressing the impact is in terms of the change in frequency of a specific flooded width parameter. A typical example could be for cross section 8, where the frequency of a 3 km 12hr flood width is decreased from a 1 in 3 year to about 1 in 5 year ARI.

7.15 Impact Assessment

The supply of water to the floodplains depends on direct rainfall and streamflow. An assessment of changes to this water supply involves analysis of rainfall and streamflow at specific points of interest in the catchment. Changes in the rainfall regime result from natural variation. Streamflow changes, however, result from two causes:

a) Artificial restriction of streamflow imposed by the dam.
b) Natural rainfall variation over the runoff generation areas upstream of the point of interest.

Integration of long term modelling and event based modelling results provides a means of estimating the combined effects of climatic variability and the direct effects of Ophthalmia Dam.

As noted in Chapter 6 the analysis of unregulated streamflow estimates from the long term catchment model and the observed streamflows, allows comparisons of any periods from 1907 to 1989. The results of the event model simulations indicate the effect of the dam alone at various locations on the Fortescue floodplain downstream of Ophthalmia Dam. These effects were then adjusted in accordance with factors derived from the long term model results to give an indication of the relative contributions of rainfall variation and dam impacts for location of interest in the floodplain.

Because the event based model simulated events in the period 1960 to 1989, there was a need to account for any bias that may have been introduced due to the higher flow years through the period from 1960 to 1981.

To assess the relative impact of the dam and climatic variations on streamflow volumes at specific floodplain locations, the following approach was adopted.

a) From Table 6.4 calculate the scaling factor X as long term average flow (1907-1989) divided by the 1960-1989 flow average.

$$X = 20229.0 / 24392.4 = 0.83$$

b) For event based modelling results calculate the 1982-1989, and 1960-1989 flow averages at each cross-section.

c) At each floodplain cross-section adjust the 1960-89 flow average from b) using the scaling factors X from a) to give the estimated long term event based average (1907-1989).

The detailed calculations using these factors are shown in Table 7.5. Comparing the post-dam average conditions (1982 to 1990) to the long term average conditions (1907 to 1990) on an event basis, the relative impact due to dam and climatic variations on streamflow volume reduction at specific cross sections in the floodplains downstream of Ophthalmia Dam are as follows:-

Cross Section No.	Impact due to dam	Impact due to climatic variations
5 (Double Channel One)	49%	51%
7 (Seven Mile Bore)	49%	51%
8 (Ethel Creek)	51%	49%
10 (Irwin's Well)	34%	66%
11 (Battle Hill)	33%	67%
12 (Five Mile Bore)	31%	69%

It is also evident from the results that similar impacts are reflected at CS 5, 7, and 8, while from CS 10 to 12, the impact due to dam is less. This again is intuitively correct due to the flow contribution from the unregulated Jiggalong system to CS 10 and 12.

The above results for flood volume may be implied for flood peaks. However, for flood width, the relationship with flood volume is more complicated. Factors such as flood duration, hydrograph shape and cross sectional profile have important effects.

The confidence intervals for the estimation of absolute flood magnitudes may be wider than could be achieved with improved hydrologic data (for example rating curve at Roy Hill gauging station). However the focus for this study is the relative magnitude of impacts due to the dam. Design flood estimation, where accuracy of the flood peak would be more important, was not the primary aim of this study.

The individual flood events were simulated using identical model inputs with the only change being the inclusion or exclusion of the dam. The reservoir routing component of the model is explicitly calculated by well established hydraulic principles. Therefore, the relative magnitudes of various measures of impact (flood volume, flood peak, and flood width) due to the dam, are more reliably estimated than the absolute magnitude of these variables. The results therefore achieved our objective of providing the best estimates of impact due to the dam.

Table 7.5
Assessment of Impact due to Dam and Climate on Modelled Flood Event Volume

	With Dam Volume (MCM)	Without Dam Volume (MCM)	Absolute Diff (MCM)	Percentage Reduction
Cross Section 5				
1960-1990 average (events)	22.2	34.1		
1982-90 average (events)	5.9	16.9		
Estimated 1907-90 average (events)		28.3		
Comparing long term 1907-90 and 1982-90 averages (events)				
natural shift			11.4	51%
due to dam			11.0	49%
due to natural shift & dam			22.4	
Cross Section 7				
1960-1990 average (events)	22.9	34.8		
1982-90 average (events)	6.2	17.2		
Estimated 1907-90 average (events)		28.9		
Comparing long term 1907-90 and 1982-90 averages (events)				
natural shift			11.7	51%
due to dam			11.0	49%
due to natural shift & dam			22.7	
Cross Section 8				
1960-1990 average (events)	23.5	36.3		
1982-90 average (events)	6.4	18.6		
Estimated 1907-90 average (events)		30.1		
Comparing long term 1907-90 and 1982-90 averages (events)				
natural shift			11.5	49%
due to dam			12.2	51%
due to natural shift & dam			23.7	
Cross Section 10				
1960-1990 average (events)	63.6	77.0		
1982-90 average (events)	25.2	38.3		
Estimated 1907-90 average (events)		63.9		
Comparing long term 1907-90 and 1982-90 averages (events)				
natural shift			25.6	66%
due to dam			13.1	34%
due to natural shift & dam			38.7	
Cross Section 11				
1960-1990 average (events)	64.4	78.0		
1982-90 average (events)	25.9	38.9		
Estimated 1907-90 average (events)		64.8		
Comparing long term 1907-90 and 1982-90 averages (events)				
natural shift			25.9	67%
due to dam			13.0	33%
due to natural shift & dam			38.9	
Cross Section 12				
1960-1990 average (events)	71.0	84.8		
1982-90 average (events)	29.3	42.2		
Estimated 1907-90 average (events)		70.4		
Comparing long term 1907-90 and 1982-90 averages (events)				
natural shift			28.2	69%
due to dam			12.9	31%
due to natural shift & dam			41.1	

Based on long term modelling, scaling factor for 1960-1990 average flow to 1907-1990 average flow = 0.83

CHAPTER 8 - FUTURE MONITORING OF CATCHMENT HYDROLOGY

To understand the hydrology of the catchment better and to manage the area in future, we recommend that the following actions be taken to obtain more hydrometric and meteorological data for the Fortescue River catchment.

a) Re-establish Roy Hill gauging station and provide additional cross sectional surveys downstream of the station.

b) Investigate the relocation of Roy Hill gauging station to a more appropriate spot or the establishment of an additional station upstream of Roy Hill.

c) Improve the network of rainfall stations in the lower part of the catchment of the Fortescue River between Ophthalmia Dam and Roy Hill station by installing more rainfall stations.

d) Introduce an interim monitoring of flood behaviours in the floodplains downstream of the dam by installing peak stage indicators at surveyed cross sections.

CHAPTER 9 - CONCLUSIONS

a) Comparing the post-dam average conditions (1982 to 1990) to the long term average conditions (1907 to 1990) on an event basis, the relative impact due to dam and climatic variations on streamflow volume reduction at specific cross sections in the floodplains downstream of Ophthalmia Dam are as follows:-

Cross Section No.	Impact due to dam	Impact due to climatic variations
5 (Double Channel One)	49%	51%
7 (Seven Mile Bore)	49%	51%
8 (Ethel Creek)	51%	49%
10 (Irwin's Well)	34%	66%
11 (Battle Hill)	33%	67%
12 (Five Mile Bore)	31%	69%

b) Analysis of rainfall data indicates that since construction of the dam, there has been a lack of large cyclone generated storm events. Although post-dam average annual rainfall totals were not significantly different from the pre-dam rainfall average, streamflow volumes were less in the post-dam period due to the lack of large storms. This is shown in the frequency plots of the width and flow variables which indicate that no large events (greater than about 5 year average recurrence interval) have occurred since dam construction.

c) The impact due to the dam for the small flow events (less than 5 year average recurrence interval) is significantly higher than for the larger events.

d) The dam has a larger impact on flows in the floodplains of the Fortescue River upstream of the Jiggalong confluence than the flows in the floodplains downstream of it. This is due to the addition of unregulated flow contribution from Jiggalong Creek to the Fortescue River downstream of Ethel Creek homestead.

e) To understand the hydrology of the catchment better and to manage the area in future, we recommend that the following actions be taken to obtain more hydrometric and meteorological data for the Fortescue River catchment.

   i) Re-establish Roy Hill gauging station and provide additional cross sectional surveys downstream of the station.

   ii) Investigate the relocation of Roy Hill gauging station to a more appropriate spot or the establishment of an additional station upstream of Roy Hill.

   iii) Improve the network of rainfall stations in the lower part of the catchment of the Fortescue River between Ophthalmia Dam and Roy Hill station by installing more rainfall stations.

   iv) Introduce an interim monitoring of flood behaviours in the floodplains downstream of the dam by installing peak stage indicators at surveyed cross sections.

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APPENDIX A
Rod Banyard - Personal Communication - Observation Bore Levels

To:	A/Supervising Engineer, Engineering Hydrology
From:	Supervising Engineer, Groundwater Branch
Subject:	Groundwater Levels - Newman Area

The behaviour of the water levels in the bores you have selected is consistent with the climatic conditions and may not be affected by the construction of Ophthalmia Dam.

Nullagine, 150 km to the north , is suffering badly due to low rainfall and 3 out of 4 TWS (town water supply) bores have failed entirely (although they were high in 1987).

W93 provided it is remote from any abstraction, indicates groundwater levels are naturally low at this time.

T387 The recharge events of '83, '84 and '85 look strange but they may be due to local rainfall (thunderstorms) or runoff from the high ground. The hydrograph is quite different to W83 in this period and makes comparison dangerous.

W81 This bore has shown the persistent decline of T387 in recent years but this may be due to the greater length of time since significant recharge.

SUMMARY

1 The low rainfall period since 1984 could account for the relatively low water levels measured in the bores.

2 Analysis of the state of the aquifer would require more regional information including depths to water table, local and regional recharge behaviour and considerable time to analyse the aquifer behaviour.

3 The falls in groundwater to 2-3 metres below peak levels should not be unusual except in areas close to recharge from water bodies of stable water levels or deep aquifers with low rates of recharge.

4 I suspect that the changes noted are close to natural variation and are influenced by the dry period.

5 I suggest you put the question to GSWA who will be able to offer more informed comment than I can.

R. Banyard
21 November 1990

APPENDIX B
Angus Davidson - Personal Communication - Observation Bore Levels

I agree with Rod Banyard's comments. The three monitoring bores are not being influenced by the dam.

Angus Davidson
Geological Survey of Western Australia

3 December 1990

APPENDIX C
Rainfall Sites - Details of missing & accumulated record

STATION NO.	MISSING PERIOD	ACCUMULATED PERIOD (+ STN CHECKED)
M004003 Balfour Downs (06/1907-) Daily Reader, CBM	10-11/1907 05/1908-12/1911 12/1912 07/1913 02,04/1914 12/1915 02-05,07/1916 12/1917 03,05,12/1918 02-03/1919 09,12/1920 08,12/1921-6/1922 07/1923 04/1924 01/1931 04/1943 12/1945 05/1950 04/1952 05/1953 04-12/1955 01/1957-09/1958 11/1958 02-12/1959 07/1960-12/1961 06-12/1964 02-10/1965 12/1965-07/1967 09/1968-08/1972 07/1973 11/1973-06/1982 11/1982 05/1990-	None
M005003 Ethel Creek (01/1907-) Daily Reader, CBM	09/1910 05/1916 01-12/1918 10/1921-12/1923 07/1925 10/1927 04,06,10/1931 10,12/1939 11-12/1940 01/1977-12/1978 01-12/1982 05-12/1983 01-04,07-12/1985 11/1989-	18-19/07/48 - 005023 28-31/07/58 - 004003 15-16/01/67 - 005023 05-06/02/67 - " 19-20/02/67 - " 20-23/01/73 - " &007151 29-30/04/79 - 007151 01-02/05/79 - " 27-28/07/80 - 005023
M005023 Roy Hill (08/1900-) Daily Reader, CBM	05-07/1901 11/1901-02/1902 05-06,08/1902 11/1902-06/1903 12/1903-08/1904 10,12/1904 02,06,08/1905 12/1905-02/1906 04,06-09,12/1906 11/1909 08/1921 12/1922 03-08,10,12/1930 06/1945 01-03,05,07-08/1952 01,03-05,07-08,10,12/1953 01,03-08/1954 10/1954-09/1955 11/1955-03/1956 05-09/1956 11/1956-03/1957 05-07/1957 10/1957-03/1958 05/1958-07/1959 11/1959-09/1960 12/1960-06/1961 08-09/1961 11/1961-03/1962 05-07,11-12/1962 06/1971 02/1975 01-12/1979 12/1982-12/1983 04/1990-	26-27/10/47 - 005003 30-31/05/71 - " 22-23/01/74 - "

STATION NO.	MISSING PERIOD	ACCUMULATED PERIOD (+ STN CHECKED)
M007062 Mundiwindi (01/1916-11/1981) Daily Reader, CBM	01/1917 02-03/1978 12/1981-	None
M007079 Sylvania (01/1950-) Daily Reader, CBM	06/1951-12/1959 05/1960-12/1962 08/1963-12/1967 07-12/1969 01-12/1976 11-12/1977 01-12/1982	27-31/01/50 - 007062 20-21/05/50 - " 4-5/06/50 - "
M007083 Turee Creek (01/1920-) Daily Reader, CBM	01/1921 06-07/1943 08-10,12/1945 07-09,11/1946 01,06,08,10-11/1947 01-10/1948 04-12/1952 07,10/1963 03/1964-12/1966 01-09/1977 08/1988-	10-11/07/73 - 007153
M007151 Newman P.O. (12/1965-) Daily Reader, CBM	11-12/1969 04/90-	None
M007153 Prairie Downs (01/1968-) Daily Reader, CBM	02,04/1977 03,07/1982 06/1985 01/1988-	18-20/08/84 - 507007
M007191 Capricorn Road House (03/1975-) Daily Reader, CBM	04-05,07-10/1977 05/1990-	20-22/05/78 - 007151 10-12/03/79 - "
M013003 Jiggalong (01/1913-) Daily Reader, CBM	08/1915 01/1932 01/1961-10/1962 08/1972-02/1975 04-09,12/1975 01-12/1977 01-06/1982 03/1983-01/1984 06-08/1984 02,05/1985 01/1987-03/1989 06/1989-	18-20/09/82 - 004003 23-24/03/75 - 005003
M505023 Roy Hill (20/09/1973-01/10/1986) Pluviograph, WAWA	24/11/73-23/01/74 09-18/03/1976 05/03-17/04/1980 10/07-09/10/1980 16-19/03/1981 11/11/82-15/01/83 14/10-06/11/1984 01/02-19/07/1985 01/10/1986-	None
M507005 Newman Bridge (10/02/1980-) Pluviograph, WAWA	12/12/1981-22/01/1982 24/02-06/03/1982 11-14/11/1983 25/11-02/12/1983 08-10/12/1983 19-22/11/1985 30/12/1985-01/01/1986 03-11/01/1986 16-18/01/1986 09-10,16-17/06/1986 28/09-01/10/1986 30/07/1987 12/04/1989-	None
M507007 South Giles (15/01/1980-) Pluviograph, WAWA	18/02-20/04/1983 15/04-28/06/1984 19/04-11/10/1985 18/10/1989-	None
M507008 East Giles (16/01/1980-) Pluviograph, WAWA	04/08-19/11/1980 07/04-24/10/1981 29/04-23/06/1985 28/08-12/10/1988 19/10/1989-	None
M507009 Southern Fortescue (31/01/1980-) Pluviograph, WAWA	27/06-19/08/1982 12/05-24/06/1985 10/10/85-05/2/1986 18/10/1989-	None

APPENDIX D
Results of Event Based Modelling

Cross Section 5 - Double Channel One

	WITH DAM							WITHOUT DAM						
	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL
EVENT	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM
11-Jan-60	3.6	3.5	3.1	5.1	4.9	4.4	0.8	14.8	13.3	12.2	20.6	18.5	17.0	2.9
29-Jan-60	3.1	2.8	2.4	4.4	3.9	3.3	0.8	15.9	11.9	10.0	22.1	16.6	13.9	3.1
06-Feb-60	31.9	29.7	25.5	34.6	33.4	30.9	6.7	184.0	112.3	84.2	63.7	50.8	45.6	26.6
11-Feb-60	1033.0	842.2	655.8	1208.6	1121.8	985.4	210.8	1307.0	880.1	726.3	1366.2	1138.6	1077.9	240.7
10-Feb-61	1.1	1.1	1.0	1.6	1.5	1.4	0.3	5.4	4.1	3.4	7.5	5.7	4.8	1.0
08-Jan-63	1.6	1.5	1.2	2.3	2.1	1.7	0.3	8.6	6.5	3.8	12.0	9.0	5.3	1.3
30-Jan-63	2.7	2.5	2.0	3.8	3.5	2.8	0.7	15.1	11.9	7.8	21.0	16.6	10.9	2.7
10-Mar-65	19.9	18.9	16.3	27.6	26.2	22.7	5.7	111.4	81.1	70.6	50.6	45.0	44.6	18.5
01-Jan-66	27.3	24.9	19.7	32.0	30.6	27.3	3.6	163.4	109.1	75.0	59.6	50.3	44.7	14.6
25-Apr-66	655.1	553.1	488.1	984.1	717.1	657.1	127.3	857.9	666.7	515.9	1128.7	1006.0	679.4	143.8
15-Jan-67	5.9	5.4	4.3	8.2	7.6	6.0	1.3	28.8	23.0	14.9	32.8	29.5	20.8	5.0
14-Dec-67	21.2	19.4	15.5	28.5	27.0	21.5	3.2	129.5	80.0	50.9	53.6	44.8	42.1	12.1
31-Jan-68	2.0	1.8	1.5	2.8	2.6	2.1	0.4	10.7	8.1	5.1	14.9	11.3	7.1	1.6
04-Mar-68	3.7	3.4	2.7	5.2	4.7	3.9	0.5	12.4	11.1	9.6	17.2	15.4	13.4	1.8
16-Jun-68	97.7	91.1	73.1	48.3	47.0	44.7	20.3	374.6	229.2	162.5	557.6	127.3	59.4	39.9
18-Feb-69	6.4	5.8	4.7	8.9	8.2	6.6	0.9	27.5	21.7	14.6	32.1	28.8	20.2	2.9
04-May-70	143.0	129.7	103.5	55.8	53.6	49.4	28.1	331.1	276.6	226.4	430.8	225.3	121.5	46.3
02-Feb-71	54.4	50.6	42.0	43.0	42.0	39.8	8.2	280.8	182.3	139.6	234.0	63.3	55.2	28.4
30-May-71	535.2	474.4	343.5	694.8	645.7	493.3	79.9	957.3	606.2	403.9	1172.8	891.6	592.7	98.6
20-Jan-73	225.4	200.3	157.8	119.4	67.4	58.5	43.0	648.3	482.3	405.0	971.2	652.2	593.5	73.3
18-Mar-73	9.9	9.0	7.3	13.8	12.6	10.2	1.4	67.4	42.5	26.1	44.6	40.0	31.3	6.0
05-Aug-73	1.1	1.0	0.8	1.6	1.5	1.2	0.1	5.8	4.7	3.4	8.1	6.5	4.7	0.6
21-Mar-75	125.5	115.1	84.9	52.9	51.2	45.8	22.3	315.7	216.1	129.8	353.0	100.1	53.6	34.9
08-Dec-75	17.3	15.9	14.3	24.0	22.1	19.8	4.0	111.5	92.0	74.1	50.7	47.2	44.7	16.4
17-Dec-75	29.8	26.5	20.0	33.4	31.5	27.7	3.6	178.7	111.4	41.2	62.6	50.6	39.6	13.2
19-Apr-76	0.9	0.9	0.7	1.3	1.2	1.0	0.1	21.3	13.7	4.3	28.5	19.0	6.0	1.4
25-Mar-77	15.2	13.6	11.1	21.1	18.9	15.4	3.0	89.6	47.8	32.5	46.7	41.3	35.0	9.8
31-Jan-78	851.2	667.8	529.9	1125.8	1008.0	690.6	145.0	1609.5	983.5	487.1	1524.5	1184.4	656.2	176.2
18-Feb-78	268.9	208.6	147.0	209.4	84.6	56.5	37.7	1225.5	448.4	183.1	1317.7	624.4	63.5	68.4
30-Mar-78	4.7	4.0	2.8	6.6	5.6	3.9	0.5	25.6	18.3	9.3	31.0	25.4	12.9	2.0
03-Aug-78	8.8	8.4	7.3	12.3	11.7	10.2	1.9	75.1	48.4	24.3	44.7	41.5	30.2	8.6
09-Feb-79	22.1	20.7	17.8	29.0	28.2	24.7	4.3	110.5	85.8	61.5	50.5	45.9	44.5	15.0
01-Mar-79	95.9	80.4	66.0	48.0	44.8	44.6	15.2	418.7	221.3	102.4	603.3	110.8	49.2	27.9
12-Mar-79	98.0	96.9	81.0	48.4	48.2	45.0	19.7	361.3	208.2	109.5	540.6	83.9	50.3	32.3
31-Jan-80	797.8	727.7	605.1	1102.4	1078.3	889.7	137.9	1611.7	948.1	627.3	1525.4	1168.7	931.5	170.4
17-Feb-80	557.4	523.0	478.0	732.2	685.1	648.7	118.2	807.3	761.0	703.4	1106.3	1089.8	1070.0	147.5
19-Apr-80	23.9	22.8	20.3	30.0	29.4	28.0	3.8	46.3	43.0	40.0	40.9	40.1	39.3	8.9
12-Jun-80	24.2	22.6	18.0	30.2	29.2	25.0	4.0	49.9	47.7	39.9	41.9	41.3	39.2	9.1
14-Feb-81	367.7	347.6	291.9	548.8	514.1	257.0	61.6	512.5	490.5	426.8	676.8	659.0	609.0	90.8
17-Feb-82	22.4	21.1	20.1	29.1	28.4	27.8	6.2	180.1	83.4	60.1	62.9	45.4	44.5	19.4
23-Feb-82	143.7	123.6	91.5	55.9	52.6	47.1	24.5	389.8	289.2	191.2	576.9	251.3	65.1	45.8
29-Mar-83	3.6	3.2	2.5	5.1	4.5	3.5	0.4	46.0	28.9	13.4	40.8	32.9	18.7	3.3
05-Apr-83	42.0	39.7	32.0	39.8	39.1	34.7	6.6	83.6	75.2	62.5	45.5	44.7	44.5	13.5
26-Apr-84	13.8	9.6	2.7	19.2	13.4	3.8	0.9	31.9	29.5	17.6	34.6	33.2	24.5	3.2
19-May-84	30.9	26.5	17.7	34.0	31.5	24.5	3.1	83.1	66.8	40.5	45.4	44.6	39.4	8.1
18-Jul-84	42.1	37.3	27.8	39.8	37.8	32.2	5.1	170.6	116.1	75.9	61.0	51.4	44.7	16.9
06-Feb-85	62.6	57.0	45.6	44.5	43.7	40.7	21.0	318.8	163.4	135.6	368.7	59.6	54.6	49.8
14-Feb-86	4.7	4.3	3.4	6.6	6.0	4.7	0.6	23.2	20.5	16.9	29.6	28.0	23.4	3.5
15-Jan-87	36.0	34.2	30.1	37.0	36.0	33.6	6.8	184.0	142.9	121.8	63.7	55.8	52.3	27.9
05-Feb-87	13.4	12.4	10.3	18.6	17.2	14.4	3.3	109.3	62.3	43.0	50.3	44.5	40.1	12.4
30-Apr-87	2.7	2.4	1.8	3.8	3.4	2.6	0.4	6.9	5.6	4.0	9.6	7.8	5.6	1.0
27-Mar-88	22.2	20.5	17.0	29.0	28.1	23.6	3.3	104.7	77.4	57.3	49.6	44.7	43.8	11.7
09-May-88	36.3	32.8	25.7	37.2	35.2	31.0	5.3	240.7	163.0	99.0	151.0	59.5	48.6	23.4
20-May-88	7.7	6.8	5.2	10.7	9.5	7.3	1.1	52.1	29.4	14.6	42.4	33.2	20.3	4.3
13-Jan-90	19.2	17.8	14.4	26.7	24.7	20.0	6.3	121.3	83.8	64.7	52.3	45.5	44.5	25.6

APPENDIX D cont'd
Results of Event Based Modelling

Cross Section 7 - Seven Mile Bore, Marys Bore

	WITH DAM							WITHOUT DAM						
	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL
EVENT	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM
11-Jan-60	3.7	3.5	3.3	22.0	21.7	21.1	0.8	14.7	13.3	12.3	45.5	42.5	40.4	3.0
29-Jan-60	3.1	2.9	2.4	20.7	20.3	19.3	0.8	15.7	12.0	10.0	47.6	39.7	35.5	3.1
06-Feb-60	32.0	29.9	25.7	68.6	66.5	62.4	7.0	182.0	110.1	82.5	95.6	93.2	89.4	27.0
11-Feb-60	1058.9	850.6	672.3	2432.5	648.5	105.0	213.8	1332.6	892.2	733.6	3080.3	902.8	183.9	243.5
10-Feb-61	1.2	1.2	1.0	16.7	16.6	16.3	0.3	5.5	4.1	3.5	25.9	22.9	21.6	1.1
08-Jan-63	1.7	1.5	1.3	17.8	17.3	16.8	0.4	8.7	6.5	3.8	32.7	28.0	22.3	1.3
30-Jan-63	2.8	2.6	2.1	20.1	19.6	18.5	0.7	15.2	11.9	7.8	46.6	39.5	30.9	2.7
10-Mar-65	20.6	19.5	16.9	57.4	55.7	50.3	6.0	109.9	81.7	71.5	93.2	89.2	86.5	18.9
01-Jan-66	28.7	26.2	20.9	65.4	62.9	57.7	3.9	160.4	112.4	75.9	95.0	93.3	87.8	14.9
25-Apr-66	665.3	557.9	497.0	104.9	103.4	102.4	129.2	887.2	665.8	517.5	872.3	104.9	102.7	145.3
15-Jan-67	6.3	5.7	4.6	27.6	26.4	23.9	1.4	28.9	23.3	15.2	65.6	60.1	46.6	5.1
14-Dec-67	21.2	19.5	15.6	58.0	55.7	47.3	3.2	130.0	79.9	51.1	93.9	88.9	80.3	12.2
31-Jan-68	2.1	1.9	1.6	18.6	18.1	17.5	0.4	10.8	8.1	5.1	37.2	31.5	25.0	1.6
04-Mar-68	5.1	4.6	3.5	25.0	23.9	21.7	0.7	13.0	12.2	10.6	41.9	40.1	36.7	1.9
16-Jun-68	106.7	98.8	78.7	93.1	92.6	88.6	21.4	374.5	225.3	170.5	100.2	96.8	95.3	41.0
18-Feb-69	6.8	6.2	5.0	28.6	27.4	24.8	1.0	27.8	22.0	15.0	64.5	58.7	46.1	3.0
04-May-70	148.3	131.3	105.5	94.6	94.0	93.0	29.0	337.2	285.5	232.8	99.4	98.3	97.0	47.4
02-Feb-71	55.8	52.0	43.1	81.9	80.6	77.5	8.5	269.9	183.4	140.6	97.9	95.6	94.3	28.8
30-May-71	549.6	476.0	344.1	103.2	102.1	99.5	81.6	928.7	604.5	403.1	1363.7	104.1	100.8	100.0
20-Jan-73	225.3	203.4	160.1	96.8	96.2	95.0	44.1	681.8	479.3	404.6	105.1	102.1	100.8	74.3
18-Mar-73	10.6	9.8	7.9	36.7	34.9	31.0	1.5	68.7	43.7	26.9	85.8	77.7	63.6	6.1
05-Aug-73	1.2	1.2	0.9	16.7	16.6	16.1	0.2	5.9	4.8	3.4	26.7	24.4	21.4	0.7
21-Mar-75	125.9	118.1	88.2	93.8	93.5	90.5	23.4	314.4	222.9	134.2	98.9	96.7	94.1	36.1
08-Dec-75	17.9	16.6	14.8	52.3	49.5	45.8	4.2	108.1	93.8	75.2	93.1	91.6	87.6	16.8
17-Dec-75	29.7	26.6	20.1	66.3	63.2	56.9	3.7	180.9	117.6	41.7	95.6	93.5	77.1	13.3
19-Apr-76	0.9	0.8	0.7	16.1	15.8	15.6	0.1	21.2	13.6	4.2	58.0	43.0	23.0	1.4
25-Mar-77	15.7	14.2	11.8	47.6	44.4	39.2	3.2	87.6	48.1	33.5	90.4	79.2	70.1	10.1
31-Jan-78	881.3	669.3	532.8	836.2	105.0	103.0	146.1	1595.5	985.0	487.5	3583.1	2173.7	102.2	176.9
18-Feb-78	267.9	207.4	147.2	97.8	96.3	94.6	37.7	1178.4	472.0	192.8	2670.4	102.0	95.9	67.5
30-Mar-78	4.8	4.3	3.2	24.4	23.3	21.0	0.5	25.7	18.5	9.7	62.4	53.6	34.7	2.1
03-Aug-78	9.0	8.5	7.5	33.3	32.3	30.1	1.9	79.2	49.2	25.2	88.7	79.6	61.9	8.7
09-Feb-79	22.8	21.7	18.8	59.6	58.4	54.2	4.5	116.8	85.4	64.0	93.5	90.0	84.4	15.4
01-Mar-79	94.1	81.4	67.1	91.7	89.2	85.3	15.6	426.3	221.9	100.0	101.2	96.7	92.8	28.4
12-Mar-79	111.0	99.3	87.2	93.2	92.7	90.3	21.4	393.1	218.8	111.9	100.6	96.6	93.3	34.2
31-Jan-80	836.4	722.8	600.0	561.7	158.7	104.0	138.6	1595.7	952.5	627.5	3583.2	1706.4	104.4	171.1
17-Feb-80	553.8	534.4	518.8	103.3	103.0	102.7	126.0	842.5	791.0	749.6	598.9	318.1	221.4	155.3
19-Apr-80	23.8	23.0	20.9	60.5	59.7	57.7	4.2	46.1	43.2	40.8	78.6	77.6	76.8	9.3
12-Jun-80	25.8	24.0	19.1	62.5	60.7	54.8	4.2	51.7	49.8	40.6	80.5	79.8	76.7	9.4
14-Feb-81	438.9	403.9	326.4	101.4	100.8	99.2	69.0	585.4	539.6	465.8	103.8	103.1	101.9	98.3
17-Feb-82	22.5	21.4	20.6	59.3	58.2	57.4	6.3	180.8	92.3	59.0	95.6	91.3	83.0	19.5
23-Feb-82	149.2	123.9	91.6	94.6	93.7	91.2	25.1	388.1	292.1	195.9	100.4	98.4	96.0	46.5
29-Mar-83	3.7	3.4	2.5	22.0	21.4	19.6	0.5	45.6	29.9	13.7	78.4	66.5	43.4	3.3
05-Apr-83	49.8	45.8	37.1	79.8	78.5	73.6	7.7	89.2	81.2	66.5	90.7	89.1	85.1	14.6
26-Apr-84	13.7	9.8	3.5	43.4	35.0	21.6	0.9	31.1	30.0	17.8	67.7	66.7	52.0	3.2
19-May-84	31.8	27.3	18.5	68.4	64.0	53.5	3.2	86.0	67.8	41.2	90.1	85.5	76.9	8.3
18-Jul-84	44.6	39.6	29.3	78.1	76.1	66.0	5.4	176.0	120.7	76.4	95.4	93.6	87.9	17.3
06-Feb-85	65.9	60.3	48.2	85.0	83.4	79.3	21.8	314.1	166.7	137.3	98.9	95.2	94.2	50.7
14-Feb-86	5.3	4.8	4.0	25.4	24.4	22.7	0.7	23.4	20.9	17.7	60.1	57.7	51.9	3.6
15-Jan-87	37.7	35.6	31.2	74.2	72.2	67.8	7.1	184.7	141.7	122.7	95.7	94.4	93.7	28.3
05-Feb-87	13.7	12.7	10.7	43.4	41.3	36.9	3.4	113.5	59.3	44.5	93.3	83.1	78.0	12.5
30-Apr-87	2.7	2.4	1.8	19.9	19.3	18.0	0.4	6.9	5.5	4.0	28.9	25.9	22.6	1.0
27-Mar-88	23.2	21.5	17.9	59.9	58.3	52.3	3.5	105.3	79.7	57.7	93.0	88.8	82.5	12.0
09-May-88	37.5	34.1	26.9	74.0	70.7	63.6	5.6	245.7	174.1	101.2	97.3	95.4	92.9	23.9
20-May-88	8.1	7.3	5.7	31.4	29.7	26.3	1.2	53.4	30.3	15.3	81.1	66.9	46.8	4.4
13-Jan-90	19.4	18.0	14.6	55.5	52.4	45.2	6.8	123.2	83.2	65.5	93.7	89.5	84.8	26.2

APPENDIX D cont'd
Results of Event Based Modelling

Cross Section 8 - Ethel Creek

	WITH DAM							WITHOUT DAM						
	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL
EVENT	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM
11-Jan-60	3.2	3.2	3.0	169.0	166.7	159.7	0.8	11.4	10.4	9.7	549.8	503.9	470.9	2.7
29-Jan-60	2.6	2.5	2.2	141.2	136.5	122.6	0.8	11.9	9.1	7.6	573.0	444.9	371.8	2.7
06-Feb-60	29.0	27.6	24.4	1209.4	1168.9	1075.3	7.1	174.3	113.5	83.3	2529.4	2116.0	1976.7	28.5
11-Feb-60	1032.8	865.0	689.9	5275.1	4902.9	4467.6	216.9	1276.9	876.5	762.8	5741.5	4930.2	4655.1	248.0
10-Feb-61	1.2	1.2	1.1	76.1	73.8	69.2	0.3	4.5	3.7	3.0	229.4	191.3	158.2	1.0
08-Jan-63	1.5	1.4	1.2	90.1	85.4	77.7	0.4	6.3	4.9	3.5	313.0	248.6	182.2	1.2
30-Jan-63	2.3	2.2	2.0	127.2	122.6	111.0	0.7	11.3	9.0	6.3	545.2	439.3	313.9	2.4
10-Mar-65	17.7	16.9	15.2	842.4	804.9	724.9	5.9	108.5	79.6	71.6	2079.4	1962.5	1831.3	20.3
01-Jan-66	24.6	22.9	18.8	1082.2	1032.3	891.9	3.7	155.3	114.6	78.9	2415.5	2124.1	1951.1	16.4
25-Apr-66	647.1	565.9	499.3	4349.1	4117.5	3911.3	131.3	837.3	659.2	534.8	4837.6	4382.6	4022.8	147.8
15-Jan-67	5.1	4.8	4.0	257.3	244.9	208.0	1.4	22.4	18.8	12.9	1018.6	894.1	620.4	4.7
14-Dec-67	17.7	16.4	13.4	842.4	779.9	640.9	2.9	121.6	82.0	59.6	2175.5	1973.6	1638.9	14.6
31-Jan-68	1.8	1.8	1.6	104.0	104.0	93.2	0.4	8.3	6.4	4.6	405.9	318.6	232.5	1.4
04-Mar-68	4.4	4.2	3.4	224.7	215.5	177.4	0.7	9.9	9.6	8.5	480.2	466.2	413.3	1.7
16-Jun-68	111.3	103.4	82.3	2100.0	2041.8	1974.2	23.0	346.4	237.5	174.4	3364.1	2866.1	2529.8	42.3
18-Feb-69	5.8	5.4	4.5	289.8	272.0	229.4	1.0	22.0	18.4	13.4	1007.0	874.9	642.4	2.7
04-May-70	146.5	132.9	107.3	2358.0	2257.9	2070.7	30.6	336.1	279.4	236.2	3321.3	3070.5	2860.2	49.6
02-Feb-71	55.8	52.3	42.6	1617.2	1597.5	1542.1	9.6	266.9	184.9	141.6	3009.8	2592.8	2322.4	29.9
30-May-71	522.7	472.4	343.6	3984.9	3822.0	3352.2	82.7	886.0	627.1	415.6	4952.6	4293.8	3625.3	103.1
20-Jan-73	222.2	201.6	162.4	2791.8	2691.3	2458.2	45.9	622.4	498.1	402.7	4280.8	3907.3	3579.8	77.2
18-Mar-73	9.1	8.4	7.0	443.0	408.6	343.6	1.4	63.6	43.1	30.1	1700.1	1545.0	1240.0	6.9
05-Aug-73	1.1	1.1	0.9	71.5	71.5	62.2	0.2	3.9	3.5	2.9	201.5	183.4	156.3	0.6
21-Mar-75	126.6	117.6	90.5	2212.1	2146.4	1994.0	24.5	315.4	225.6	134.9	3235.2	2808.5	2273.3	38.5
08-Dec-75	15.1	14.4	14.0	721.7	689.1	669.0	4.1	108.8	93.1	76.8	2081.6	2000.4	1916.2	19.3
17-Dec-75	24.2	22.0	17.3	1070.6	1007.6	822.3	3.3	177.1	119.2	50.3	2546.2	2158.2	1586.0	14.6
19-Apr-76	0.8	0.8	0.7	57.6	57.6	52.9	0.1	14.7	8.8	1.3	703.1	427.5	80.8	1.0
25-Mar-77	13.8	12.5	10.9	661.3	601.8	525.1	3.1	84.5	50.1	34.1	1979.6	1584.8	1356.2	11.1
31-Jan-78	828.3	682.8	541.5	4816.4	4447.9	4043.9	148.1	1541.2	1025.3	486.8	6216.7	5259.5	3869.9	181.8
18-Feb-78	260.7	207.0	147.0	2979.6	2717.9	2361.5	38.3	1077.4	499.5	191.9	5368.0	3912.1	2634.7	70.0
30-Mar-78	4.0	3.7	2.9	206.2	189.9	155.9	0.5	19.6	14.6	7.7	930.6	696.6	379.9	1.8
03-Aug-78	8.0	7.6	6.8	391.9	374.7	335.4	1.9	71.3	51.3	30.4	1826.2	1591.7	1250.7	10.1
09-Feb-79	20.8	19.6	17.0	972.3	930.6	809.0	4.4	110.3	87.1	66.2	2092.6	1985.8	1742.4	16.5
01-Mar-79	94.9	82.1	68.1	2004.8	1973.8	1774.2	17.0	391.4	224.0	109.7	3537.2	2800.4	2087.9	31.0
12-Mar-79	113.6	101.4	90.6	2116.8	2027.6	1994.3	23.2	376.4	231.6	118.8	3479.9	2837.5	2155.1	37.3
31-Jan-80	770.6	724.2	604.7	4674.8	4556.8	4231.8	141.1	1529.1	996.8	642.0	6198.0	5199.7	4335.0	175.5
17-Feb-80	555.3	545.2	531.0	4086.1	4055.4	4010.8	131.2	857.8	817.7	757.0	4886.0	4791.4	4640.4	159.7
19-Apr-80	22.1	21.2	19.3	1009.9	982.6	914.4	4.2	45.9	42.8	40.6	1560.9	1543.4	1530.7	10.4
12-Jun-80	21.8	20.5	16.8	1001.2	964.8	798.3	3.8	52.1	49.6	41.0	1596.2	1582.2	1533.2	10.3
14-Feb-81	470.3	431.3	346.0	3815.0	3681.1	3362.6	74.3	611.6	566.6	489.1	4251.0	4119.6	3877.5	103.9
17-Feb-82	21.2	20.2	18.7	983.9	955.3	886.4	5.9	176.4	91.1	61.8	2542.0	1995.5	1671.1	19.9
23-Feb-82	143.8	124.1	93.1	2338.2	2193.5	2000.4	26.2	361.6	277.5	198.7	3423.4	3061.5	2675.9	48.9
29-Mar-83	3.0	2.8	2.3	159.7	148.3	125.7	0.4	36.3	28.7	16.6	1420.4	1200.7	791.3	4.0
05-Apr-83	52.4	48.9	38.5	1597.9	1577.7	1485.2	9.0	91.9	84.1	69.3	1997.5	1978.6	1792.9	16.1
26-Apr-84	9.8	6.5	2.1	475.5	322.3	115.6	0.6	25.8	23.7	14.6	1116.9	1055.5	697.8	2.8
19-May-84	25.8	23.0	16.2	1116.9	1036.5	774.3	3.0	82.7	68.6	40.0	1975.3	1781.1	1526.8	9.5
18-Jul-84	44.7	38.9	30.4	1554.1	1496.7	1250.6	6.3	174.7	122.5	78.8	2531.8	2182.0	1948.5	18.7
06-Feb-85	66.9	61.6	50.4	1754.1	1667.3	1586.2	23.2	292.8	166.9	137.9	3136.1	2485.2	2295.2	53.5
14-Feb-86	4.7	4.3	3.8	238.7	220.1	195.0	0.8	19.0	16.4	14.2	902.8	783.4	679.9	3.1
15-Jan-87	34.9	33.4	29.3	1379.9	1335.9	1218.8	7.2	183.8	142.1	123.6	2586.4	2325.9	2190.3	29.7
05-Feb-87	11.5	10.8	9.2	554.5	520.3	445.6	3.1	108.5	66.1	43.0	2079.4	1740.2	1544.4	13.8
30-Apr-87	2.1	2.0	1.6	117.9	113.3	95.9	0.3	4.7	4.1	3.3	238.7	208.5	173.7	0.9
27-Mar-88	20.0	18.8	15.8	949.2	891.8	756.0	3.3	104.3	81.1	60.0	2048.6	1971.3	1640.9	13.6
09-May-88	33.7	31.6	26.2	1345.2	1283.2	1129.3	5.8	237.6	169.6	103.4	2866.9	2501.1	2042.3	26.6
20-May-88	6.7	6.0	4.9	331.6	300.6	246.6	1.1	49.2	38.5	25.0	1579.7	1484.0	1094.3	6.6
13-Jan-90	15.9	14.8	12.2	758.8	708.2	586.7	6.5	112.6	81.2	67.2	2109.5	1971.7	1759.0	29.6

