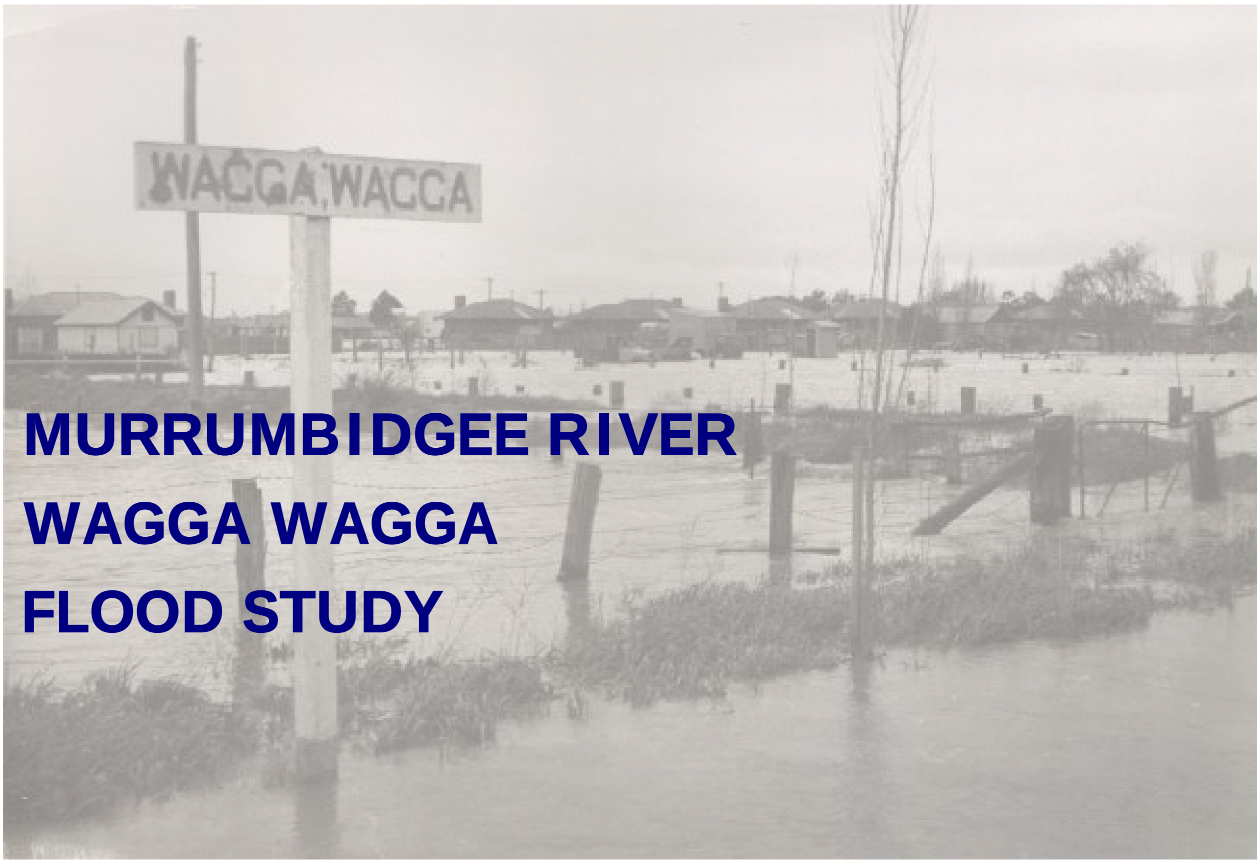
THE COUNCIL OF THE CITY OF WAGGA WAGGA

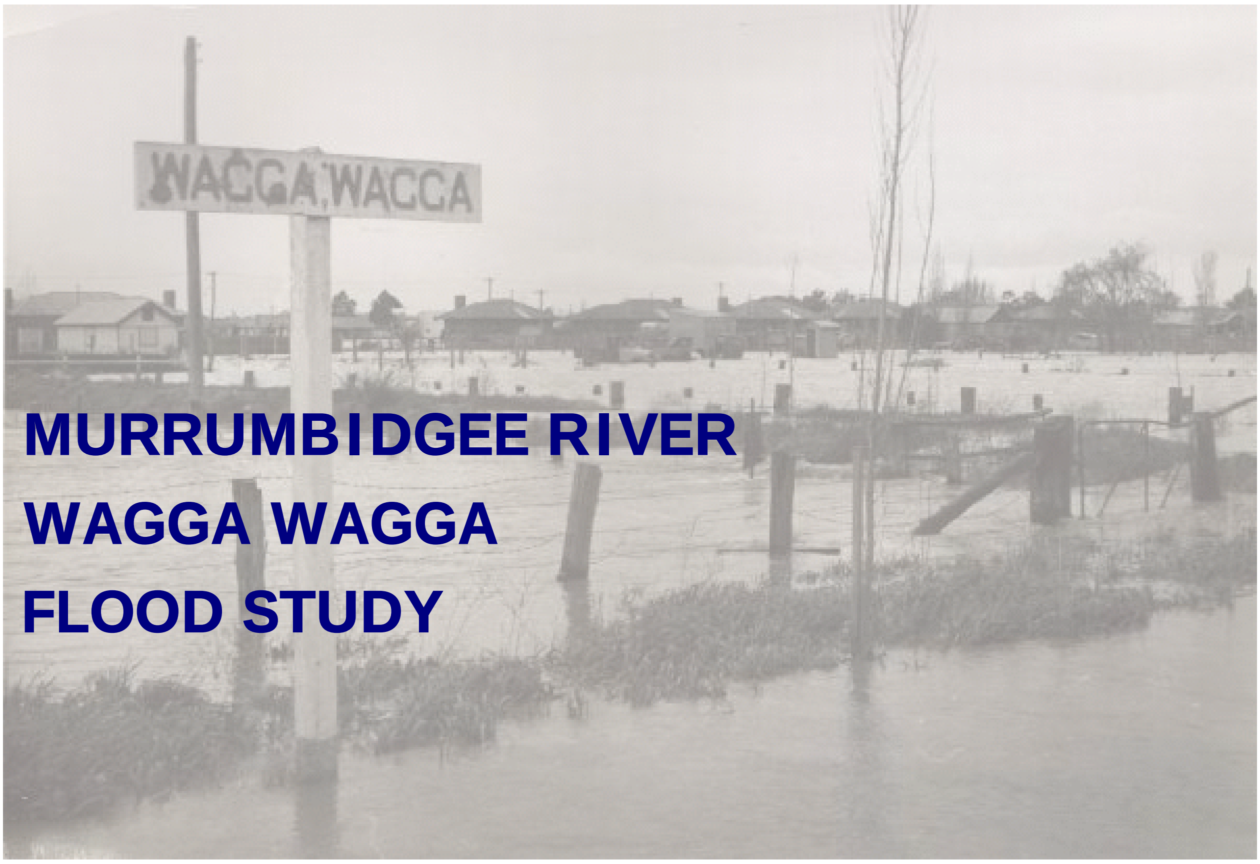


MURRUMBIDGEE RIVER
WAGGA WAGGA
FLOOD STUDY

SEPTEMBER 2004

WEBB, McKEOWN & ASSOCIATES PTY LTD

THE COUNCIL OF THE CITY OF WAGGA WAGGA



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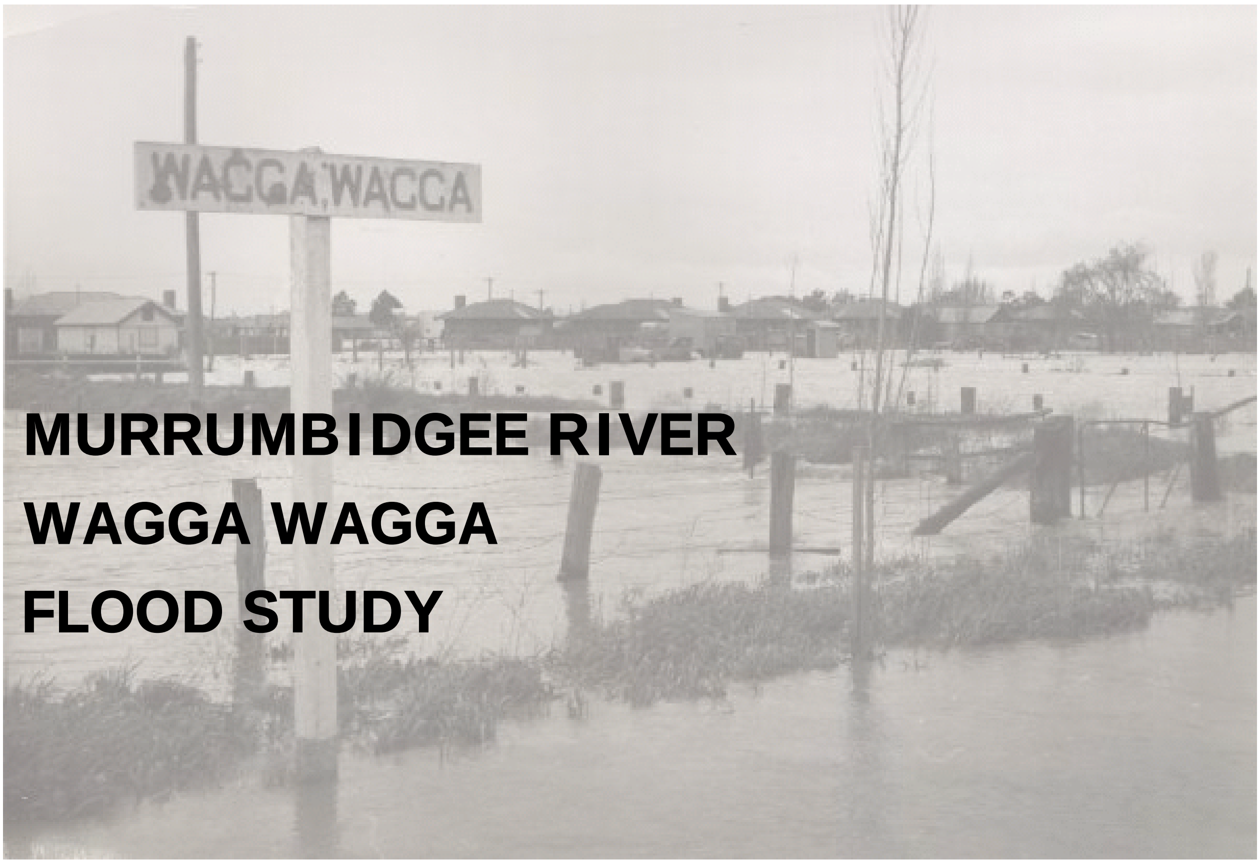

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WAGGA WAGGA
FLOOD STUDY

SEPTEMBER 2004

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MURRUMBIDGEE RIVER - WAGGA WAGGA FLOOD STUDY

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FOREWORD

The State Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through the following four sequential stages:

1. *Flood Study*
   - determines the nature and extent of the flood problem.