APPENDIX D cont'd
Results of Event Based Modelling

Cross Section 10 - Irwins Well

	WITH DAM							WITHOUT DAM						
	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL
EVENT	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM
11-Jan-60	17.6	17.1	15.8	133.8	130.2	120.2	4.3	22.3	21.7	20.8	208.0	192.6	170.8	6.0
29-Jan-60	5.2	5.2	4.9	39.6	39.2	37.3	2.2	11.2	9.7	8.8	85.2	73.4	66.5	3.9
06-Feb-60	85.5	84.1	82.6	1008.4	996.5	984.7	32.1	226.4	171.2	143.7	1612.9	1317.1	1286.1	54.0
11-Feb-60	1534.8	1406.2	1244.1	4160.1	4018.3	3832.6	420.7	1708.2	1419.8	1195.3	4331.5	4033.9	3776.7	452.7
10-Feb-61	5.4	5.4	5.1	41.1	40.7	38.8	1.7	7.7	7.5	7.2	58.6	57.0	54.8	2.4
08-Jan-63	5.7	5.6	5.5	43.4	42.2	41.8	2.6	8.5	8.0	7.4	64.6	60.6	56.2	3.4
30-Jan-63	5.6	5.4	5.2	42.6	41.3	39.6	2.8	10.5	9.5	8.2	79.9	71.9	62.7	4.3
10-Mar-65	60.1	59.3	56.3	806.4	799.3	774.3	19.5	130.3	119.2	114.0	1237.6	1197.2	1178.6	35.4
01-Jan-66	63.5	59.9	52.3	833.1	804.4	741.4	12.3	193.3	153.4	117.8	1325.4	1310.4	1192.2	25.9
25-Apr-66	1124.9	1036.7	930.2	3696.1	3641.3	3467.0	244.1	1277.5	1079.7	927.9	3870.9	3659.1	3461.7	260.9
15-Jan-67	9.7	9.3	8.6	73.8	70.9	65.2	4.0	21.0	19.2	15.0	176.4	146.0	113.7	6.9
14-Dec-67	18.1	17.0	14.5	137.6	129.6	110.1	5.5	123.1	89.5	61.6	1211.5	1041.3	818.0	17.7
31-Jan-68	4.3	4.2	3.9	32.7	31.9	29.7	1.5	9.1	7.9	6.6	69.2	60.0	50.2	2.4
04-Mar-68	32.7	31.6	29.0	460.7	433.2	369.6	8.0	37.3	36.3	32.9	572.5	549.2	466.1	8.9
16-Jun-68	344.6	322.2	272.6	2441.6	2424.3	2111.1	70.7	513.1	453.0	381.2	2636.9	2515.7	2494.1	90.7
18-Feb-69	15.2	14.7	13.5	115.6	111.7	102.4	3.6	26.4	24.5	21.2	307.6	262.3	180.0	5.1
04-May-70	321.2	297.2	258.0	2423.5	2377.2	1953.5	70.8	504.0	423.5	385.2	2619.5	2516.9	2500.3	90.7
02-Feb-71	111.1	105.5	93.9	1168.0	1147.6	1077.2	27.0	319.0	245.1	191.9	2421.8	1815.1	1324.9	47.3
30-May-71	978.8	891.8	724.1	3577.7	3376.7	3007.7	210.3	1385.7	1146.6	845.6	3994.8	3720.9	3256.2	231.3
20-Jan-73	487.7	473.7	430.7	2586.7	2558.0	2514.9	110.6	841.0	782.6	668.1	3244.2	3107.6	2912.9	139.6
18-Mar-73	24.7	23.6	20.7	266.3	239.1	167.9	4.8	77.2	59.7	45.0	941.1	803.1	680.1	11.7
05-Aug-73	5.0	4.9	4.5	38.0	37.5	34.2	1.0	6.5	6.4	5.9	49.4	48.3	44.9	1.4
21-Mar-75	293.8	279.2	248.1	2340.2	2182.5	1847.1	69.7	416.3	361.1	288.9	2518.8	2462.9	2287.4	83.4
08-Dec-75	44.9	43.7	40.3	679.1	669.0	640.3	13.1	135.6	117.2	101.0	1256.9	1190.0	1131.1	29.8
17-Dec-75	48.5	45.9	39.3	709.3	687.5	621.9	8.5	203.2	142.6	83.8	1362.5	1282.2	994.5	22.3
19-Apr-76	1.1	1.1	1.0	8.4	8.0	7.6	0.2	6.1	3.2	1.9	46.4	24.3	14.5	0.7
25-Mar-77	31.6	30.7	29.7	434.0	412.1	388.3	9.2	97.9	72.2	54.5	1110.4	901.8	759.2	18.5
31-Jan-78	1406.0	1384.3	1340.6	4018.1	3993.2	3943.1	419.8	1802.6	1431.7	1368.2	4424.8	4047.5	3974.8	455.2
18-Feb-78	319.6	271.1	201.8	2422.3	2095.4	1347.8	52.1	1039.2	614.9	278.0	3642.3	2823.5	2169.4	85.1
30-Mar-78	42.9	41.4	35.4	662.4	649.4	527.3	7.5	54.2	48.2	39.0	757.0	706.9	613.5	8.5
03-Aug-78	12.8	12.5	11.8	97.3	94.7	89.6	4.2	72.8	58.7	38.6	906.4	794.2	602.9	13.3
09-Feb-79	77.2	74.8	67.7	941.1	922.0	866.3	20.5	163.2	144.2	117.2	1314.1	1288.2	1190.2	33.8
01-Mar-79	180.1	163.5	137.3	1320.5	1314.2	1263.1	35.6	449.8	294.1	194.5	2509.7	2343.7	1325.9	50.3
12-Mar-79	250.8	241.8	228.9	1876.2	1779.0	1639.3	70.6	416.7	311.0	257.5	2518.7	2415.6	1948.1	86.9
31-Jan-80	931.3	913.3	818.8	3469.5	3428.4	3186.3	274.2	1569.2	1144.8	848.6	4194.1	3718.8	3264.0	313.5
17-Feb-80	1404.8	1368.0	1282.3	4016.7	3974.6	3876.3	440.3	1549.4	1513.6	1452.3	4174.6	4139.2	4071.1	470.3
19-Apr-80	93.8	92.0	88.0	1076.7	1061.6	1029.2	32.5	122.9	118.9	112.2	1210.8	1196.4	1172.0	39.6
12-Jun-80	83.9	80.0	72.8	995.2	962.8	906.0	18.8	118.2	112.4	103.2	1193.7	1172.7	1139.2	26.3
14-Feb-81	1152.8	1130.3	1077.7	3728.0	3702.2	3658.3	356.5	1318.2	1281.7	1204.6	3917.5	3875.7	3787.4	384.5
17-Feb-82	62.3	60.2	56.1	823.7	807.5	772.5	18.1	213.8	136.5	97.5	1476.9	1260.0	1106.8	32.4
23-Feb-82	238.8	231.5	209.8	1746.7	1667.9	1433.4	72.5	473.2	400.0	333.5	2557.1	2523.2	2433.0	95.1
29-Mar-83	7.4	7.2	6.7	56.3	55.0	51.0	1.5	30.8	26.4	21.1	414.5	307.6	177.9	5.0
05-Apr-83	201.6	194.8	182.4	1345.2	1326.0	1321.3	54.1	237.1	228.7	211.7	1728.3	1637.3	1454.6	61.4
26-Apr-84	87.9	56.6	54.8	1028.1	776.7	762.0	15.6	95.6	68.6	60.0	1091.5	873.4	805.4	17.5
19-May-84	59.6	53.4	40.7	802.2	750.6	643.8	8.0	111.5	97.9	75.5	1169.4	1110.1	927.3	16.4
18-Jul-84	179.2	166.1	138.5	1320.1	1315.2	1267.3	34.3	272.8	235.0	200.2	2113.6	1705.1	1330.5	46.8
06-Feb-85	184.9	174.7	150.8	1322.3	1318.4	1309.5	70.3	365.4	276.6	241.7	2469.6	2154.6	1778.2	102.9
14-Feb-86	87.3	81.5	70.3	1023.2	975.1	886.8	18.9	94.7	88.1	76.6	1084.1	1029.6	936.0	20.8
15-Jan-87	101.4	97.9	88.8	1132.7	1110.3	1035.9	24.1	245.1	202.7	170.4	1814.7	1357.4	1316.8	47.8
05-Feb-87	28.7	27.6	24.9	363.5	337.7	272.1	9.3	123.0	88.9	65.0	1211.1	1036.2	844.6	21.7
30-Apr-87	5.0	4.9	4.5	38.0	37.3	33.9	1.3	6.3	6.2	5.7	47.9	46.8	43.5	1.7
27-Mar-88	85.8	82.2	73.6	1010.8	980.8	912.4	19.0	161.8	147.6	128.6	1313.6	1300.5	1231.5	30.9
09-May-88	136.9	129.5	109.7	1261.6	1234.6	1162.9	28.3	326.7	255.9	190.4	2427.8	1931.7	1324.4	48.3
20-May-88	21.0	19.8	16.9	176.4	150.2	128.2	4.9	71.0	59.5	46.0	892.2	801.4	688.4	12.4
13-Jan-90	48.1	45.9	40.0	705.9	687.7	638.3	23.1	132.1	100.7	90.5	1244.2	1130.1	1049.8	51.3

APPENDIX D cont'd
Results of Event Based Modelling

Cross Section 11 - Battle Hill

	WITH DAM							WITHOUT DAM						
	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL
EVENT	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM
11-Jan-60	15.7	15.3	14.3	34.0	33.5	32.3	4.1	19.5	19.4	18.8	38.6	38.5	37.8	5.7
29-Jan-60	4.9	4.8	4.6	21.1	21.0	20.7	2.1	9.4	8.5	8.1	26.5	25.4	25.0	3.7
06-Feb-60	85.5	84.0	82.6	268.5	255.7	243.6	33.2	223.9	171.8	143.3	977.9	825.9	709.9	55.4
11-Feb-60	1527.7	1407.9	1249.5	1344.9	1342.8	1340.3	424.5	1687.9	1430.5	1195.8	1348.9	1343.1	1339.5	457.7
10-Feb-61	5.2	5.1	4.9	21.4	21.3	21.1	1.7	7.0	7.0	6.8	23.6	23.5	23.3	2.4
08-Jan-63	5.5	5.5	5.3	21.8	21.8	21.6	2.6	7.1	7.0	6.8	23.7	23.6	23.4	3.3
30-Jan-63	5.1	5.1	4.8	21.3	21.3	21.0	2.8	8.4	8.0	7.3	25.3	24.8	24.0	4.2
10-Mar-65	60.3	59.4	56.4	68.6	65.7	62.7	20.4	128.8	119.4	114.1	603.5	534.3	495.8	36.9
01-Jan-66	63.0	59.7	52.4	89.6	66.0	58.8	13.3	187.1	153.1	117.5	873.1	768.4	520.6	27.0
25-Apr-66	1116.6	1038.4	934.6	1338.2	1336.5	1334.1	246.5	1260.2	1085.9	931.7	1340.5	1337.7	1334.0	263.3
15-Jan-67	8.1	7.9	7.5	24.9	24.7	24.2	3.9	16.1	15.3	12.2	34.5	33.6	29.8	6.5
14-Dec-67	15.9	15.1	13.1	34.3	33.4	30.9	5.3	117.6	90.9	64.0	521.4	314.7	97.0	18.5
31-Jan-68	4.1	4.0	3.7	20.1	20.0	19.7	1.5	7.8	7.0	6.2	24.6	23.6	22.7	2.3
04-Mar-68	30.3	29.4	27.2	43.0	42.7	41.8	8.1	35.4	34.2	31.4	44.8	44.4	43.4	9.2
16-Jun-68	343.3	323.0	274.0	1220.3	1203.9	1114.4	71.9	491.9	458.0	383.4	1310.9	1307.1	1249.6	91.0
18-Feb-69	13.7	13.3	12.3	31.6	31.1	29.9	3.5	22.4	21.6	19.3	40.1	39.8	38.4	5.0
04-May-70	318.4	297.0	258.4	1200.2	1177.1	1071.9	72.3	494.0	425.7	384.3	1311.1	1284.5	1250.3	91.5
02-Feb-71	111.0	105.7	94.2	473.0	433.8	342.8	27.9	301.8	244.8	191.9	1186.9	1034.9	888.0	48.2
30-May-71	970.3	887.9	731.0	1334.9	1333.0	1329.3	212.0	1355.8	1148.1	860.6	1341.9	1338.7	1332.3	233.7
20-Jan-73	486.8	470.6	426.3	1310.3	1308.5	1285.0	113.4	830.5	780.2	669.1	1331.6	1330.4	1326.8	141.5
18-Mar-73	21.2	20.4	18.4	39.6	39.3	37.3	4.6	84.9	66.2	52.6	263.4	114.4	59.0	13.6
05-Aug-73	4.4	4.3	4.0	20.5	20.4	20.0	1.0	5.6	5.5	5.2	21.9	21.8	21.4	1.3
21-Mar-75	291.7	277.8	247.7	1162.8	1124.8	1042.8	70.0	404.8	361.3	290.1	1265.8	1233.8	1158.4	83.5
08-Dec-75	44.8	43.7	40.4	51.3	50.2	46.9	13.6	134.7	116.6	102.5	646.8	513.9	410.9	31.0
17-Dec-75	48.0	45.5	38.6	54.4	52.0	46.0	9.3	200.4	140.9	84.6	913.9	692.4	260.6	22.1
19-Apr-76	1.0	1.0	1.0	16.4	16.4	16.4	0.2	3.4	1.7	1.7	19.3	17.3	17.3	0.5
25-Mar-77	29.0	28.7	28.1	42.5	42.4	42.2	9.2	96.6	74.1	54.8	363.4	175.7	61.1	19.0
31-Jan-78	1404.2	1383.3	1340.7	1342.7	1342.4	1341.7	422.2	1766.1	1425.4	1366.8	1350.9	1343.0	1342.1	458.8
18-Feb-78	312.9	270.2	201.6	1195.8	1104.0	917.2	52.0	952.5	652.6	285.6	1334.5	1325.9	1146.2	87.5
30-Mar-78	42.4	40.3	35.0	48.9	46.8	44.7	8.2	52.8	48.4	39.7	59.2	54.8	46.4	9.4
03-Aug-78	11.8	11.5	10.9	29.4	29.0	28.2	4.1	71.6	59.1	44.0	156.3	65.4	50.5	14.3
09-Feb-79	76.8	74.7	67.9	196.7	180.6	127.5	21.4	160.4	143.9	115.9	791.0	714.4	509.1	35.3
01-Mar-79	178.6	162.9	137.2	846.9	798.5	665.2	36.8	418.3	292.6	187.2	1277.9	1165.2	873.4	49.6
12-Mar-79	249.8	241.5	227.8	1048.5	1026.0	988.5	72.1	392.7	310.4	256.9	1256.3	1193.8	1068.0	85.9
31-Jan-80	928.0	910.2	810.2	1333.9	1333.5	1331.1	272.5	1529.7	1152.1	857.6	1344.9	1338.8	1332.3	313.6
17-Feb-80	1402.3	1366.3	1282.4	1342.7	1342.1	1340.8	446.1	1546.2	1512.5	1449.1	1345.3	1344.5	1343.4	476.0
19-Apr-80	93.6	91.8	88.0	337.7	322.6	289.9	33.3	122.3	118.9	112.2	555.9	530.9	481.6	40.5
12-Jun-80	83.5	80.0	72.2	251.4	221.7	161.1	19.8	118.0	112.4	102.3	524.4	483.6	409.1	27.7
14-Feb-81	1150.2	1128.7	1076.4	1338.8	1338.4	1337.4	360.5	1314.9	1279.8	1203.5	1341.3	1340.8	1339.6	391.5
17-Feb-82	62.0	60.2	56.3	81.8	68.1	62.7	17.9	212.7	139.6	98.4	947.4	682.4	378.4	31.8
23-Feb-82	236.5	230.7	209.5	1012.3	996.5	938.6	73.8	462.9	394.8	327.3	1307.6	1257.8	1207.4	95.7
29-Mar-83	6.2	6.1	5.7	22.6	22.5	22.0	1.3	24.3	21.4	18.4	40.8	39.7	37.2	4.7
05-Apr-83	200.8	194.9	182.4	915.0	897.2	858.7	55.5	236.6	229.0	211.7	1012.6	991.8	944.7	62.9
26-Apr-84	75.2	56.3	54.9	184.3	62.7	61.2	15.9	84.2	68.5	60.0	257.4	132.3	66.3	17.8
19-May-84	58.4	53.5	40.9	64.7	59.9	47.4	9.3	110.7	97.8	75.3	470.8	373.8	185.0	17.4
18-Jul-84	177.6	165.6	138.7	843.9	806.9	676.1	35.8	266.3	236.0	199.9	1093.5	1011.0	912.6	49.2
06-Feb-85	185.2	175.2	151.2	867.2	836.3	762.7	71.7	350.0	274.7	243.9	1225.7	1116.5	1032.6	103.2
14-Feb-86	86.6	81.5	70.3	277.9	234.5	146.2	19.9	94.4	87.9	76.7	344.6	289.3	195.6	21.7
15-Jan-87	101.1	97.9	88.9	400.5	374.1	297.6	25.1	238.7	203.1	168.7	1018.3	921.2	816.6	48.8
05-Feb-87	25.5	24.7	22.9	41.2	40.9	40.2	9.0	120.8	90.8	66.5	544.9	313.8	117.1	22.2
30-Apr-87	4.3	4.2	3.9	20.4	20.3	19.8	1.2	5.3	5.2	4.8	21.6	21.4	21.0	1.6
27-Mar-88	85.8	82.2	73.7	271.1	239.9	172.6	20.4	161.3	146.5	128.7	793.7	733.1	602.4	32.3
09-May-88	136.6	128.8	110.5	660.7	603.6	469.6	29.4	321.2	256.0	188.8	1202.5	1065.5	878.3	48.9
20-May-88	17.5	16.7	14.6	36.2	35.2	32.7	4.7	63.0	53.1	41.5	89.6	59.5	48.0	12.5
13-Jan-90	48.1	46.0	40.1	54.5	52.5	46.6	24.0	117.1	96.5	87.0	517.8	362.7	281.1	52.1

APPENDIX D cont'd
Results of Event Based Modelling

Cross Section 12 - Five Mile Bore

	WITH DAM							WITHOUT DAM						
	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL	PEAK DISCHARGE m^3/s			FLOOD WIDTH m			VOL
EVENT	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM	QMAX	Q12HR	Q24HR	WMAX	W12HR	W24HR	MCM
11-Jan-60	17.8	17.2	15.6	39.0	37.7	34.2	4.5	21.9	21.4	19.7	46.4	45.8	43.3	6.2
29-Jan-60	4.8	4.8	4.7	10.6	10.6	10.3	2.2	9.1	8.4	8.1	20.0	18.4	17.8	3.8
06-Feb-60	87.8	86.6	84.1	793.7	792.0	788.4	36.7	217.9	173.8	145.7	919.2	884.5	856.7	58.9
11-Feb-60	1540.6	1460.8	1317.8	4094.4	4024.6	3782.3	451.5	1666.4	1505.8	1294.3	4105.0	4091.5	3742.5	485.3
10-Feb-61	5.6	5.5	5.3	12.3	12.1	11.7	2.0	7.4	7.3	7.1	16.3	16.1	15.6	2.7
08-Jan-63	6.1	6.0	6.0	13.4	13.3	13.2	2.8	7.5	7.4	7.1	16.5	16.2	15.6	3.6
30-Jan-63	5.2	5.1	5.0	11.4	11.2	11.0	3.1	7.7	7.6	7.5	16.9	16.8	16.5	4.5
10-Mar-65	64.3	62.9	59.1	679.4	670.4	625.4	22.9	132.4	122.8	117.4	843.6	834.0	828.7	39.8
01-Jan-66	66.1	64.3	59.3	691.2	679.1	631.2	16.3	196.4	160.1	121.1	906.8	871.0	832.4	30.2
25-Apr-66	1110.0	1058.5	981.7	3430.3	3193.3	2791.4	259.8	1223.8	1115.8	985.7	3623.1	3440.2	2811.2	276.2
15-Jan-67	9.8	9.4	8.5	21.5	20.6	18.7	5.2	17.7	16.4	13.3	38.8	35.9	29.1	7.7
14-Dec-67	15.3	14.7	13.1	33.6	32.3	28.8	6.0	542.8	112.1	84.9	1182.0	823.4	789.4	29.4
31-Jan-68	4.6	4.5	4.3	10.1	9.8	9.5	1.8	7.7	7.1	6.5	16.9	15.6	14.2	2.6
04-Mar-68	36.2	34.9	31.3	65.9	64.2	59.2	9.2	41.3	39.8	35.4	108.8	70.7	64.8	10.4
16-Jun-68	374.7	353.4	302.8	1033.6	1012.6	962.6	80.6	538.5	495.3	408.0	1179.6	1152.8	1066.6	99.5
18-Feb-69	15.1	14.7	13.5	33.1	32.2	29.6	4.3	23.2	22.5	20.3	48.2	47.2	44.2	5.8
04-May-70	331.7	312.0	285.8	991.1	971.6	952.8	80.4	507.8	454.4	434.0	1162.0	1112.4	1092.2	99.7
02-Feb-71	117.7	112.9	103.4	829.0	824.3	814.9	31.7	317.9	254.8	197.6	977.5	937.5	908.0	52.1
30-May-71	948.0	887.3	754.5	2623.8	2331.5	1850.6	223.1	1267.0	1142.3	897.2	3696.3	3485.0	2373.1	243.5
20-Jan-73	488.1	475.1	438.4	1145.7	1132.9	1096.6	122.2	824.5	785.1	671.0	2068.7	1928.3	1630.5	149.0
18-Mar-73	22.8	21.9	19.9	47.7	46.5	43.6	5.5	82.8	72.4	61.5	786.4	732.6	661.1	15.7
05-Aug-73	4.3	4.2	4.0	9.5	9.2	8.7	1.2	5.4	5.4	5.1	11.9	11.8	11.2	1.5
21-Mar-75	299.9	293.1	270.0	959.8	956.4	945.0	83.3	459.7	405.2	314.6	1117.7	1063.8	974.3	96.9
08-Dec-75	50.2	49.5	47.0	366.9	345.5	274.1	16.4	136.0	120.4	107.3	847.1	831.7	818.7	34.3
17-Dec-75	49.8	48.1	43.9	355.3	306.6	183.8	12.0	203.6	151.1	88.7	912.2	862.0	795.1	25.0
19-Apr-76	41.4	29.3	10.5	111.7	56.5	23.1	3.0	41.4	29.3	11.2	111.7	56.5	24.7	3.3
25-Mar-77	34.0	32.2	29.2	62.9	60.5	56.4	11.0	101.6	79.5	57.7	813.1	779.0	584.5	21.1
31-Jan-78	1394.3	1376.9	1337.9	3911.9	3882.5	3816.4	432.3	1562.0	1376.3	1353.0	4096.2	3881.4	3841.9	467.4
18-Feb-78	310.9	268.8	201.7	970.6	944.4	911.2	52.1	826.5	621.3	284.4	2077.1	1489.8	952.1	84.4
30-Mar-78	44.6	42.5	37.1	204.5	142.1	67.2	9.1	54.8	51.1	43.1	500.4	394.2	161.6	10.5
03-Aug-78	11.2	11.0	10.6	24.6	24.2	23.2	4.4	69.8	59.2	44.3	715.5	627.2	195.8	15.1
09-Feb-79	78.9	76.9	72.0	775.1	762.0	730.1	24.4	163.2	146.2	125.4	874.0	857.2	836.6	38.4
01-Mar-79	178.2	164.9	141.1	888.8	875.7	852.1	40.5	421.6	297.5	195.6	1080.0	958.6	906.0	53.5
12-Mar-79	249.5	242.4	231.5	934.8	931.3	925.9	88.4	414.3	346.9	306.6	1072.8	1006.2	966.3	102.1
31-Jan-80	913.1	887.3	796.7	2450.0	2331.6	1957.9	268.7	1320.0	1115.8	880.3	3786.1	3440.2	2302.4	311.6
17-Feb-80	1383.2	1352.9	1277.7	3893.1	3841.8	3714.4	502.4	1528.7	1499.7	1428.4	4093.4	4090.4	3969.7	532.5
19-Apr-80	93.5	91.8	87.9	802.1	799.5	793.9	38.2	122.4	118.8	112.2	833.7	830.1	823.6	45.4
12-Jun-80	84.9	81.8	77.4	789.5	785.0	765.2	21.6	119.5	114.7	106.7	830.8	826.1	818.1	29.6
14-Feb-81	1314.4	1148.0	1128.5	3776.6	3494.7	3461.7	453.7	1368.9	1296.6	1266.0	3868.9	3746.5	3694.7	484.5
17-Feb-82	63.3	62.5	60.2	672.8	667.5	652.5	20.5	208.3	140.9	102.7	914.5	851.9	814.2	34.4
23-Feb-82	237.0	230.9	212.1	928.7	925.6	916.4	79.4	448.3	398.2	339.6	1106.4	1056.9	998.9	101.1
29-Mar-83	5.8	5.7	5.4	12.8	12.5	11.9	1.5	21.4	19.6	17.6	45.8	42.9	38.6	4.7
05-Apr-83	224.8	219.5	204.3	922.6	920.0	912.5	65.8	263.2	255.5	235.4	941.6	937.8	927.9	73.2
26-Apr-84	77.3	65.1	63.4	764.6	684.6	673.6	18.5	87.0	76.4	70.3	792.6	758.4	718.5	20.4
19-May-84	67.5	61.5	48.4	700.4	661.3	314.7	11.3	116.2	103.9	84.2	827.5	815.4	788.5	19.5
18-Jul-84	181.4	169.5	143.2	892.0	880.2	854.2	39.0	277.8	242.2	204.0	948.8	931.2	912.4	52.6
06-Feb-85	198.9	188.9	166.0	909.3	899.4	876.8	80.1	347.3	284.4	254.0	1006.6	952.1	937.1	112.4
14-Feb-86	90.8	85.4	75.2	798.1	790.3	750.8	23.8	98.2	92.7	82.5	808.9	800.9	786.1	25.6
15-Jan-87	104.1	101.4	95.1	815.6	812.9	804.4	27.5	244.5	207.4	178.4	932.4	914.0	889.1	51.5
05-Feb-87	26.2	25.6	23.7	52.3	51.4	48.9	9.6	120.3	92.3	69.5	831.6	800.3	713.7	23.5
30-Apr-87	3.9	3.8	3.6	8.6	8.4	7.9	1.3	4.9	4.8	4.5	10.8	10.5	9.8	1.7
27-Mar-88	89.5	86.3	79.1	796.2	791.5	776.1	23.5	169.3	153.7	132.2	880.0	864.6	843.4	35.6
09-May-88	137.3	130.1	112.0	848.4	841.3	823.4	31.3	321.4	259.1	192.5	981.0	939.6	903.0	50.7
20-May-88	18.7	17.7	15.6	41.0	38.7	34.3	5.7	62.3	54.1	43.4	666.3	479.9	168.7	14.0
13-Jan-90	64.1	61.5	54.7	678.1	660.8	498.2	29.3	119.6	97.4	88.1	830.9	807.7	794.1	57.9

APPENDIX E
Backwater Analysis of Fortescue River

Name of Cross Sections

Cross Section No.	Name	Cross Section No.	Name
1	Ophthalmia	11	Battle Hill
2	Ethel Gorge	12	Five Mile Bore
3	Big Bend	13	McCarthy Well
4	Spinifex Bore	14	Airstrip
5	Double Channel One	15	Homestead
6	Double Channel Two	16	Roy Hill
7	Seven Mile Bore	17	Downstream Roy Hill A
8	Ethel Creek	18	Downstream Roy Hill B
9	Walkers Bore	19	Old Gauging Site
10	Irwins Well	20	Blue Bush Well
		21	"Marsh"