2. *Floodplain Risk Management Study*
   - evaluates management options for the floodplain in respect of both existing and proposed development.

3. *Floodplain Risk Management Plan*
   - involves formal adoption by Council of a plan of management for the floodplain.

4. *Implementation of the Plan*
   - construction or implementation of floodplain risk management measures to protect existing development,
   - use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Murrumbidgee River - Wagga Wagga Flood Study constitutes the first stage of the management process. This study has been prepared by Webb, McKeown & Associates for the City of Wagga Wagga Council and provides the basis for the future management of flood prone lands in the Murrumbidgee River floodplain at Wagga Wagga.

SUMMARY

The Murrumbidgee River rises on the western slopes of the Snowy Mountains and has a catchment area of some 26,400 square kilometres at Wagga Wagga. The city has experienced a considerable history of flooding that has shaped the past and will continue to shape the future development of the city and the region.

This Flood Study has been developed to define the extent of flooding for a range of design events in accordance with the 2001 NSW Floodplain Management Manual. This information will be used for development control purposes to ensure that the future growth of the city is in accordance with best management practice and consistent with the principles of ecologically sustainable development.

A previous Flood Study for Wagga Wagga was completed in 1988. This present study reviews the earlier work and expands upon it using current information and techniques. A rigorous flood frequency analysis of all past flood records was undertaken to determine the magnitude of the design events. A RUBICON hydraulic (computer) model was established, calibrated to historical data and used to determine design flood levels. An examination of the location and extent of overtopping of the Main Town levee at Wagga Wagga was also undertaken.

An important outcome of this work was that the August 1974, previously considered to be a 1 in 90 ARI event, is now considered to be a 1 in 60 ARI event. This conclusion was reached after detailed analysis of the historical flood record and in particular, the inclusion of several flood events which occurred prior to the start of the "official" flood record in 1886. Previous studies have not relied upon this information which has been accurately documented by a former alderman and resident, Mr J E Gormly.

The information provided in this Flood Study is the most up-to-date analysis of flooding at Wagga Wagga and should be adopted by Council for development control purposes. The modelling and results incorporate the many significant changes to the floodplain which have occurred since the previous flood studies were undertaken. Such changes can have a localised and/or cumulative effect on flood levels. An estimate of the order of accuracy of the design flood levels is ±0.5 m. This accuracy could be improved upon by analysis of any future flood events where suitable calibration data becomes available. It is therefore recommended that Council undertake a detailed flood data collection exercise following future events to ensure that all relevant data are collected and available for use in future studies.

GLOSSARY

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a peak flood discharge of 500 m^3/s or larger occurring in any one year (see average recurrence interval).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the 1986 Floodplain Development Manual (see flood planning area).
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood storage areas Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.

freeboard A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as "greenhouse" and climate change. Freeboard is included in the flood planning level.

hazard A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Floodplain Management Manual.

hydraulics Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or

- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

- major overland flow paths through developed areas outside of defined drainage reserves; and/or

- the potential to affect a number of buildings along the major flow path.

mathematical/computer models The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a Floodplain Risk Management study.
Probable Maximum Precipitation (PMP)	The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.
probability	A statistical measure of the expected change of flooding (see annual exceedance probability).
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to "water level". Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.

1. INTRODUCTION

The Murrumbidgee River at Wagga Wagga has a long history of flooding. Earlier flood studies for the City of Wagga Wagga determined design flood levels, velocities and discharges throughout the floodplain. However, in light of subsequent advances in hydrologic and hydraulic modelling a review of this work was required. As the first stage in the development of an updated Floodplain Management Plan, Webb, McKeown & Associates were engaged by Wagga Wagga City Council to conduct a review of the Flood Study. The reasons for this review include:

- more technologically advanced hydraulic models have become available,
- significant developments/alterations to the floodplain have been made such as the construction/raising of the North Wagga Wagga levee,
- earlier studies did not consider larger floods such as the PMF or overtopping of the Main Town levee.

The primary objectives of this study were to:

- review all existing historical flood information,
- complete a flood frequency analysis in line with the latest methodologies,
- establish a numerical hydraulic model to determine flood flows, velocities and levels for a range of design events including the PMF,
- determine the probability and locations of overtopping of the Main Town levee.

This report details findings and results of the investigation with key elements being:

- a summary of available data,
- documentation of the flood frequency analysis,
- calibration and verification of an updated hydraulic model,
- determination of design flood behaviour.

All levels provided in this report are in metres (m) to Australian Height Datum (AHD) (which is the standard national survey reference with 0 mAHD approximating mean sea level) unless otherwise stated. The magnitude of floods are referred to in this report according to their Average Recurrence Interval (ARI - that is occurs in an average of 1 in y years) .

1.1 Catchment Description - Murrumbidgee River

The Murrumbidgee River is a major tributary of the Murray River system and drains some 100,000 km^2 in the southern inland area of New South Wales. The catchment (Figure 1) is bounded on the east by the Great Dividing Range, to the north and south by the Lachlan and Murray Rivers respectively, and with the boundary of the lower Murray-Darling catchment to the west.

From its source in the Fiery Range of the Snowy Mountains, the Murrumbidgee River flows in a south-easterly direction near Cooma and then turns northwards towards Canberra. Burrinjuck Dam is located downstream of Yass and Canberra and captures an area of some 13,000 km^2.

The river then flows in a westerly direction past the towns of Gundagai and Wagga Wagga. Just north of Gundagai the Tumut River (4,000 km^2) on which the Blowering Dam is situated enters the Murrumbidgee. The catchment to Wagga Wagga is some 26, 400 km^2.

Downstream of Wagga Wagga the floodplain becomes increasingly less well defined. The major towns to the west are Narrandera, Hay and Balranald. Further description of the catchment is provided in Reference 1.

1.2 Study Area - City of Wagga Wagga

The Murrumbidgee River at Wagga Wagga has a catchment area of some 26,400 km^2. The original settlement of North Wagga Wagga is situated on the northern floodplain with the majority of the city and recent developments now located on the high ground of the southern bank. A large part of the city remains on the floodplain and is protected from flooding by levee banks, termed the North Wagga Wagga levee and the Main Town levee (south). The main road crossing point used to be Hampden Bridge but this is now closed and has been replaced by the nearby Wiradjuri Bridge and the recently constructed Gobbagombalin Bridge. At Hampden Bridge the floodplain is some 3 km wide but this reduces to approximately 1.4 km at Gobbagombalin Bridge. Upstream of Wagga Wagga the river is crossed by the Eunony Road Bridge and the main southern railway. The extent of the study area is shown on Figures 2 and 3.

1.3 Flood History

Since early European settlement in the 1840's, the City of Wagga Wagga has experienced flooding on numerous occasions. These events have caused considerable damage, inconvenience and loss of life. The consideration of flooding has been an integral component of development of the city and the region, and remains so even today.

Official records of river levels are available at Hampden Bridge from 1886 onwards, with estimated river levels available for the preceding period to 1838 provided in Reference 2 and other sources. The flood record is extremely variable with five major floods occurring in 1974 and frequent flooding experienced in the period from 1950 to 1956. There have also been long periods of no flooding, such as from 1939 to 1949, 1960 to 1970 and 1992 to 2003.

Flood levels presented in this report are generally quoted in metres relative to Australian Height Datum (mAHD) except where the discussion relates to gauge levels at Hampden Bridge. Most local residents also refer to gauge levels rather than mAHD. The gauge zero at Hampden Bridge is 170.05 mAHD. (Therefore, a value of 170.05 m is added to the gauge reading to convert to mAHD).

The sheer magnitude of the volume of floodwaters generated by the catchment means that it is impossible to significantly reduce the peak flood flows, even with the construction of major dams such as Burrinjuck, Blowering and Tantangara in the Snowy Mountains. The main means of protecting the City from inundation has been the construction of Council and private levee banks together with controls imposed on new development by Council.

1.4 Levee Banks

1.4.1 General

Since the mid 1800's, when the scale of the flood problem became known, local residents have constructed levee banks on the floodplain and placed buildings on higher ground. Following the 1956 floods Council decided to construct a levee bank (the Main Town levee) to protect the city located on the southern floodplain. The Main Town levee was subsequently upgraded in the late 1970's and again more recently in 1983 following the August 1974 flood. This event is generally considered to be the largest flood accurately recorded, although the October 1844 and July 1853 events probably exceeded it by approximately 0.2 m. The levee currently provides protection from inundation up to a level of approximately the August 1974 event plus a freeboard of 1m.

Temporary levees have been constructed around the village of North Wagga Wagga since at least the mid 1930's. These levees were formalised as more permanent structures in 1990 so as to provide protection up to approximately 0.5 to 1 m below the level of the August 1974 event.

There are several other low banks located on the floodplain, including the levee constructed in 1992 which protects the Gumly Gumly area. This provides protection to approximately a 1 in 10 ARI event. Figure 2 shows the location of the main levee banks within the study area.

1.4.2 Changes to the Floodplain

A substantial change to the floodplain (e.g. construction of a levee bank, bridge, channel, excavation or other structure or activities) may affect flood behaviour and hence the distribution of flows across the floodplain. There is no accurate chronological history of when such changes have occurred. The best available summary of the significant changes which are known is provided in Table 1.