HEC-2 input data file

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T1      UPPER FORTESCUE HYDROLOGIC SURVEY
T2      OCTOBER 1990
T3      CROSS SECTIONS 21 - 1
J1   -10       0       0       0       0       1    0.05     100     405
J3     1       4       7       8      25      38      43
NC 0.025   0.025   0.035     0.1    0.03
NH     6   0.035  2000.0   0.025  5800.0   0.035  8166.2   0.025  8272.6   0.035
NH 10342   0.025 12200.0
X1    21      65  8015.5  8496.2     0.0     0.0     0.0
X3     0
GR 410.0     0.0   407.0  1100.0   406.6  1600.0   408.0  2000.0   410.0  2250.0
GR 411.0  4250.0   410.0  5800.0   409.0  6500.0   408.6  6598.5   408.5  6673.1
GR 408.2  6747.2   408.1  6829.0   407.8  6921.2   407.6  6999.6   407.5  7045.8
GR 407.2  7195.3   407.2  7298.8   407.3  7418.0   407.1  7512.9   406.6  7586.7
GR 406.7  7663.3   406.9  7752.7   406.9  7857.2   407.3  8015.5   407.3  8015.5
GR 407.2  8145.9   406.5  8146.4   407.1  8166.2   406.7  8178.1   406.1  8215.7
GR 404.3  8221.4   403.8  8230.2   404.0  8245.7   404.2  8256.5   406.2  8266.2
GR 406.1  8266.3   406.6  8272.6   406.9  8315.1   406.4  8316.1   407.2  8496.2
GR 407.1  8574.0   406.9  8754.7   406.0  8782.1   406.9  8815.1   406.9  8901.2
GR 406.9  8935.7   405.3  8947.5   406.6  8969.1   406.8  9043.7   407.2  9164.4
GR 407.2  9315.8   407.2  9427.7   407.1  9440.5   407.4  9621.1   407.6  9772.8
GR 408.0  9875.4   407.7 10009.5   407.9 10148.5   408.5 10255.7   408.0   10342
GR 408.3 10397.7   408.3 10475.6   408.7 10743.7   408.9 10867.9   410.0 12200.0
NH     5   0.025  6768.0   0.035  7495.9   0.025  7665.1   0.035  8790.5   0.025
NH 10218
X1    19      75  7365.5  7846.2  3398.0  3398.0  3398.0
X3     0
GR 410.5     0.0   410.3    77.3   410.3   145.7   410.3   240.4   410.7   306.3
GR 409.8   330.4   409.6   396.3   409.8   473.3   409.7   522.9   409.9   617.8
GR 409.8   712.5   410.0   816.4   410.8   903.4   411.1  1003.1   411.4  1100.3
GR 411.4  1113.2   413.0  3400.0   410.0  4850.0   409.0  5850.0   408.6  5948.5
GR 408.5  6023.1   408.2  6097.2   408.1  6179.0   407.8  6271.2   407.6  6349.6
GR 407.5  6395.8   407.2  6545.3   407.2  6648.8   407.3  6768.0   407.1  6862.9
GR 406.6  6936.7   406.7  7013.3   406.9  7102.7   406.9  7207.2   407.3  7365.5
GR 407.3  7365.5   407.2  7495.9   406.5  7496.4   407.1  7516.2   406.7  7528.1
GR 406.1  7565.7   404.3  7571.4   403.8  7580.2   404.0  7595.7   404.2  7606.5
GR 406.2  7616.2   406.1  7616.3   406.6  7622.6   406.9  7665.1   406.4  7666.1
GR 407.2  7846.2   407.1  7924.0   406.9  8104.7   406.0  8132.1   406.9  8165.1
GR 406.9  8251.2   406.9  8285.7   405.3  8297.5   406.6  8319.1   406.8  8393.7
GR 407.2  8514.4   407.2  8665.8   407.2  8777.7   407.1  8790.5   407.4  8971.1
GR 407.6  9122.8   408.0  9225.4   407.7  9359.5   407.9  9498.5   408.5  9605.7
GR 408.0  9692.4   408.3  9747.7   408.3  9825.6   408.7 10093.7   408.9   10218
NH     3   0.025  3500.0   0.035  7821.1   0.025 10800.0
X1    18      38  7668.9  8371.6  1282.0  1282.0  1282.0
X3     0
GR 413.0     0.0   410.5  1950.0   410.3  2027.3   410.3  2095.7   410.3  2190.4
GR 410.7  2256.3   409.8  2280.4   409.6  2346.3   409.8  2423.3   409.7  2472.9
GR 409.9  2567.8   409.8  2662.5   410.0  2766.4   410.8  2853.4   411.1  2953.1
GR 411.4  3050.3   411.4  3063.2   413.0  3500.0   407.1  7300.0   407.9  7441.3
GR 407.6  7565.2   407.7  7607.5   407.7  7668.9   406.9  7760.1   406.3  7821.1
GR 403.9  7830.9   404.5  7849.2   404.9  7859.1   406.6  7865.9   407.0  7868.7
GR 407.1  8041.0   407.1  8217.7   407.3  8371.6   407.4  8508.4   407.1  8658.3
GR 407.1  8730.4   406.8  8827.8   410.0 10800.0
NH     3   0.025  9999.9   0.035 10891.4   0.025 11060.2
X1    17      66  9999.9 10335.3  1279.0  1279.0  1279.0
X3     0
GR 412.0       0   410.5  2599.9   410.3  2677.2   410.3  2745.6   410.3  2840.3
GR 410.7 2906.21   409.8  2930.3   409.6  2996.2   409.8  3073.2   409.7  3122.8
GR 409.9 3217.68   409.8  3312.4   410.0  3416.3   410.8  3503.3   411.1  3603.0
GR 411.4 3700.17   411.4  3713.1   410.5  4949.9   410.3  5027.2   410.3  5095.6
GR 410.3 5190.32   410.7  5256.2   409.8  5280.3   409.6  5346.2   409.8  5423.2
GR 409.7 5472.78   409.9  5567.7   409.8  5662.4   410.0  5766.3   410.8  5853.3
GR 411.1 5953.02   411.4  6050.2   411.4  6063.1   408.1  9999.9   406.2 10014.2
GR 407.9 10019.3   407.3 10030.4   407.8 10048.0   407.1 10051.9   407.7 10054.8
GR 407.8 10066.0   406.5 10070.3   406.8 10078.6   405.7 10084.7   405.9 10095.5
GR 408.0 10105.1   407.5 10118.1   408.3 10165.4   407.6 10251.1   405.5 10255.5
GR 405.7 10267.9   407.4 10276.5   407.7 10294.7   407.3 10308.9   408.0 10321.7
GR 408.7 10335.3   408.4 10347.9   408.6 10404.2   408.9 10436.3   408.9 10541.9
GR 409.2 10660.3   409.1 10757.1   409.1 10827.1   409.2 10891.4   409.3 11006.1
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GR 409.3 11060.2
NH     2   0.025  4540.0   0.035  5601.4
X1    16      45  5036.1  5338.2  1562.0  1562.0  1562.0
X3     0
GR 410.5     0.0   410.3    77.3   410.3   145.7   410.3   240.4   410.7   306.3
GR 409.8   330.4   409.6   396.3   409.8   473.3   409.7   522.9   409.9   617.8
GR 409.8   712.5   410.0   816.4   410.8   903.4   411.1  1003.1   411.4  1100.3
GR 411.4  1113.2   413.0  4540.0   409.3  4900.0   409.0  4923.3   408.8  4958.4
GR 409.1  4995.9   409.5  5036.1   408.5  5051.1   408.6  5073.7   408.6  5107.9
GR 407.2  5131.8   407.8  5141.9   408.5  5157.7   407.3  5171.0   408.5  5177.4
GR 409.0  5181.1   407.4  5193.1   408.7  5198.5   408.6  5214.0   407.9  5220.5
GR 408.4  5225.4   408.3  5257.3   407.5  5261.6   409.0  5269.3   409.3  5299.7
GR 405.9  5305.5   408.5  5314.8   409.8  5338.2   411.4  5376.2   414.2  5601.4
NH     3   0.025  6500.0   0.035  6939.1   0.025  6968.6
X1    15      36  6790.7  6955.6  1941.0  1941.0  1941.0
X3     0
GR 412.0     0.0   410.9  2800.0   410.7  2927.2   410.8  3018.9   410.9  3102.0
GR 410.9  3142.0   411.0  3268.8   411.2  3386.9   411.5  3545.2   411.5  3691.3
GR 411.8  3779.6   411.7  3779.6   411.7  3857.4   411.3  6500.0   411.2  6552.7
GR 411.0  6585.7   410.8  6606.5   411.2  6639.9   411.7  6695.2   411.5  6764.1
GR 410.9  6790.7   410.9  6790.8   406.2  6804.2   406.2  6829.4   405.9  6850.0
GR 406.4  6863.8   407.6  6868.8   407.7  6869.6   408.6  6894.9   409.3  6904.8
GR 409.5  6910.6   408.7  6922.2   408.4  6926.9   409.3  6939.1   411.0  6955.6
GR 411.3  6968.6
NH     5   0.025  2524.6   0.035  2930.6   0.025  3003.7   0.035  3136.0   0.025
NH3254.7
X1    14      46  2921.3  3085.0  1816.0  1816.0  1816.0
X3     0
GR 410.8     0.0   410.8   113.4   410.8   191.3   410.8   253.1   410.9   363.3
GR 410.9   493.9   410.7   621.2   410.8   712.8   410.9   795.9   410.9   835.9
GR 411.0   962.7   411.2  1080.8   411.5  1239.2   411.5  1385.2   411.8  1473.5
GR 411.7  1473.6   411.7  1551.3   411.8  1677.5   412.1  1788.1   412.2  1882.9
GR 412.3  1959.7   412.7  2084.7   412.1  2220.5   412.1  2337.4   412.0  2443.5
GR 411.9  2524.6   411.9  2551.1   412.0  2609.6   411.7  2688.0   411.4  2745.9
GR 411.3  2789.9   410.4  2856.1   409.5  2921.3   408.5  2928.6   408.0  2930.6
GR 408.9  2932.2   408.9  2954.0   405.9  2975.0   406.0  2991.8   408.7  3003.7
GR 409.1  3006.4   411.2  3085.0   412.4  3136.0   412.3  3191.4   412.8  3247.8
GR 413.0  3254.7
NH     5   0.025  1832.3   0.035  2072.9   0.025  2368.6   0.035  2530.4   0.025
NH2641.1
X1    13      37  2197.5  2405.4  1751.0  1751.0  1751.0
X3     0
GR 413.2     0.0   413.2   110.6   413.3   215.1   413.3   309.2   413.2   413.6
GR 413.1   511.1   413.2   604.4   413.3   708.5   413.4   819.0   413.4   908.3
GR 413.5   990.5   413.3  1096.1   413.2  1199.6   413.3  1300.2   413.4  1435.2
GR 413.6  1530.7   414.1  1614.3   414.5  1664.4   413.9  1832.3   414.0  1869.0
GR 413.7  1934.7   413.1  2004.5   412.7  2072.9   412.6  2197.5   409.8  2209.3
GR 411.5  2236.1   411.9  2300.3   412.5  2315.2   406.1  2334.8   406.6  2347.2
GR 406.1  2360.6   409.1  2368.6   411.5  2405.4   412.0  2479.1   412.7  2530.4
GR 413.6  2620.3   414.0  2641.1
NH     7   0.025  1191.9   0.035  1400.5   0.025  1641.1   0.035  1761.0   0.025
NH2584.6   0.035  3008.0   0.025  4133.1
X1    12      86  2584.6  2879.8  7501.0  7501.0  7501.0
X3     0
GR 414.0     0.0   413.3    17.1   413.2    95.5   413.0   167.0   413.3   254.1
GR 412.7   259.4   413.2   269.0   412.9   375.3   413.1   450.6   413.2   513.8
GR 413.2   592.2   413.2   675.8   413.0   761.5   413.0   812.9   413.1   890.4
GR 413.0   957.7   413.2  1022.2   413.3  1117.4   413.4  1191.9   413.3  1276.3
GR 412.9  1400.5   412.4  1512.6   412.3  1586.2   412.5  1641.1   412.8  1686.6
GR 412.9  1761.0   412.4  1822.8   412.3  1871.0   412.9  1920.0   412.9  1940.4
GR 412.5  1989.4   412.5  2070.3   412.0  2124.9   412.2  2175.4   412.1  2233.2
GR 411.9  2273.7   412.1  2304.4   411.9  2315.8   412.0  2327.3   412.1  2338.9
GR 412.1  2385.6   412.1  2429.5   411.5  2437.1   412.0  2445.3   412.0  2506.6
GR 412.0  2528.1   411.6  2535.4   412.0  2549.5   412.3  2584.6   412.3  2623.4
GR 411.8  2650.6   410.1  2655.4   410.0  2668.2   410.3  2677.7   412.2  2686.6
GR 412.3  2710.4   411.9  2713.9   410.0  2718.7   410.5  2719.2   411.9  2721.9
GR 412.3  2735.5   411.8  2736.2   410.2  2739.5   410.4  2745.0   411.9  2749.3
GR 412.2  2773.8   411.8  2792.6   412.1  2801.6   412.0  2839.5   412.3  2879.8
GR 412.1  2910.8   412.1  2934.0   412.6  3008.0   412.3  3106.0   412.5  3186.1
GR 412.6  3253.2   412.7  3319.9   412.8  3342.0   413.0  3492.0   413.4  3604.8
GR 413.4  3673.0   413.4  3758.8   413.4  3872.8   413.6  3962.6   413.8  4050.2
GR 413.2  4133.1
NH     5   0.025   671.4   0.035   770.2   0.025   807.3   0.035   895.1   0.025
NH1390.5
X1    11      21   762.8   986.2  9713.0  9713.0  9713.0
X3     0
GR 416.7     0.0   416.4    40.7   416.2   144.9   416.1   257.7   415.9   411.1
GR 415.4   504.2   416.0   570.3   416.1   671.4   415.9   762.8   415.1   770.2
GR 413.3   782.8   413.3   798.0   413.8   807.3   415.7   824.6   415.9   895.1
GR 416.0   986.2   415.6  1080.8   415.6  1158.5   415.7  1215.2   416.5  1315.5
GR 418.1  1390.5
NH     3   0.025  2979.3   0.035  4504.8   0.025  5646.0
X1    10     100  3093.6  4635.8  7813.0  7813.0  7813.0
X3    10       0       0       0       0       0       0       0       0       0
GR 420.0     0.0   420.0    59.3   420.3   130.1   420.1   191.2   420.2   200.3
GR 420.3   294.1   420.3   376.8   419.9   494.9   419.6   604.9   419.7   694.6
GR 419.5   799.2   419.4   843.9   419.2   939.6   418.9  1059.3   418.8  1117.8
GR 418.9  1150.1   418.8  1225.0   418.9  1253.2   418.7  1328.5   418.9  1399.0
GR 418.9  1484.9   418.7  1554.3   418.5  1598.3   418.3  1659.2   418.5  1723.8
GR 418.7  1760.0   418.6  1817.3   418.3  1872.9   418.6  1937.4   418.5  2048.6
GR 418.4  2153.1   418.2  2266.3   418.2  2368.6   418.2  2450.2   418.1  2511.8
GR 418.5  2577.3   418.4  2608.3   418.3  2626.9   418.0  2652.8   418.4  2700.9
GR 418.5  2776.9   418.6  2838.3   418.7  2904.1   418.8  2979.3   418.6  3045.1
GR 418.1  3093.6   417.4  3120.8   416.2  3130.1   416.4  3138.8   417.6  3146.6
GR 418.0  3217.1   418.0  3258.1   418.1  3323.6   418.0  3401.3   417.9  3467.5
GR 417.8  3536.9   417.8  3611.7   417.7  3691.0   417.4  3740.1   417.6  3765.8
GR 417.7  3786.8   416.9  3794.6   417.1  3805.7   416.8  3818.8   416.0  3828.3
GR 416.5  3834.2   417.3  3836.2   417.3  3883.0   417.0  3887.2   417.6  3907.4
GR 417.5  3934.2   416.6  3937.4   417.2  3944.0   417.5  3948.1   417.7  3980.6
GR 416.9  4033.5   417.4  4047.8   417.3  4116.5   417.4  4175.7   417.2  4184.7
GR 416.6  4194.7   417.4  4210.1   417.4  4324.6   417.6  4418.0   417.7  4504.8
GR 417.9  4569.3   418.0  4635.8   417.9  4689.3   417.8  4721.9   417.8  4774.9
GR 417.6  4856.2   417.5  4904.7   417.2  4985.3   417.3  5081.3   417.5  5197.3
GR 417.5  5270.7   417.4  5345.0   417.3  5451.5   417.4  5536.4   417.5  5646.0
NH     5   0.025    84.0   0.035  1104.8   0.025  3481.3   0.035  6833.7   0.025
NH9109.5
X1     9     100     0.0  4807.5  7267.0  7267.0  7267.0
X3    10       0       0       0       0       0       0       0       0       0
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GR	422.2	0.0	421.8	84.0	421.9	114.3	421.7	157.4	421.6	193.6
GR	421.7	222.4	421.4	243.9	421.7	259.3	421.5	277.2	421.8	307.2
GR	420.9	329.2	421.7	354.7	421.2	379.3	421.7	402.4	421.2	438.1
GR	421.6	456.1	421.4	482.4	422.3	755.4	422.2	967.0	422.5	1104.8
GR	422.3	1289.9	422.3	1382.6	421.6	1520.4	421.7	1601.4	421.8	1761.5
GR	421.6	1847.0	421.8	1934.8	422.1	2098.5	422.2	2182.7	422.2	2296.6
GR	422.0	2331.3	422.2	2380.1	422.2	2425.8	422.2	2472.6	422.4	2507.4
GR	422.4	2562.3	422.4	2615.7	421.9	2681.5	421.6	2729.8	421.7	2808.9
GR	421.6	2864.2	421.2	2892.0	421.6	2942.7	420.4	2955.8	420.9	2971.7
GR	421.1	2988.3	421.3	3014.1	421.9	3039.1	421.7	3053.4	421.9	3101.2
GR	421.1	3137.6	422.0	3201.6	422.1	3295.0	422.3	3406.7	422.3	3481.3
GR	422.3	3546.6	422.1	3750.0	422.1	3832.6	421.8	3885.8	422.1	4078.4
GR	421.8	4181.1	421.8	4245.3	421.1	4305.9	421.5	4317.2	421.2	4334.1
GR	421.5	4393.2	421.8	4588.5	421.9	4750.4	422.0	4807.5	421.9	4898.0
GR	422.0	4988.4	421.9	5071.6	421.8	5142.4	421.9	5547.3	421.7	5663.1
GR	421.8	5702.5	421.7	5765.5	421.8	5824.9	421.7	5876.7	421.5	5920.2
GR	421.7	5944.2	421.4	5965.7	421.7	6055.9	421.3	6259.4	421.7	6357.8
GR	421.3	6487.9	421.5	6536.0	421.1	6680.3	421.5	6752.8	421.2	6804.8
GR	421.1	6833.7	421.4	6995.2	421.3	7096.2	421.4	7197.4	421.2	7577.9
GR	421.1	7707.7	421.1	7983.8	421.0	8051.9	421.1	8286.3	421.2	9109.5
NH	3	0.025	229.7	0.035	4664.5	0.025	8929.7			
X1	8	99	0.0	4618.5	6239.0	6239.0	6239.0			
X3	10	0	0	0	0	0	0	0	0	0
GR	425.7	0.0	423.5	173.3	422.6	179.2	422.9	184.0	423.6	190.4
GR	424.0	229.7	423.9	263.1	422.8	268.2	423.0	280.1	423.8	286.8
GR	424.4	312.4	424.4	400.8	423.7	723.7	423.2	1361.9	423.2	1411.9
GR	423.0	1537.0	423.0	1599.4	423.0	1653.8	423.0	1721.2	423.1	1785.1
GR	423.3	1872.5	423.4	2334.8	422.9	2505.7	423.0	2578.6	423.0	2605.8
GR	422.5	2646.0	422.7	2734.5	422.6	2836.9	422.6	2886.2	422.5	2963.2
GR	422.3	3027.1	421.0	3035.7	421.0	3056.1	422.1	3060.8	422.4	3073.5
GR	422.4	3139.6	422.4	3181.3	422.4	3463.9	422.4	3531.9	422.5	3605.4
GR	422.6	3693.8	422.6	3781.5	422.6	3875.2	422.6	3925.6	422.5	4001.4
GR	422.2	4036.4	421.6	4064.3	422.7	4164.9	422.8	4296.7	422.8	4398.1
GR	422.8	4521.7	422.9	4618.5	422.9	4664.5	423.0	4710.5	422.9	4760.2
GR	422.9	4835.2	422.9	4894.7	422.9	4984.4	422.9	5066.2	422.9	5156.2
GR	422.9	5218.3	422.9	5303.4	422.8	5365.0	422.7	5476.5	422.6	5593.7
GR	422.5	5673.7	422.5	5728.7	422.4	5847.7	422.4	5921.1	422.4	6009.4
GR	422.4	6118.5	422.2	6232.3	422.1	6335.6	422.0	6446.4	422.0	6598.4
GR	421.9	6738.8	422.0	6783.7	422.1	6864.3	422.2	6933.8	422.8	7025.8
GR	422.3	7107.3	422.4	7189.4	422.3	7268.3	422.3	7399.9	422.2	7484.2
GR	422.0	7632.9	422.0	7694.2	421.9	7760.0	421.6	7867.2	421.8	7954.7
GR	421.9	8107.5	421.9	8185.1	421.8	8283.5	421.7	8424.8	421.7	8528.5
GR	421.6	8665.5	421.5	8764.6	421.4	8861.9	421.4	8929.7		
NH	3	0.025	4734.6	0.035	5228.6	0.025	6707.9			
X1	7	76	5140.5	5248.6	10171.0	10171.0	10171.0			
X3	10	0	0	0	0	0	0	0	0	0
GR	438.0	0.0	437.8	81.5	437.7	165.1	437.7	241.5	437.6	311.4
GR	437.5	376.8	437.4	465.5	437.4	540.2	437.2	632.5	437.1	702.3
GR	437.2	781.6	437.2	878.0	437.2	947.3	437.0	987.7	436.9	1057.5
GR	436.9	1129.8	436.8	1180.1	436.7	1283.9	436.5	1410.4	436.4	1519.5
GR	436.4	1617.6	436.4	1722.7	436.5	1823.0	436.6	1946.6	436.5	2009.3
GR	436.6	2078.9	436.5	2164.6	436.5	2253.3	436.5	2360.4	436.4	2480.3
GR	436.3	2604.8	436.2	2709.2	436.2	2808.4	436.0	2897.8	436.2	2979.0
GR	436.1	3045.2	436.0	3168.6	436.0	3284.4	436.0	3371.1	436.2	3466.8
GR	436.4	3543.2	436.4	3632.4	436.3	3758.2	436.3	3861.7	436.2	3967.3
GR	436.1	4093.0	436.0	4151.2	436.0	4216.0	436.1	4276.3	436.1	4369.1
GR	436.4	4459.4	436.5	4572.0	436.5	4653.5	437.0	4734.6	436.6	4883.3
GR	436.6	4946.5	436.3	5087.7	436.4	5140.5	434.0	5152.2	432.8	5188.1
GR	432.4	5228.6	432.4	5242.7	436.8	5248.6	436.5	5282.5	436.1	5290.7
GR	436.1	5346.4	435.1	5741.5	435.0	5814.6	435.0	5844.6	435.0	5849.3
GR	434.7	5969.8	434.5	6101.7	434.6	6268.3	434.7	6372.2	434.5	6563.3
GR	435.1	6707.9								
NH	6	0.035	217.9	0.025	290.9	0.035	465.7	0.025	2620.9	0.035
NH	3232.8	0.025	3501.6							
X1	6	54	0.0	304.4	12387.0	12387.0	12387.0			
X3	0									
GR	450.2	0.0	450.2	24.7	450.1	90.5	450.0	119.9	449.3	127.1
GR	448.7	137.1	449.0	153.2	447.8	182.2	446.5	197.6	445.2	201.1
GR	444.9	217.9	444.7	236.7	444.3	261.9	447.8	273.4	448.7	290.9
GR	450.1	304.4	449.9	380.4	449.9	465.7	449.8	586.5	449.8	668.5
GR	449.7	668.6	449.9	795.8	449.9	892.4	449.8	994.3	449.6	1277.2
GR	449.6	1393.8	449.2	1572.2	449.1	1677.3	449.3	1797.4	449.1	1868.4
GR	449.3	1910.4	449.3	1991.0	449.3	2095.9	449.3	2207.8	449.4	2331.6
GR	449.4	2479.2	449.4	2620.9	449.3	2726.0	449.6	2835.4	449.5	2874.7
GR	448.6	2912.5	447.7	2934.7	446.6	2966.8	446.3	2996.2	446.0	2998.3
GR	446.0	3002.4	446.8	3005.9	447.5	3088.9	448.5	3175.7	449.0	3232.8
GR	449.6	3316.8	449.7	3391.0	449.8	3453.7	449.8	3501.6		
NH	4	0.035	361.8	0.025	2131.6	0.035	2303.8	0.025	3155.4	
X1	5	68	0.0	342.2	8823.0	8823.0	8823.0			
X3	0									
GR	460.6	0.0	459.8	19.6	457.6	47.1	460.2	63.5	456.8	69.5
GR	456.6	98.1	460.2	107.4	455.8	137.0	459.8	193.1	453.6	202.0
GR	459.8	245.7	452.7	255.2	452.6	277.5	458.0	306.4	460.2	342.2
GR	460.3	361.8	460.2	419.6	460.0	507.1	460.0	611.7	460.0	694.0
GR	459.6	788.0	458.9	884.2	458.9	942.5	458.9	997.1	458.8	1074.8
GR	458.6	1128.5	458.7	1186.0	458.7	1257.0	458.8	1329.2	459.1	1402.1
GR	458.9	1479.2	458.7	1543.0	458.4	1634.8	458.0	1694.3	458.1	1713.7
GR	457.6	1786.6	457.6	1841.3	457.5	1932.6	457.5	2007.2	458.4	2084.7
GR	458.1	2131.6	457.1	2153.8	456.9	2194.4	456.8	2232.5	456.7	2243.3
GR	456.5	2259.0	457.1	2277.5	458.2	2303.8	458.2	2359.5	458.1	2429.9
GR	458.2	2496.3	458.0	2535.7	457.1	2590.5	457.8	2591.2	457.8	2591.3
GR	457.8	2608.6	457.0	2653.1	457.0	2692.5	457.3	2734.4	457.1	2766.7
GR	456.9	2806.7	457.0	2843.3	457.1	2904.5	457.2	2960.2	457.4	3043.2
GR	458.0	3092.8	458.4	3123.7	458.9	3155.4				
NH	5	0.025	109.4	0.035	290.4	0.025	416.0	0.035	452.6	0.025
NH	4500.0									
X1	4	19	81.2	422.4	8305.0	8305.0	8305.0			
X3	0	0	0	0	0	0	0	0	0	0
GR	476.1	0.0	474.2	21.0	469.6	81.2	468.1	109.4	468.2	132.7
GR	468.7	172.7	470.1	230.1	469.7	266.4	468.8	290.4	467.8	324.0
GR	467.3	327.1	466.5	354.4	466.5	390.0	466.6	416.0	469.2	422.4
GR	468.3	452.6	469.0	498.4	468.6	522.9	480.0	4500.0		
NH	3	0.025	205.7	0.035	498.7	0.025	613.0			
X1	3	26	220.7	461.6	9301.0	9301.0	9301.0			
X3	0	0	0	0	0	0	0	0	0	0
GR	481.1	0.0	480.7	32.2	479.9	75.8	478.9	150.5	478.4	179.5
GR	477.9	205.7	476.4	220.7	474.5	223.8	474.4	242.2	474.6	252.1
GR	476.4	264.3	475.8	302.0	475.3	319.5	475.2	340.6	476.5	350.7

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GR 476.9    372.0    475.6    398.1    475.5    423.3    476.1    431.9    476.9    461.6
GR 476.7    474.4    477.0    498.7    477.0    521.3    477.2    533.7    477.9    588.3
GR 479.1    613.0
NH     3    0.025    688.2    0.035   1072.1    0.025   1160.5
X1     2       41    702.5   1141.1   9611.0   9611.0   9611.0
X3     0        0        0        0        0        0        0        0        0        0
GR 493.9      0.0    493.8     83.3    493.6    166.3    493.7    220.3    494.5    337.5
GR 494.1    378.0    493.9    463.8    494.4    525.2    494.4    581.9    493.7    631.1
GR 493.4    679.6    492.6    688.2    490.4    702.5    488.8    727.5    488.5    745.8
GR 489.5    773.9    490.0    798.0    489.5    814.1    489.3    845.2    487.5    853.3
GR 488.5    869.1    487.9    879.2    488.9    887.4    487.8    893.4    488.8    907.7
GR 488.7    915.3    489.7    917.3    488.9    920.9    489.1    930.9    488.4    949.7
GR 489.8    967.0    488.6    973.5    488.9    986.6    487.9   1003.0    488.5   1033.9
GR 487.3   1040.8    489.4   1067.8    488.7   1072.1    489.6   1096.6    490.4   1141.1
GR 491.1   1160.5
NH     4    0.035    356.3    0.025    400.7    0.035    504.2    0.025    512.9
X1     1       36     15.3    512.9   6598.0   6598.0   6598.0
X3     0        0        0        0        0        0        0        0        0        0
GR 505.3      0.0    502.6     15.3    499.7     23.9    499.4     38.3    499.6     68.7
GR 499.3     99.8    500.4    111.6    502.1    119.1    500.3    133.0    500.0    151.7
GR 498.8    218.3    499.2    240.6    498.8    260.9    498.3    282.0    497.8    310.8
GR 498.2    326.4    498.2    335.8    498.1    352.4    498.7    356.3    499.1    360.3
GR 498.6    367.6    498.0    368.1    498.3    378.4    498.8    381.2    498.9    383.1
GR 498.0    385.7    498.2    396.6    499.0    400.7    498.8    411.0    497.7    413.7
GR 497.3    429.5    496.7    454.7    497.5    482.2    498.2    504.2    499.5    507.4
GR 501.4    512.9
EJ

ER
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APPENDIX E cont'd
Example of HEC-2 result

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*********************************************************          ***************************************
*  WATER SURFACE PROFILES                               *          * U.S. ARMY CORPS OF ENGINEERS        *
*  VERSION OF NOVEMBER 1976                             *          * THE HYDROLOGIC ENGINEERING CENTER   *
*  UPDATED MAY 1984                                     *          * 609 SECOND STREET, SUITE D          *
*  IBM-PC-XT VERSION AUGUST 1985                        *          * DAVIS, CALIFORNIA 95616             *
*  RUN DATE  11-28-90    TIME  10:39:13                 *          * (916) 440-2105 (FTS) 448-2105       *
*********************************************************          ***************************************


                    X     X  XXXXXXX   XXXXX             XXXXX
                    X     X  X        X     X           X     X
                    X     X  X        X                       X
                    XXXXXXX  XXXX     X         XXXXX    XXXXX
                    X     X  X        X                 X
                    X     X  X        X     X           X
                    X     X  XXXXXXX   XXXXX            XXXXXXX

 11-28-90     10:39:13                                                                              PAGE
1

                                                                        THIS RUN EXECUTED 11-28-90
*****************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED MAY  1984
  ERROR CORR -  01,02,03,04,05,06
  MODIFICATION -  50,51,52,53,54,55,56
  IBM-PC-XT VERSION AUGUST 1985
*****************************************************

T1       UPPER FORTESCUE HYDROLOGIC SURVEY
T2       OCTOBER 1990
T3       CROSS SECTIONS 21 - 1

J1  ICHECK     INQ      NINV      IDIR       STRT     METRIC    HVINS      Q       WSEL       FQ

     -10.       0.        0.        0.    .000000      1.00       .1     100.   405.000     .000

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     1.000     4.000     7.000     8.000    25.000    38.000    43.000    .000      .000      .000

 11-28-90     10:39:13                                                                              PAGE
2

   SECNO     DEPTH     CWSEL     CRIWS     WSELK      EG        HV        HL       OLOSS   BANK ELEV
   Q         QLOB      QCH       QROB      ALOB       ACH       AROB      VOL      TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL        XNCH      XNR       WTN      ELMIN     SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL     IDC       ICONT     CORAR    TOPWID    ENDST

*PROF 1

CCHV=    .100 CEHV=     .030
1490 NH CARD USED
*SECNO 21.000
    21.00     1.20    405.00       .00    405.00    405.36       .36       .00       .00    407.30
     100.       0.      100.        0.        0.       37.        0.        0.        0.    407.20
      .00      .00      2.67       .00      .000      .025      .000      .000    403.80   8219.18
  .005091       0.        0.        0.         0         0         0       .00     41.20   8260.38

1490 NH CARD USED
*SECNO 19.000

1645 INT SEC ADDED BY RAISING SEC      19.00,      .000FT AND MULTIPLYING BY     1.000

3265 DIVIDED FLOW

3301 HV CHANGED MORE THAN HVINS

     1.01     2.32    406.12       .00       .00    406.18       .06       .78       .03    407.30
     100.       0.       98.        2.        0.       88.        8.       57.       50.    407.20
      .22      .00      1.11       .29      .035      .025      .035      .000    403.80   7565.15
  .000373     850.      850.      850.         5         0         0       .00     77.42   8310.94

1645 INT SEC ADDED BY RAISING SEC      1.01,      .000FT AND MULTIPLYING BY     1.000

3265 DIVIDED FLOW

     1.02     2.62    406.42       .00       .00    406.46       .04       .28       .00    407.30
     100.       0.       94.        6.        0.      108.       21.      153.      141.    407.20
      .50      .00       .87       .29      .035      .024      .035      .000    403.80   7545.43
  .000294     850.      850.      850.         3         0         0       .00    135.63   8316.17

1645 INT SEC ADDED BY RAISING SEC      1.02,      .000FT AND MULTIPLYING BY     1.000

 11-28-90     10:39:13                                                                              PAGE
3
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    SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
    Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
    TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
    SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID     ENDST


3265 DIVIDED FLOW

      1.03      2.86    406.66       .00       .00    406.68       .02       .22       .00    407.30
      100.        0.       89.       11.        1.      135.       37.      281.      330.    407.20
       .88       .04       .66       .28      .035      .020      .035      .000    403.80   6928.52
   .000232      850.      850.      850.         2         0         0       .00    309.75   8339.79

1645 INT SEC ADDED BY RAISING SEC        1.03,      .000FT AND MULTIPLYING BY      1.000

3265 DIVIDED FLOW

     19.00      3.04    406.84       .00       .00    406.85       .01       .16       .00    407.30
      100.        3.       82.       15.       24.      174.       63.      466.      718.    407.20
      1.43       .10       .47       .24      .035      .021      .035      .000    403.80   6900.43
   .000162      850.      850.      850.         2         0         0       .00    602.76   8407.51

1490 NH CARD USED
*SECNO 18.000

3265 DIVIDED FLOW

     18.00      3.28    407.18       .00       .00    407.19       .01       .34       .00    407.70
      100.        0.       78.       22.        3.      188.       74.      804.     1782.    407.30
      2.35       .07       .41       .30      .035      .027      .025      .000    403.90   7249.19
   .000509     1282.     1282.     1282.         8         0         0       .00   1057.29   9061.32

1490 NH CARD USED
*SECNO 17.000

3265 DIVIDED FLOW

     17.00      2.44    407.94       .00       .00    407.96       .02       .77       .00    408.10
      100.        0.      100.        0.        0.      170.        0.     1082.     2620.    408.70
      2.95       .00       .59       .00      .025      .035      .035      .000    405.50  10001.07
   .000731     1279.     1279.     1279.         3         0         0       .00    253.30  10320.68

 11-28-90     10:39:13                                                                                 PAGE
4

    SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
    Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
    TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
    SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID     ENDST

1490 NH CARD USED
*SECNO 16.000

3265 DIVIDED FLOW

     16.00      3.06    408.96       .00       .00    408.97       .02      1.01       .00    409.50
      100.        0.      100.        0.        4.      180.        0.     1358.     3047.    409.80
      3.74       .13       .55       .00      .035      .035      .035      .000    405.90   4930.89
   .000576     1562.     1562.     1562.         5         0         0       .00    294.02   5323.02

1490 NH CARD USED
*SECNO 15.000

3265 DIVIDED FLOW

     15.00      3.39    409.29       .00       .00    409.30       .01       .33       .00    410.90
      100.        0.      100.        0.        0.      257.        0.     1786.     3463.    411.00
      5.13       .00       .39       .00      .035      .035      .035      .000    405.90   6795.40
   .000078     1941.     1941.     1941.         2         0         0       .00    134.36   6938.90

1490 NH CARD USED
*SECNO 14.000
     14.00      3.56    409.46       .00       .00    409.48       .02       .18       .00    409.50
      100.        0.      100.        0.        0.      150.        0.     2156.     3674.    411.20
      5.89       .00       .66       .00      .035      .023      .035      .000    405.90   2921.63
   .000128     1816.     1816.     1816.         2         0         0       .00     98.06   3019.69

1490 NH CARD USED
*SECNO 13.000
     13.00      3.56    409.66       .00       .00    409.69       .03       .21       .00    412.60
      100.        0.      100.        0.        0.      123.        0.     2396.     3807.    411.50
      6.49       .00       .81       .00      .035      .023      .035      .000    406.10   2323.91
   .000117     1751.     1751.     1751.         0         0         0       .00     53.20   2377.11

1490 NH CARD USED
*SECNO 12.000

1645 INT SEC ADDED BY RAISING SEC       12.00,   -1.950FT AND MULTIPLYING BY       .621

 11-28-90     10:39:13                                                                                 PAGE
5

    SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
    Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
    TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
    SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID     ENDST
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3265 DIVIDED FLOW

     1.01      2.41    410.46       .00       .00    410.47       .01       .77       .00    410.35
     100.       52.       45.        3.      119.      107.       16.     3082.     5253.    410.35
     8.97       .43       .42       .21      .025      .035      .034      .000    408.05    937.17
  .000455     3751.     3751.     3751.         3         0         0       .00    718.24   1958.45

1645 INT SEC ADDED BY RAISING SEC       1.01,   1.950FT AND MULTIPLYING BY    1.610

3265 DIVIDED FLOW

    12.00      2.28    412.28       .00       .00    412.28       .01      1.82       .00    412.30
     100.       42.       57.        1.      112.      132.        9.     4013.     8122.    412.30
    11.57       .37       .43       .17      .025      .035      .035      .000    410.00   2094.45
  .000518     3751.     3751.     3751.         6         0         0       .00    811.53   2960.47

1490 NH CARD USED
*SECNO 11.000

3265 DIVIDED FLOW

    11.00      2.49    415.79       .00       .00    415.83       .04      3.54       .00    415.90
     100.        5.       90.        5.       22.      100.       26.     5964.    13969.    416.00
    14.79       .22       .91       .19      .025      .019      .025      .000    413.30    432.73
  .000271     9713.     9713.     9713.         4         0         0       .00    392.40   1225.71

1490 NH CARD USED
*SECNO 10.000

3265 DIVIDED FLOW

3280 CROSS SECTION      10.00 EXTENDED        .34 METERS

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      418.10 ELREA=       418.00

    10.00      1.84    417.84       .00       .00    417.84       .00      2.01       .00    418.10
     100.        0.      100.        0.        0.      423.        0.     8195.    19907.    418.00
    23.98       .00       .24       .00      .025      .034      .025      .000    416.00   3103.65
  .000245     7813.     7813.     7813.         3         0         0       .00   1127.66   4550.38

 11-28-90     10:39:13                                                                                  PAGE
6

   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN        SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

1490 NH CARD USED
*SECNO 9.000

3265 DIVIDED FLOW

3280 CROSS SECTION       9.00 EXTENDED        .45 METERS

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      422.20 ELREA=       422.00

     9.00      1.25    421.65       .00       .00    421.66       .01      3.82       .00    422.20
     100.        0.      100.        0.        0.      196.        0.    10445.    27503.    422.00
    27.94       .00       .51       .00      .025      .029      .027      .000    420.40    175.26
  .001824     7267.     7267.     7267.         3         0         0       .00    963.02   4491.29

1490 NH CARD USED
*SECNO 8.000

3265 DIVIDED FLOW

3280 CROSS SECTION       8.00 EXTENDED       1.50 METERS

3685 20 TRIALS ATTEMPTED WSEL,CWSEL
3710 WSEL ASSUMED BASED ON MIN DIFF

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      425.70 ELREA=       422.90

     8.00      1.90    422.90    422.11       .00    422.90       .00      1.36     23.94    425.70
     100.        0.      100.        0.        0.      755.        0.    13413.    36800.    422.90
    41.03       .00       .13       .00      .025      .035      .025      .000    421.00    177.24
  .000079     6239.     6239.     6239.        20        12         0       .00   2017.11   4617.88

1490 NH CARD USED
*SECNO 7.000

1645 INT SEC ADDED BY RAISING SEC       7.00,  -8.550FT AND MULTIPLYING BY    4.590

3301 HV CHANGED MORE THAN HVINS

3685 20 TRIALS ATTEMPTED WSEL,CWSEL

 11-28-90     10:39:13                                                                                  PAGE
7

   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN        SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
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3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      428.38 ELREA=      426.38

     1.01       .40    424.25    424.25       .00    424.38       .13       .69       .00    427.85
     100.        0.      100.        0.        0.       63.        0.    14454.    39685.    428.25
    41.47       .00      1.59       .00      .025      .027      .025      .000    423.85  23816.81
  .011839     2543.     2543.     2543.        20        21         0       .00    252.13  24068.93

1645 INT SEC ADDED BY RAISING SEC      1.01,   2.850FT AND MULTIPLYING BY    .739

3301 HV CHANGED MORE THAN HVINS

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      431.05 ELREA=      429.85

     1.02       .99    427.69       .00       .00    427.71       .02      3.32       .01    430.70
     100.        0.      100.        0.        0.      176.        0.    14758.    40323.    431.10
    42.72       .00       .57       .00      .025      .030      .025      .000    426.70  17546.43
  .000470     2543.     2543.     2543.         7         0         0       .00    249.97  17796.40

1645 INT SEC ADDED BY RAISING SEC      1.02,   2.850FT AND MULTIPLYING BY    .647

3301 HV CHANGED MORE THAN HVINS

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      433.72 ELREA=      433.33

     1.03       .72    430.27       .00       .00    430.37       .09      2.66       .00    433.55
     100.        0.      100.        0.        0.       73.        0.    15076.    40823.    433.95
    43.24       .00      1.37       .00      .025      .030      .025      .000    429.55  11376.07
  .004035     2543.     2543.     2543.         3         0         0       .00    143.36  11519.43

 11-28-90     10:39:13                                                                   PAGE
8

    SECNO     DEPTH     CWSEL     CRIWS     WSELK        EG        HV        HL     OLOSS  BANK ELEV
        Q      QLOB       QCH      QROB      ALOB       ACH      AROB       VOL       TWA LEFT/RIGHT
     TIME      VLOB       VCH      VROB       XNL      XNCH       XNR       WTN     ELMIN       SSTA
    SLOPE     XLOBL      XLCH     XLOBR    ITRIAL       IDC     ICONT     CORAR    TOPWID      ENDST

1645 INT SEC ADDED BY RAISING SEC      1.03,   2.850FT AND MULTIPLYING BY    .455

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=      436.40 ELREA=      436.80

     7.00      1.63    434.03       .00       .00    434.08       .05      3.70       .00    436.40
     100.        0.      100.        0.        0.      105.        0.    15303.    41124.    436.80
    43.98       .00       .95       .00      .025      .031      .025      .000    432.40   5152.05
  .000744     2543.     2543.     2543.         5         0         0       .00     92.84   5244.89

1490 NH CARD USED
*SECNO 6.000

1645 INT SEC ADDED BY RAISING SEC      6.00,  -5.950FT AND MULTIPLYING BY   1.181

     1.01      1.44    439.79       .00       .00    439.88       .09      5.80       .00    444.25
     100.        0.      100.        0.        0.       76.        0.    15864.    41656.    444.15
    45.28       .00      1.32       .00      .025      .026      .025      .000    438.35    235.78
  .001212     6194.     6194.     6194.         5         0         0       .00     79.08    314.86

1645 INT SEC ADDED BY RAISING SEC      1.01,   5.950FT AND MULTIPLYING BY    .847

     6.00      1.68    445.98       .00       .00    446.06       .08      6.18       .00    450.20
     100.        0.      100.        0.        0.       80.        0.    16347.    42113.    450.10
    46.67       .00      1.24       .00      .025      .026      .035      .000    444.30    199.00
  .000836     6194.     6194.     6194.         5         0         0       .00     68.41    267.42