Table 1: Summary of Changes to the Floodplain

Date	Works on the Floodplain	Comment
Pre 1960 and continuing	Narrung Street Sewage Treatment Ponds: • **1914** - The site was first developed as a sewage plant for the town of Wagga Wagga. • **early 1950's** - A formalised series of treatment ponds were constructed between the plant and the river. • **1967/1968** - The ponds were upgraded to the current configuration including construction of four ponds west of the Bomen rising main. • **approx. 1977** - Three ponds west of the Bomen rising main were removed in order to reduce upstream flood levels. The bank around the emergency overflow pond (the remaining pond to the west) may have also been lowered at the same time. • **mid 1990's** - A floodway was partially constructed through the ponds.	Council is aware of the restriction caused by construction of the banks around the treatment ponds (Reference 3) and is currently addressing this issue including the associated environmental/public health issues.
1930s	Gobba weir and levee	(Upgrading to eastern end in late 1960's/early 70's)
1962	Main Town levee constructed on southern floodplain.	Limited the width of floodplain.
1971	Levee constructed at the western (downstream) end of Kurrajong Lagoon.	Up to 1 m high and 200 m long. This prevents floodwaters up to 9.3 m on the gauge (179.35 mAHD) from entering the northern floodway and cutting the Junee Road.
1975	Raising of East Street and Mill Street levee to 179.3 mAHD.	
1975	Eunony Bridge was completed. In the August 1974 flood the bridge was only partially constructed with the approaches constructed by the time of the October 1975 flood.	
1975	The Gumly Gumly levee was temporarily raised to its present level following the August 1974 flood.	
1978-1983	The Main Town levee was upgraded to approximately 1 m above the 1974 flood level.	
1978	A levee was constructed around the Allonville Motel and the access road to the Murray Cod Hatchery was raised.	
Late 1980's	The Sturt Highway was raised by up to 0.2 m.	
1990	Construction of the North Wagga Wagga levee.	
1992	The Gumly Gumly levee was formalised to approximately the 1 in 10 ARI event.	
1995	Construction of Wiradjuri Bridge	Minor alterations to access road between Wiradjuri and Parken Pregan bridges
1997	Construction of Gobbagombalin Bridge	Changes to northern edge of floodplain from Gobba lagoon to Coolamon Road

In addition to the above, there are also various quarries, buildings and in fill and development on the floodplain that have or will impact on the distribution of flood flows.

2. DATA

A comprehensive data search was undertaken within the available timeframe including:

- review of previous studies and other references,
- provision of a questionnaire and newsletter to local residents,
- interviews with local residents,
- obtaining gauging and stream height data from the Department of Land and Water Conservation's (now Department of Infrastructure, Planning and Natural Resources - DIPNR) Pinneena 6 surface water data CD (Reference 4),
- discussions with Council officers,
- review of aerial photographs.

2.1 Previous Studies

A number of studies have been undertaken in the area and the following reports (in chronological order) are of particular relevance to the present study.

2.1.1 Murrumbidgee River Flood Mitigation Study - November 1977 (Reference 1)

This report was not reviewed in detail as part of this present study. The content of the report was summarised in Reference 5 as follows.

The purpose of the study was to:

- *assemble a database comprising flooding and related data,*
- *assess the need for flood mitigation,*
- *identify practical flood mitigation strategies.*

A number of individuals and organisations were contacted as part of the study and a public meeting was held in Gundagai. Many expressed concern regarding development on the floodplain outside the levee. The major issues were identified in the report and the recommendations stressed the need for management of development on the floodplain.

2.1.2 Floodplain Management Study - Murrumbidgee River at Wagga Wagga - 1979 (Reference 5)

This study followed on from Reference 1 and included the establishment of a computer model (steady-state backwater type) of the floodplain and the hydraulic evaluation of over ten floodplain management proposals.

Further studies (References 6 and 7) were also carried out but are of no relevance to the present investigation.

2.1.3 Wagga Wagga Flood Study - 1988 (Reference 8)

This study established an unsteady state quasi two-dimensional hydraulic model (CELLS) of the floodplain. The model was calibrated using the available August 1974 flood level data and verified against the October 1975 and October 1976 events. A flood frequency analysis of an annual series of peak discharges was also undertaken (the period of data used in this analysis is not stated). The results were:

ARI	Discharge at Hampden Bridge (m^3/s)
1 in 10	2090
1 in 20	3010
1 in 50	4580
1 in 100	6100

The August 1974 flood was assumed to have a peak flow of 5700 m^3/s and approximated a 1 in 90 ARI event. The study subsequently analysed various mitigation and development measures.

2.1.4 Hydraulic Investigation - Narrung Street STW - 1999 (Reference 3)

The Narrung Street sewage treatment works are located approximately one kilometre north-west of the City of Wagga Wagga on the southern side of the Murrumbidgee River. The site was first developed as a treatment plant around 1914 and has been continually upgraded during the intervening period. The formalised series of ponds were constructed between the treatment plant itself and the river in the early 1950's and further upgrading occurred in 1967/68.

The 1999 hydraulic investigation was undertaken to determine the effect of the treatment ponds upon flood levels, flows and velocities for a range of flood events. Previous studies found that flood levels were increased as a result of the treatment pond upgrading works carried out in 1967/68.

The 1999 study re-established the hydraulic model used in Reference 8 and produced design flood levels for a range of flood events. The study concluded that removal of three ponds in 1977 and the creation of a floodway in the mid 1990's had partially reduced the impact by up to 0.08 m (based on preliminary analysis). The nett effect of the works carried out since 1967/68 was a maximum increase in flood level of +0.12 m immediately upstream of the ponds for an August 1974 size event. This impact reduced to ±0.05 m within 500 m further upstream and ±0.03 m at North Wagga Wagga and Hampden Bridge. There was no discernible impact upstream of the railway bridge. In the 1 in 5 and 1 in 2 ARI size events, there was little flow of floodwaters across the floodplain for pre 1967/68 conditions and hence no impacts.

Enlarging the partially completed floodway through the ponds to a 20 m wide channel would produce no significant reduction in flood level in an August 1974 type event but would provide a minor benefit in a 1 in 5 ARI event.

2.1.5 Wagga Wagga - Renewal of Murrumbidgee River Bridge and Viaducts - 2002 (Reference 9)

The aim of this study was to assess the impacts on flood levels associated with replacement of the viaduct and railway bridge structure for a range of floods from the 1 in 10 ARI to the PMF.

An XP-SWMM floodplain model was established based upon the CELLS hydraulic model used in Reference 8. Flood frequency analysis (Log Pearson III) was undertaken using the Pinneena annual peak flow data for the period 1892-1997. The results indicated flows for the design events to be approximately 10% lower than Reference 8. Thus the August 1974 flood approximated a 1 in 100 ARI event whilst in Reference 8 it was considered to be only a 1 in 90 ARI event.

The hydraulic analysis of the proposed crossing renewal options indicated a potential increase in level of up to 0.04 m in the August 1974 flood, 0.02 to 0.06 m in the 1 in 2000 ARI event and 0.01 to 0.15 m in the PMF. No conclusion was provided about which replacement scenario was preferred.

2.1.6 Burrinjuck Dam Dambreak Study (Draft) - March 2001 (Reference 10)

This study reviewed the hydrologic risk of the spillway configuration at Burrinjuck Dam. A number of scenarios were investigated including the PMF event with and without dam failure and the impacts along the Murrumbidgee River as far downstream as Wagga Wagga were calculated. A comparison study described below (Reference 11) investigated the likelihood of dam failure in a PMF event.

2.1.7 Burrinjuck Dam Assessment of Spillway Adequacy Using a Joint Probability Approach - March 2001 (Reference 11)

This study derived the design floods for Burrinjuck Dam and a joint probability analysis was undertaken to derive the outflow frequency curve. It was found that the PMF discharge of 28,650 m^3/s was less than the dam crest flood of 32,200 m^3/s. Hence the spillway configuration could pass the PMF design event.

2.2 Topographic and Hydrographic Survey

Earlier flood studies undertaken for Wagga Wagga have resulted in the availability of a wide variety of topographic and hydrographic survey data. The accuracy and suitability of the data varies due to the variety of sources, applications and changes in technology under which the data were collected.

This previous survey data have been updated and supplemented where necessary by Council surveys conducted specifically for this study. In addition, on behalf of DIPNR, Public Works conducted a survey of levee crest elevations for the Main Town and North Wagga Wagga levees in July 2002 (Reference - R2824/00001). Inspection of these data revealed that the surveyors followed the wrong alignment near Narrung Street (refer Appendix C). Council therefore preferred that their detailed survey of the levee crest undertaken in 2001 be adopted instead.

The location and extent of survey information available for use in this study are shown on Figure 4. Table 2 details the history of this survey.

Table 2: Survey History

Approximate Survey History	Description/Source	Reference No.
1970's	Eunony Bridge Road Profile	8
1971-1972	1:4000 Orthophotomaps	n/a
1977-1979	SKM & Partners Studies	1, 5
1980	Meadowbank Bridge	8
1980's	Gobbagombalin Bridge	8
1982	Council Survey Plan D335	8
1987-1988	Council Floodplain Survey	8
2002	DIPNR Levee Crest Survey	n/a
2002	Railway Natural Surface - Railway Infrastructure Corp.	9
2002-2003	Council Survey for this Flood Study	n/a

2.3 Photographs

Council and the local newspaper hold a considerable number of flood photographs dating back to the late 1800's. This record is valuable for indicating the extent and height of past floods. It would be valuable if the records were amalgamated into a digital form that could be used in subsequent studies.

2.4 Data from Pinneena 6 (Reference 4)

2.4.1 Description

Flood heights, rating curves, cross-sections and other details for the Hampden Bridge gauge at Wagga Wagga (No. 410001) are available from the Pinneena 6 surface water archive CD (Reference 4).

Hampden Bridge was the first stream gauging station established on the Murrumbidgee River. Records are available from October 1868 but there are significant gaps in the data set up until 1885. By 1900, a further four stations were added (Gundagai, Narrandera, Hay and Balranald). There was a considerable expansion in the number of gauges on the Murrumbidgee River following constitution of the Snowy Mountains Authority in 1949.

Up until 1972 the Hampden Bridge gauge was read manually and generally only a daily water level was available. Additional levels during flood events are sometimes available. An automatic gauge which allows a complete and accurate definition of the flood hydrograph has been installed since 1972.