1490 NH CARD USED
*SECNO 5.000

3265 DIVIDED FLOW

     5.00      2.31    454.91       .00       .00    455.00       .09      8.95       .00    460.60
     100.        0.      100.        0.        0.       75.        0.    17035.    42630.    460.20
    48.52       .00      1.33       .00      .025      .035      .035      .000    452.60    200.11
  .001255     8823.     8823.     8823.         4         0         0       .00     48.78    289.88

 11-28-90     10:39:13                                                                   PAGE
9

    SECNO     DEPTH     CWSEL     CRIWS     WSELK        EG        HV        HL     OLOSS  BANK ELEV
        Q      QLOB       QCH      QROB      ALOB       ACH      AROB       VOL       TWA LEFT/RIGHT
     TIME      VLOB       VCH      VROB       XNL      XNCH       XNR       WTN     ELMIN       SSTA
    SLOPE     XLOBL      XLCH     XLOBR    ITRIAL       IDC     ICONT     CORAR    TOPWID      ENDST

1490 NH CARD USED
*SECNO 4.000
     4.00       .92    467.42       .00       .00    467.53       .10     12.53       .00    469.60
     100.        0.      100.        0.        0.       70.        0.    17638.    43213.    469.20
    50.13       .00      1.43       .00      .025      .025      .027      .000    466.50    326.39
  .001847     8305.     8305.     8305.         5         0         0       .00     91.62    418.01

1490 NH CARD USED
*SECNO 3.000

1645 INT SEC ADDED BY RAISING SEC      3.00,  -3.950FT AND MULTIPLYING BY   1.739
```

```
3265 DIVIDED FLOW

3301 HV CHANGED MORE THAN HVINS

     1.01     1.66   472.11      .00      .00   472.13      .02     4.59      .01   472.45
     100.       0.     100.       0.       0.     178.       0.   18216.   44011.   472.95
    52.43      .00      .56      .00     .035     .035     .027     .000   470.45   384.79
  .000613    4651.    4651.    4651.        5        0        0      .00   251.82   750.12

1645 INT SEC ADDED BY RAISING SEC      1.01,   3.950FT AND MULTIPLYING BY     .575

3265 DIVIDED FLOW

     3.00     1.76   476.16      .00      .00   476.19      .04     4.07      .00   476.40
     100.       0.     100.       0.       0.     116.       0.   18901.   44961.   476.90
    53.94      .00      .86      .00     .035     .035     .027     .000   474.40   221.10
  .001349    4651.    4651.    4651.        3        0        0      .00   156.50   433.85

1490 NH CARD USED
*SECNO 2.000

3265 DIVIDED FLOW

     2.00     1.72   489.02      .00      .00   489.05      .03    12.85      .00   490.40
     100.       0.     100.       0.       0.     138.       0.   20123.   46861.   490.40
    57.62      .00      .73      .00     .035     .035     .027     .000   487.30   724.07
  .001326    9611.    9611.    9611.        4        0        0      .00   238.98  1080.80

 11-28-90     10:39:13                                                                              PAGE
10

    SECNO    DEPTH    CWSEL    CRIWS    WSELK       EG       HV       HL    OLOSS  BANK ELEV
    Q        QLOB     QCH      QROB     ALOB        ACH      AROB     VOL   TWA    LEFT/RIGHT
    TIME     VLOB     VCH      VROB     XNL         XNCH     XNR      WTN   ELMIN        SSTA
    SLOPE    XLOBL    XLCH     XLOBR    ITRIAL      IDC      ICONT    CORAR TOPWID      ENDST

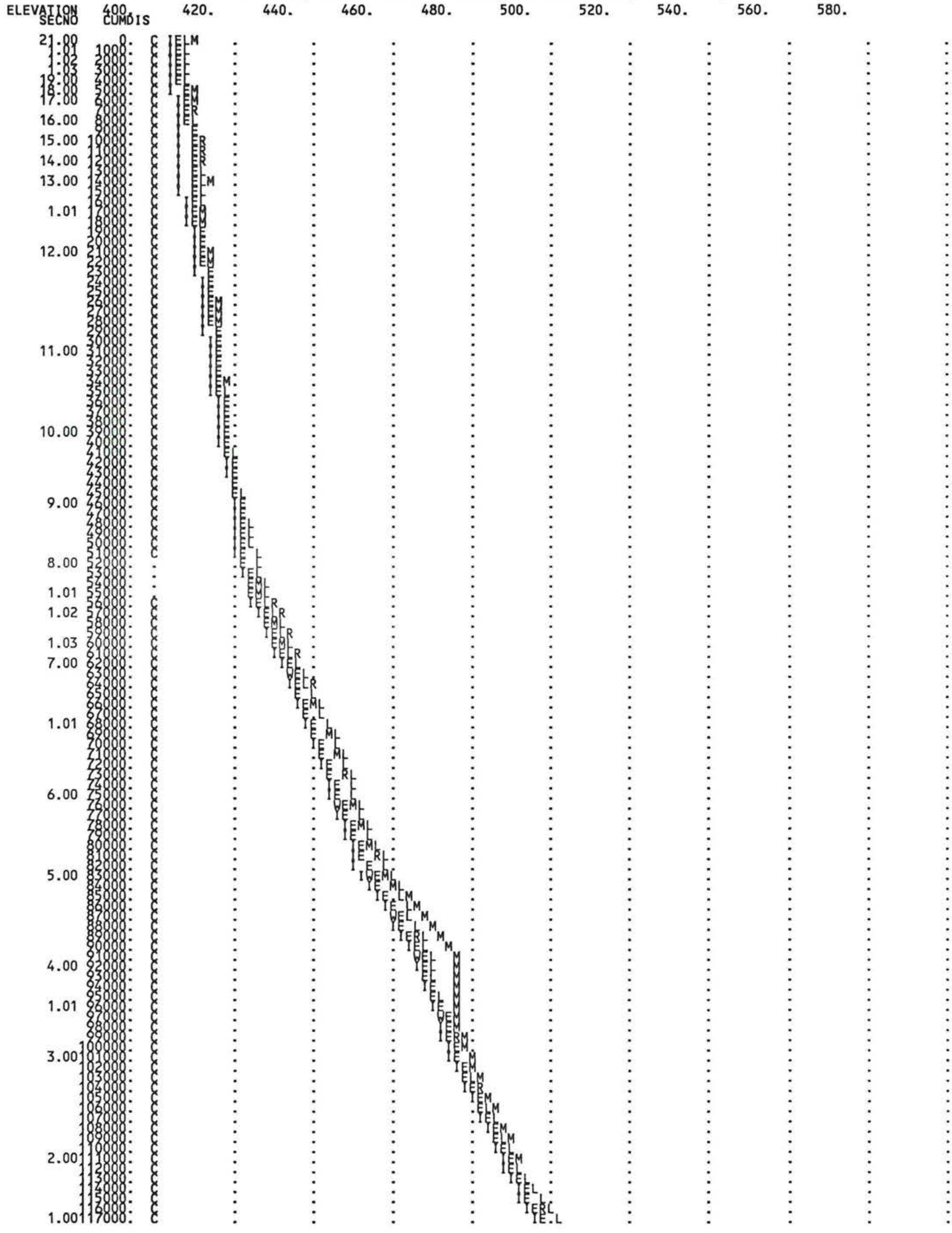
1490 NH CARD USED
*SECNO 1.000

3265 DIVIDED FLOW

     1.00     1.59   498.29      .00      .00   498.33      .05     9.28      .00   502.60
     100.       0.     100.       0.       0.     105.       0.   20924.   48260.   501.40
    59.54      .00      .95      .00     .035     .028     .027     .000   496.70   282.95
  .001496    6598.    6598.    6598.        4        0        0      .00   184.89   504.41
```

APPENDIX E cont'd
Profile for Stream Cross Sections 21 - 1

PLOTTED POINTS (BY PRIORITY)-E-ENERGY,W-WATER SURFACE,I-INVERT,C-CRITICAL W.S.,L-LEFT BANK,R-RIGHT BANK,M-LOWER END STA



FIGURES

List of Figures

1 Location Plan
2 Location of Surveyed Cross Sections
3 Location of Rainfall and Streamflow Gauging Stations and Thiessen Polygons
4 Rainfall Sites - Periods of Available Record
5 Mt Newman - Station E11 - Mean Daily Evaporation (1981 - 1990)
6 Annual Rainfall Series - Balfour Downs, Ethel Creek, Roy Hill, Mundiwindi, Sylvania, and Newman P.O.
7 Annual Rainfall Series - Prairie Downs, Capricorn Road House, Jiggalong, South Giles, East Giles, and Southern Fortescue
8 Box Plots - Ethel Creek Daily Rainfall (M005 003)
9 Box Plots - Newman P.O. Daily Rainfall (M007 151)
10 Box Plots - Jiggalong Daily Rainfall (M013 003)
11 Box Plots - Roy Hill Daily Rainfall (M005 023)
12 Dam and Bore Water Levels
13 Location of Groundwater Bores - T387, W81 and W93
14 Comparison of Simulated and Recorded Monthly Runoffs at Newman Bridge
15 Comparison of Simulated and Recorded Daily Runoffs at Newman Bridge
16 Estimated Monthly Flows at Newman Bridge
17 Comparison of Estimated Annual Totals at Ophthalmia Dam with Tahal's and GHD'S
18 Subdivision of Fortescue River Catchment
19 Sub-Areas of Fortescue River Catchment
20 Schematised Layout of Fortescue River Catchment for FLOUT model
21 Regions used for Calculations of Antecedent Catchment Conditions
22 Procedure used for Calculations of Runoff Coefficient
23 Derived Rating Curve for Roy Hill Gauging Station
24 Event Model - Comparison of Modelled and Observed Hydrographs
25 FLOUT Calibration Events - Rainfall Distribution
26 FLOUT Calibration Events - Flow Distribution
27 Ophthalmia Dam - Monthly Median Dam Levels
28 Simulated Flood Hydrographs at Upstream & Downstream of Jiggalong Confluence for Ten Largest Modelled Events
29 Simulated Flood Hydrographs at Upstream & Downstream of Jiggalong Confluence for Ten Largest Modelled Events
30 FLOUT Modelled Results - Post-Dam Events at Cross Section 5 (Double Channel One)
31 FLOUT Modelled Results - Post-Dam Events at Cross Section 7 (Seven Mile Bore)
32 FLOUT Modelled Results - Post-Dam Events at Cross Section 8 (Ethel Creek)