Construction of the Snowy Mountains Scheme, and in particular Burrinjuck Dam (construction started in 1912 with significant upgrading works undertaken in 1956 and the 1980's/90's) and Blowering Dam (1968), has had a significant influence on the low flow record. They have also affected the high (flood) flow record. The exact extent is unknown as it depends upon the available storage in the dams at the time of the flood and the rate of release of the floodwaters. There is no readily available means of adjusting the flood record to account for the dams and other factors (deforestation, land irrigation, channel works, construction of levee banks and other works on the floodplain at Wagga Wagga). Some of these may increase flows and flood heights (deforestation, levee banks) whilst others may reduce flows and flood heights (dams). This issue is discussed further in Section 3.3.2.

2.4.2 Stream Gauging

Water levels at a stream gauging station are recorded either manually (gauge readers) or automatically and are converted to a discharge or flow using an estimated rating curve (height-discharge relationship). The rating curve is derived from velocity readings taken at different river depths and times, together with a survey of the river cross-sectional area. Over 600 stream gaugings have been undertaken at Hampden Bridge since 1892 with 60 rating curves developed (refer Graphs 1 and 2). The availability of these data have resulted in a reasonably accurate estimate of inbank flows. However, whilst high flow gaugings are available (1 at >10 m, 9 at >9 m, 28 at >8 m) it is likely that the flow estimates for significant overbank events are less reliable as it is impossible to accurately gauge the 3 km wide floodplain.

Pinneena uses the rating curve current at the time of the stream height measurement to determine the discharge. This can mean the same water level, recorded in different years, is assigned a different discharge (refer Graph 2). This approach is valid when there are changes to the stream morphology (channel erosion, sedimentation) that alter the height-discharge relationship. However, it is probably invalid when the change in rating curve is due to the addition of more accurate data or a change in approach to determining the high flow rating.

The highest gauging at Hampden Bridge is 10.3 m (approximate discharge of 4200 m^3/s) on 31st August 1974 which was approximately 0.4 m below the flood peak. Discharges above the highest gauging are obtained by extrapolating the rating curve.

2.4.3 Analysis of Flood Record

Graphs 3, 4 and 5 collectively provide a record of the daily peak water levels for the period 1868 to 2002. There are significant gaps in the record from 1868 to 1885 and also from 1906 to 1907.

A listing of the annual flood peaks (1886-2002) is summarised in Table 3 and shown on Graph 6. This analysis indicates that there are 69 occurrences, over 6 m, 31 over 8 m, 16 over 9 m and 5 over 10 m. Graph 6 indicates that the range of annual peaks varies considerably (from <2 m to over 10 m) and there are no significant periods of consistently large or small annual flood peaks.

Table 3: Summary of Annual Flood Peaks (1886 to 2002)

Year	Month	Gauge Height (m)	Year	Month	Gauge Height (m)	Year	Month	Gauge Height (m)
1886	Dec	6.60	1925	May	10.11	1965	Aug	2.59
1887	Jul	8.38	1926	Jun	6.20	1966	Nov	7.19
1888	Dec	4.88	1927	Oct	3.81	1967	Mar	2.59
1889	Sep	7.77	1928	Jul	3.96	1968	Aug	6.15
1890	Jul	6.86	1929	Oct	2.74	1969	Jun	7.65
1891	Jun	10.47	1930	Oct	4.60	1970	Sep	8.87
1892	Oct	8.36	1931	Jun	9.60	1971	Feb	8.46
1893	Jun	7.26	1932	Sep	7.65	1972	Sep	4.26
1894	Apr	9.14	1933	Sep	5.56	1973	Aug	5.79
1895	Jun	5.28	1934	Oct	9.20	1974	Aug	10.74
1896	Jun	3.96	1935	Oct	6.33	1975	Oct	9.58
1897	Jan	4.88	1936	Jul	7.62	1976	Oct	9.38
1898	Feb	5.18	1937	Oct	3.58	1977	Jul	4.16
1899	Aug	7.24	1938	Sep	2.36	1978	Sep	8.91
1900	Jul	9.96	1939	Aug	8.61	1979	Oct	3.72
1901	Nov	6.81	1940	Sep	2.29	1980	Jul	3.45
1902	Dec	2.44	1941	Jan	3.76	1981	Jul	6.30
1903	Sep	6.10	1942	Jul	6.33	1982	Aug	3.02
1904	Jul	3.81	1943	Oct	5.97	1983	Aug	8.85
1905	Jul	8.38	1944	Jul	1.70	1984	Aug	8.96
1906	Oct	8.69	1945	Nov	3.35	1985	Sep	5.92
1907	Dec	3.12	1946	Jul	4.88	1986	Nov	7.06
1908	Sep	4.80	1947	Dec	5.89	1987	Jun	4.68
1909	Aug	7.24	1948	May	4.93	1988	Dec	5.41
1910	Sep	4.57	1949	Oct	6.71	1989	Apr	9.38
1911	Jul	4.57	1950	Mar	10.06	1990	Jul	7.65
1912	Sep	6.83	1951	Sep	7.77	1991	Jul	9.61
1913	Jul	6.02	1952	Jun	9.70	1992	Oct	7.93
1914	Mar	3.51	1953	Nov	7.77	1993	Oct	8.85
1915	Sep	6.86	1954	Feb	3.40	1994	Feb	3.91
1916	Oct	8.74	1955	Aug	8.43	1995	Jul	7.62
1917	Oct	8.64	1956	Jul	9.60	1996	Oct	7.54
1918	Aug	7.93	1957	Jul	2.24	1997	Jan	4.11
1919	Oct	2.74	1958	Oct	7.14	1998	Sep	5.23
1920	Aug	6.66	1959	Oct	9.07	1999	Jan	4.21

Year	Month	Gauge Height (m)	Year	Month	Gauge Height (m)	Year	Month	Gauge Height (m)
1921	Sep	7.44	1960	Sep	8.92	2000	Sep	6.69
1922	Aug	9.17	1962	Sep	6.78	2001	Oct	4.68
1923	Oct	7.44	1963	Aug	4.42	2002	Jan	3.33
1924	Aug	7.77	1964	Oct	7.75			

Graph 7 summarises the month of occurrence of the annual flood peaks. It clearly indicates that the main period of potential flooding occurs from June to October.

A summary of the months where daily flood peaks have exceeded 6 m (256), 7 m (155), 8 m (76), 9 m (27) and 10 m (5) is shown on Graph 8. For this analysis it was assumed that individual peaks were separated by at least two days. The results indicate that the majority of floods occur in the period of June to October (the same period as the annual flood peaks). However three of the five events greater than 10 m occurred outside this period with one in March, April and May.

Table 4 provides a ranking of the flood peaks greater than 8 m (separated by at least 2 days) for the period 1886 to 2002.

Table 4: Ranking of Flood Peaks >8 m (1886 to 2002)

Rank	Gauge Height (m)	Date	Rank	Gauge Height (m)	Date	Rank	Gauge Height (m)	Date	Rank	Gauge Height (m)	Date
1	10.74	30/08/1974	20	9.19	07/09/1974	39	8.84	31/10/1952	58	8.46	14/02/1971
2	10.67	28/04/1870	21	9.17	31/07/1922	40	8.76	14/06/1931	59	8.46	24/02/1971
3	10.47	29/06/1891	22	9.14	21/01/1891	41	8.75	29/06/1975	60	8.43	28/08/1955
4	10.11	29/05/1925	23	9.14	22/04/1894	42	8.74	12/09/1894	61	8.41	29/06/1894
5	10.06	25/03/1950	24	9.12	16/06/1956	43	8.74	09/10/1916	62	8.38	08/07/1887
6	9.96	07/07/1900	25	9.07	06/04/1950	44	8.71	28/07/1956	63	8.38	15/07/1905
7	9.91	15/05/1870	26	9.07	24/10/1959	45	8.69	04/07/1872	64	8.38	04/06/1952
8	9.73	14/07/1891	27	9.05	07/04/1989	46	8.69	06/10/1906	65	8.38	09/06/1952
9	9.70	19/06/1952	28	8.99	10/07/1956	47	8.69	01/10/1970	66	8.36	21/10/1892
10	9.61	15/07/1991	29	8.96	31/07/1984	48	8.64	23/10/1917	67	8.33	06/05/1956
11	9.60	26/06/1931	30	8.94	15/04/1974	49	8.61	28/03/1894	68	8.31	21/07/1894
12	9.60	30/06/1956	31	8.94	30/01/1984	50	8.61	18/08/1934	69	8.31	21/07/1917
13	9.58	28/10/1975	32	8.92	24/10/1950	51	8.61	26/08/1939	70	8.23	31/08/1916
14	9.38	16/04/1989	33	8.92	28/09/1960	52	8.59	20/07/1956	71	8.22	17/07/1975
15	9.38	20/10/1976	34	8.91	11/09/1978	53	8.56	21/10/1956	72	8.18	02/07/1939
16	9.22	19/10/1974	35	8.90	06/10/1974	54	8.53	06/08/1891	73	8.08	26/01/1887
17	9.22	05/06/1870	36	8.87	26/09/1970	55	8.53	31/05/1900	74	8.08	04/08/1960
18	9.20	21/06/1870	37	8.85	28/08/1983	56	8.46	08/10/1917	75	8.05	31/07/1891
19	9.20	28/10/1934	38	8.85	07/10/1993	57	8.46	19/05/1956	76	8.03	26/10/1974

2.4.4 Data Prior to 1886

Prior to 1886 there is only limited official height data available from Pinneena (refer Graph 3). A compilation of flood heights from 1838 was made by J E Gormly, a former alderman and resident of the City of Wagga Wagga, and published in *"61 Floods at Wagga Wagga"* (Reference 2) and is included in Appendix A. Whilst anecdotal evidence such as this can often be unreliable, the author's comments add confidence to this data set. For example, he understands the importance of a fixed reference point, noting the confusion over flood data at Gundagai where the gauge was raised 2 feet in 1892 and lowered 2½ feet in 1927. He also disregards flood data from an unofficial gauge at Wagga Wagga which was fixed to a growing gum tree, preferring to use the official gauge on the river bridge which had "no ups and downs since it was originally fixed in about 1862". A document by the Bureau of Meteorology (Reference 12) also lists large historical floods at Wagga Wagga and is included in Appendix A. Further sources include Council's own record and historical flood data mentioned in the Daily Advertiser newspaper. A summary compilation of all known events which exceeded 8 m prior to 1886 is provided in Table 5 together with the data source.

Table 5: Flood Peaks >8 m (pre 1886)

Day	Month	Year	Gauge Height (m)				
			Pinneena	BOM	Council	Gormly	Newspaper
25	Sep	1844	n/a	n/a	n/a	8.89	n/a
16	Oct	1844	n/a	10.97 (4)	10.97 (2)	9.80	n/a
n/a	Aug	1845	n/a	n/a	n/a	9.37	n/a
29	Jul	1847	n/a	n/a	n/a	9.17	n/a
20	Aug	1851	n/a	n/a	n/a	9.53	n/a
25/26	Jun	1852	n/a	10.67	10.67	10.67	n/a
3	Jul	1853	n/a	n/a	n/a	9.50	n/a
14	Jul	1853	n/a	10.90 (2)	10.90 (2)	11.04	10.90 (4)
n/a	Aug	1856	n/a	n/a	n/a	8.59	n/a
n/a	Oct	1857	n/a	n/a	n/a	8.66	n/a
n/a	Jun	1860	n/a	n/a	n/a	8.61	n/a
15	Jun	1864	n/a	n/a	n/a	8.99	n/a
20	Jun	1864	n/a	n/a	n/a	8.99	n/a
19	Jul	1864	n/a	n/a	n/a	9.25	n/a
23	Jun	1867	n/a	n/a	n/a	9.60	n/a
31	Jul	1867	n/a	9.32 (2)	9.32 (3)	9.70	9.32 (1,4)
8	Oct	1867	n/a	n/a	n/a	9.49	n/a
n/a	Jul	1869	n/a	9.09 (2)	9.09 (2)	n/a	9.09 (3,4)
18	Oct	1869	n/a	n/a	n/a	9.09	n/a
27/28	Apr	1870	10.67	10.67	10.67 (2)	10.67	10.67
14/15	May	1870	9.91	9.91 (2)	10.06 (2)	10.08	9.75
5	Jun	1870	9.22	9.22 (2)	9.22 (2)	9.22	n/a
21	Jun	1870	9.20	n/a	n/a	9.22	n/a
13	Jul	1870	n/a	n/a	n/a	8.99	n/a
27	Jul	1870	n/a	n/a	n/a	9.04	n/a
10	Aug	1870	n/a	n/a	n/a	8.99	n/a
11	Sep	1870	n/a	n/a	n/a	9.17	n/a
1	Nov	1870	n/a	n/a	n/a	9.14	n/a

Day	Month	Year	Gauge Height (m)				
			Pinneena	BOM	Council	Gormly	Newspaper
22	Jun	1871	n/a	n/a	n/a	8.97	n/a
4	Jul	1872	8.69	n/a	n/a	8.71	n/a
n/a	n/a	1876	n/a	n/a	n/a	8.99	n/a
n/a	Nov	1878	n/a	8.99 (2)	8.99 (2)	n/a	n/a
20	Sep	1879	n/a	9.35	9.35	9.35	n/a
29	Jun	1891	10.47	10.46	10.46	10.49	10.52

Notes:

1. Assumed misprint as listed as, 20' 7" instead of 30' 7"
2. Exact date not specified - month and year only.
3. Newspaper states 1867 not 1869.
4. Exact date not specified - year only.

n/a Data not available.

It should be noted that the different sources in Table 5 do not always agree. This reflects the inherent uncertainty in such historical data.

Questions are always raised about the accuracy of flood height data obtained from old or anecdotal sources. More than likely floods did actually occur on the indicated dates but the height they reached compared to the Hampden Bridge gauge cannot be confirmed and for this reason the data should be used with caution. Of particular significance is the five events greater than 10 m in the period from 1844 to 1891 inclusive(48 years), as there are only three in the period since (112 years).

2.4.5 Comparison with Council's Peak Height Record

Council provided a listing of their record of peak heights for events over 8.2 m at the gauge. This list was used to source some of the events prior to 1886 (refer above). A comparison was made with the Pinneena data and the following conclusions obtained:

- there is generally good agreement between the records with only minor differences in height and dates,
- the only Pinneena records not included in Council's data set are: 8.46 m on 24th February 1971, 8.69 m on 4th July 1872 and 9.20 m on 21st June 1870,
- there are numerous pre 1886 records missing from the Pinneena data set as indicated in Table 5. Additionally, Council records indicate flood heights of 8.41 m and 8.23 m on 27th and 29th June 1975 respectively which are not consistent with the Pinneena data,
- the majority of the records indicate identical flood levels or within ±0.02 m. There are however, 10 events with differences of 0.1 m or greater, with a maximum difference of 0.6 m. No explanation for these discrepancies can be found.

2.4.6 Comparison with Heights from Gundagai

As a means of checking the reliability of the early Wagga Wagga data, peak height data were also obtained from Pinneena for the gauge at Gundagai (No 410004). Unfortunately whilst flow records are available since 1886, heights are only on the CD since October 1973. Graph 9 compares the events over 6 m at Wagga Wagga with those at Gundagai for the period since 1973 to 1997. The results obviously indicate a strong relationship but peaks can vary by up to ±1 m from the mean. There is little chance of gauge error as both are automatic over this period.

Although there is no official data record at Gundagai prior to 1886 there is anecdotal evidence of floods at Gundagai (and for the Murrumbidgee in general) for several of the pre 1886 events at Wagga Wagga. For example, BOM (Reference 12) notes flooding at Gundagai in 1844, 1852, 1853 and 1878 and general flooding of the Murrumbidgee in 1867. This anecdotal evidence is repeated in Table 6 below and adds confidence that significant floods were also experienced at Wagga Wagga in these years.

Table 6: Anecdotal Evidence of Flooding at Gundagai

Year	Comment in "A Bureau of Meteorology Flood Forecasting System" (Reference 12)
1844	"Murrumbidgee in flood. Gundagai 4 feet under water."
1852	"Murrumbidgee in high flood surrounding country at Gundagai inundated, township swept away and 89 out of population of 250 perished."
1853	Murrumbidgee in high flood considerable damage at Gundagai;'
1867	"Disastrous floods in the Hunter, Hawkesbury Murrumbidgee and other rivers."
1878	"Murrumbidgee in flood and at Gundagai at 25 ft."

2.5 Peak Flood Heights

The August 1974 flood is well documented in terms of recorded flood levels. Flood levels were collected by both Wagga Wagga City Council and the then Department of Main Roads. This data was collated in the 1988 Flood Study (Reference 8) and is presented in Figures 5a and 5b for the western and eastern portions of the study area respectively. Less abundant information was available for the floods of October 1975 and October 1976. These data are presented in Figures 6a & b and 7a & b respectively.

Since 1976, significant floods have occurred in 1989 and 1991. Whilst Council has plentiful information about when roads and flood gates were closed in relation to the river level at the gauge, there is very little direct peak flood level data for those floods. A newsletter was distributed in Wagga Wagga during Water Week (October 2002) asking the public for additional information.

Little additional data was forthcoming and this is probably because there have been no significant floods for over 10 years.

3. HYDROLOGY

3.1 Approach Adopted

There are two basic approaches to undertaking design flood analysis.

- The *rainfall/runoff routing approach* where rainfalls are input to a hydrologic model and routed through the catchment. Inflows to the study area are then obtained from the hydrologic model and input to a hydraulic model to derive the required flood behaviour information. Where historical flood height and flow data are available, the hydrologic and hydraulic models can be calibrated to increase the reliability of the results. Design rainfall data are available from AR&R (Reference 13).

- The *flood frequency approach* is a statistical procedure which is applied to historical peak flows (after conversion from observed flood height data) to enable determination of design discharges and flood levels for given average recurrence intervals.

The relative merits of these methods are canvassed at some length in AR&R. The reliability of the flood frequency approach depends largely upon the length and quality of the observed record and accuracy of the rating curve. With the rainfall/runoff approach, the accuracy depends upon a number of factors including:
- the calibration of the hydrologic model to historical streamflow data,
- the assumed design rainfall patterns and rainfall depths from AR&R,
- assumptions regarding the joint probability of rainfalls over the various tributaries,
- assumptions regarding the effect of dams in the upper catchments,
- the assumed areal reduction factor.

The flood frequency approach was adopted in this study for the following reasons:
- the rainfall/runoff approach would require an extensive hydrologic study which could not be justified as part of this study. Additionally, given the complexity of the Murrumbidgee River system upstream of Wagga Wagga, it is doubtful whether a detailed hydrologic study would lead to more reliable results,
- the flood height data required for a flood frequency approach were readily available from the Hampden Bridge gauge at Wagga Wagga,
- a number of gaugings have been undertaken at Hampden Bridge and Pinneena provides several rating curves. In addition, the use of a hydraulic model can enhance the quality of the high flow rating extensions.

The main advantages of the flood frequency approach are:
- a long length of good quality flood height data are available (i.e. over 100 years of record). This is a critical determinant of the accuracy of the flood frequency approach,

- no assumptions are required regarding the rainfall/runoff relationships,
- all parameters or factors (for example loss rates) which affect flood magnitude are inherently accounted for and no separate estimates are required,
- the effect of construction of dams in the upper catchment has been accounted for in the period of record since their construction,
- confidence limits can be readily estimated.

The major limitations of the flood frequency approach are:

- whilst high flow gauging data are available the accuracy is probably only of the order of ±25%,
- it is not possible to determine the true form of the probability distribution of floods. Different distributions produce similar results over most of the range of values but can have very different tails at the higher end. The extrapolated upper range can therefore produce very different estimates for the larger flood events. The choice of distribution therefore has a significant bearing on the results and particularly the larger (less frequent) events,
- changes to the local topography such as levee banks, hydraulic controls and construction of dams in the upper catchment have affected the homogeneity of the data set,
- short to medium term climatic changes may influence the flood record. This is an emerging field in NSW that has the potential to have a significant bearing upon design flood estimation. This problem is illustrated in Graph 10 which shows that the cumulative monthly discharges were generally less than the average in the period from 1900 to 1950 while the reverse generally occurs from 1950 to the present. A rapid rise in the graph is evident in the period from 1950 to 1956, which contained 16 floods greater than 8 m, and again with 10 floods in the period from 1974 to 1976. The more gradual rise from 1989 to 1994 contained only 4 floods.