33 FLOUT Modelled Results - Post-Dam Events at Cross Section 10 (Irwin's Well)
34 FLOUT Modelled Results - Post-Dam Events at Cross Section 11 (Battle Hill)
35 FLOUT Modelled Results - Post-Dam Events at Cross Section 12 (Five Mile Bore)
36 FLOUT Modelled Results - Frequency Plots at Cross Section 5 (Double Channel One)
37 FLOUT Modelled Results - Frequency Plots at Cross Section 7 (Seven Mile Bore)
38 FLOUT Modelled Results - Frequency Plots at Cross Section 8 (Ethel Creek)
39 FLOUT Modelled Results - Frequency Plots at Cross Section 10 (Irwin's Well)
40 FLOUT Modelled Results - Frequency Plots at Cross Section 11 (Battle Hill)
41 FLOUT Modelled Results - Frequency Plots at Cross Section 12 (Five Mile Bore)
42 Impacts of Ophthalmia Dam on Downstream Areas
43 Flood Width and Flow Relationship
44 Cross Section Profiles - Cross Section 1 to 6
45 Cross Section Profiles - Cross Section 7 to 12
46 Cross Section Profiles - Cross Section 13 to 18
47 Cross Section Profiles - Cross Section 19 to 21

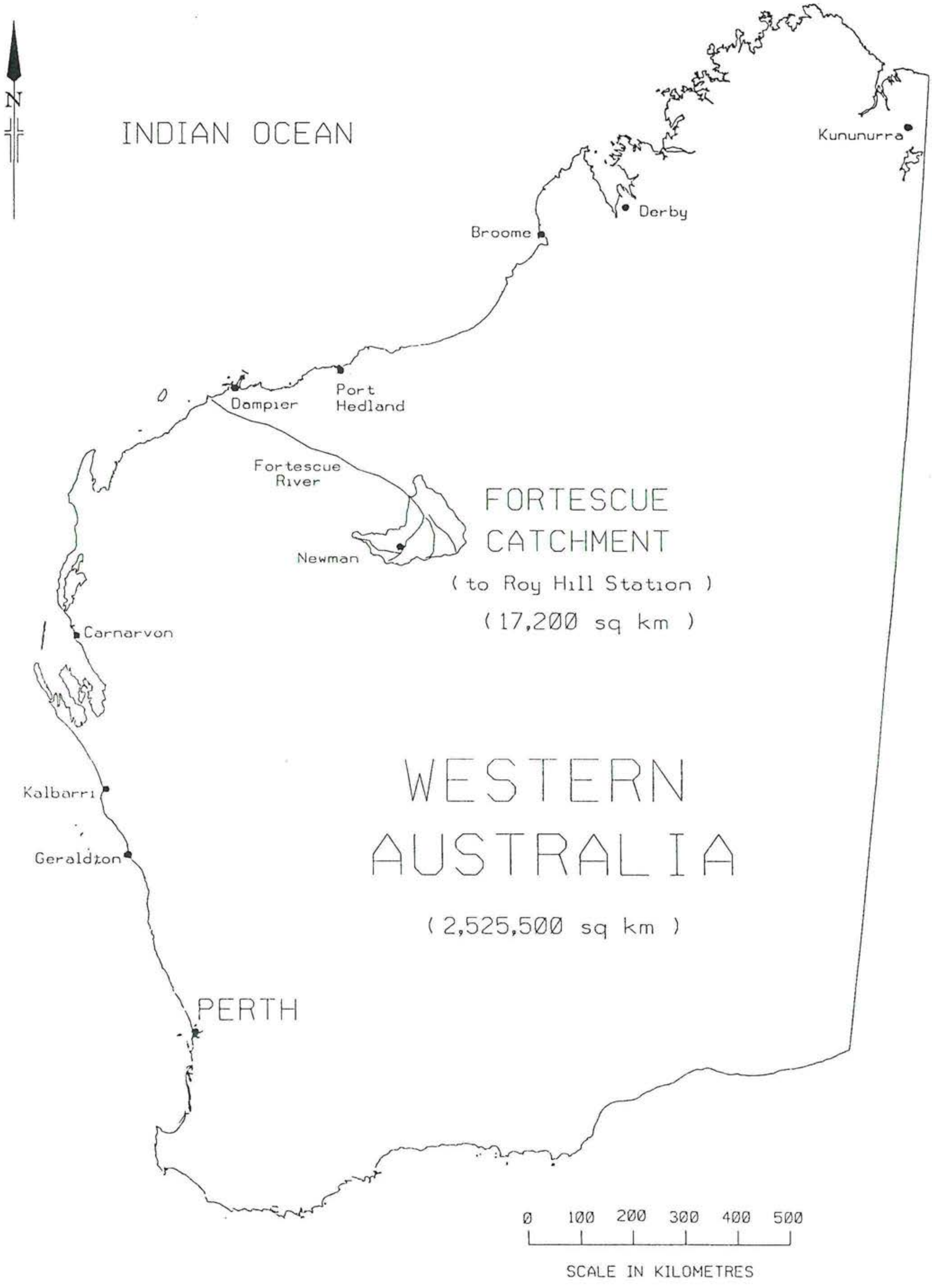


Fig. 1 Location Plan

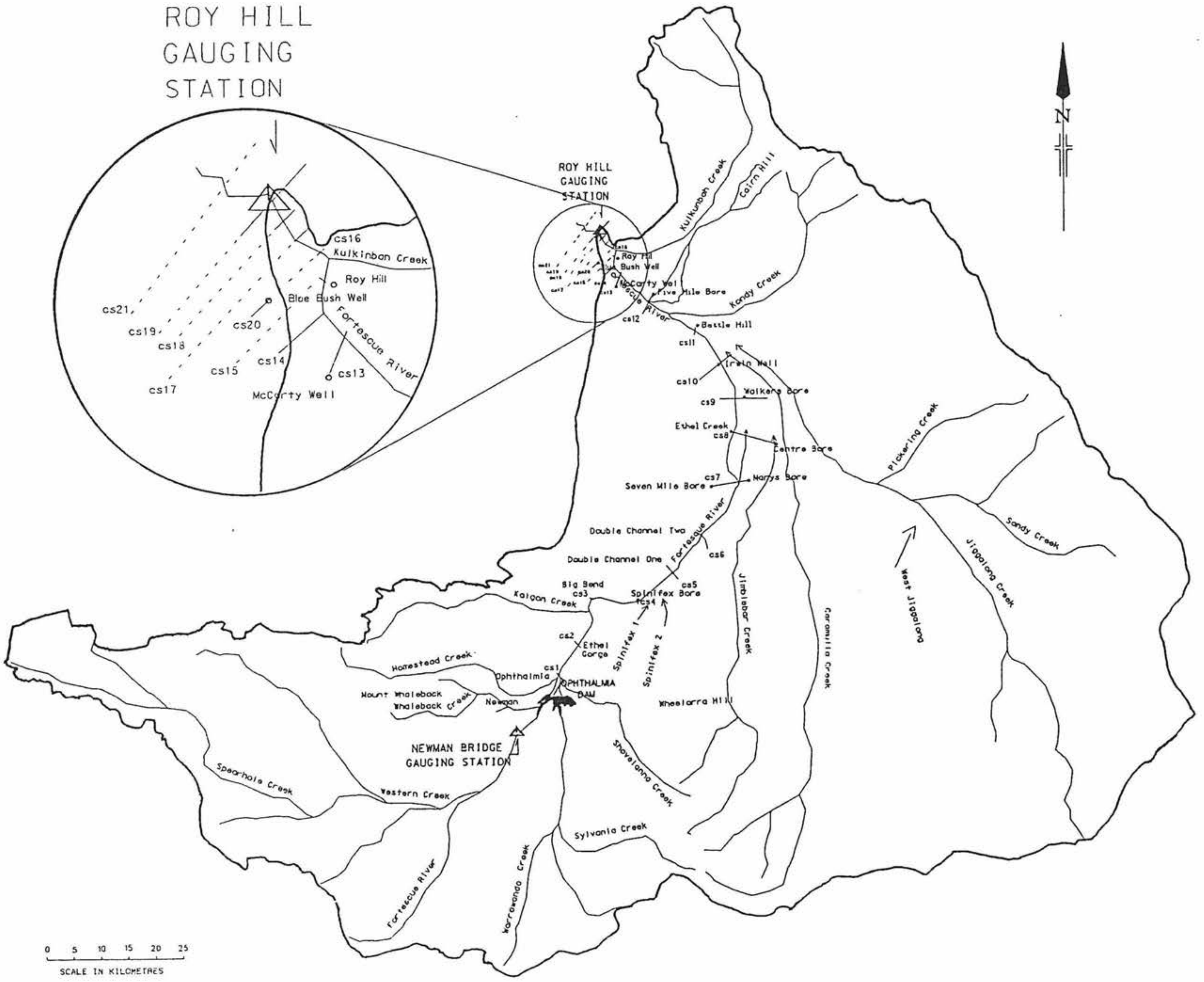


Fig. 2 Location of Surveyed Cross Sections

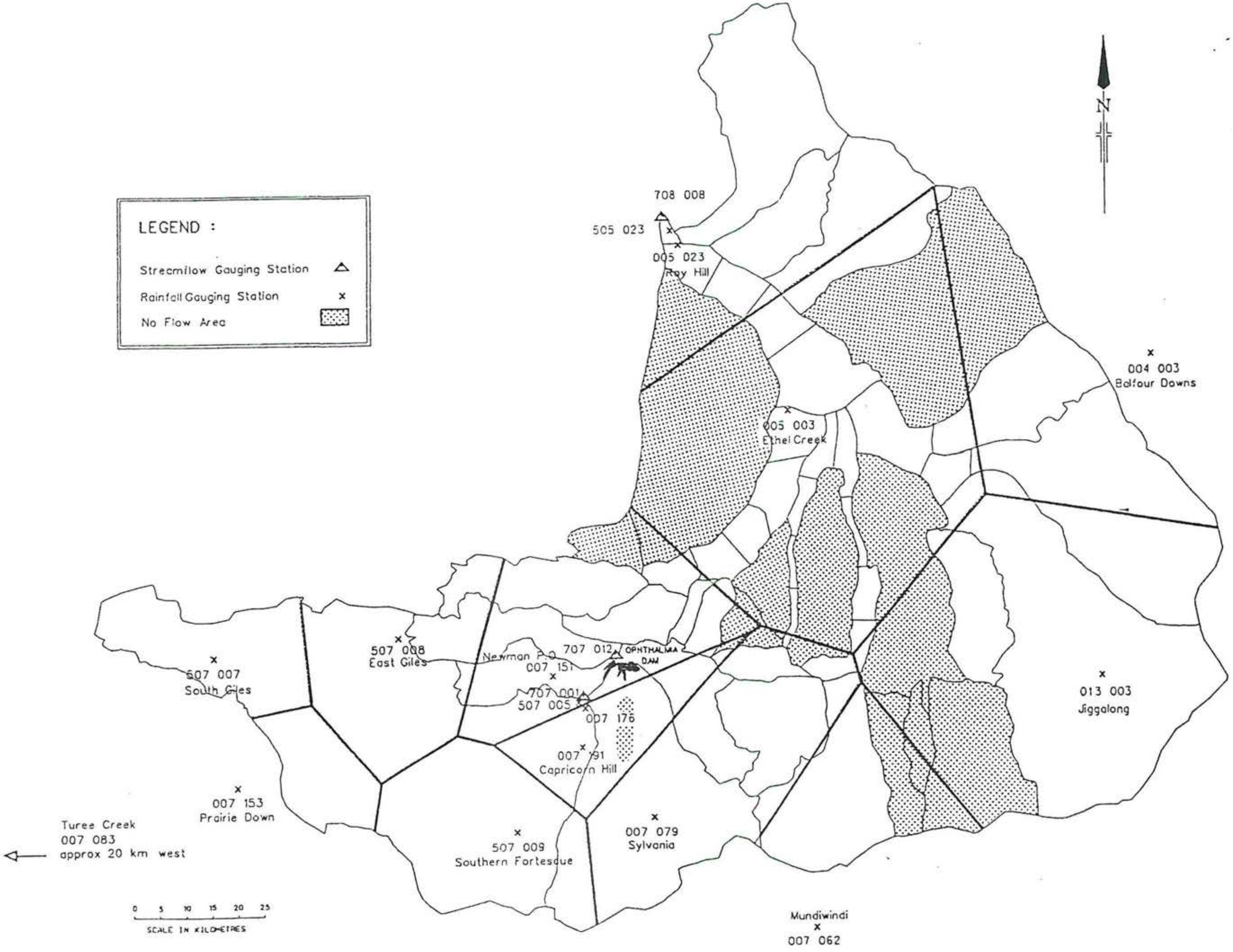


Fig. 3 Location of Rainfall and Streamflow Gauging Stations and Thiessen Polygons

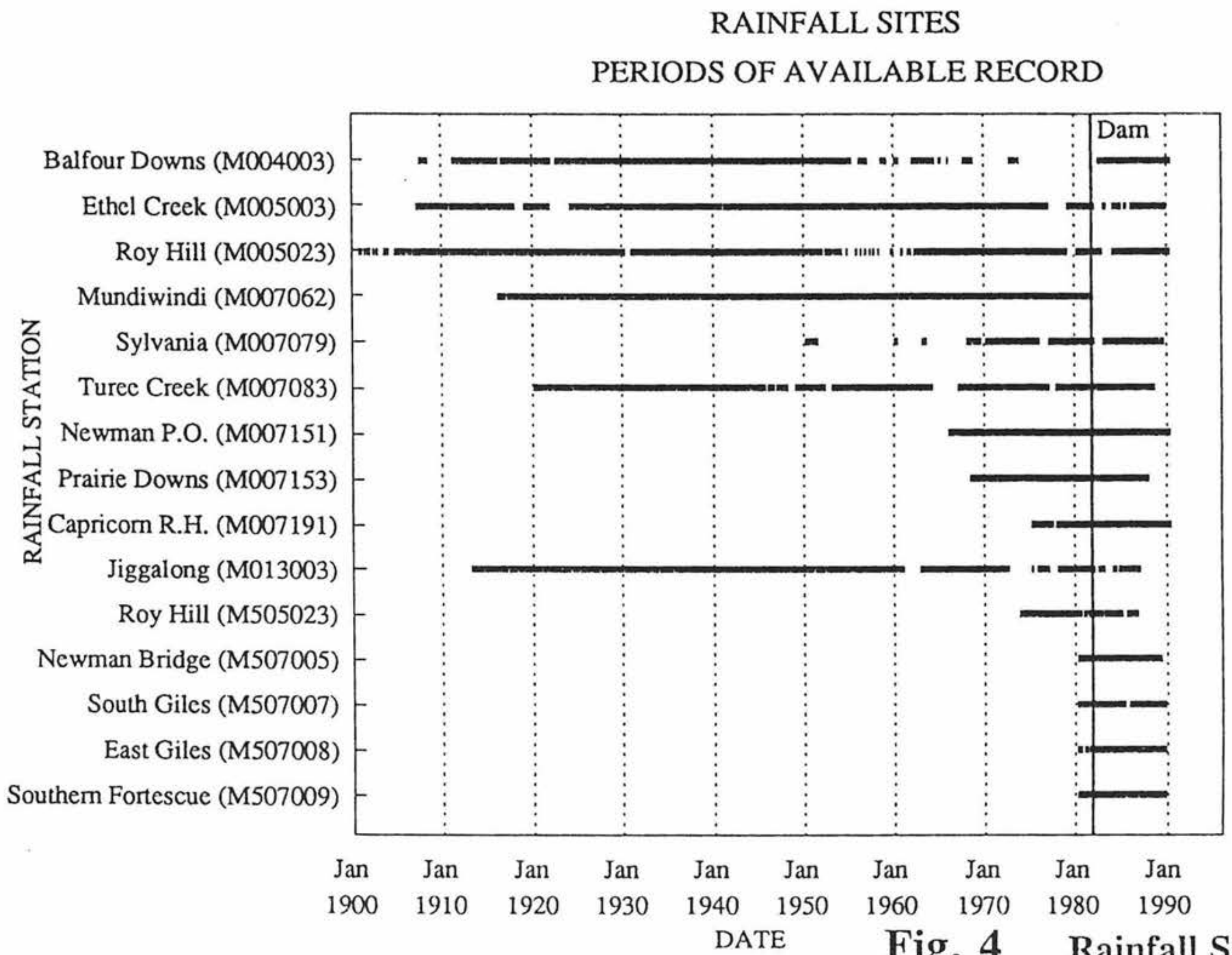


Fig. 4 **Rainfall Sites - Periods of Available Record**

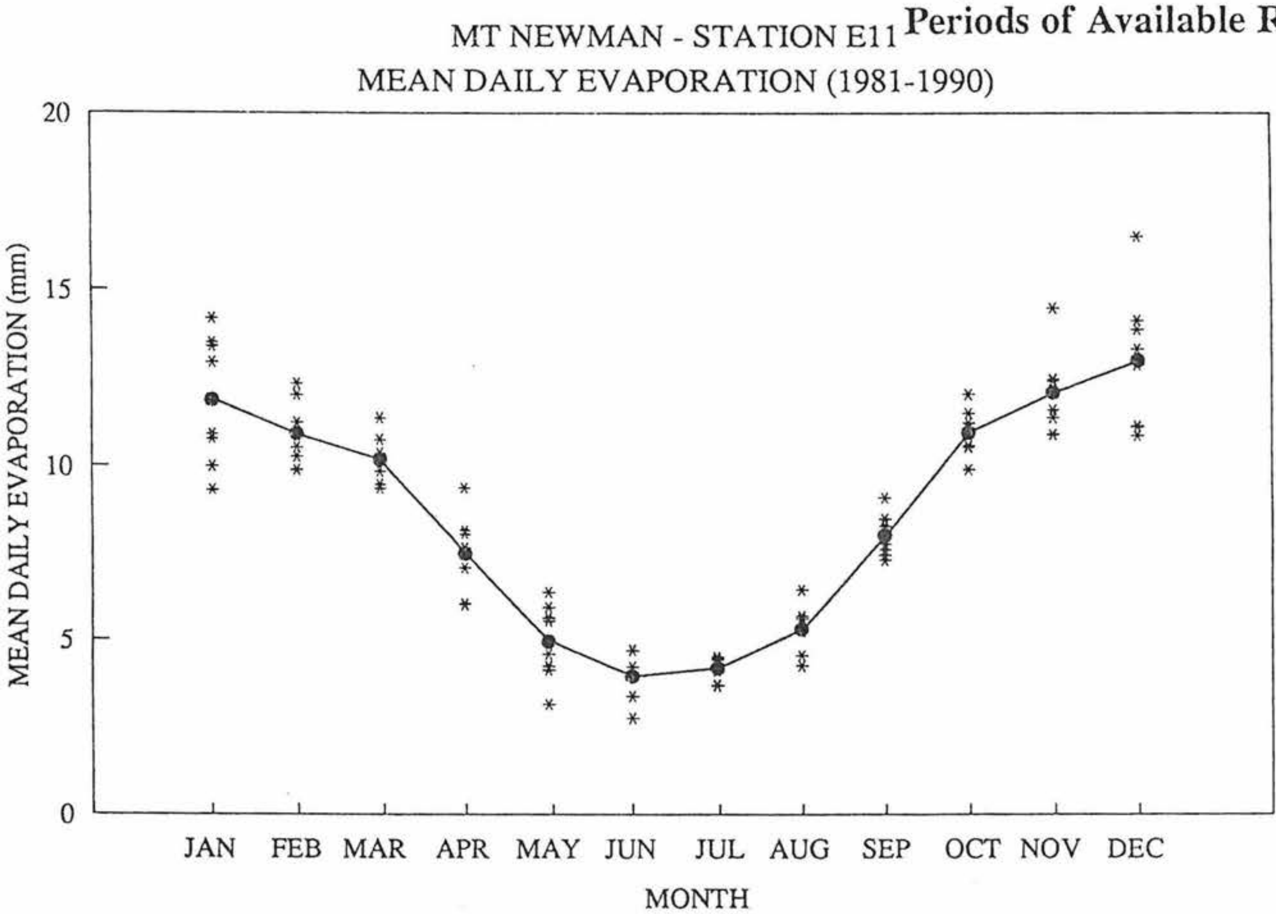


Fig. 5 **Mt Newman - Station E11 - Mean Daily Evaporation (1981 - 1990)**

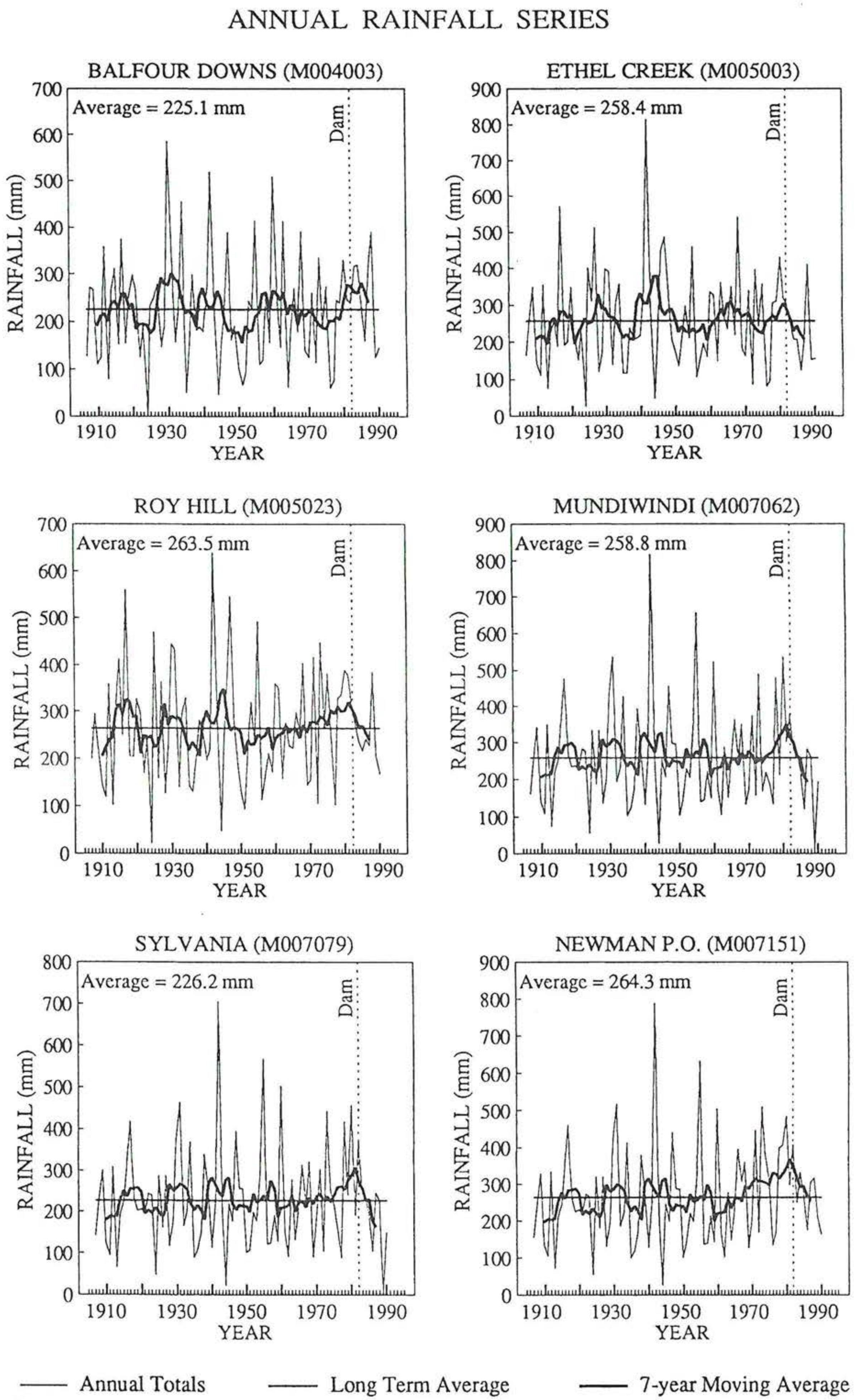


Fig. 6 **Annual Rainfall Series - Balfour Downs, Ethel Creek, Roy Hill, Mundiwindi, Sylvania, and Newman P.O.**

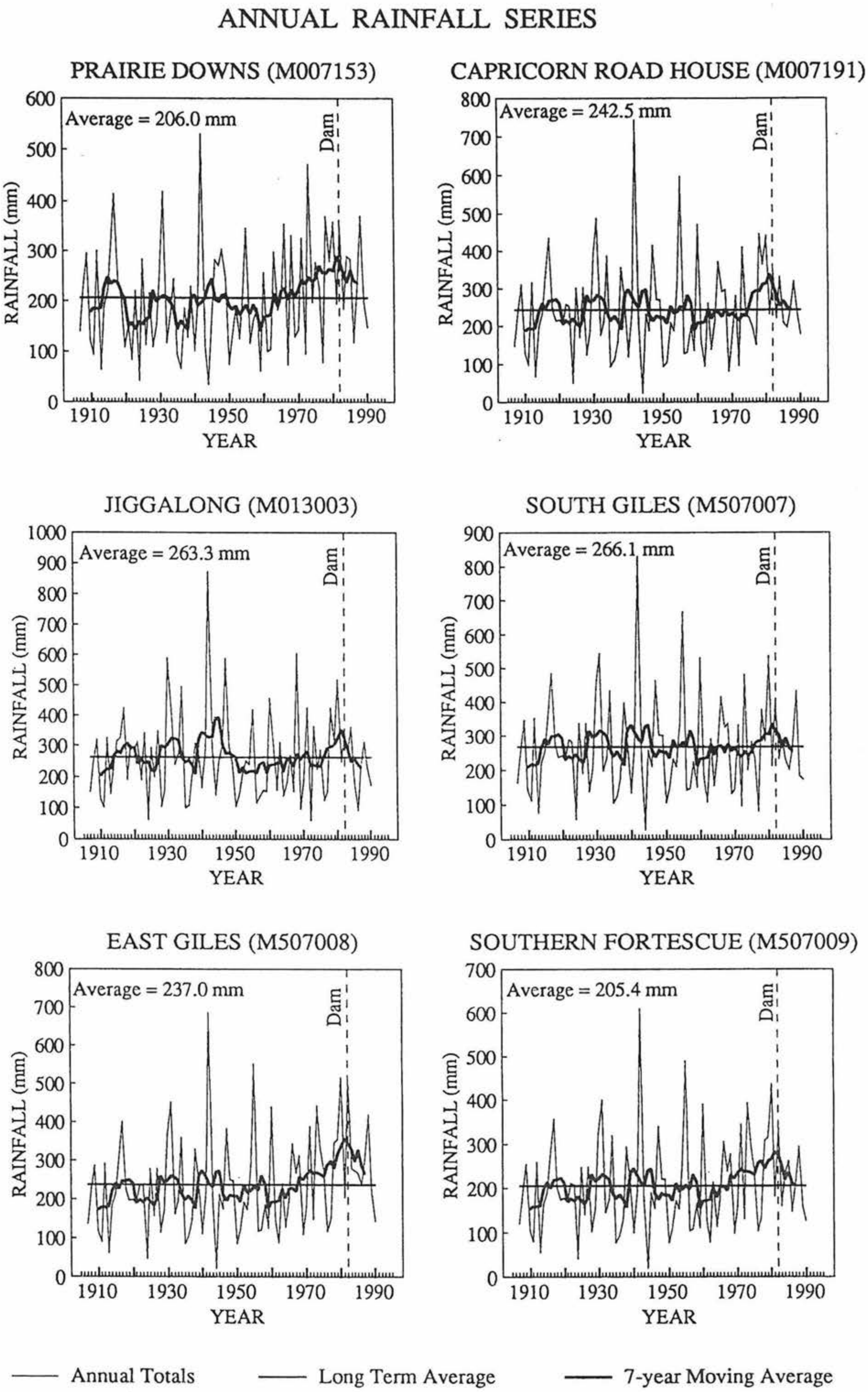
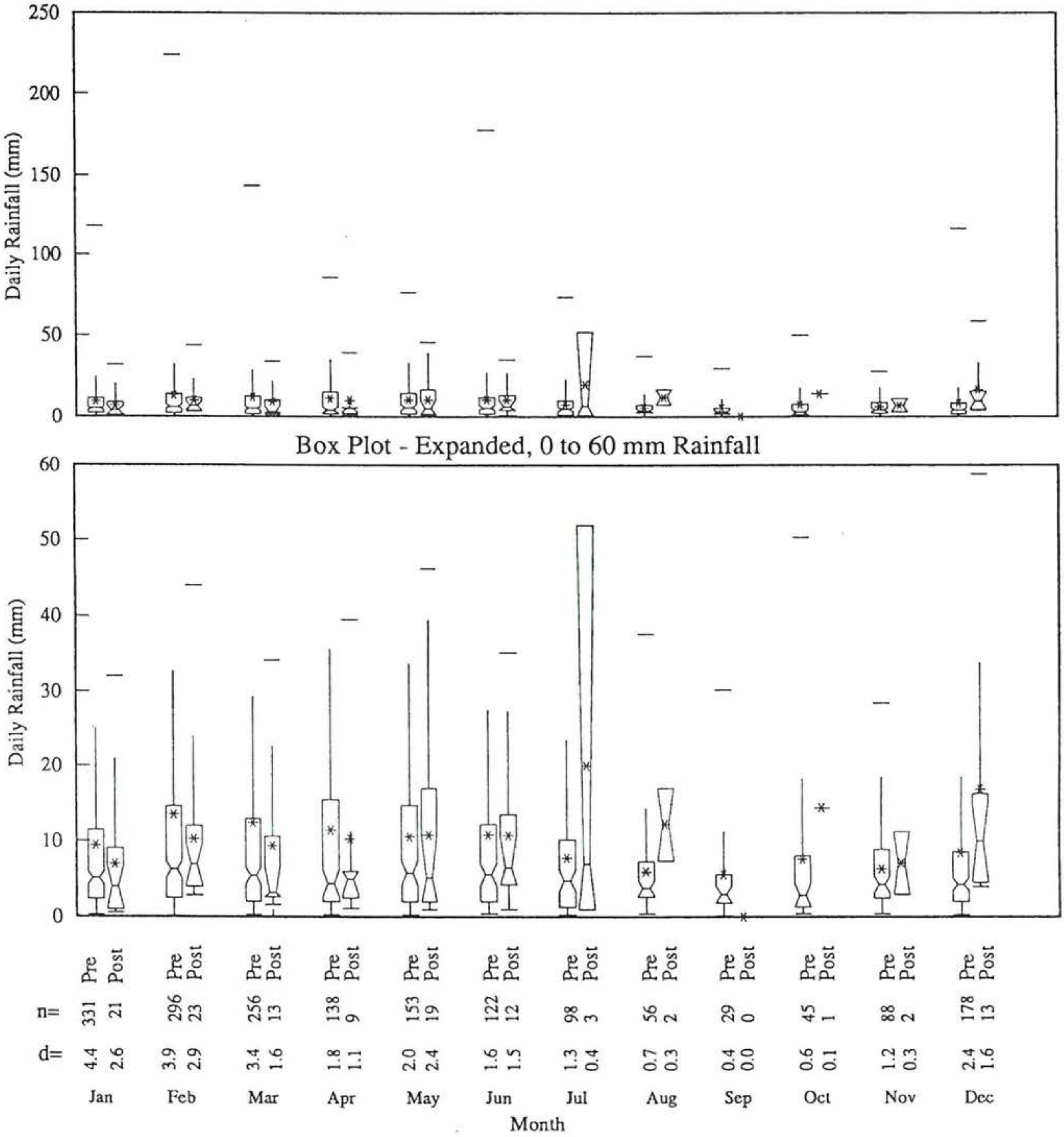


Fig. 7 **Annual Rainfall Series - Prairie Downs, Capricorn Road House, Jiggalong, South Giles, East Giles, and Southern Fortescue**

ETHEL CREEK RAINFALL (M005003) (1907-1989)
Box Plot - Full Scale



Only non-zero, raw data used in analysis.
(ie. Missing record excluded.)

n = Number of non-zero observations.

d= No of raindays per month

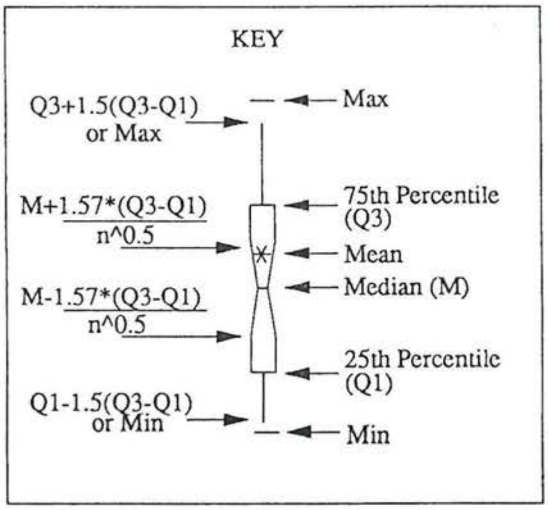


Fig. 8 Box Plots - Ethel Creek Daily Rainfall (M005 003)

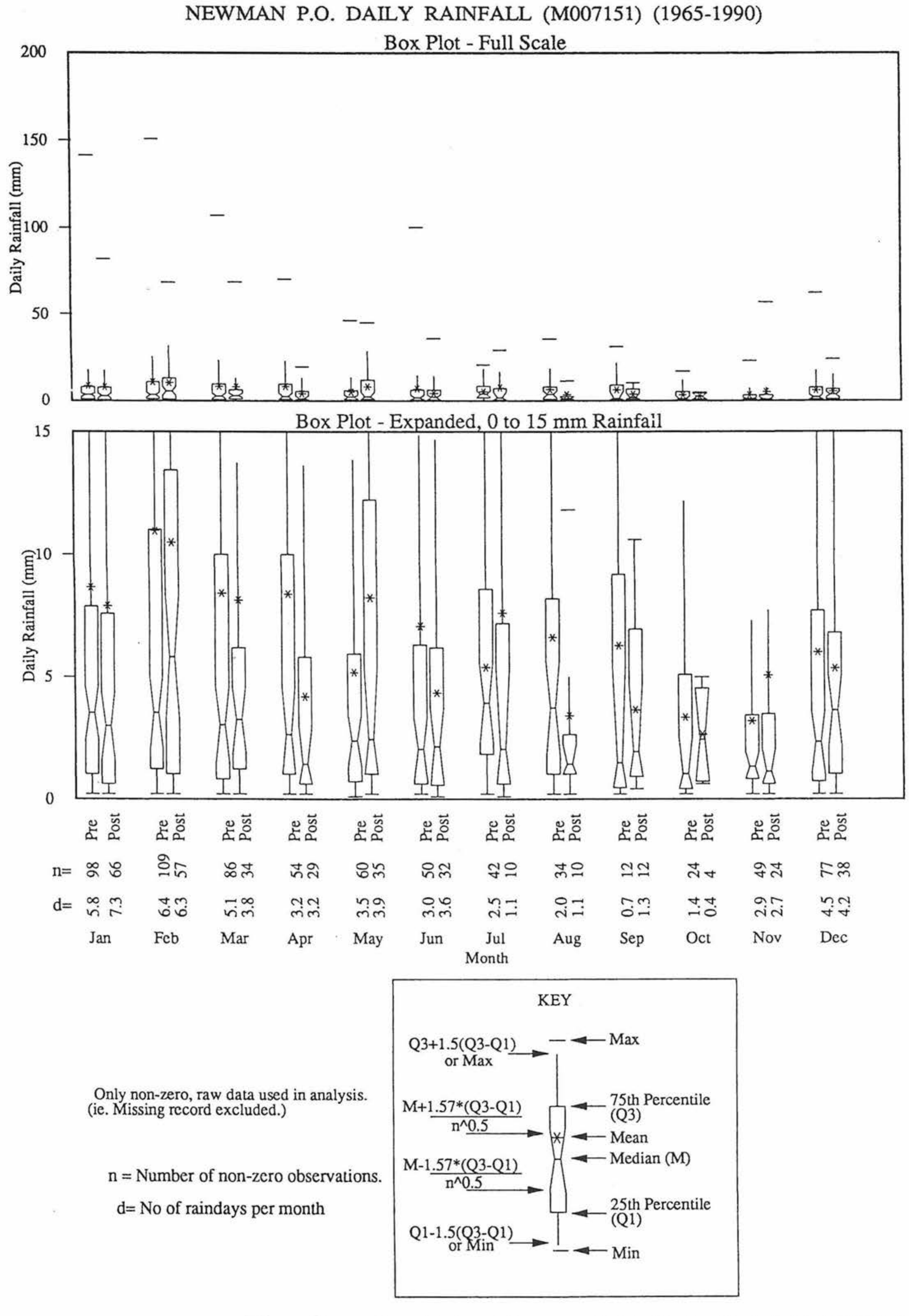


Fig. 9 Box Plots - Newman P.O. Daily Rainfall (M007 151)

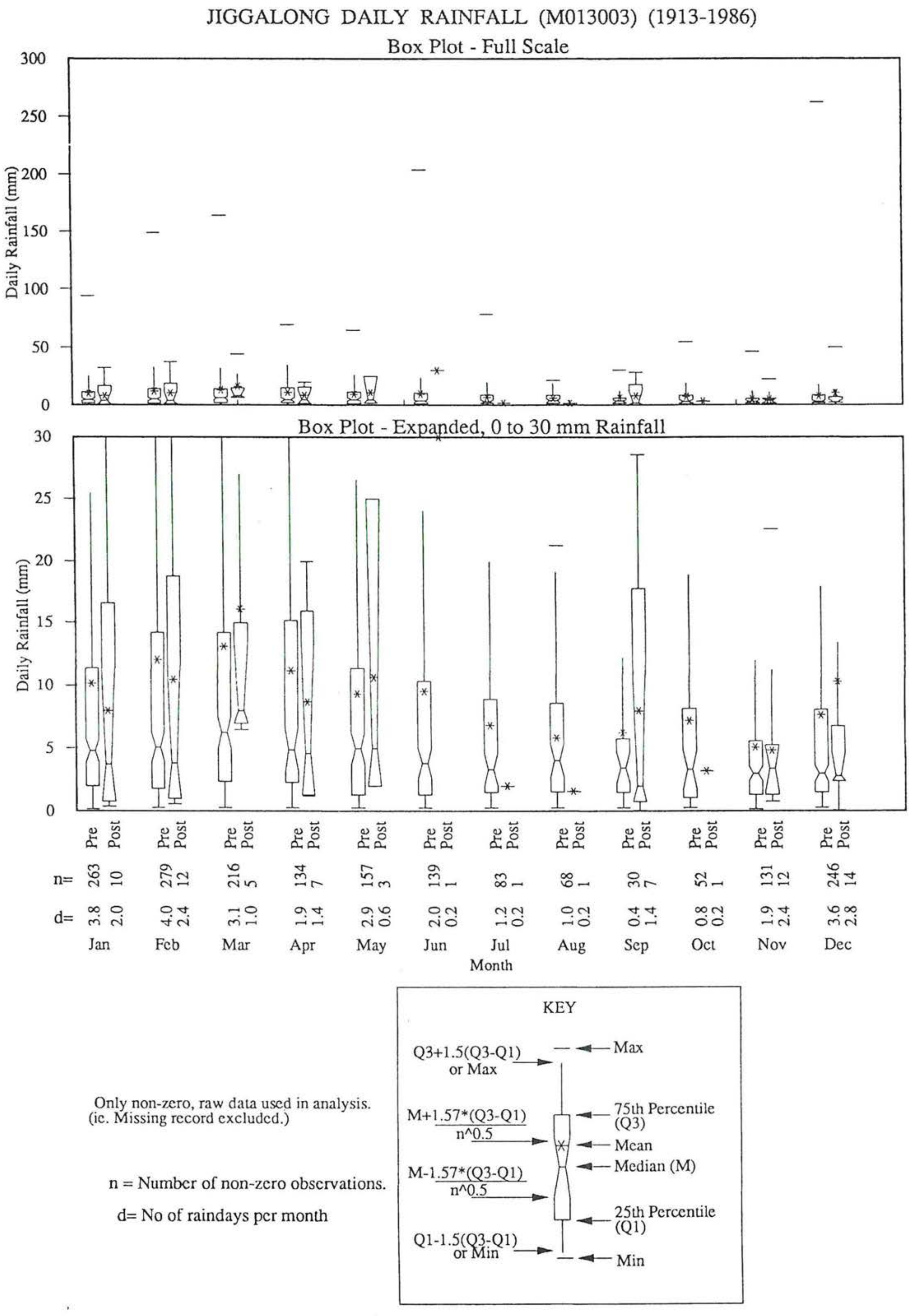


Fig. 10 **Box Plots - Jiggalong Daily Rainfall (M013 003)**

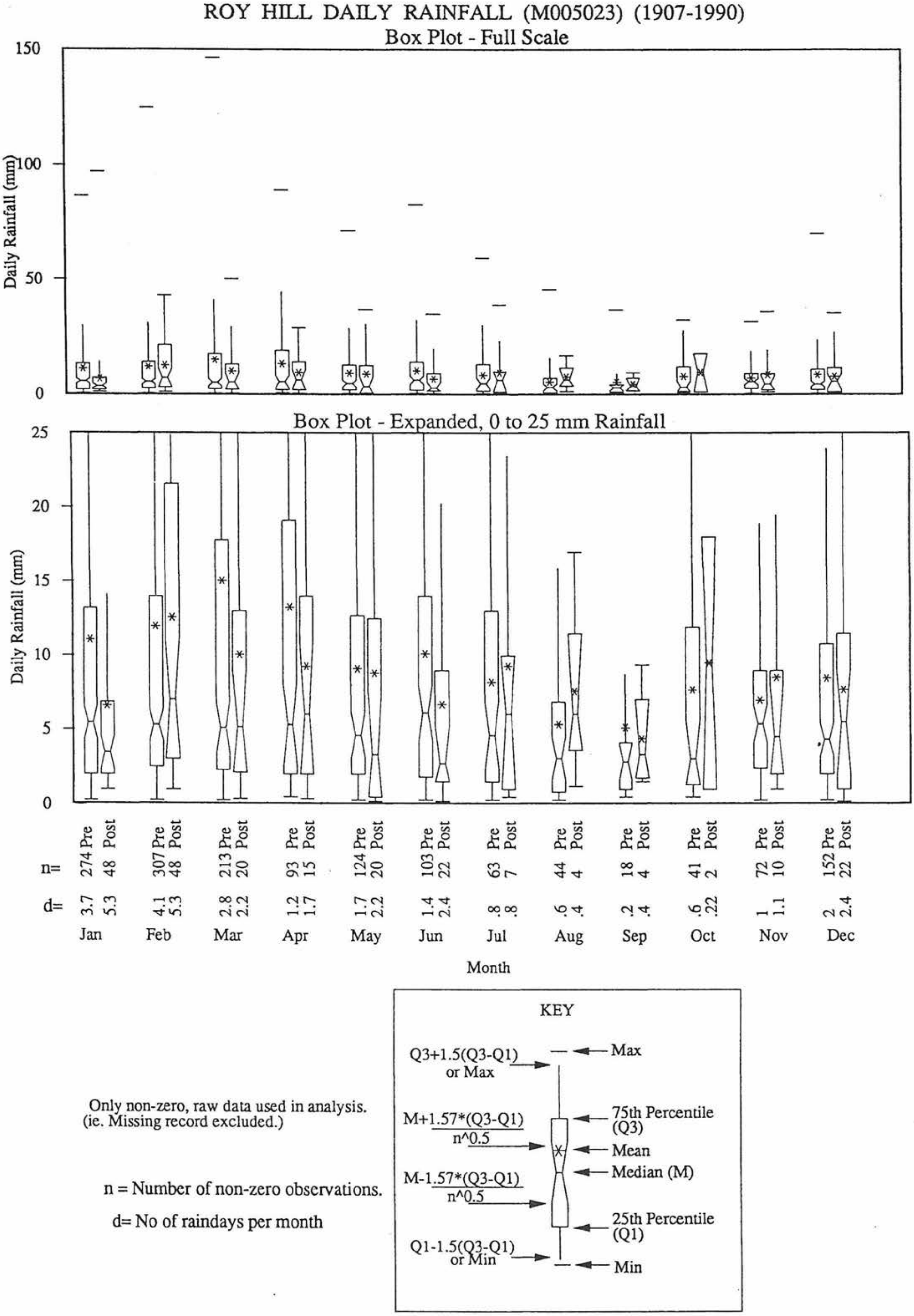


Fig. 11 **Box Plots - Roy Hill Daily Rainfall (M005 023)**

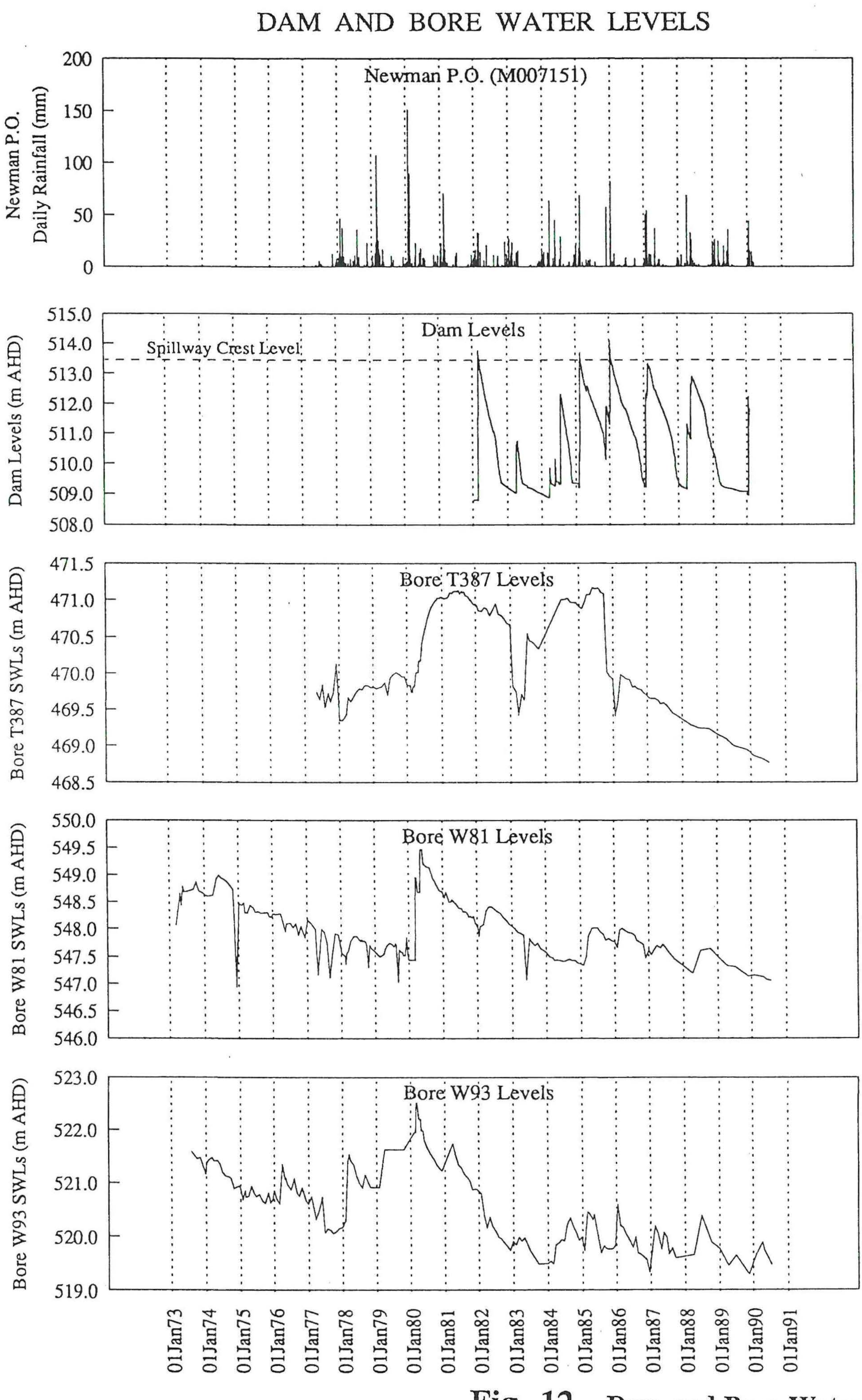


Fig. 12 **Dam and Bore Water Levels**

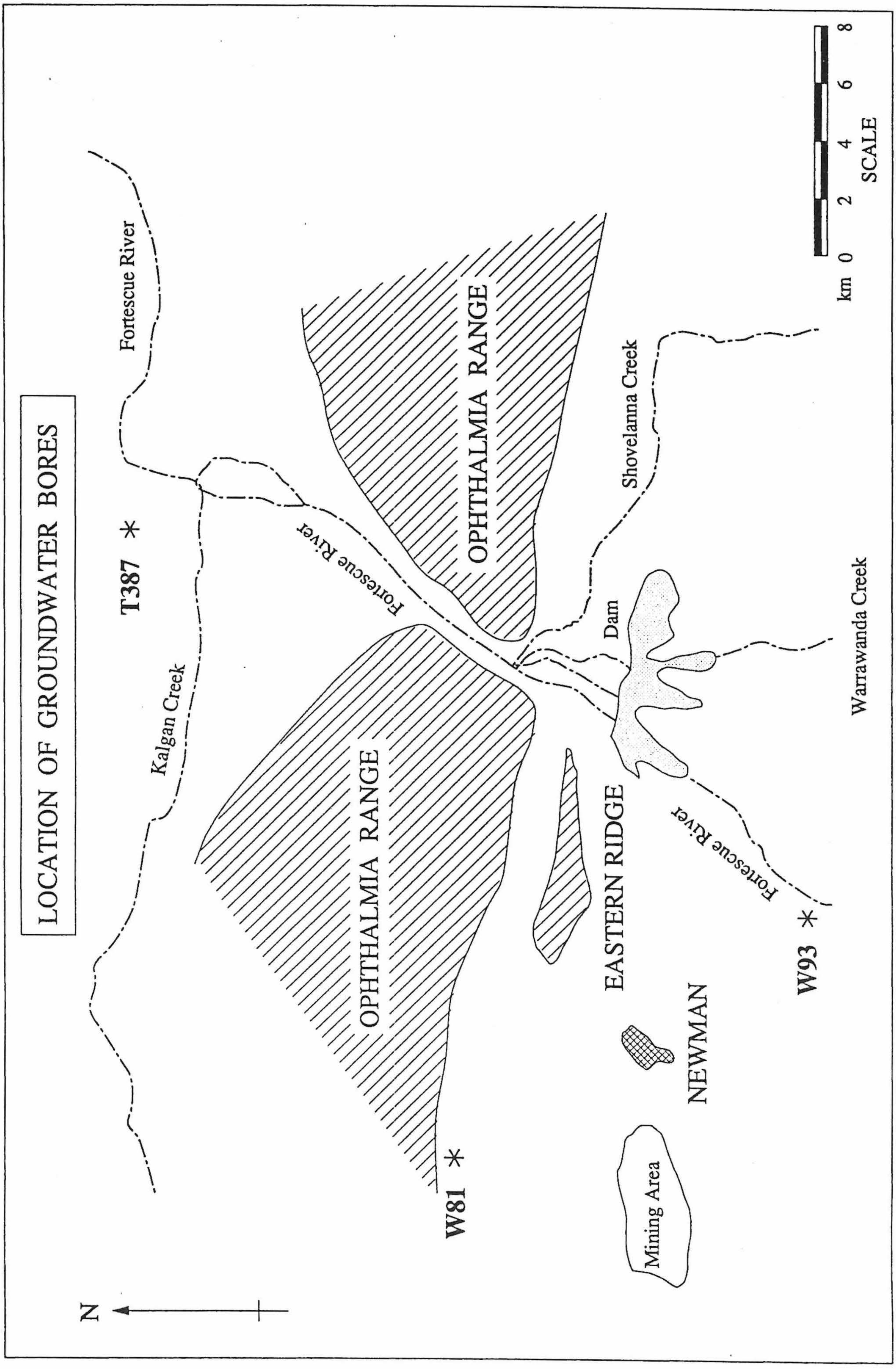


Fig. 13 Location of Groundwater Bores - T387, W81 and W93

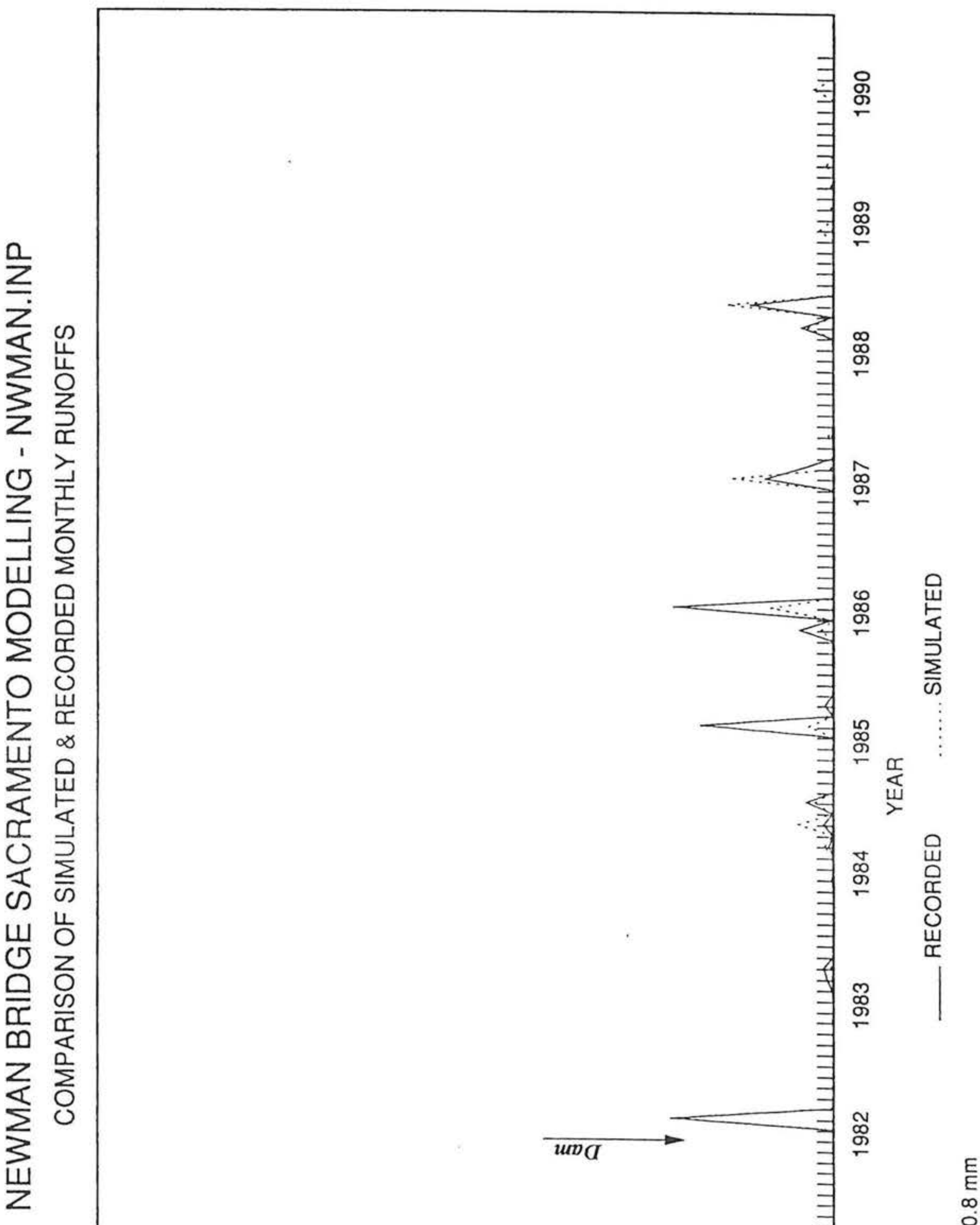