Even with these deficiencies, the balance was still very much in favour of using the flood frequency approach.

3.2 Flood Frequency Analysis - Theory

3.2.1 Series Type

AR&R recommends that flood frequency analysis should be applied to peak flows or discharges. In frequency analysis of flows, the fitting of a particular distribution may be carried out graphically by subjectively drawing a curve through the plotted points, or analytically, by fitting a probability distribution. The data may consist of either an *annual series*, where the largest peak in each year is used, or a *partial series*, where all floods above a selected base value are used. The relative merits of each method are discussed in detail in AR&R.

In general an annual series approach is preferable as there are more methods and experience available. A partial series approach can have advantages in some cases, especially if there are uncertainties with smaller floods. Such uncertainties include rating curves for low flow events and missing records. A partial series analysis has not been undertaken due to the high quality and quantity of the annual series data set.

Whilst a complete flood record is only available from 1892 onwards, it is also possible to include pre 1892 events (termed outliers) to extend the flood record.

3.2.2 Probability Distribution

Many types of probability distributions have been applied to flood frequency analysis and this is a very active field of research. However it is not possible to determine the "correct" form of the distribution and there is no rigorous "proof" that any particular distribution is more appropriate than another. AR&R provides further discussion on this issue. Two broad approaches are possible. One is to use a range of distributions and adopt the one which provides the "best fit". The other is to use a single distribution for all regions. AR&R proposes the latter and recommends Log Pearson III. AR&R also advises however that *"designers are encouraged to examine procedures and data carefully and to adopt other procedures if the data and circumstances warrant"*. For example in the USA the Log Pearson III distribution has been strongly criticised.

Since publication of AR&R in 1987 there have been significant developments in the field of flood frequency analysis both in Australia and overseas. The approach adopted in this study reflects these developments.

3.2.3 Fitting Method

Recent research has suggested that the fitting method is as important as the adopted distribution. The traditional fitting method has generally been based on moments and this makes the fit very sensitive to the highest and lowest values. Recent research has shown that L-moment and Bayesian likelihood approaches are much more robust than traditional moment fitting.

A Bayesian maximum likelihood approach has been adopted in preference to L-moments because the method readily lends itself to include limited information about events outside the continuous period of record,

The Flike flood frequency analysis software developed by Kuzera (Reference 14) uses the Bayesian approach and was therefore utilised in this study.

3.3 Flood Frequency Analysis at Wagga Wagga

3.3.1 Rating Curve

The rating curve (height-discharge relationship) adopted for the conversion of the recorded gauge heights into streamflows is critical to the success of flood frequency analysis.

Pinneena uses the rating curve current at the time of the event to determine the discharge. This approach allows for changes in the bed profile (erosion and deposition) over time to be accounted for. The disadvantages of this approach is that it does not include information from subsequent gaugings that can more closely define the “true” rating and in particular from subsequent high flow gaugings (such as in the August 1974 flood). The rating for the annual peaks from 1892 to 1997 obtained from Pinneena is plotted on Graph 11. It clearly shows that the rating curves can be separated into two periods (pre and post 1932). The reason for this discontinuity is unknown but is not reflected in the actual gaugings (refer Graph 2). The rating curves from Pinneena were therefore not used in this present study which instead used flows calculated from the RUBICON model. Two rating curves from RUBICON were adopted, one for present day conditions and one prior to the Main Town levee being built in 1962 (refer Graph 12).

3.3.2 Adopted Data Set

The data available for the period 1892 to 2002 is not homogeneous as there have been numerous changes in the catchment. The biggest has probably been the construction of Burrinjuck Dam, although land clearing is also likely to be a significant factor. The dam does not split the data set into two distinct periods as the dam has been modified twice (1956 and 1995) and took 16 years to build (1912 to 1928). There have also been other large dams built on the catchment (e.g. Blowering) and the amount of water used for irrigation has been steadily increasing, until the imposition of the Murray Darling basin cap on total water extractions in July 1997.

These factors made it impossible to construct a homogeneous data set, so the following assumptions were adopted. The period from 1892 to 2002 was assumed to be representative of existing conditions (although adjustments were made to the rating curve to account for construction of the Main Town levee in 1962). This was considered reasonable as the 1925 flood occurred just prior to the dam being completed and was therefore significantly attenuated. Whilst all floods prior to 1925 would not be attenuated there was no other large event between 1892 and 1925 that might significantly influence the high flow record.

Prior to 1892 several large events occurred which cannot be ignored (refer Table 5). The July 1853 event was larger than August 1974 and the June 1852, April 1870 and June 1891 events were only slightly smaller. The October 1844 event was discarded because of the large variation in its recorded height (refer Table 5). While it is impossible to calculate what these flows would be in present day conditions their peak heights at Wagga Wagga were generally 0.5 m or more higher than the 1925 flood. It is therefore reasonable to assume that these events would have exceeded 3500 m^3/s (the size of the 1925 flood) even if the dam was in place.

The adopted data set (1892 to 2002) is shown in Table 7. Several probability distributions were tested including Log Pearson III, generalised extreme value and the Gumbel distributions. The Log Pearson III gave clearly the best fit. The Log Pearson III frequency analysis for the continuous data from 1892 to 2002 is shown on Figure 8. The same historical period with the inclusion of the four larger events between 1838 to 1892 (1852, 1853, 1870, 1891) is shown on Figure 9 (fits for the other distributions are shown in Appendix D). The results are shown in Table 8 and compared on Figure 10.

Table 7: Adopted Annual Maxima Data (1892 to 2002)

Year	Month	Peak Stage (mAHD)	Peak Flow (m^3/s)	Year	Month	Peak Stage (mAHD)	Peak Flow (m^3/s)
1892	Oct	178.41	976	1948	May	174.98	373
1893	Jun	177.31	693	1949	Oct	176.76	593
1894	Apr	179.19	1673	1950	Mar	180.11	3427
1895	Jun	175.33	417	1951	Sep	177.82	793
1896	Jun	174.01	260	1952	Jun	179.75	2558
1897	Jan	174.93	366	1953	Nov	177.82	793
1898	Feb	175.23	404	1954	Feb	173.45	209
1899	Aug	177.29	688	1955	Aug	178.48	1041
1900	Jul	180.01	3131	1956	Jul	179.65	2352
1901	Nov	176.86	609	1957	Jul	172.29	112
1902	Dec	172.49	143	1958	Oct	177.19	668
1903	Sep	176.15	520	1959	Oct	179.12	1599
1904	Jul	173.86	244	1960	Sep	178.97	1489
1905	Jul	178.43	997	1961	Dec	177.21	673
1906	Oct	178.74	1277	1962	Sep	176.83	605
1907	Dec	173.17	188	1963	Aug	174.47	310
1908	Sep	174.85	356	1964	Oct	177.80	789
1909	Aug	177.29	688	1965	Aug	172.64	143
1910	Sep	174.62	328	1966	Nov	177.24	679
1911	Jul	174.62	328	1967	Mar	172.64	143
1912	Sep	176.88	614	1968	Aug	176.20	527
1913	Jul	176.07	509	1969	Jun	177.70	768
1914	Mar	173.56	217	1970	Sep	178.92	1448
1915	Sep	176.91	618	1971	Feb	178.51	1065
1916	Oct	178.79	1323	1972	Sep	174.31	292
1917	Oct	178.69	1229	1973	Aug	175.84	479
1918	Aug	177.98	829	1974	Aug	180.79	5298
1919	Oct	172.79	160	1975	Oct	179.63	2332
1920	Aug	176.71	585	1976	Oct	179.43	2008
1921	Sep	177.49	728	1977	Jul	174.21	281
1922	Aug	179.22	1698	1978	Sep	178.96	1480
1923	Oct	177.49	728	1979	Oct	173.77	236
1924	Aug	177.82	793	1980	Jul	173.50	212
1925	May	180.16	3567	1981	Jul	176.35	553
1926	Jun	176.25	536	1982	Aug	173.07	182
1927	Oct	173.86	244	1983	Aug	178.90	1436
1928	Jul	174.01	260	1984	Aug	179.01	1528
1929	Oct	172.79	160	1985	Sep	175.97	496

Year	Month	Peak Stage (mAHD)	Peak Flow (m^3/s)	Year	Month	Peak Stage (mAHD)	Peak Flow (m^3/s)
1930	Oct	174.65	332	1986	Nov	177.11	653
1931	Jun	179.65	2352	1987	Jun	174.73	341
1932	Sep	177.70	768	1988	Dec	175.46	432
1933	Sep	175.61	451	1989	Apr	179.43	2008
1934	Oct	179.25	1747	1990	Jul	177.70	770
1935	Oct	176.38	556	1991	Jul	179.66	2313
1936	Jul	177.67	762	1992	Oct	177.98	857
1937	Oct	173.63	224	1993	Oct	178.90	1461
1938	Sep	172.41	132	1994	Feb	173.96	255
1939	Aug	178.66	1203	1995	Jul	177.67	782
1940	Sep	172.34	130	1996	Oct	177.59	763
1941	Jan	173.81	239	1997	Jan	174.16	275
1942	Jul	176.38	556	1998	Sep	175.28	389
1943	Oct	176.02	503	1999	Jan	174.26	282
1944	Jul	171.75	84	2000	Sep	176.74	568
1945	Nov	173.40	205	2001	Oct	174.73	330
1946	Jul	174.93	366	2002	Jan	173.38	200
1947	Dec	175.94	493				

Table 8: Frequency Analysis - Log Pearson III - Comparison of Data Sets

Data Set	ARI (1 in y)					
	5	**10**	**20**	**50**	**100**	**500**
1892-2002 (90% confidence limits)	1200 *(1000-1400)*	1800 *(1500-2300)*	2600 *(2000-3500)*	3900 *(2800-6000)*	5200 *(3500-8600)*	9400 *(5400-19200)*
1892-2002 + 4 events larger than 3500 m^3/s in the period 1838 to1892 (90% confidence limits)	1300 *(1100-1500)*	2000 *(1700-2500)*	3000 *(2400-4000)*	4800 *(3500-7200)*	6700 *(4500-10900)*	13300 *(7400-27100)*

The results demonstrate how sensitive the discharge estimate for rarer events can be due to the inclusion of large early historical floods. Both fits are considered to be good with the inclusion of the four pre 1892 events being slightly better at the high end (refer Figures 8 and 9). The 90% confidence bands in Figures 8 and 9 reveal the level of uncertainty inherent in any flood frequency analysis. This demonstrates the importance of including freeboard in any design or planning levels. It is noted that both fits fall within the 90% confidence limits of the other and the difference between the fits in a 1 in 100 ARI event amounts to 300mm at Hampden Bridge. From a risk management perspective it is therefore prudent to adopt the fit including the four pre 1892 event.