Fig. 14 Comparison of Simulated and Recorded Monthly Runoffs at Newman Bridge

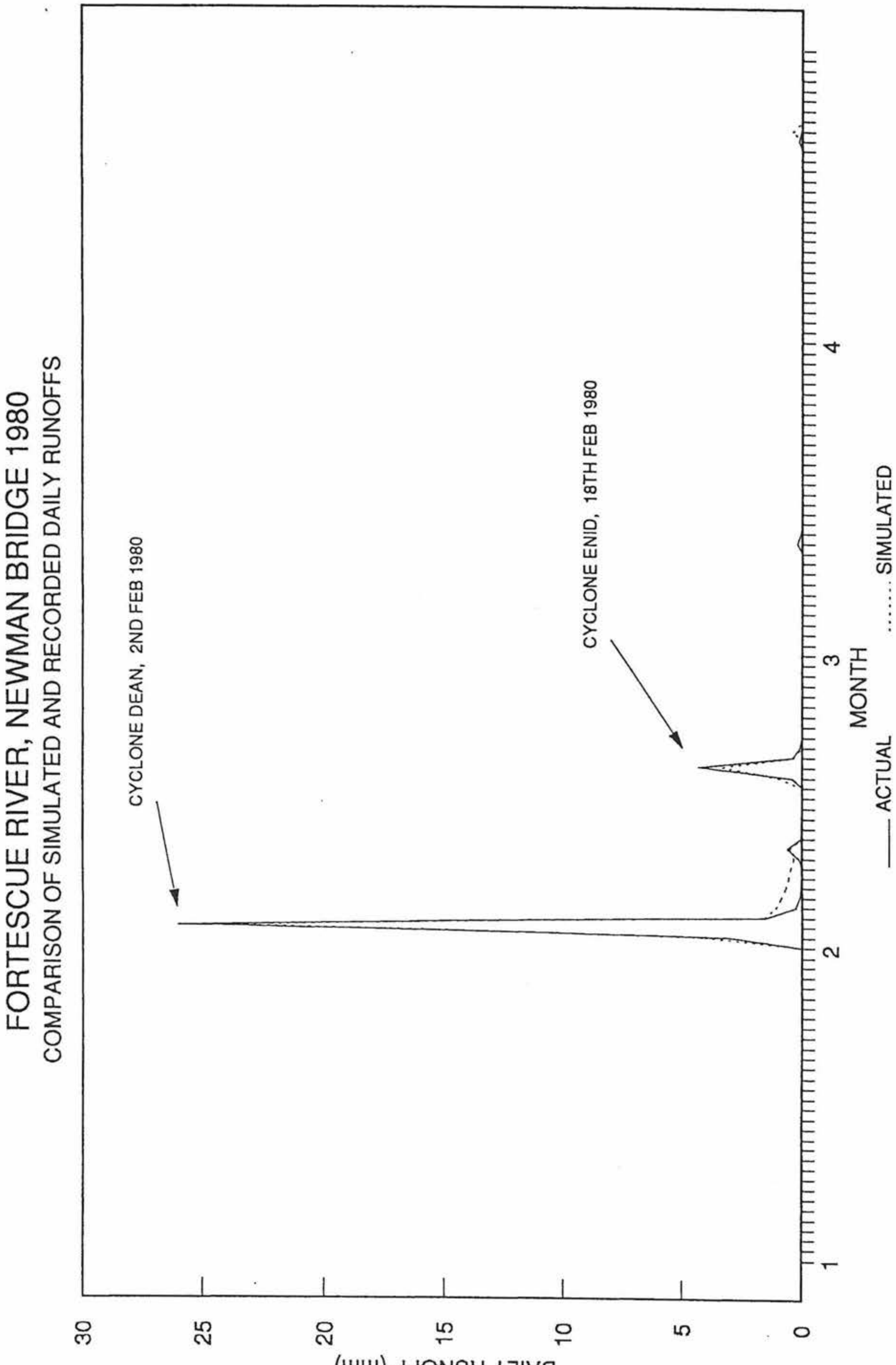


Fig. 15 **Comparison of Simulated and Recorded Daily Runoffs at Newman Bridge**

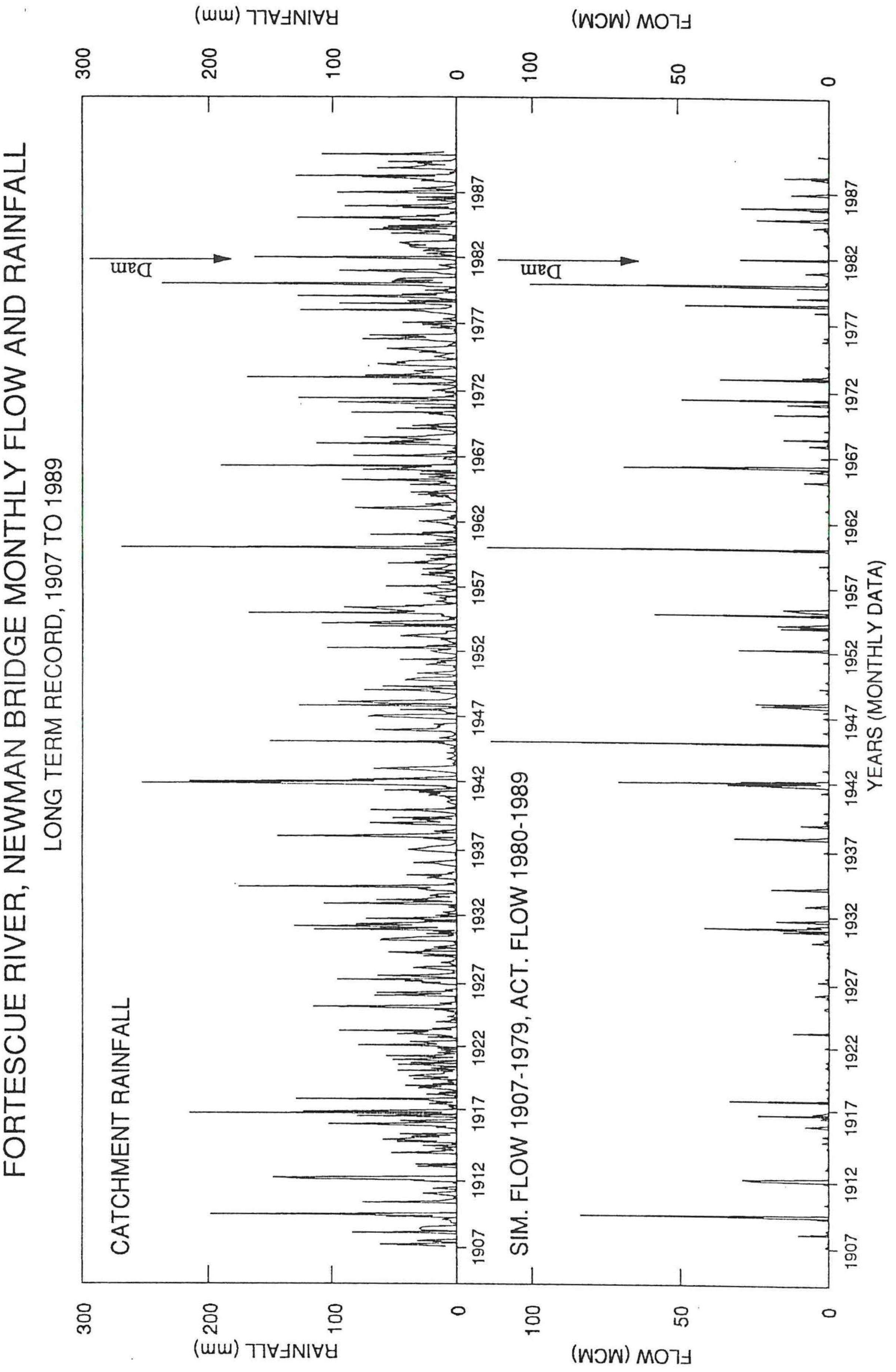


Fig. 16 **Estimated Monthly Flows at Newman Bridge**

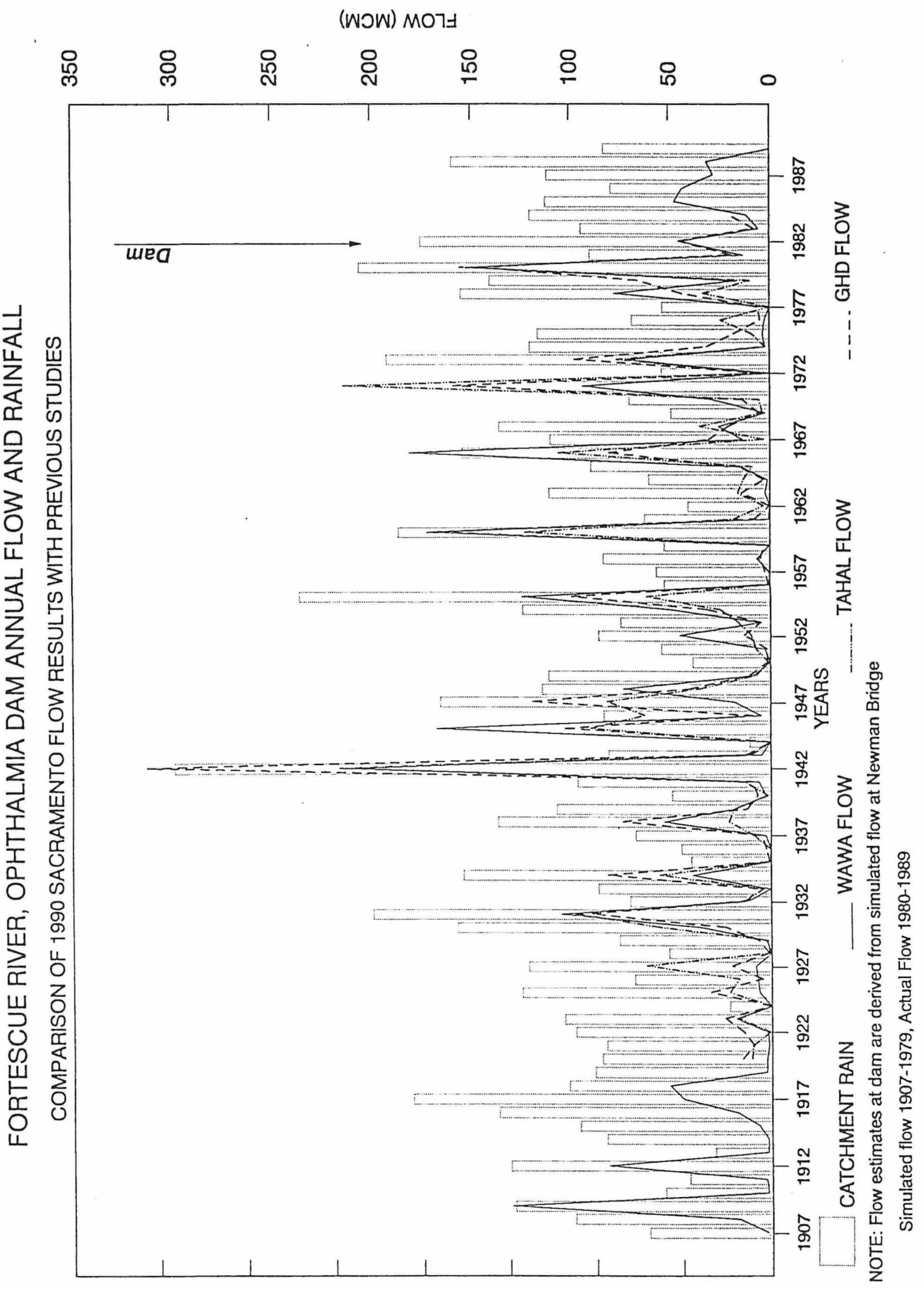


Fig. 17 **Comparison of Estimated Annual Totals at Ophthalmia Dam with Tahal's and GHD'S**

Fig. 18 Subdivision of Fortescue River Catchment

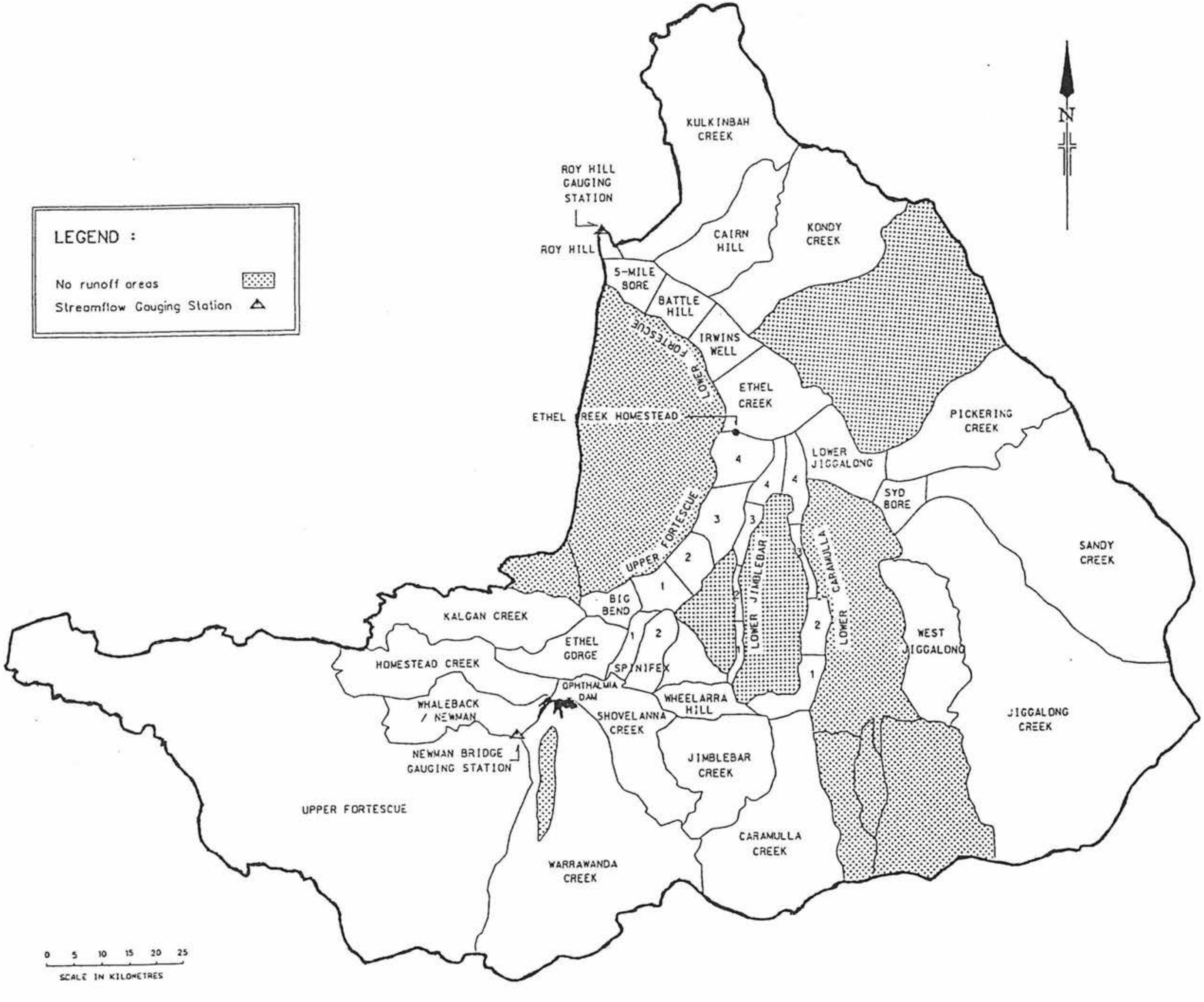


Fig. 19 Sub-Areas of Fortescue River Catchment

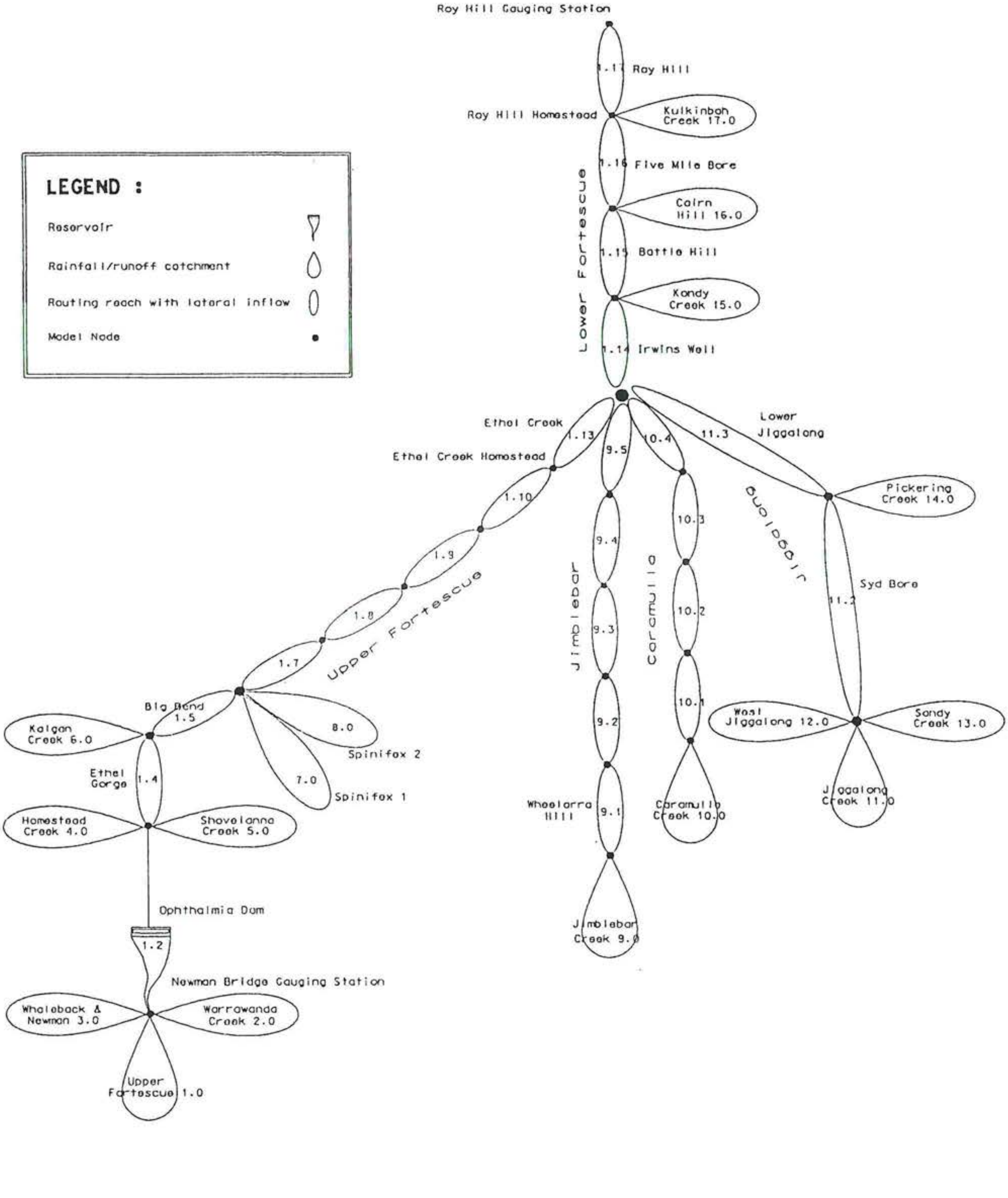


Fig. 20 Schematised Layout of Fortescue River Catchment for FLOUT model

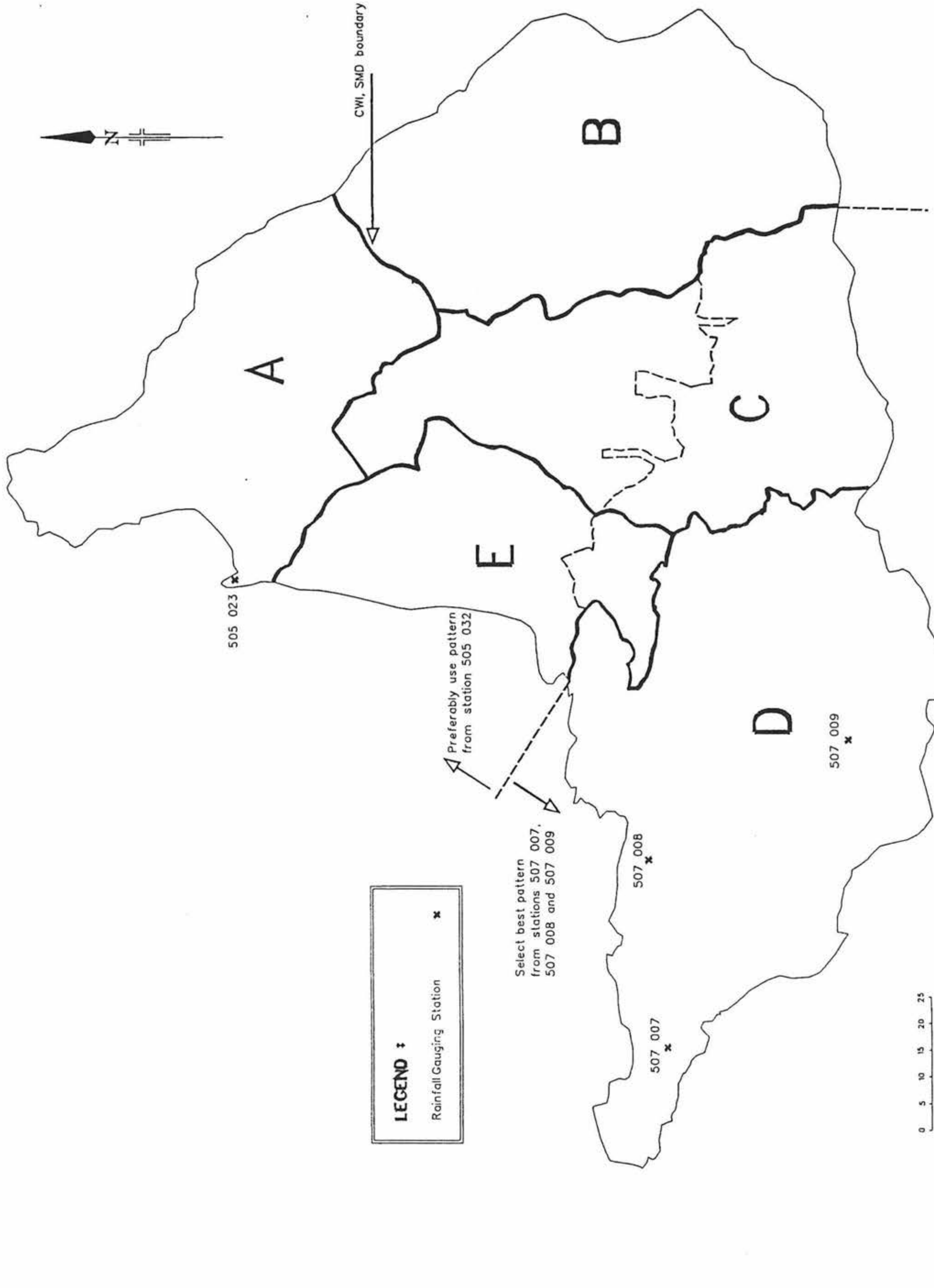


Fig. 21 **Regions used for Calculations of Antecedent Catchment Conditions**

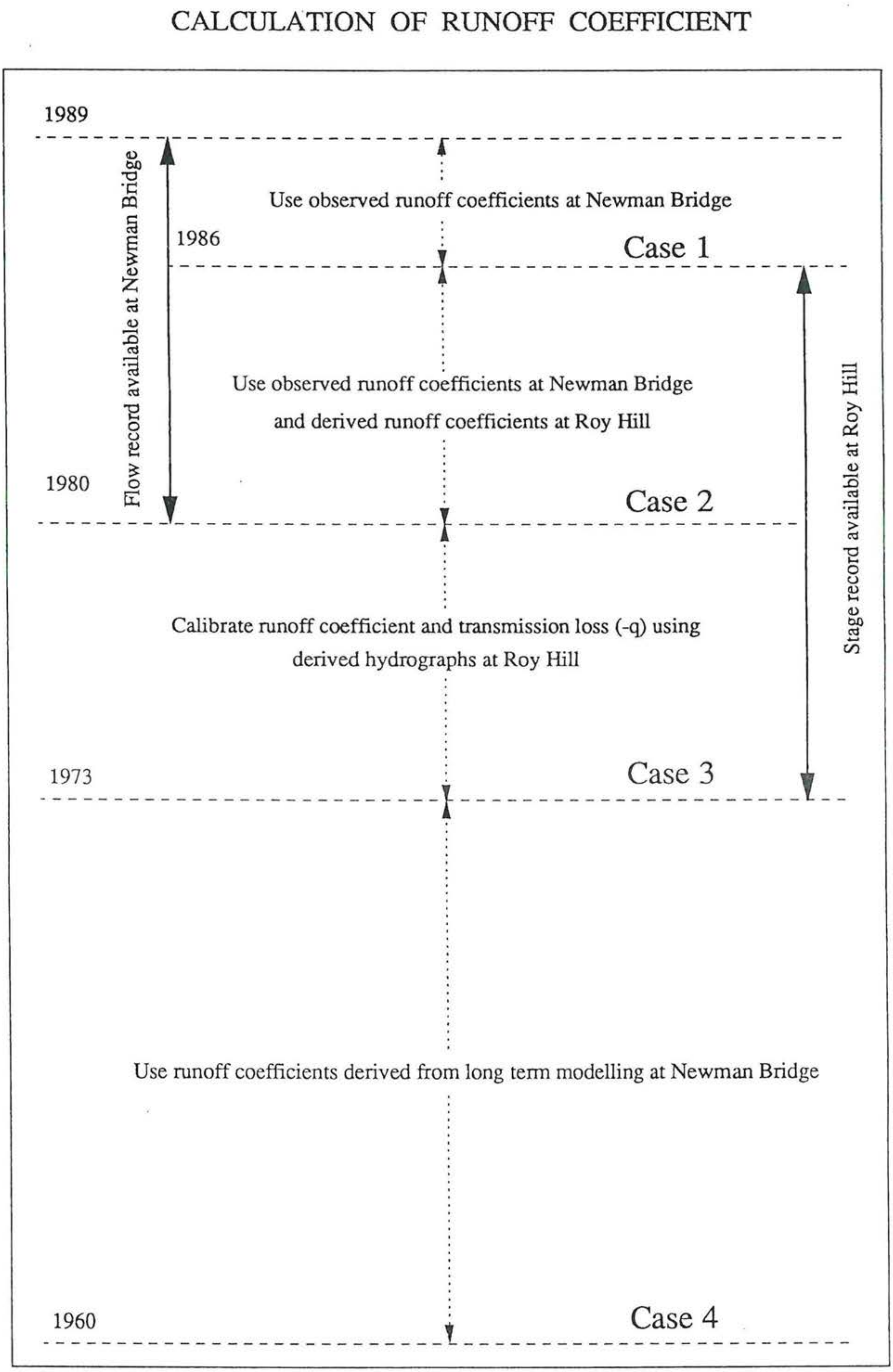


Fig. 22 **Procedure used for Calculations of Runoff Coefficient**

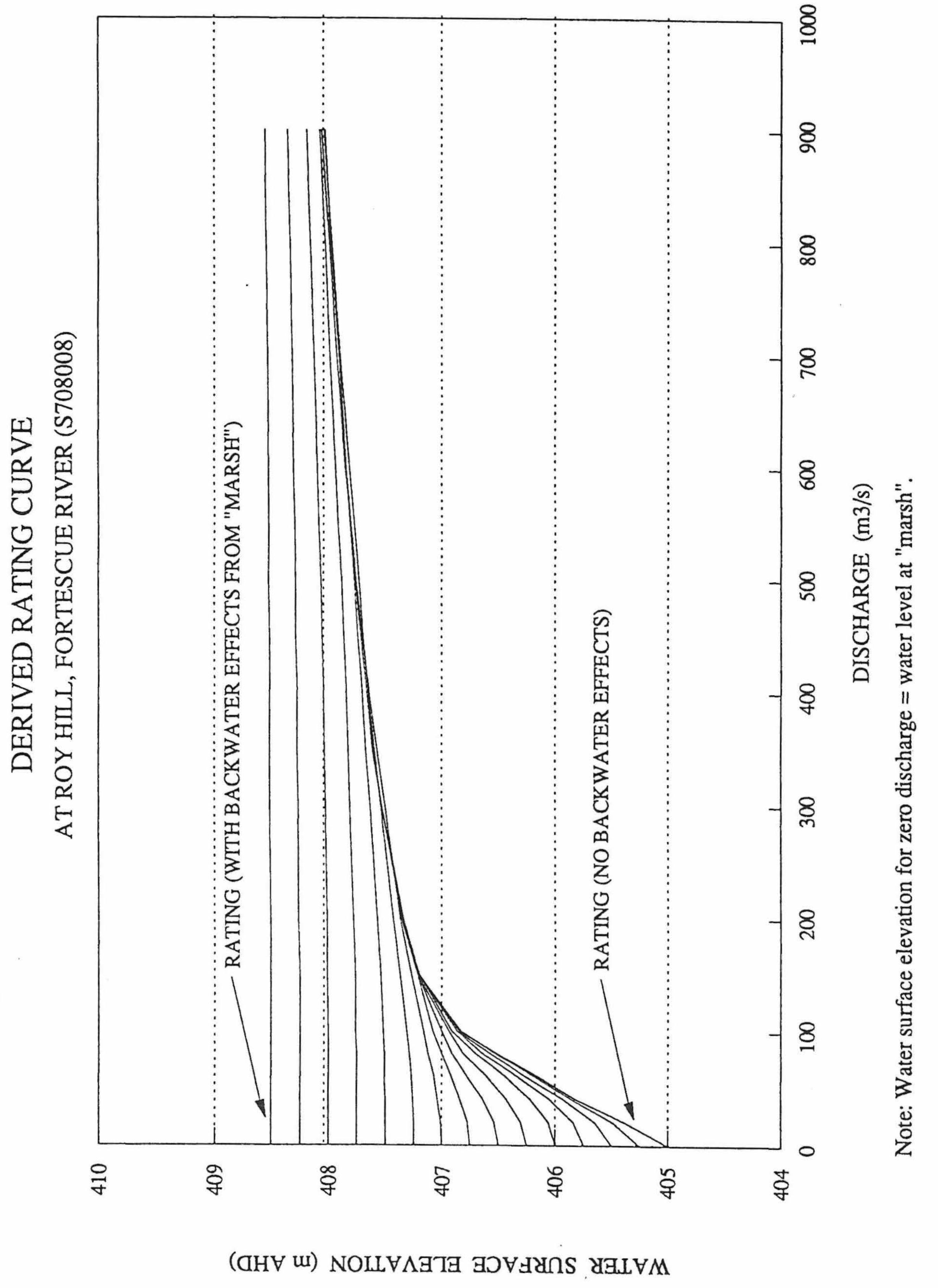


Fig. 23 Derived Rating Curve for Roy Hill Gauging Station

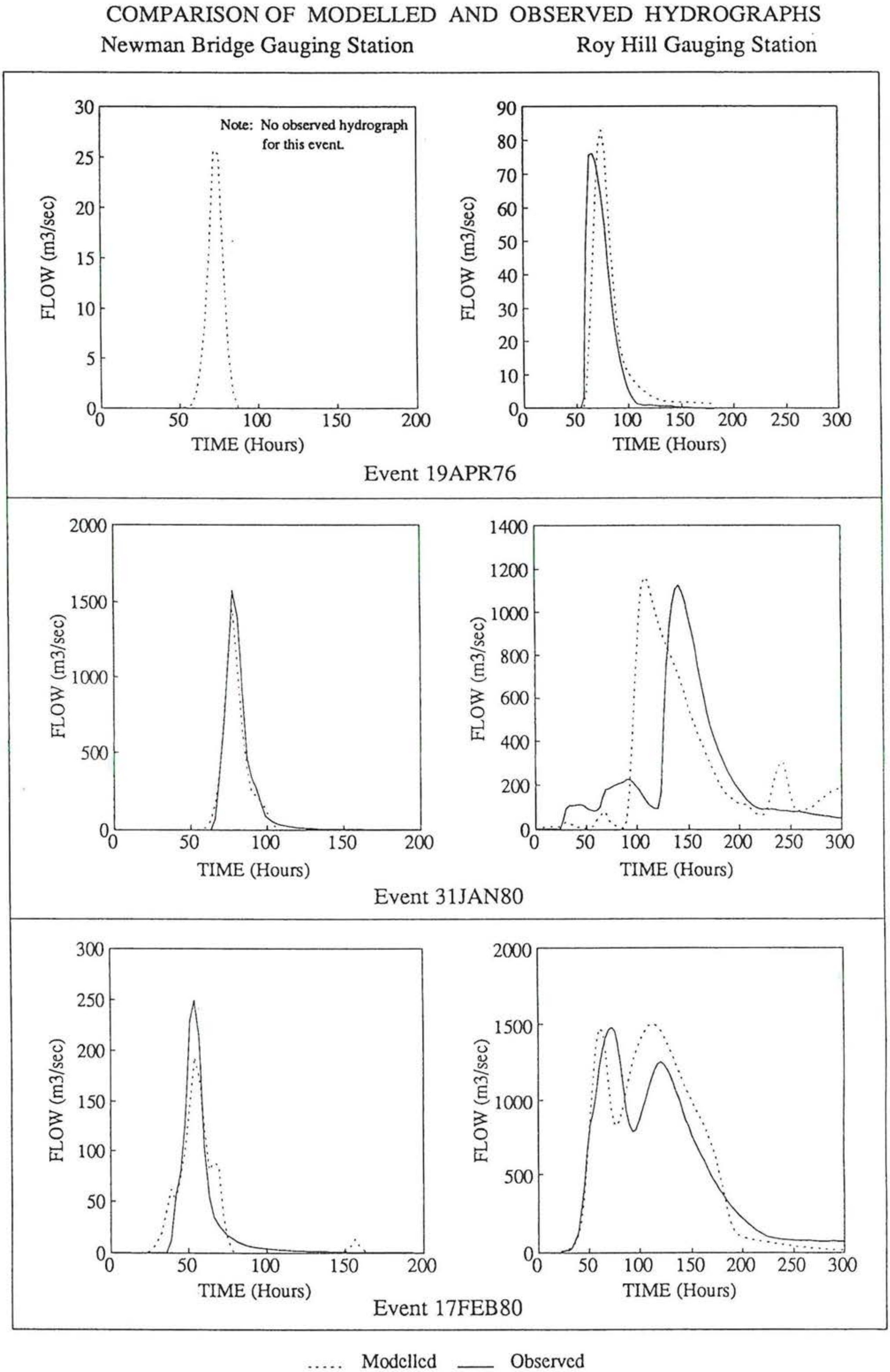


Fig. 24 **Event Model - Comparison of Modelled and Observed Hydrographs**

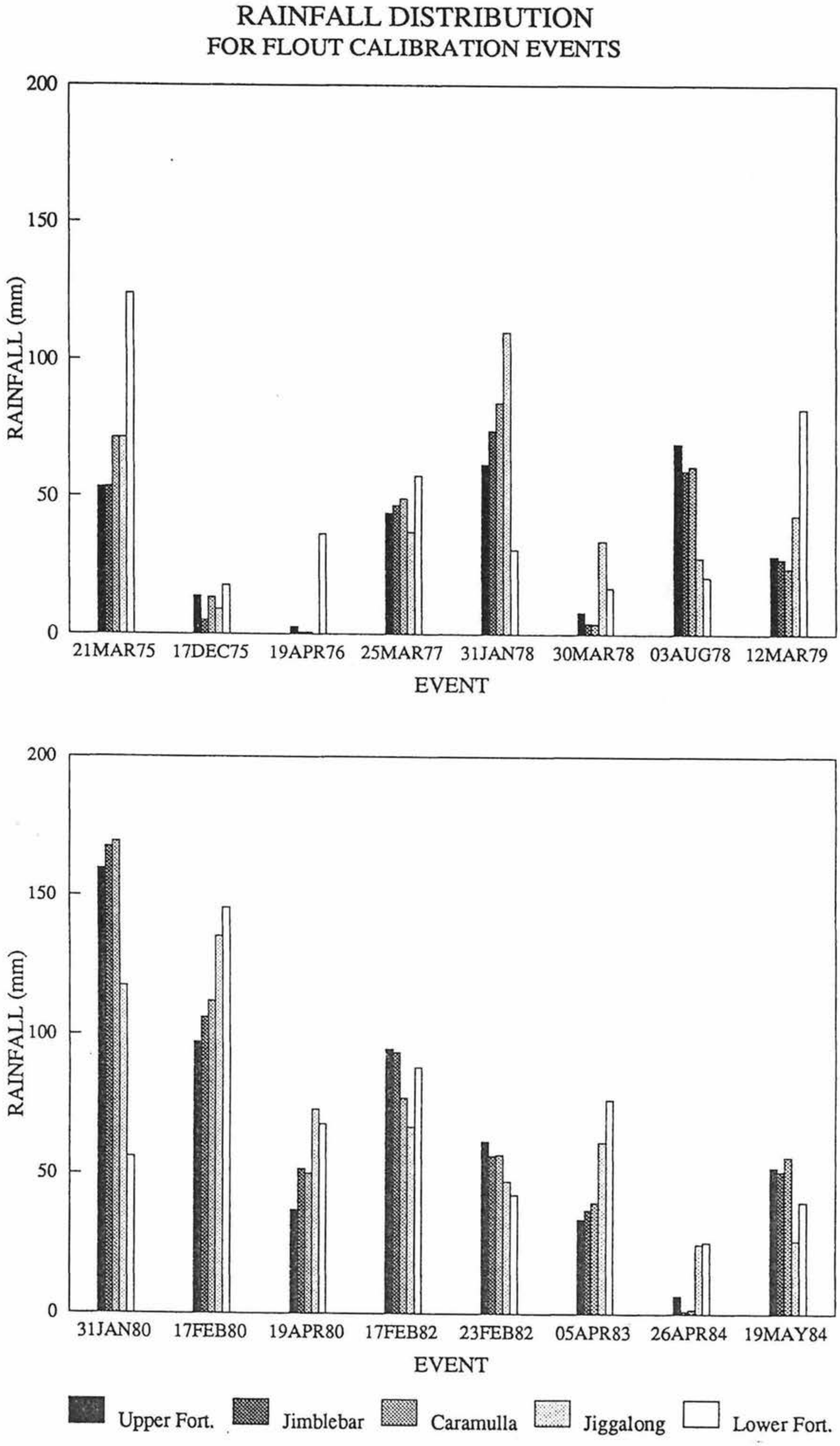
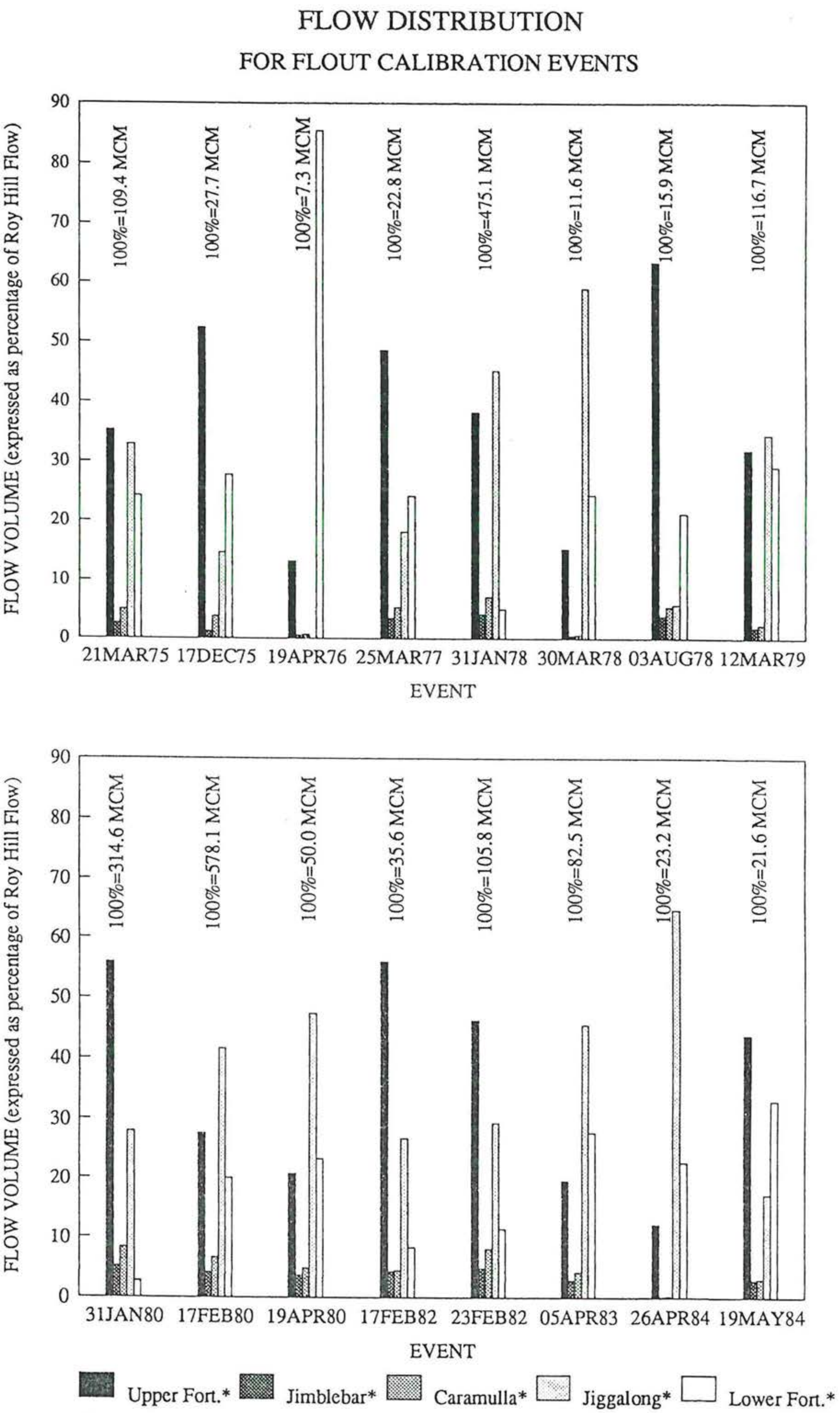


Fig. 25 FLOUT Calibration Events - Rainfall Distribution



*These represent the net flow contributions from each branch of the river system assuming that there is no dam present.

Fig. 26 FLOUT Calibration Events - Flow Distribution

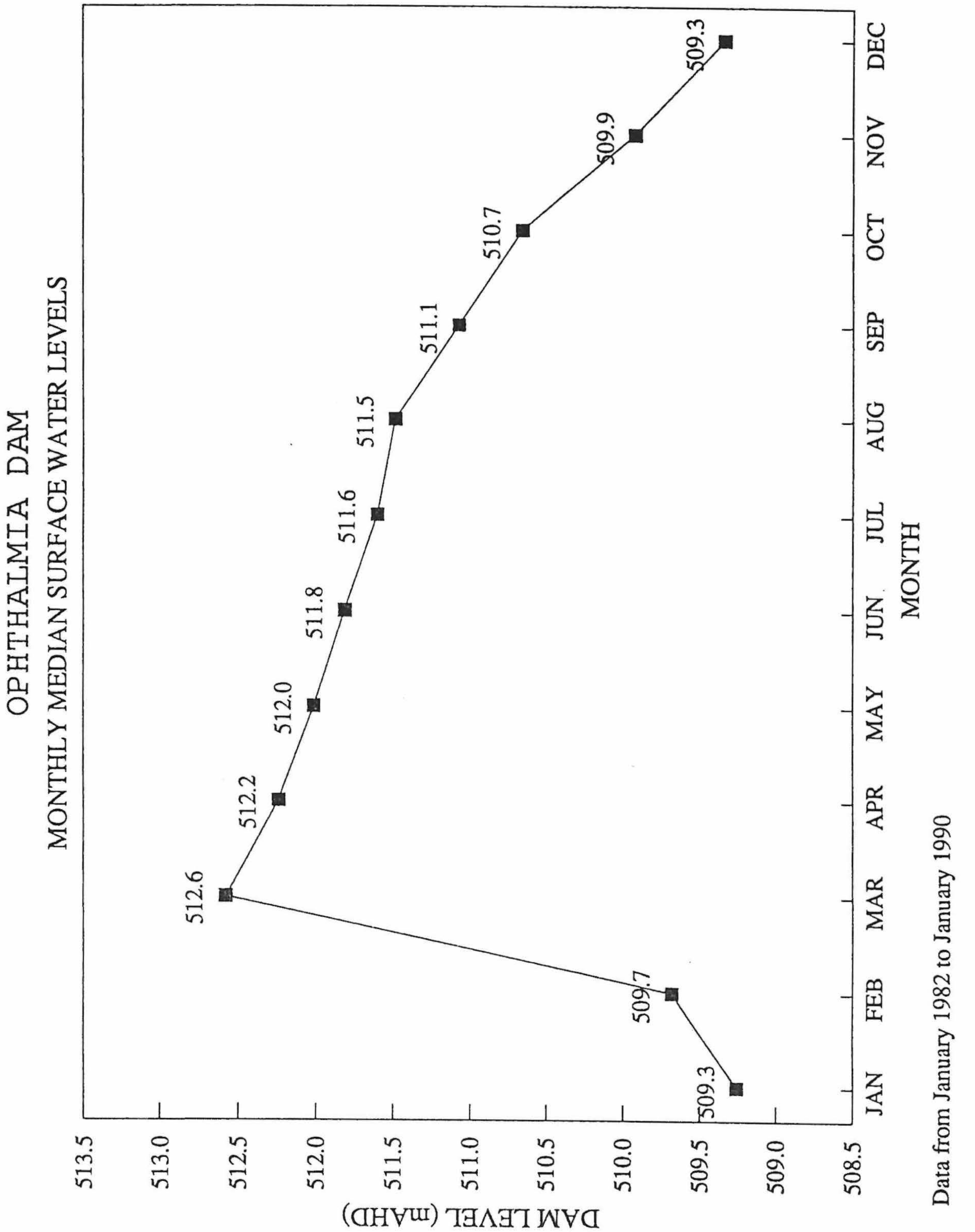
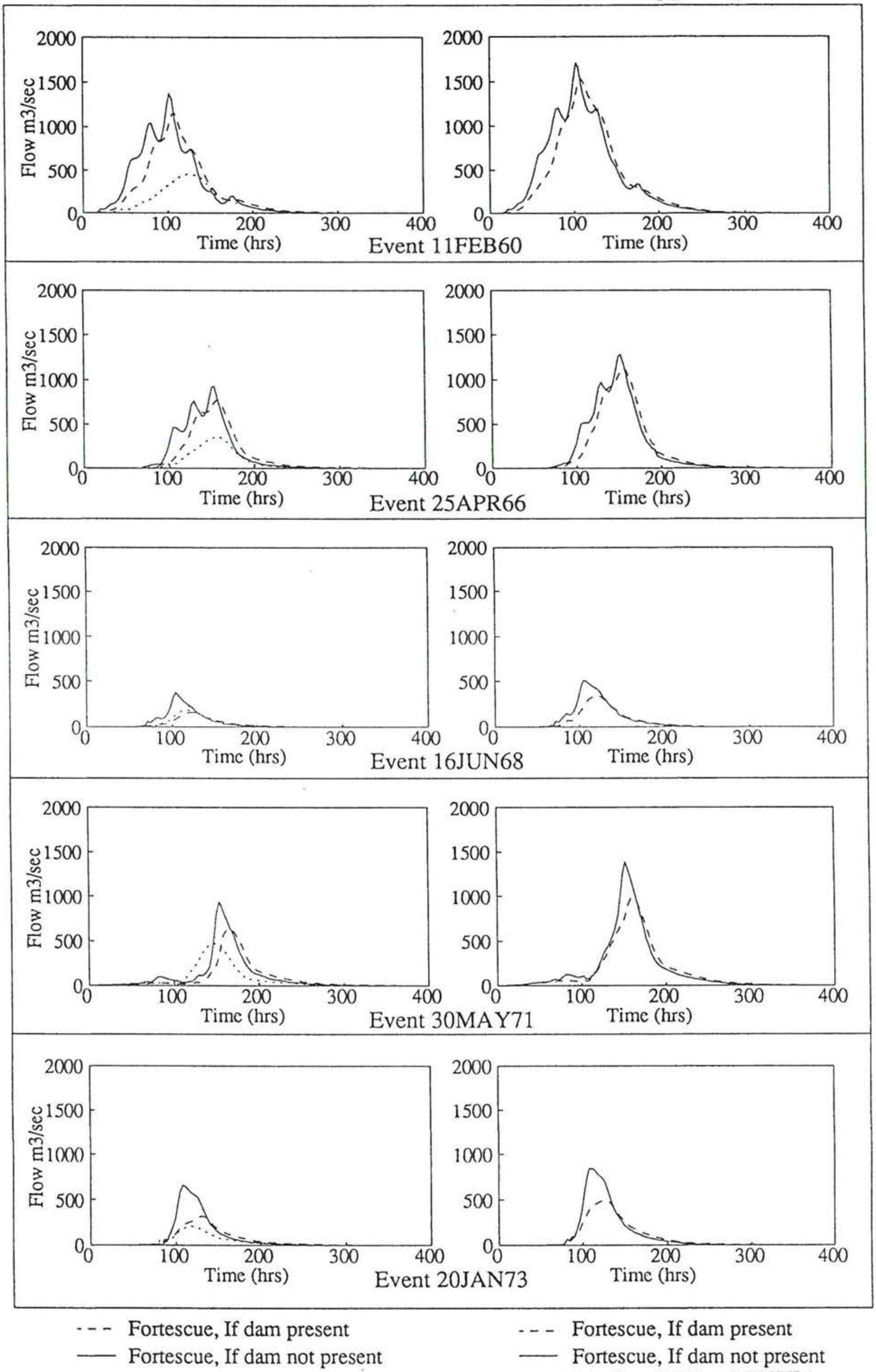


Fig. 27 **Ophthalmia Dam - Monthly Median Dam Levels**

HYDROGRAPHS FOR THE TEN LARGEST MODELLED EVENTS

Upstream of Jiggalong Confluence — Downstream of Jiggalong Confluence



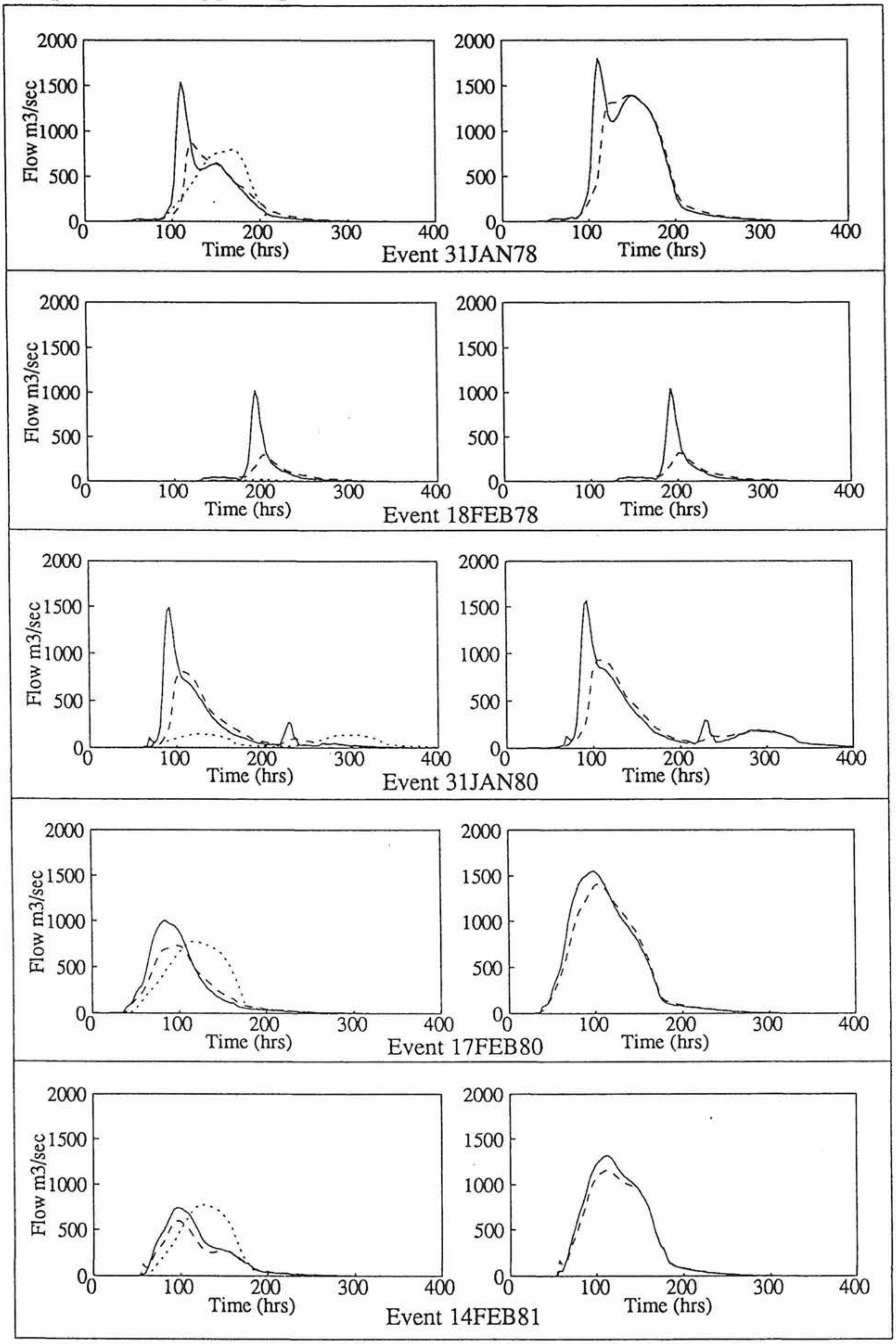
- - - Fortescue, If dam present
—— Fortescue, If dam not present
······ Jiggalong

- - - Fortescue, If dam present
—— Fortescue, If dam not present

Fig. 28 Simulated Flood Hydrographs

HYDROGRAPHS FOR THE TEN LARGEST MODELLED EVENTS

Upstream of Jiggalong Confluence   Downstream of Jiggalong Confluence



- - - Fortescue, If dam present
—— Fortescue, If dam not present
······ Jiggalong

- - - Fortescue, If dam present
—— Fortescue, If dam not present

Fig. 29 Simulated Flood Hydrographs

FLOUT MODELLING RESULTS

For Post-Dam Events at Cross Section 5 (Double Channel One)

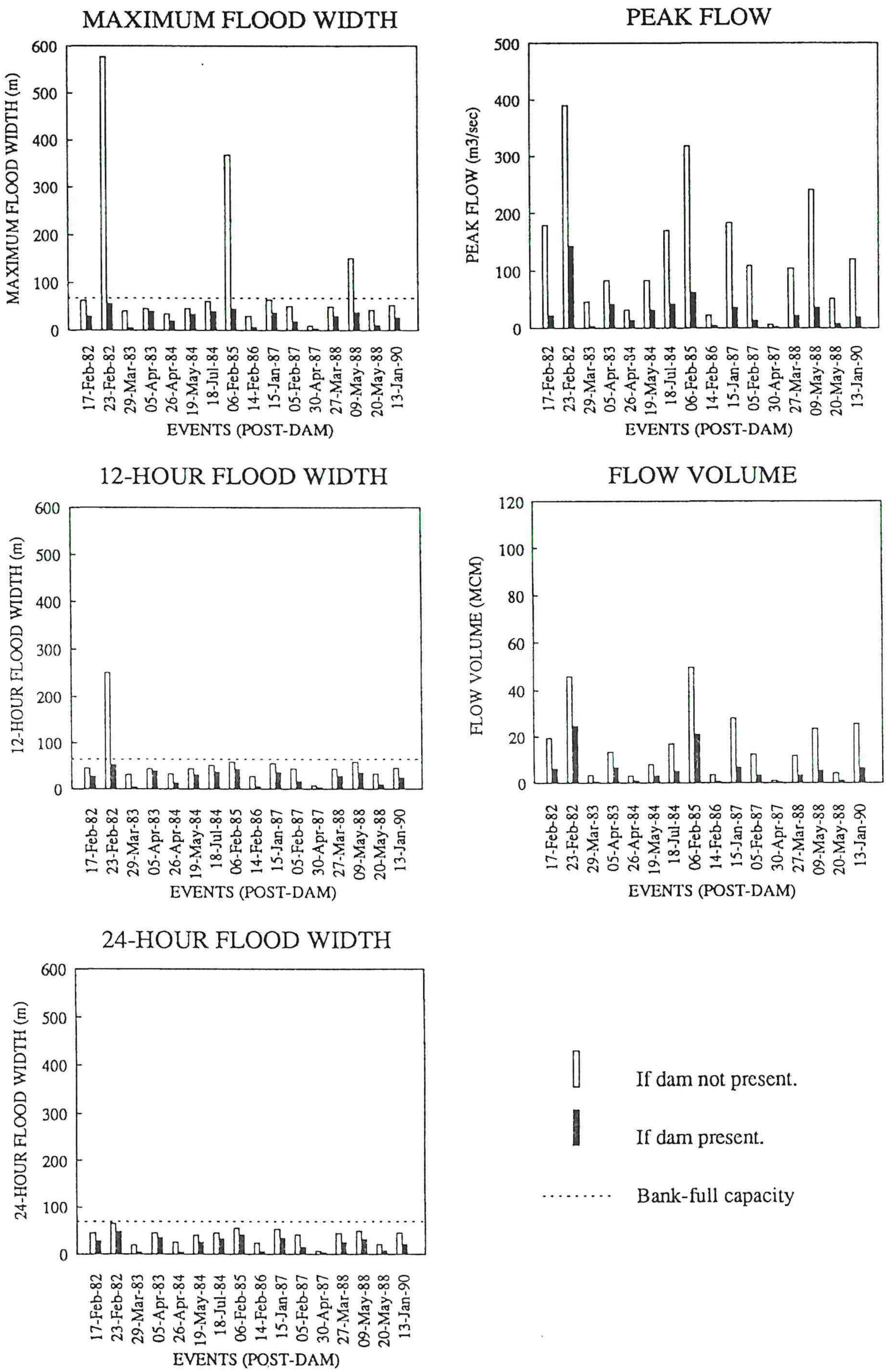


Fig. 30 **FLOUT Modelled Results - Post-Dam Events at Cross Section 5 (Double Channel One)**

FLOUT MODELLING RESULTS

For Post-Dam Events at Cross Section 7 (Seven Mile Bore)

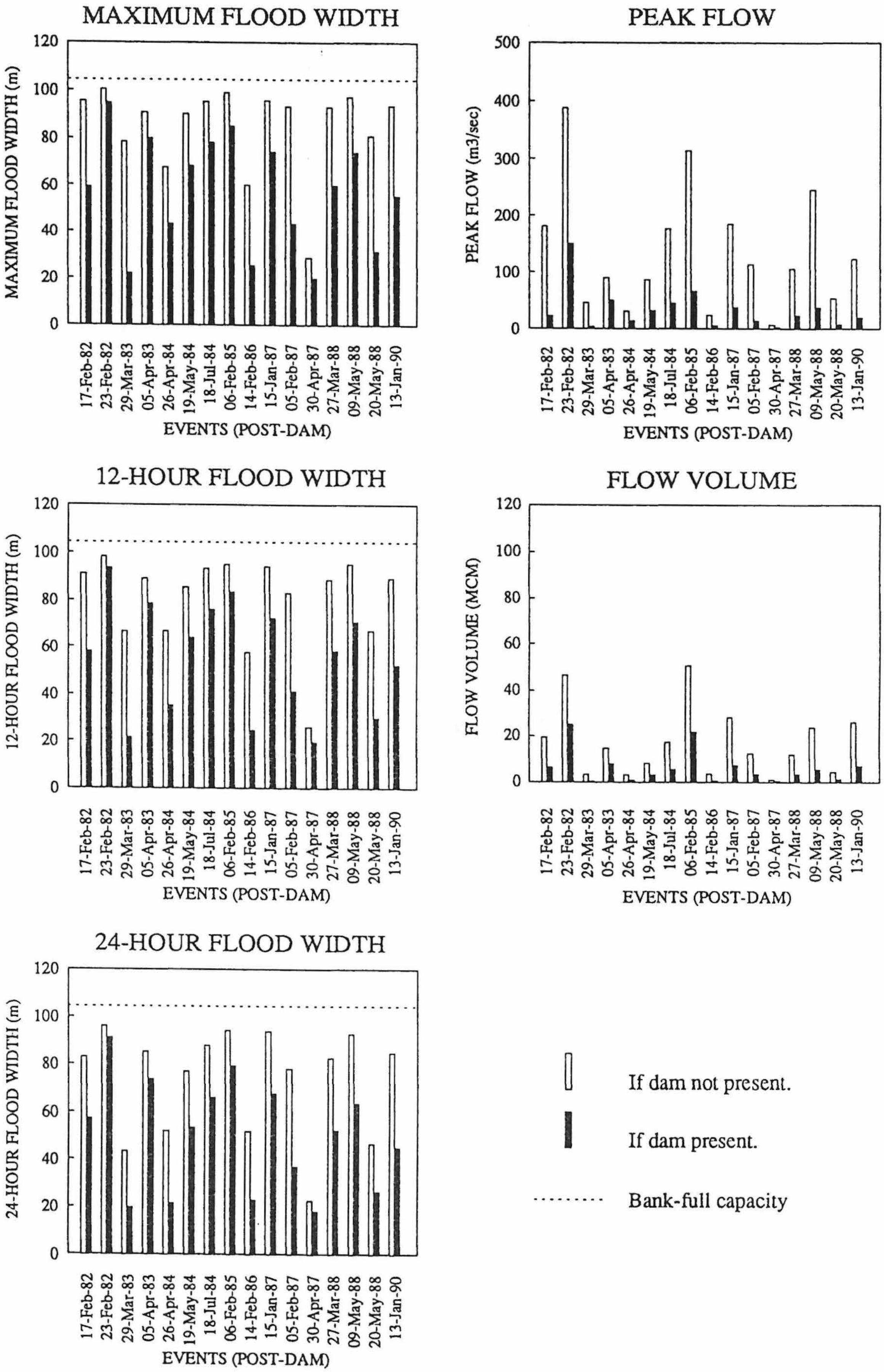


Fig. 31 FLOUT Modelled Results - Post-Dam Events at Cross Section 7 (Seven Mile Bore)