Table 9 shows design discharges and levels at Hampden Bridge with and without Expected Probability Adjustment for the data set including the four events prior to 1892. The Expected Probability Adjustment is used to account for sample bias and results in a slight increase in magnitude for larger events.

Table 9: Frequency Analysis Results at Hampden Bridge

ARI	Sample Data		Expected Probability Adjustment	
(1 in y)	Discharge (m^3/s)	Level (mAHD)	Discharge (m^3/s)	Level (mAHD)
5	1300	178.7	1300	178.7
10	2000	179.3	2000	179.3
20	3000	180.0	3000	180.0
50	4800	180.8	4900	180.8
100	6700	181.4	6900	181.4
500	13300	182.4	14900	182.6

The stage frequency relationships from Table 9 are shown graphically on Figure 11.

3.4 Derivation of Extreme Flood

The catchment area to Wagga Wagga is 26,400 km^2. Calculating a PMF for Wagga Wagga however is complicated by the presence of Burrinjuck Dam 170 km upstream of the town. The catchment to Burrinjuck Dam is around 13,000 km^2. Extensive work on the PMF at Burrinjuck Dam was carried out by the DLWC (now DIPNR) and is documented in:

- Burrinjuck Dam Dambreak Study, Draft 2001 (Reference 10),
- Burrinjuck Dam Assessment of Spillway Adequacy Using a Joint Probability Approach 2001 (Reference 11).

In these reports it was concluded that the spillway would be adequate for passing a PMF event, even assuming a Dam Full scenario at the onset of flooding. Hence a PMF at Wagga Wagga due to dam failure is not considered in this present study.

A RORB hydrologic model was used in these studies to calculate the inflows to the dam. It was found that the 24 hour PMF flow of 44,000 m^3/s was around 6 times larger than the 72 hour 1 in 100 ARI flow of 7,300 m^3/s.

It is not possible to derive a PMF at Wagga Wagga using flood frequency and the establishment of a runoff-routing model could not be justified. It was therefore decided to extrapolate a similar relationship between the 1 in 100 ARI and PMF peak flows at Burrinjuck Dam for Wagga Wagga. Given the larger catchment size and less mountainous terrain to Wagga Wagga, and the probable longer critical storm duration, a factor of 5 was adopted. This gives a PMF flow at Wagga Wagga of around 34,000 m^3./s.

4. HYDRAULIC MODELLING

4.1 Background

A CELLS model (a quasi two-dimensional hydraulic model developed in the 1970s and 80s) of the Murrumbidgee floodplain at Wagga Wagga was previously established for the 1988 Flood Study (Reference 8) by the then Department of Water Resources (now DIPNR). A major limitation of this model was the fact it did not incorporate the area within the Main Town levee. Hence the possibility of overtopping of this levee in larger events, including the PMF, could not be modelled. Also, there have been numerous changes to the floodplain and advancements in modelling techniques since 1988. A review of the flood study was therefore warranted.

4.2 General Approach

AR&R provides a summary of available hydraulic models. The choice of models depends on many factors, including nature of the topography, available data, the aims of the study and the availability of the model.

A steady state model uses a constant flow value. For a study area such as the Murrumbidgee River at Wagga Wagga, an unsteady state model is necessary to enable adequate simulation of the flood hydrograph with its variance of flow over time. A one dimensional model allows flow along only single paths or reaches. A quasi two-dimensional model uses one dimensional flow paths but allows for interconnecting branches and overflow branches or weirs. It is therefore able to represent interactions (flow transfers) between the main river and the overbank flow path areas. A fully two-dimensional model allows water to flow in any direction and does not need to use any pre-defined channels or flow paths.

A fully two-dimensional model could not be justified for this study due to the limited quantity and quality of available survey data. The cost of obtaining adequate survey data was investigated but could not be justified at this time. Such a model would offer no significant advantages over a quasi two-dimensional model. A quasi two-dimensional unsteady state RUBICON model covering the study area was therefore adopted to provide the basis for this study.

The RUBICON model (Reference 15) has the following features:

- it is mathematically rigorous,
- it is easy to establish and then modify to reflect topographic or hydraulic changes,
- it is a technologically advanced model which is well structured and can accurately model hydraulic controls providing high quality output.

The model simulates flood behaviour (water level, flow distribution and velocity) across the floodplain as a series of flow path branches or channels. The hydraulic characteristics of each branch or channel is then defined by waterway area, resistance to flow (roughness) and other controlling features or structures.

4.3 Model Establishment

The RUBICON model structure was set up within the limits of the study area based on the knowledge of the extent of flooding and flood flow patterns in the August 1974 event. In addition, the area of Wagga Wagga behind the Main Town levee was specifically included. The model layout extends from downstream of the settlement of Braehour to Kallewanda (near the Malebo range) downstream of Wagga Wagga as shown on Figure 12. The cross-sectional and hydraulic characteristics used to define the model data were taken from the available survey information (refer Figure 4). The model cross-sections were modified to present conditions applicable at different points in time for the historical storms (i.e. pre - post North Wagga Wagga levee, etc.).

Input to the hydraulic model at the upstream limit consisted of inflow hydrographs that matched either the recorded heights at Hampden Bridge, or for the design events, the peak discharges obtained from the flood frequency analysis. The shape of the inflow hydrograph for the design events was based upon the August 1974 hydrograph. Stream roughness parameters (Manning's "n" values which represent the frictional resistance) were initially based on previous investigations and experience and then adjusted within reasonable limits to produce peak water surface profiles that best simulated the recorded flood heights.

Once the RUBICON model had been set up and calibrated it was used to determine design levels, flows and velocities throughout the floodplain for a range of flood events including the PMF.

4.4 Model Calibration

Given the magnitude of the August 1974 flood and the abundance of recorded flood height data available, this event was adopted for calibration purposes.

The stage and discharge hydrographs at Hampden Bridge for this event were extracted from the Pinneena data set. The inflow hydrograph at the upstream limit of the model was tuned until the output from RUBICON at Hampden Bridge matched the Pinneena data (refer Figure 13). The resulting discharge hydrograph is shown on Figure 14. A rating curve was also obtained from the model results and compared to the gaugings from Pinneena (refer Figure 15). From this it is evident that there is good agreement. The hysteresis loop in the model output shows the level of natural uncertainty that is inherent in both flood gauging and modelling. The larger floods at Wagga Wagga were generally gauged on the falling limb and hence it is the falling limb from the model output which should match the gaugings.

Once a good fit to the Pinneena data was achieved at Hampden Bridge, Manning's "n" values were then adjusted within reasonable limits to produce a water surface profile that simulated the recorded flood height data throughout the floodplain. The resulting distribution of modelled peak heights across the floodplain for the August 1974 event are shown on Figures 5a and 5b together with the observed flood level information. The adopted peak height profile with available flood height data for the main river channel is shown on Figure 16.

There is some scatter within the numerous observed levels, and it is therefore impossible to match every point along the profile. The variations can often be explained by localised hydraulic influences as well as the source and reliability of some data points. The adopted profiles typically conform to the data trends in terms of hydraulic gradient and average level, and overall the model fit is considered to be good, being mostly within ±0.3 m.

4.5 Model Verification

The events of October 1975 and October 1976 were chosen for model verification purposes as they are two of the more recent large flood events for which there is a reasonable amount of recorded data.

Some modifications were required to be made to the model for each event in order to represent major changes which had occurred to the floodplain since the August 1974 flood. Most notably, this included the raising of the East Street/Mill Street levee at North Wagga Wagga and construction of Gumly Gumly levee.

As with August 1974, the inflow hydrographs for both events were tuned until the modelled stage hydrograph at Hampden Bridge closely matched the hydrograph extracted from Pinneena (refer Figures 17 and 20 for the 1975 and 1976 events respectively). The resulting discharge hydrographs are shown on Figures 18 and 21. Once a good fit at Hampden Bridge was achieved, the modelled peak height data were compared against recorded flood levels throughout the study area. The distributed flood level results are compared on Figures 6a & 6b and 7a & 7b for the 1975 and 1976 events respectively. The peak height profiles are shown on Figures 19 and 22. From these it can be seen that there is a reasonable fit to most data. Again, it is impossible to match every point along the profiles due to localised hydraulic influences as well as the source and reliability of some data points.

4.6 Design Flood Behaviour

Following calibration and verification of the hydraulic model to the historical flood events, modifications to the hydraulic model were then made to account for the significant identifiable changes which have occurred to the physical features of the floodplain in more recent years (refer Section 1.4.2). These changes (as listed in Table 1) include the raising of the North Wagga Wagga and Gumly Gumly levees and construction of the Eunony, Wiradjuri and Gobbagombalin bridges.

Design inflow hydrographs were derived to replicate the relevant peak discharge from the flood frequency analysis at Hampden Bridge (refer Section 3). The shape of these design hydrographs was based on the 1974 flood hydrograph. These hydrographs were then input to the RUBICON hydraulic model to establish design flood behaviour for a range of flood magnitudes (1 in 10, 1 in 20, 1 in 50, and 1 in 100 ARI frequencies as well as a PMF). The design discharge and stage hydrographs for Hampden Bridge are respectively shown on Figures 23 and 24 with the peak height profile on Figure 25. The design flood contours, and flow and velocity information are indicated on Figures 26 to 35. Indicative hazard maps are shown in Appendix E.

5. LEVEE OVERTOPPING

Following determination of the design flood discharges the hydraulic model was used to ascertain the location and estimated frequency of overtopping of the Main Town levee at Wagga Wagga.

5.1 Survey Data

A survey of the Main Town levee crest was undertaken for DIPNR in July 2002. While most of the survey was accurate it was found that the surveyors followed the wrong alignment near Narrung Street (refer Appendix C). Council therefore preferred that their detailed survey of the levee crest undertaken in 2001 be adopted instead.