FLOUT MODELLING RESULTS
For Post-Dam Events at Cross Section 8 (Ethel Creek)

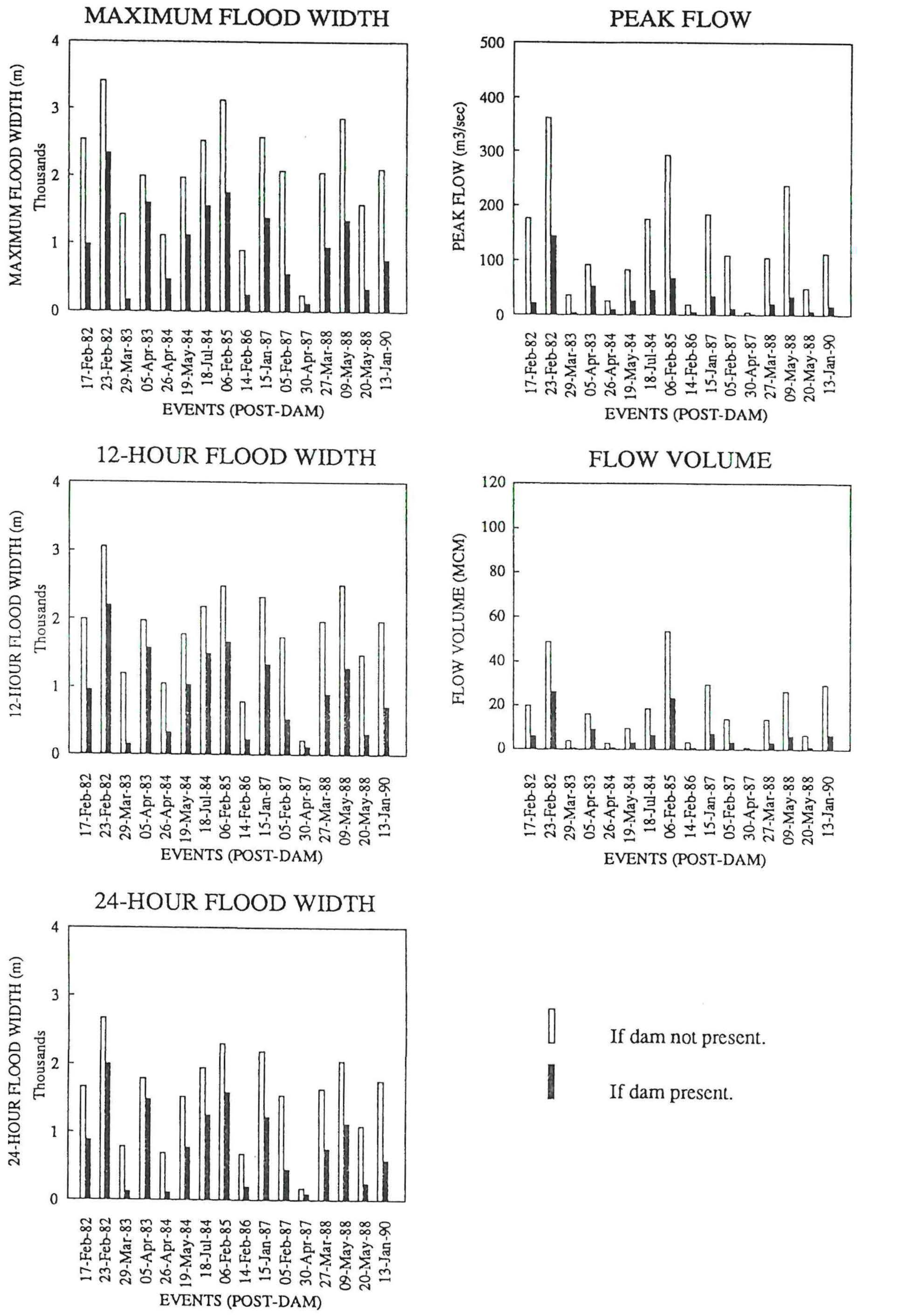


Fig. 32 **FLOUT Modelled Results - Post-Dam Events at Cross Section 8 (Ethel Creek)**

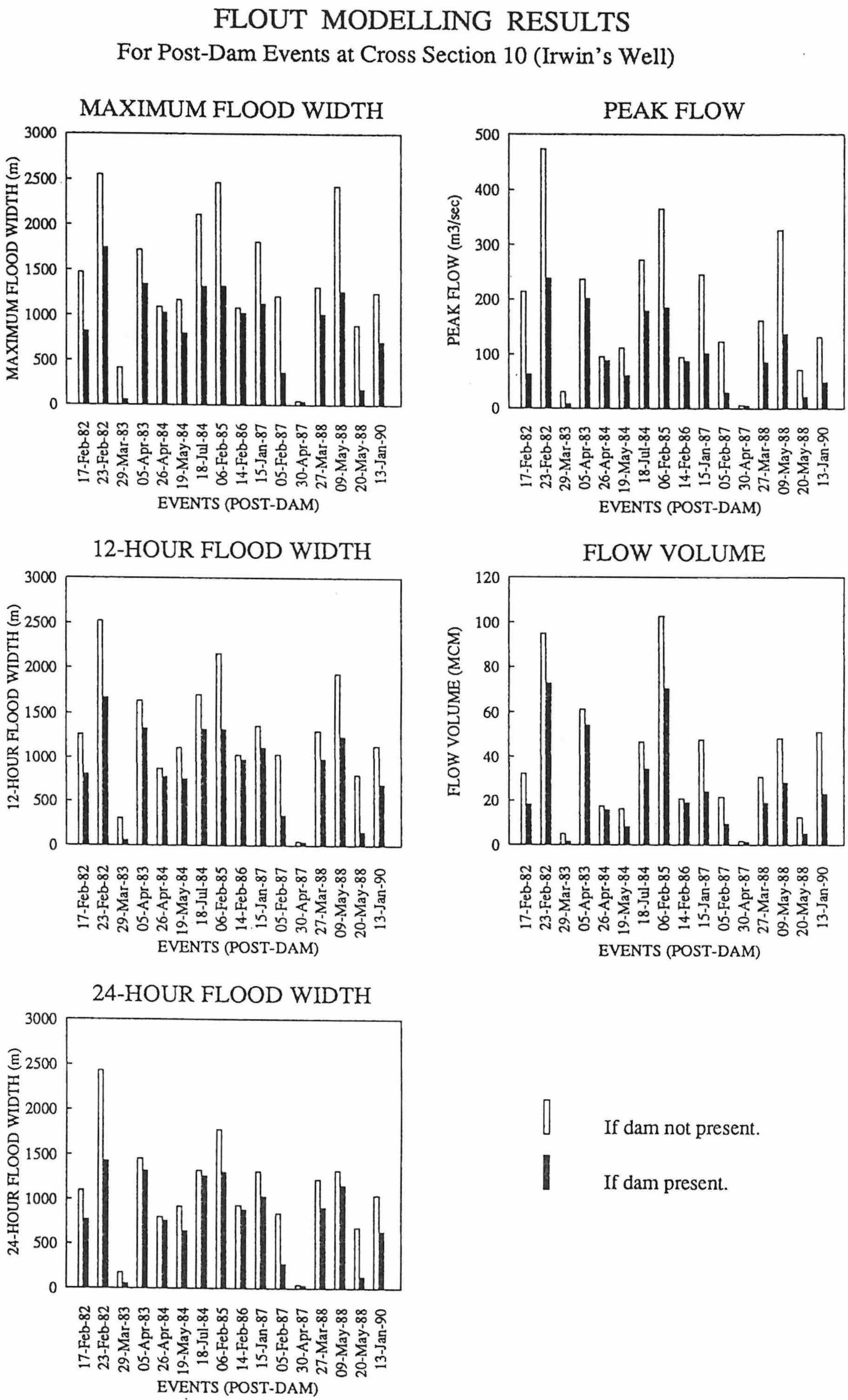


Fig. 33 **FLOUT Modelled Results - Post-Dam Events at Cross Section 10 (Irwin's Well)**

FLOUT MODELLING RESULTS

For Post-Dam Events at Cross Section 11 (Battle Hill)

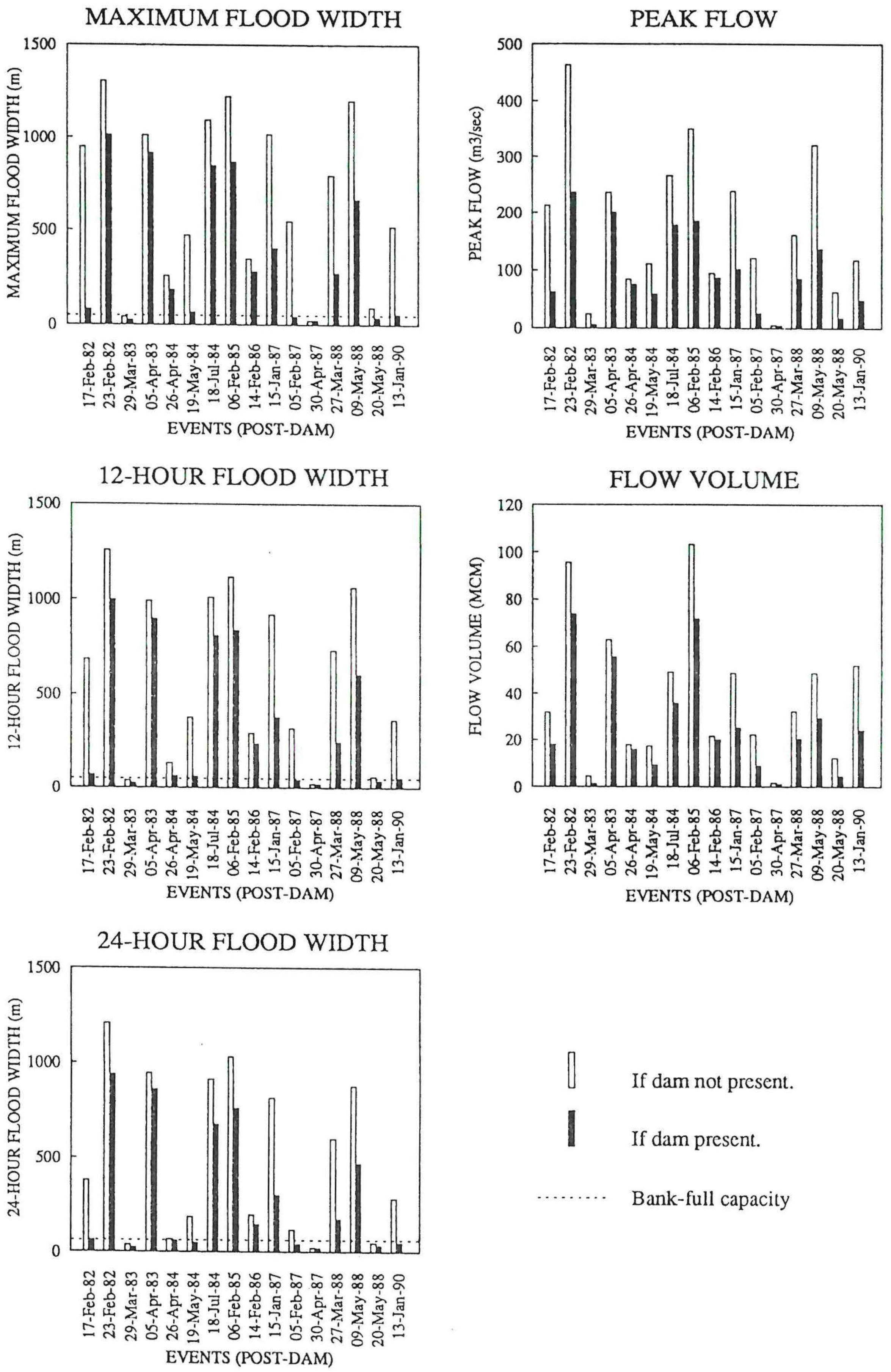


Fig. 34 **FLOUT Modelled Results - Post-Dam Events at Cross Section 11 (Battle Hill)**

FLOUT MODELLING RESULTS

For Post-Dam Events at Cross Section 12 (Five Mile Bore)

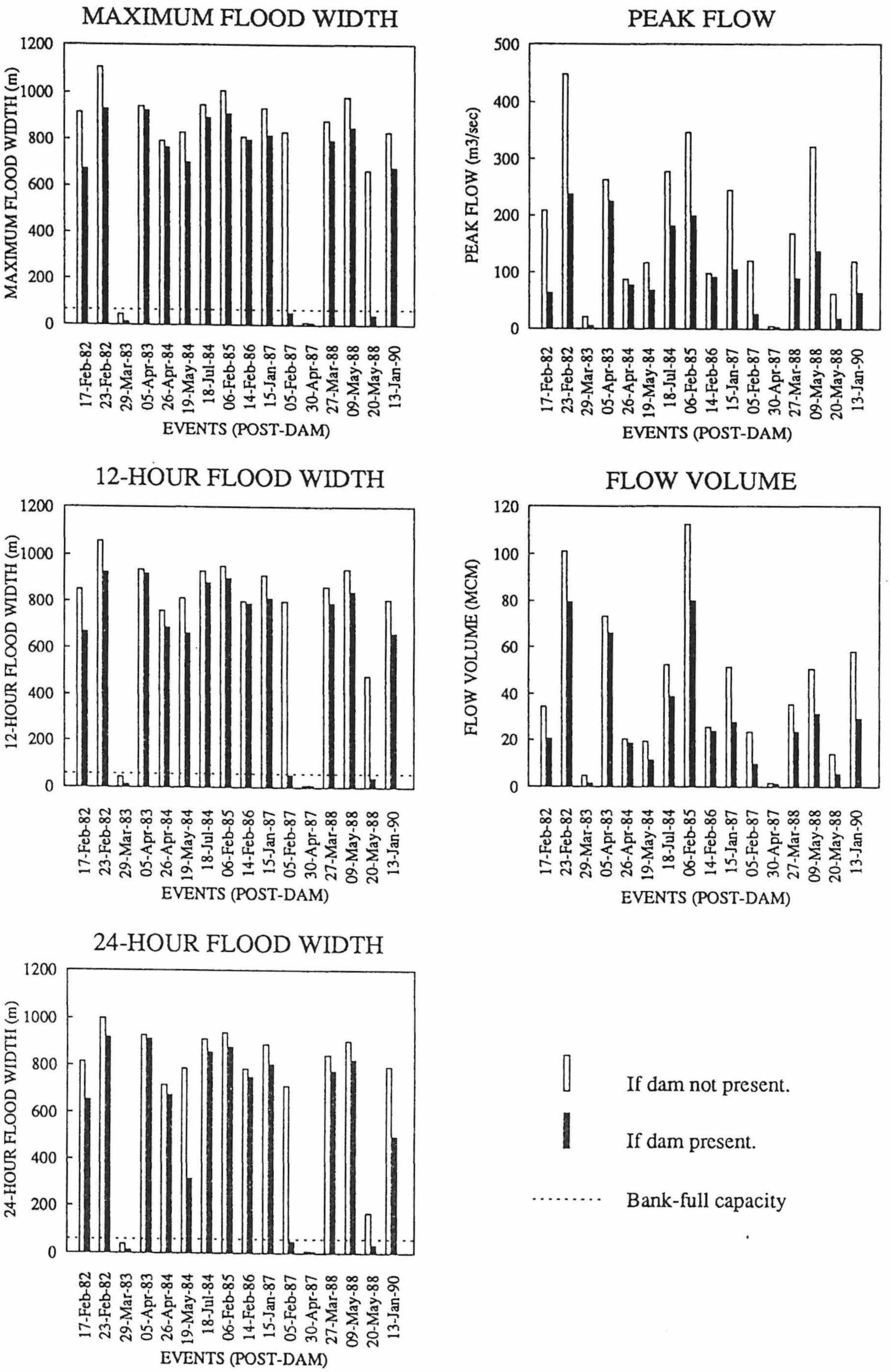


Fig. 35 FLOUT Modelled Results - Post-Dam Events at Cross Section 12 (Five Mile Bore)

FLOUT MODELLING RESULTS

At Cross Section 5 (Double Channel One)

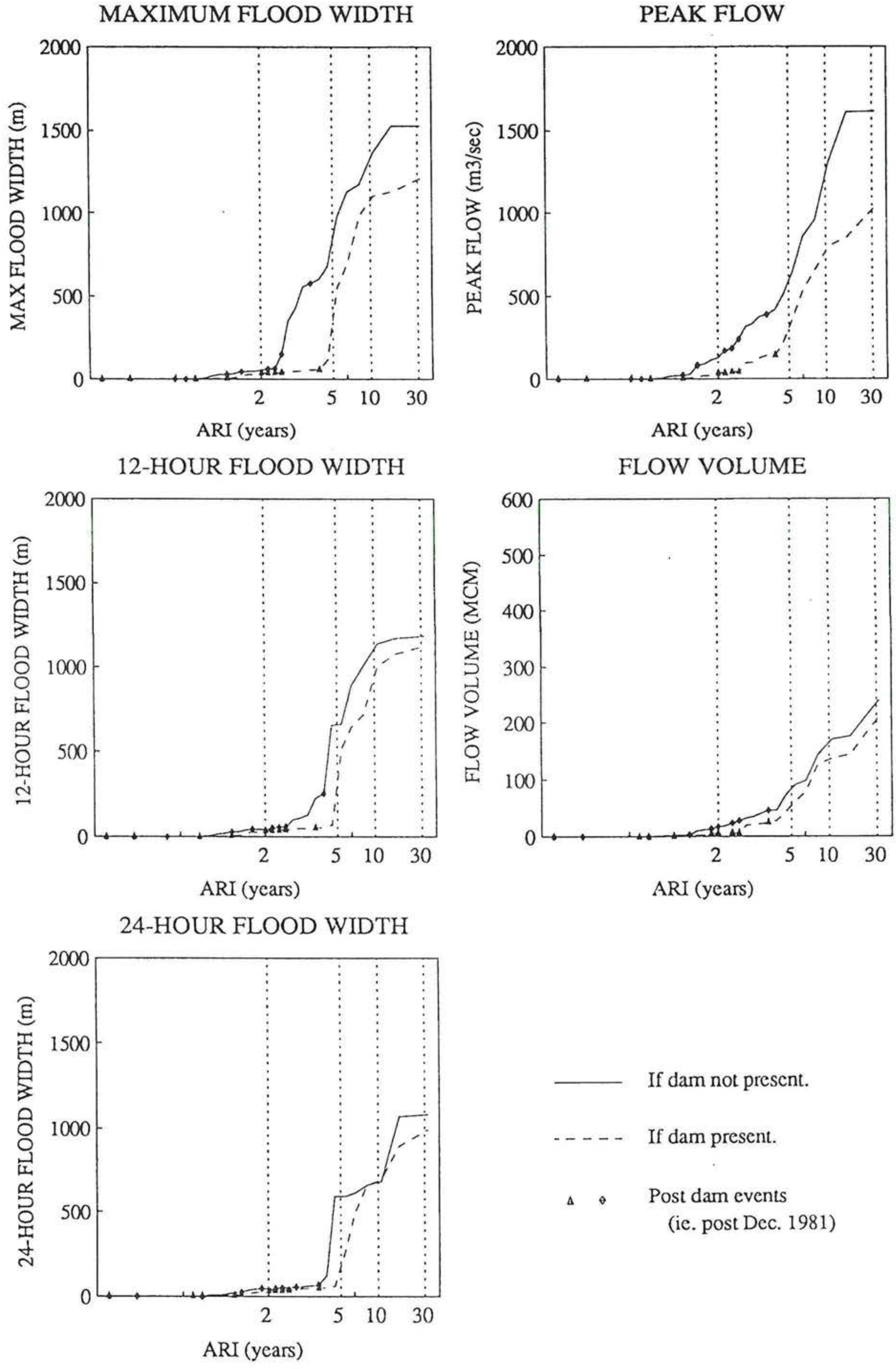


Fig. 36 FLOUT Modelled Results - Frequency Plots at Cross Section 5 (Double Channel One)

FLOUT MODELLING RESULTS

At Cross Section 7 (Seven Mile Bore)

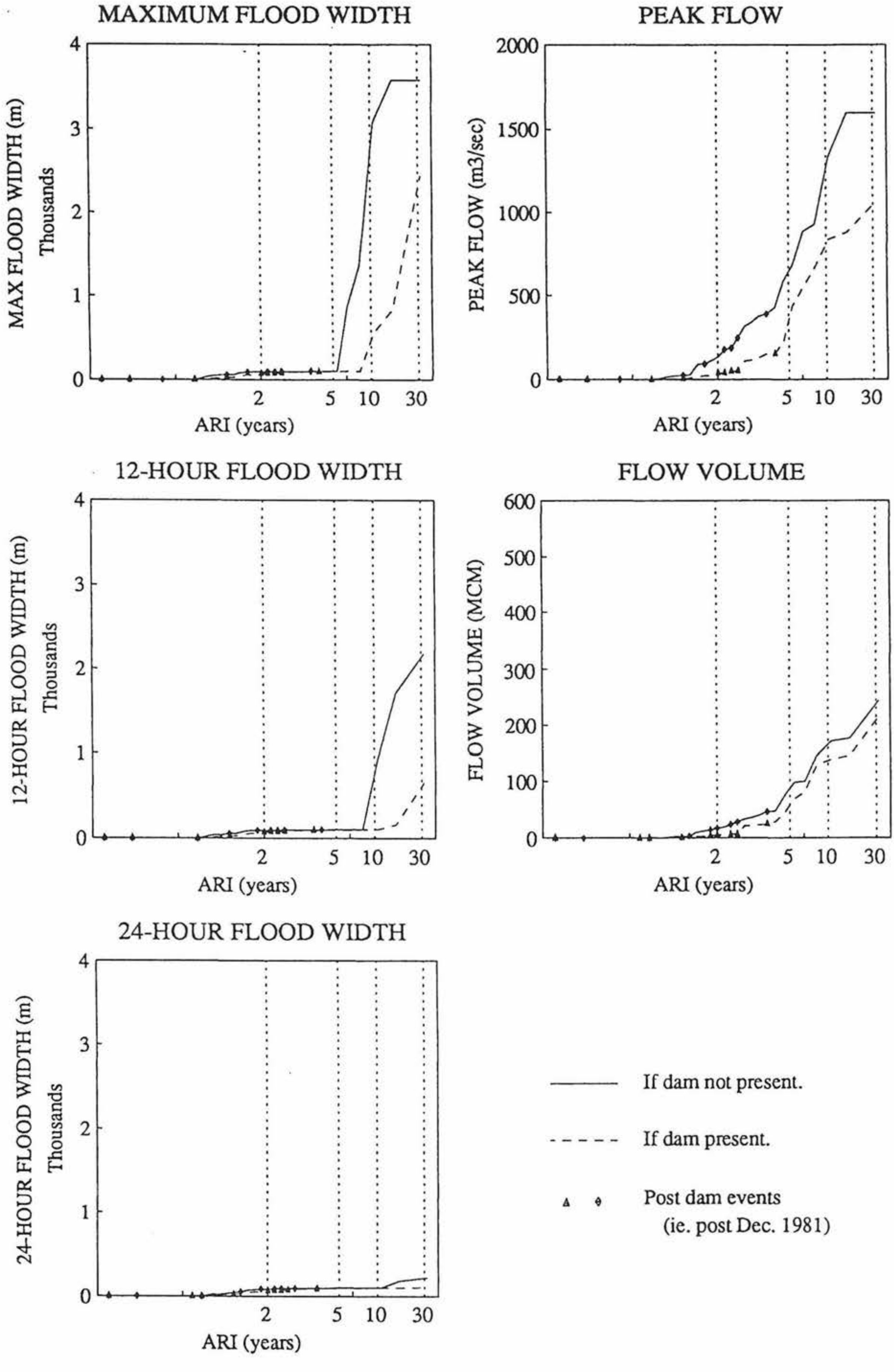


Fig. 37 FLOUT Modelled Results - Frequency Plots at Cross Section 7 (Seven Mile Bore)

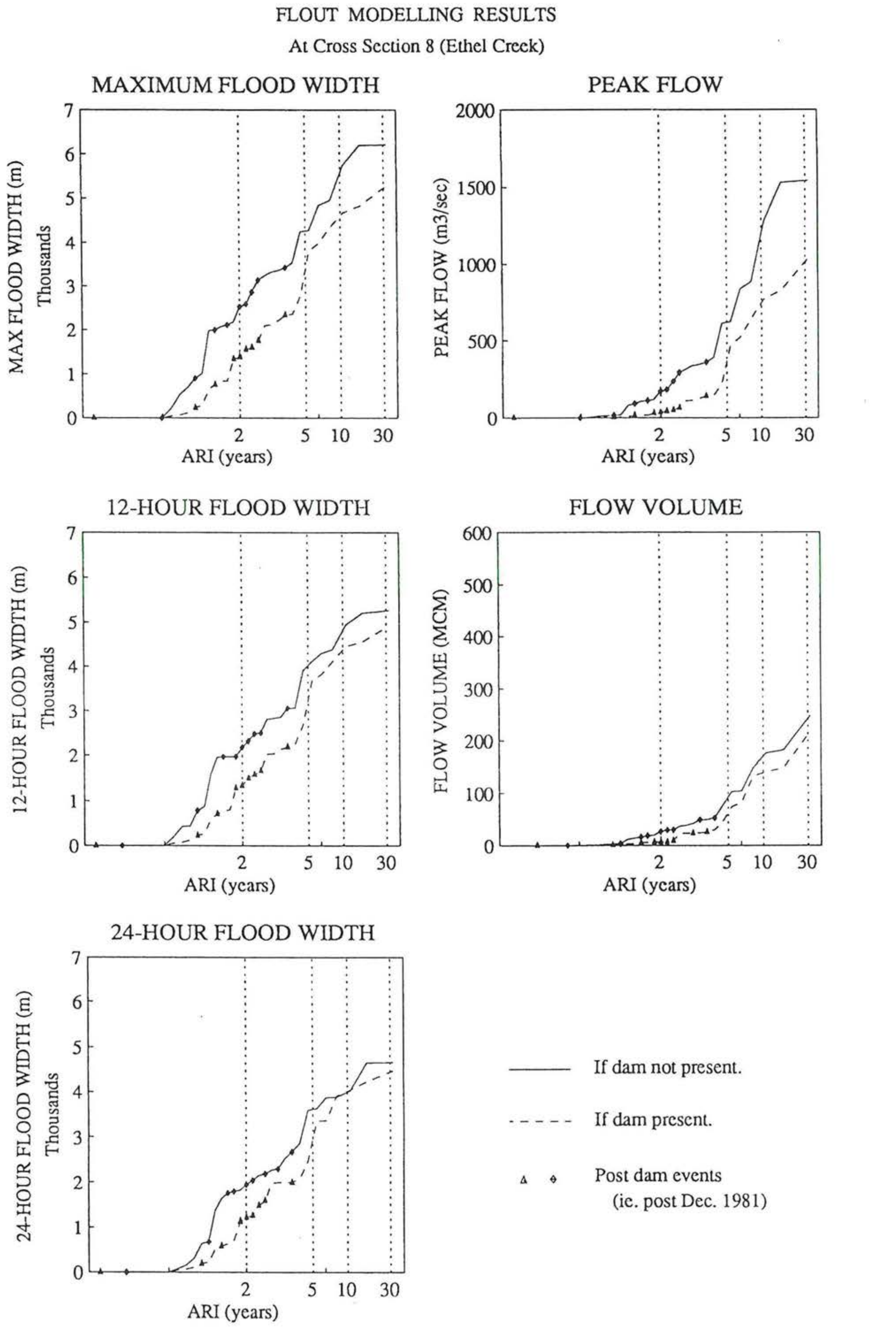


Fig. 38 FLOUT Modelled Results - Frequency Plots at Cross Section 8 (Ethel Creek)

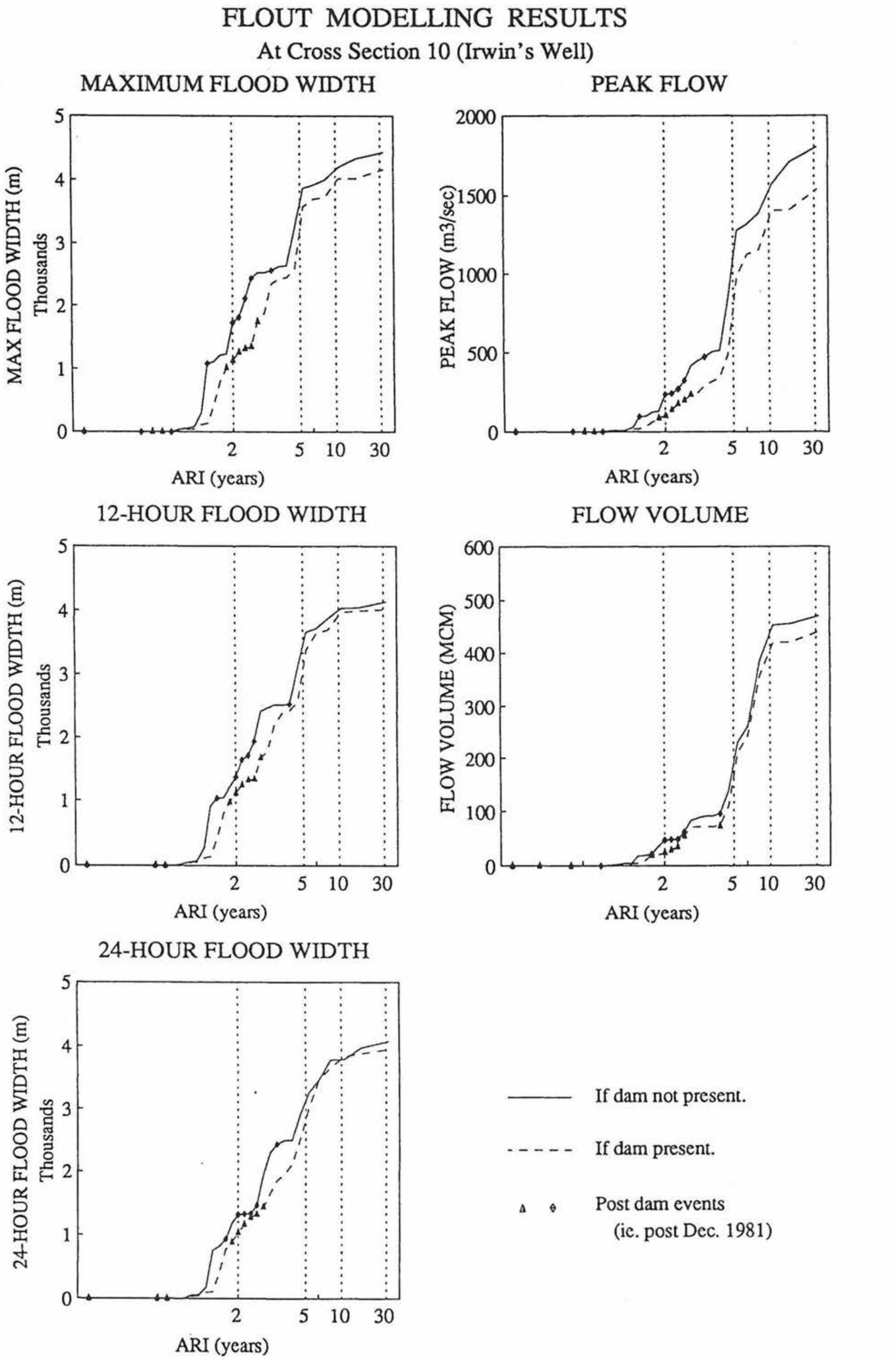


Fig. 39 FLOUT Modelled Results - Frequency Plots at Cross Section 10 (Irwin's Well)

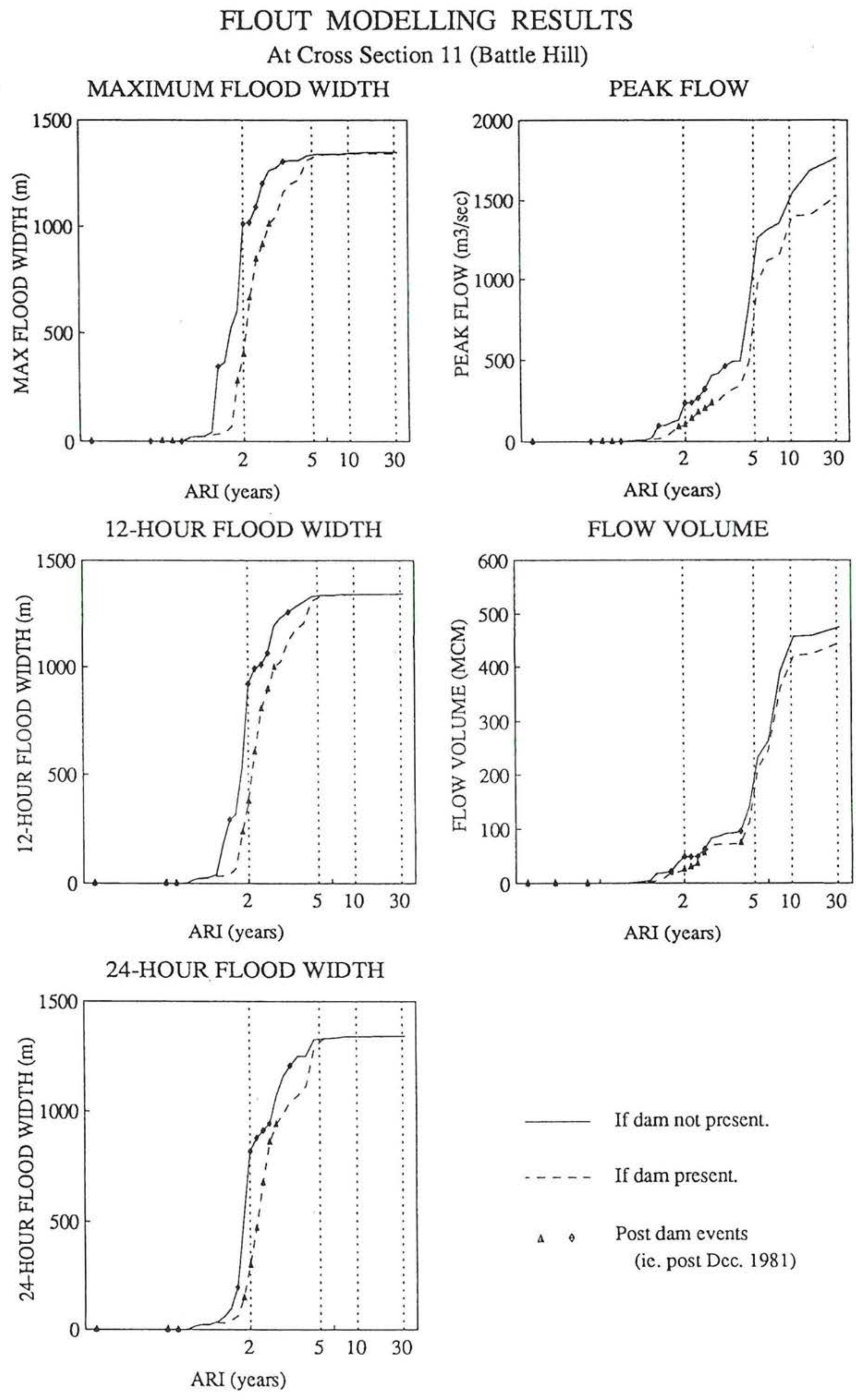


Fig. 40 **FLOUT Modelled Results - Frequency Plots at Cross Section 11 (Battle Hill)**

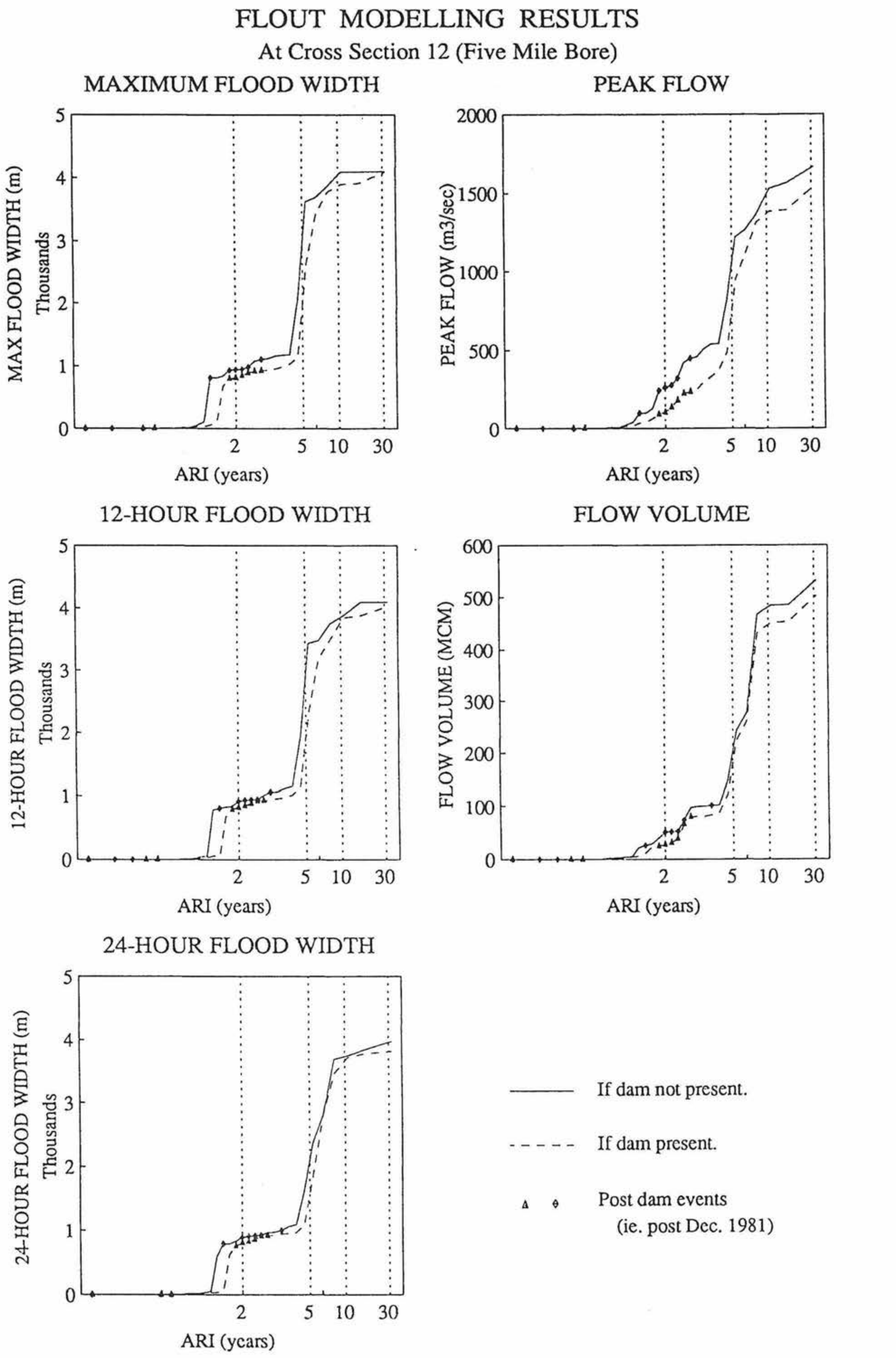
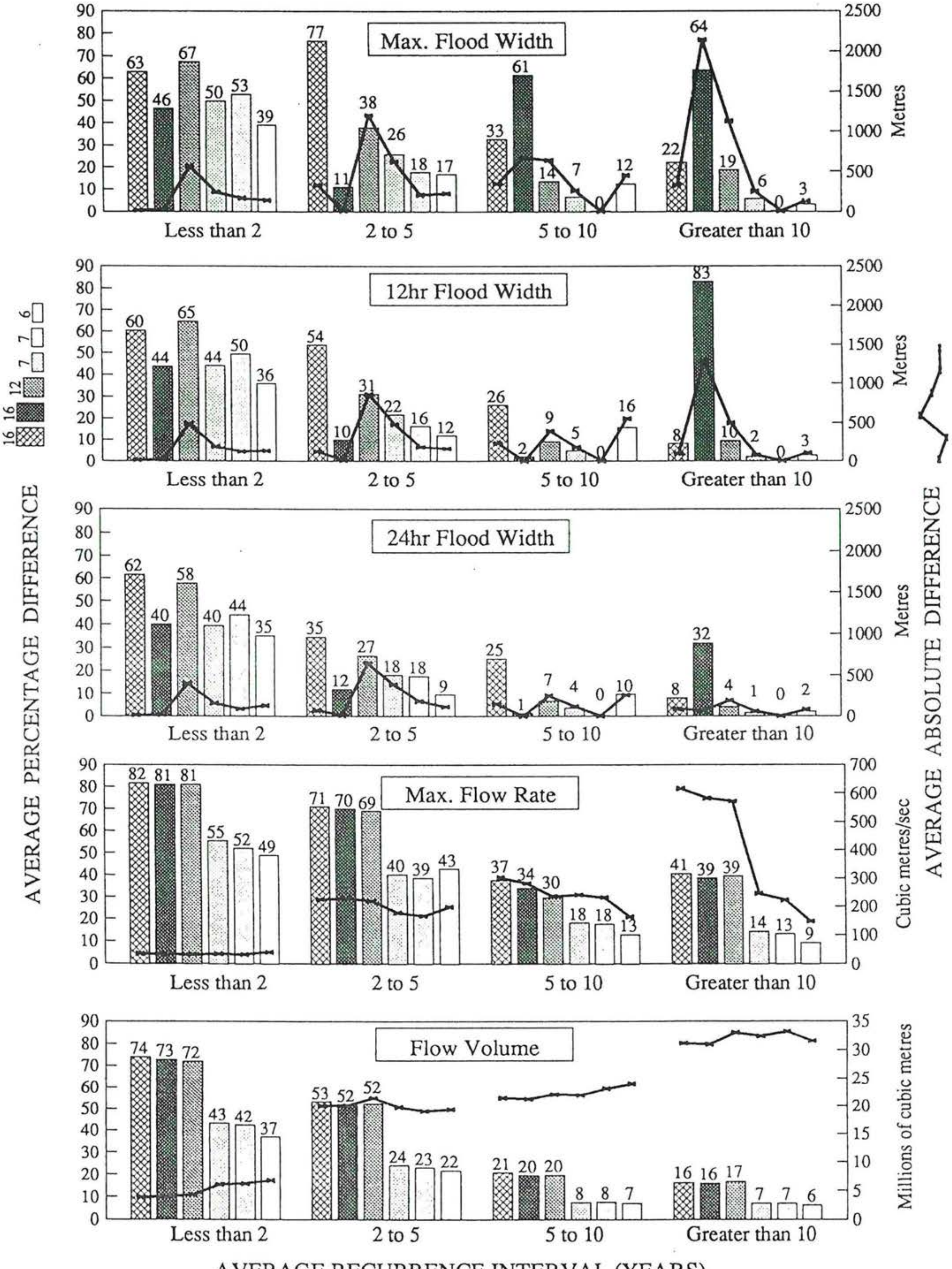


Fig. 41 **FLOUT Modelled Results - Frequency Plots at Cross Section 12 (Five Mile Bore)**

EFFECTS OF OPHTHALMIA DAM ON DOWNSTREAM AREAS



CS 5	CS 7	CS 8	CS 10	CS 11	CS 12
Double Channel One	Seven Mile Bore	Ethel Creek	Irwin's Well	Battle Hill	Five Mile Bore

Fig. 42 Impacts of Ophthalmia Dam on Downstream Areas

FLOOD-WIDTH vs FLOW RELATIONSHIPS

At Cross Sections 5, 7, 8, 10, 11 and 12

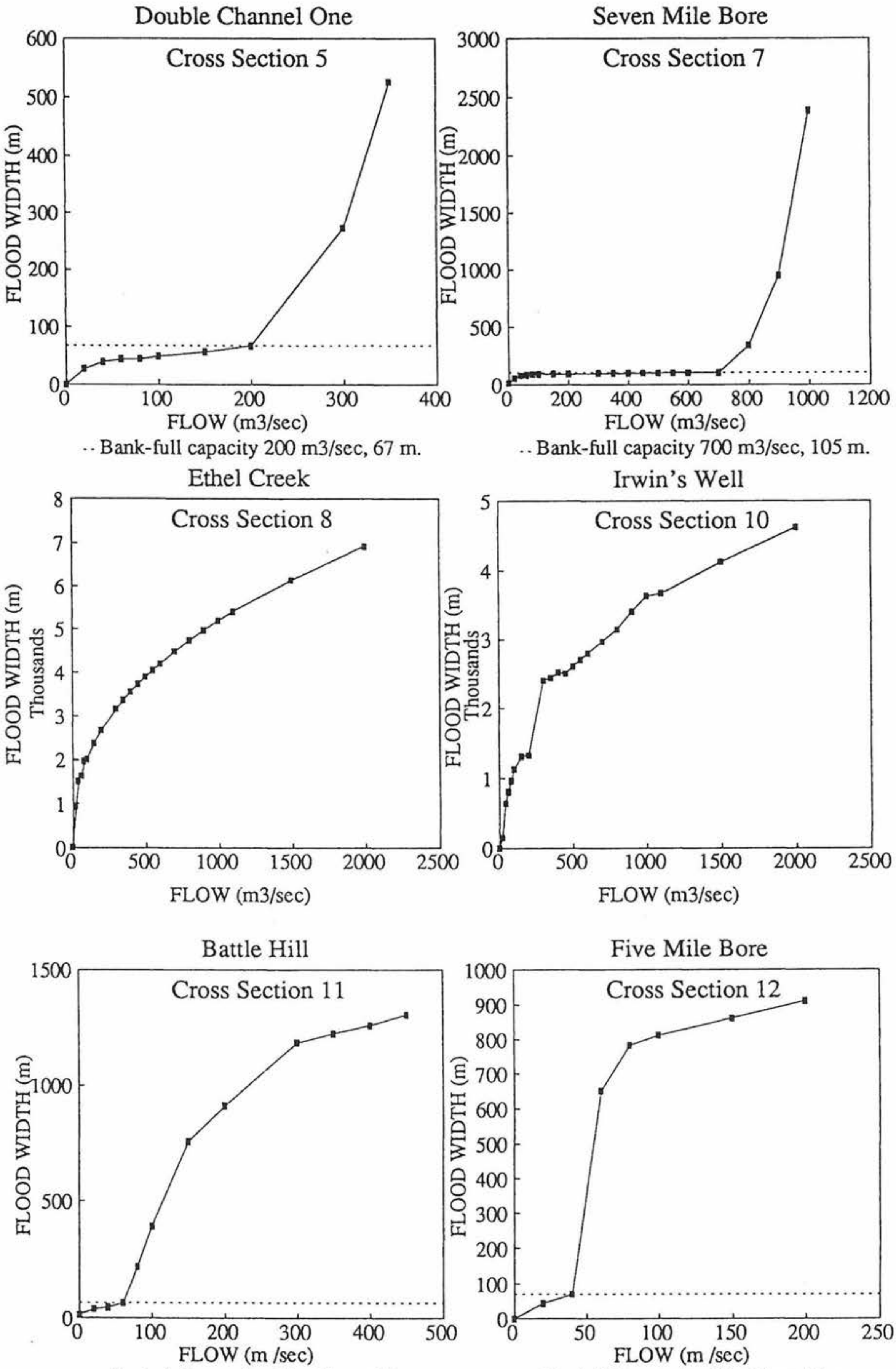


Fig. 43 Flood Width and Flow Relationship

CROSS SECTION PROFILES

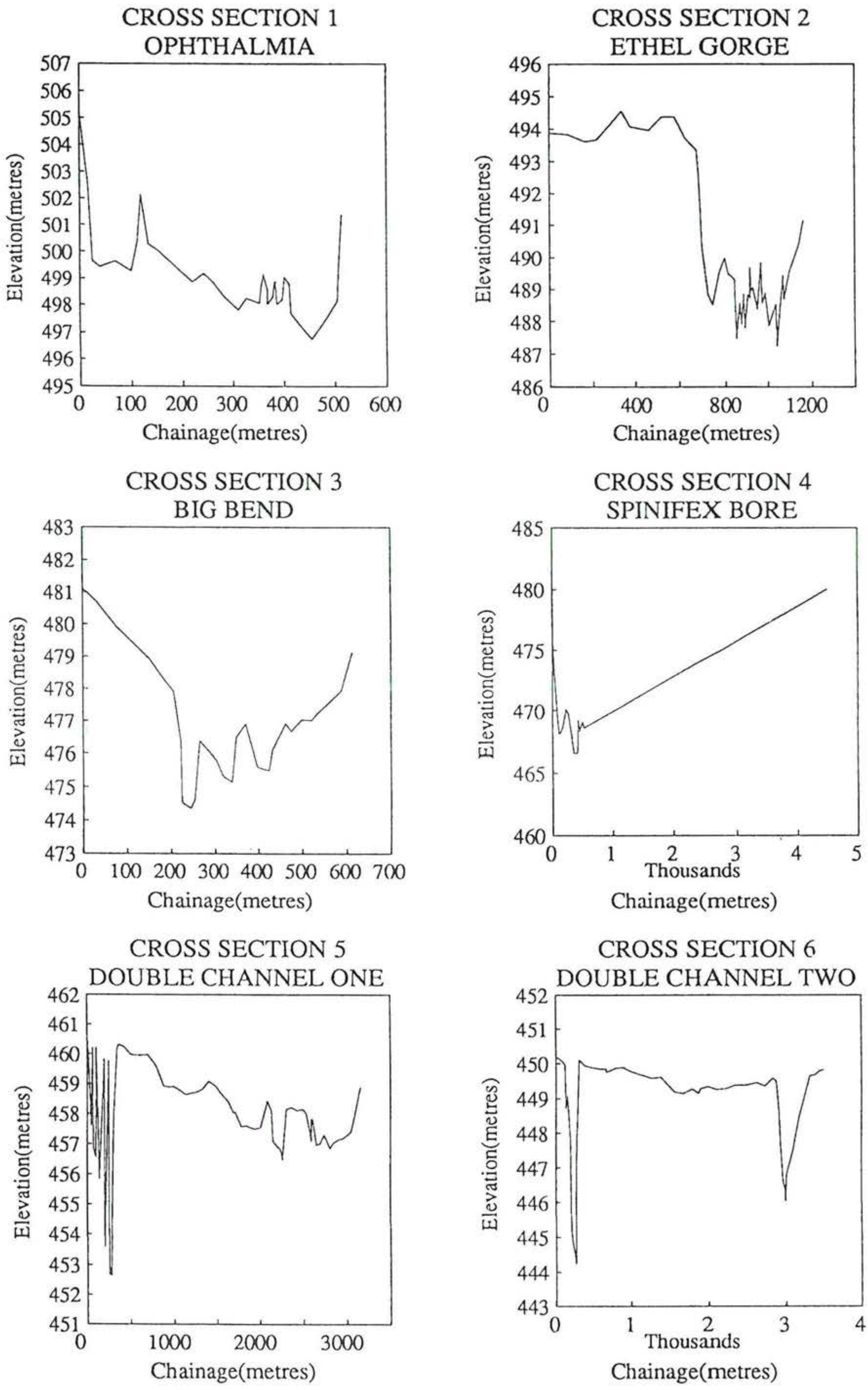


Fig. 44 **Cross Section Profiles - Cross Section 1 to 6**

CROSS SECTION PROFILES

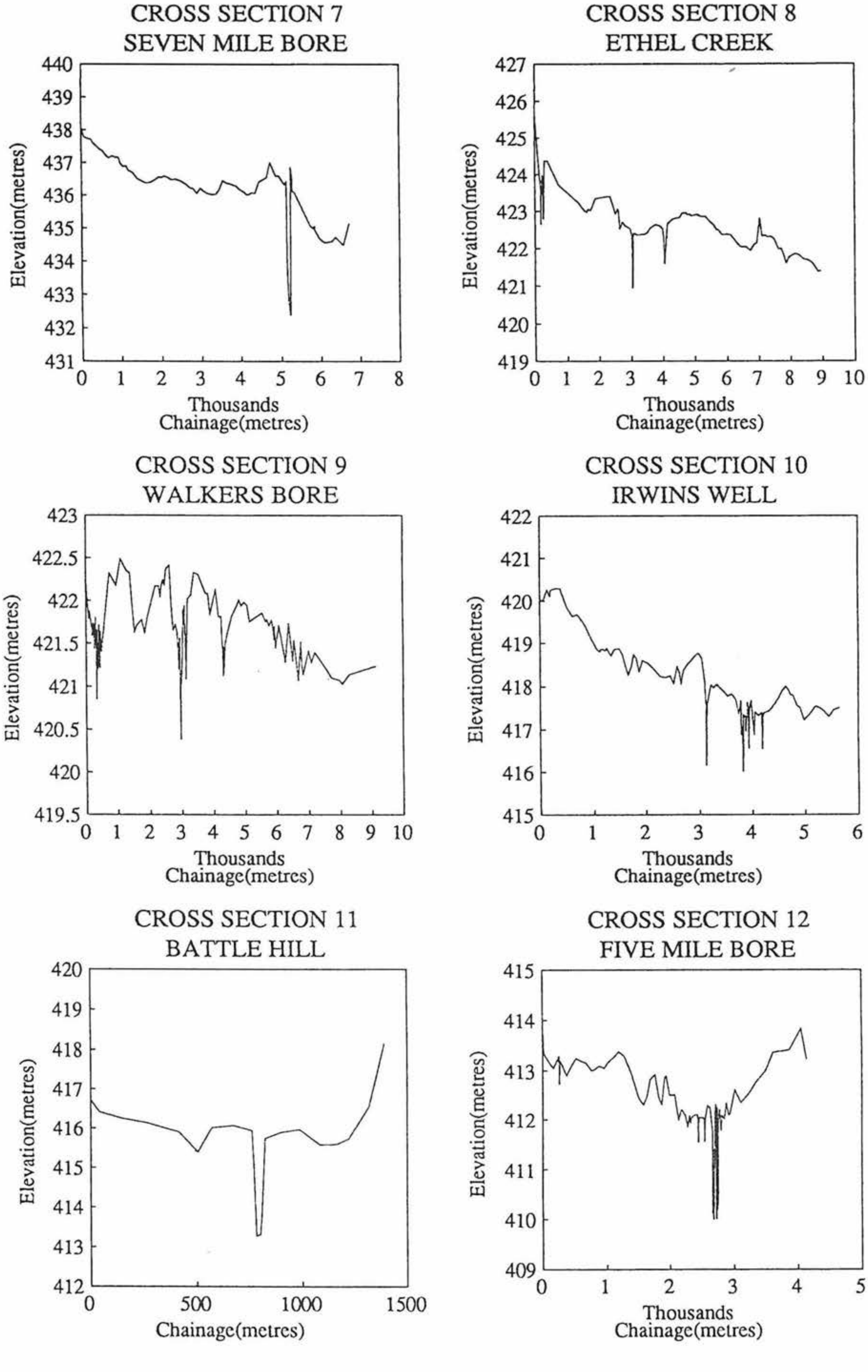


Fig. 45 **Cross Section Profiles - Cross Section 7 to 12**

CROSS SECTION PROFILES

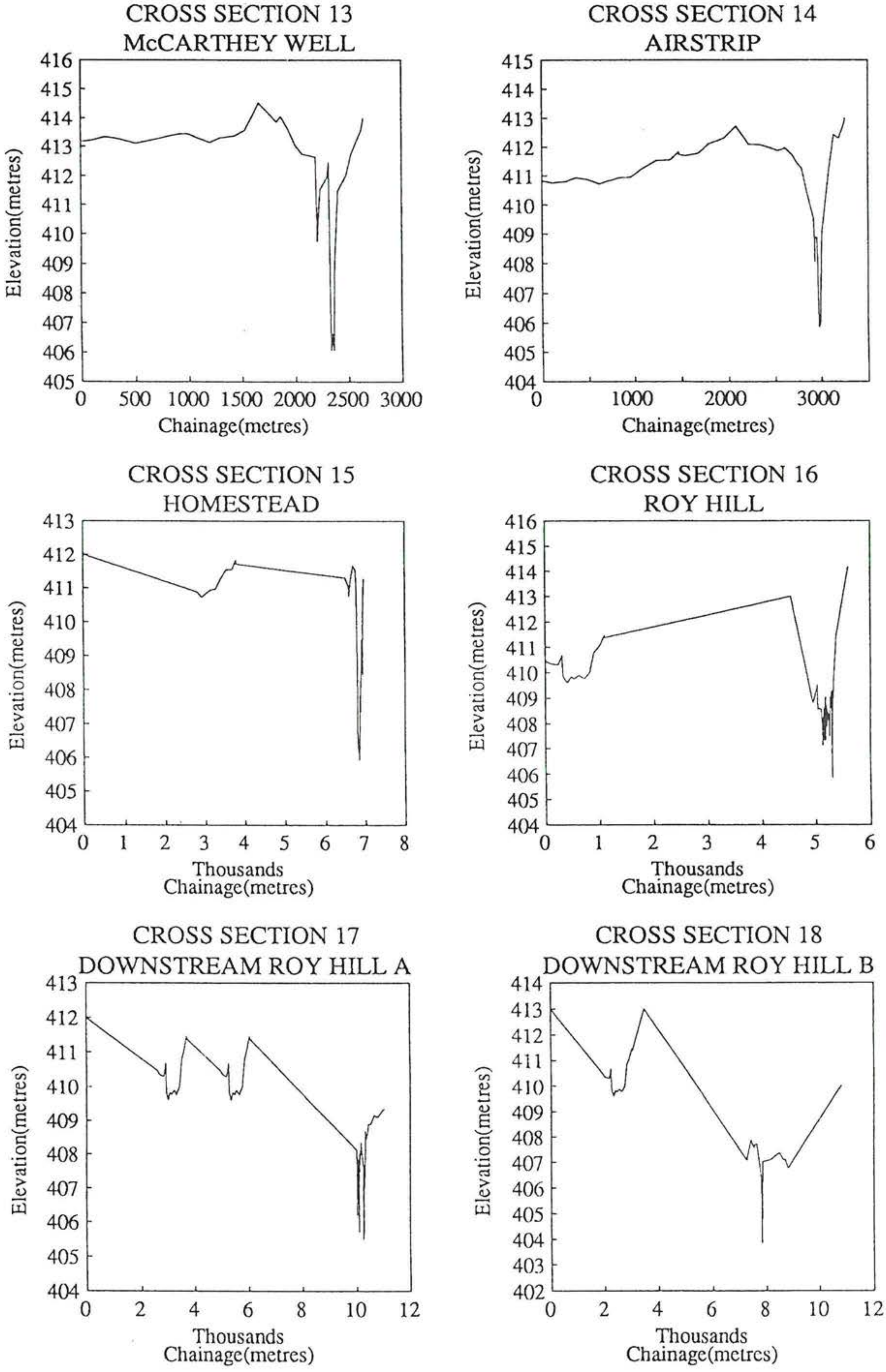
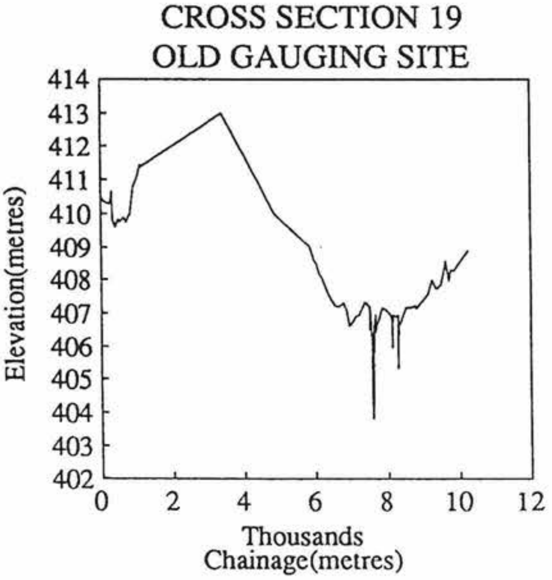
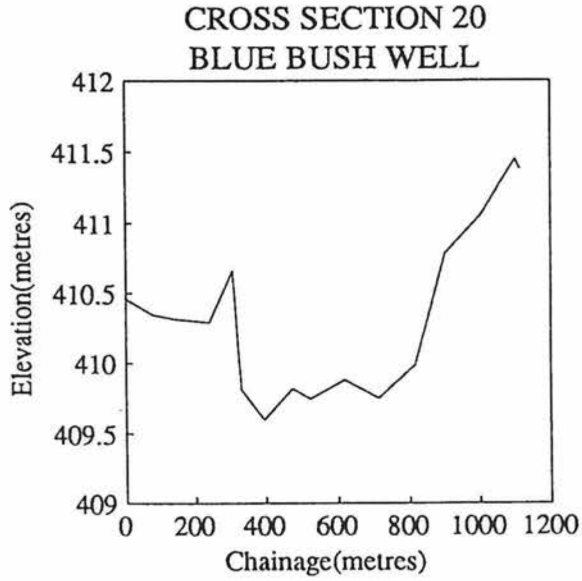


Fig. 46 Cross Section Profiles - Cross Section 13 to 18

CROSS SECTION PROFILES





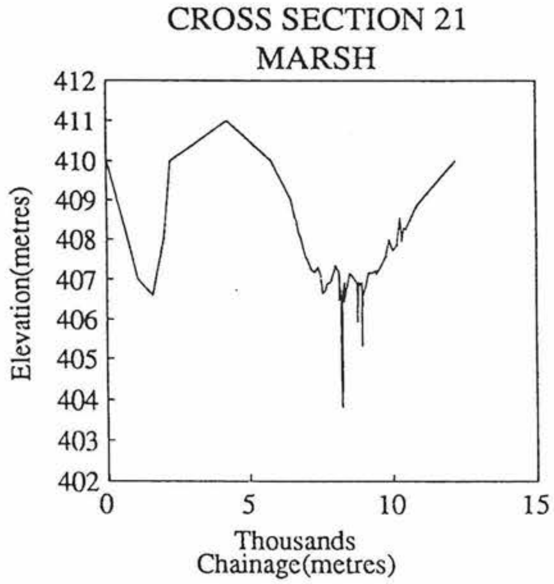


Fig. 47 **Cross Section Profiles - Cross Section 19 to 21**