In times of flood, it is likely that any low sections in the Main Town levee would be raised through either sandbagging or closure of the flood gates. Figure 36 shows the levee profile allowing for such adjustments - most notably at Hammond Avenue and Copland Street.

5.2 Methodology

The levee profile indicated on Figure 36 was subdivided into eight sections which were represented in the RUBICON model as a series of weirs. Each section of weir was joined to the most appropriate adjoining river (or floodplain) model node to account for the interaction of hydraulic gradients between the river and floodplain.

5.3 Results

5.3.1 Size of Overtopping Event

A comparison of the levee profile with the peak height profiles for the 1974 flood and the 1 in 50 and 1 in 100 year ARI design events is shown on Figure 37. It is evident from these results that the levee provides protection from inundation in events up to and including the 1 in 50 ARI event with a freeboard of around 0.5m (this assumes that sandbagging at Copland Street and Hammond Avenue is effective). The levee is first overtopped in around the 1 in 70 ARI event and in a 1 in 100 ARI event the levee would be overtopped in several places. For the PMF event the levee would be overtopped by some 5 m.

5.3.2 Overtopping Locations

Based on the profiles presented in Figure 37, it can be seen that potential levee overtopping locations include Copland Street and Hammond Avenue, the sections upstream and downstream of Hampden Bridge, and some sections near Narrung Street. Assuming the sandbagging at Copland Street and Hammond Avenue is effective, the first place that would be overtopped is the section between Wagga Beach and Hampden Bridge. This would then be followed by the section downstream of Hampden Bridge and then at the low point near Narrung Street. It should be noted however that the place where the levee first overtops will depend on the actual flood gradient in the Murrumbidgee River. Not all floods are the same and the gradient can vary from that of the design events.

6. MAPPING

Note:

***Flood inundation mapping** can only be completed where a digital terrain map (DTM) is available. To create such a DTM for the entire floodplain at Wagga Wagga would require a detailed survey to be undertaken. The cost of such an exercise would not be warranted except in the more densely populated areas such as Gumly Gumly, North Wagga Wagga and the main town of Wagga Wagga itself.*

***Animation of flood model results** may also show localised peculiarities due to lack of detailed survey. From a technical perspective, given the coarseness of the survey on which the hydraulic model is based, obtaining detailed survey for animation purposes could not be justified.*

7. INTERNAL FLOODING OF CBD

7.1 Local Stormwater Runoff

Stormwater runoff from the CBD area cannot drain naturally to the Murrumbidgee River due to obstruction by the levee. To overcome this problem there are two pumps at Mason Street (each capable of a rate of around 0.6m^3/s) and a further two at Flowerdale Lagoon (each with a rate of around 1 m^3/s). The efficiency of these pumps depends on the water level in the Murrumbidgee River. Elevated river levels cause these pumping efficiencies to quickly drop-off and it becomes harder and harder to remove stormwater from within the levee. Fortunately, the joint probability of these two events coinciding is very small as they would be produced by different meteorological situations. Stormwater flooding of the CBD would typically be caused by localised severe convective activity directly over Wagga Wagga while elevated river levels are the result of widespread continuous rainfall over a large area of the catchment (which is around 26,400km^2 at Wagga Wagga) including the Snowy Mountains.

Although detailed hydrologic modelling of the CBD catchment has not been undertaken (and is not within the scope of this study) experience has shown that internal flooding problems due to local stormwater runoff is generally not a major issue. The town pumps are generally adequate for removing stormwater, although during larger downpours and/or prolonged wet periods there may be temporary localised flooding of low lying areas especially in the vicinity of the pumps.

7.2 Levee Overtopping

7.2.1 Peak Flow

The other scenario for flooding of the CBD to occur is when the Murrumbidgee overtops the levee. Peak flows over various sections of the levee for the 1 in 100 ARI and 1 in 200 ARI events are shown in Table 10. For the 1 in 200 ARI event, the maximum rate of water entering the City is over 1000 m^3/s which is hundreds of times greater than the maximum combined pumping rate available. The pumps would therefore be quickly overwhelmed resulting in excess ponding of runoff and flooding of the CBD. Even in a 1 in 100 ARI event the rate of water overtopping the levee would be around fifteen times greater than the combined pumping rate.

Table 10: Peak Flow over Levee (m^3/s)

Location Section	1 in 100 ARI	1 in 200 ARI
Copland and Hammond Avenues	0	150
Vicinity of Railway Bridge	0	160
Between Wagga Beach and Hampden Bridge	35	260
Downstream of Hampden Bridge	15	290
Narrung St	<1	90
Upstream of Gobba Bridge	0	90
Downstream of Gobba Bridge	0	35
Flowerdale Lagoon	0	0

Note: These values are indicative only and presume that sandbagging is effective - especially at Copland Street and Hammond Avenue. The overtopping locations also depend on the shape of the flood hydrograph (rate of rise, peak and volume) which may vary from the design event and produce a different gradient along the river.

7.2.2 Flood Behaviour

Any water overtopping the levee would quickly rush to fill up the lowest lying areas of town such as the western areas near Olympic Way and Flowerdale Lagoon. To reach these areas the floodwaters would generally take the most convenient flow paths such as (but not necessarily) along the roads. The overtopping locations and major flow paths would be defined as high hazard floodway due to the large high velocity flows experienced. The low lying receiving areas would have low velocities and would initially be defined as low hazard flood storage. However the hazard would quickly rise (to high hazard storage) as the flood depths increased. The extent of these storage areas would also rapidly expand as the depth of water increased and engulfed, more and more of the surrounding areas.

As an example, Figure 38 shows a stage hydrograph representative of conditions inside the main Wagga town levee for a 1 in 200 ARI event. The water level in town is shown to rise steadily until it reaches a peak flood level of around 181 mAHD. This would see most of the town inundated with many parts more than a metre or two deep in water. It should also be noted that this peak level is reached in less than 12 hours of the levee first overtopping.

For the 1 in 100 ARI event the peak flood level in town reaches just over 178 mAHD which means that it would be mainly the low lying areas near Olympic Way and Flowerdale Lagoon that would be inundated. However high hazard areas would still be present in the vicinity of the overtopping locations.

8. ACKNOWLEDGMENTS

This study was funded by Wagga Wagga City Council and the Department of Infrastructure, Planning and Natural Resources and was undertaken by Webb, McKeown & Associates Pty Ltd, Consulting Engineers.

The advice and information supplied by Wagga Wagga City Council, the Department, other authorities and local residents is gratefully acknowledged.

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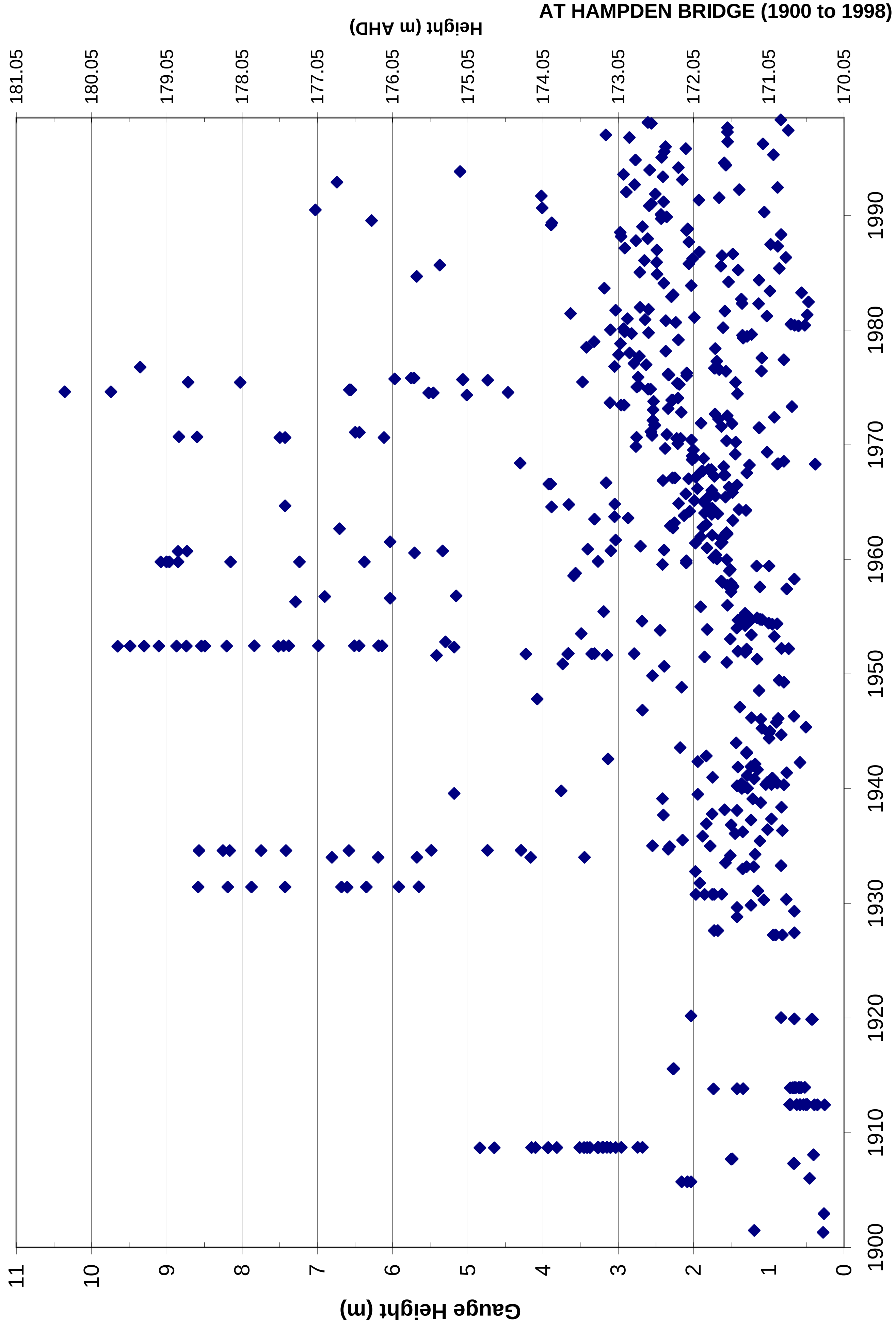
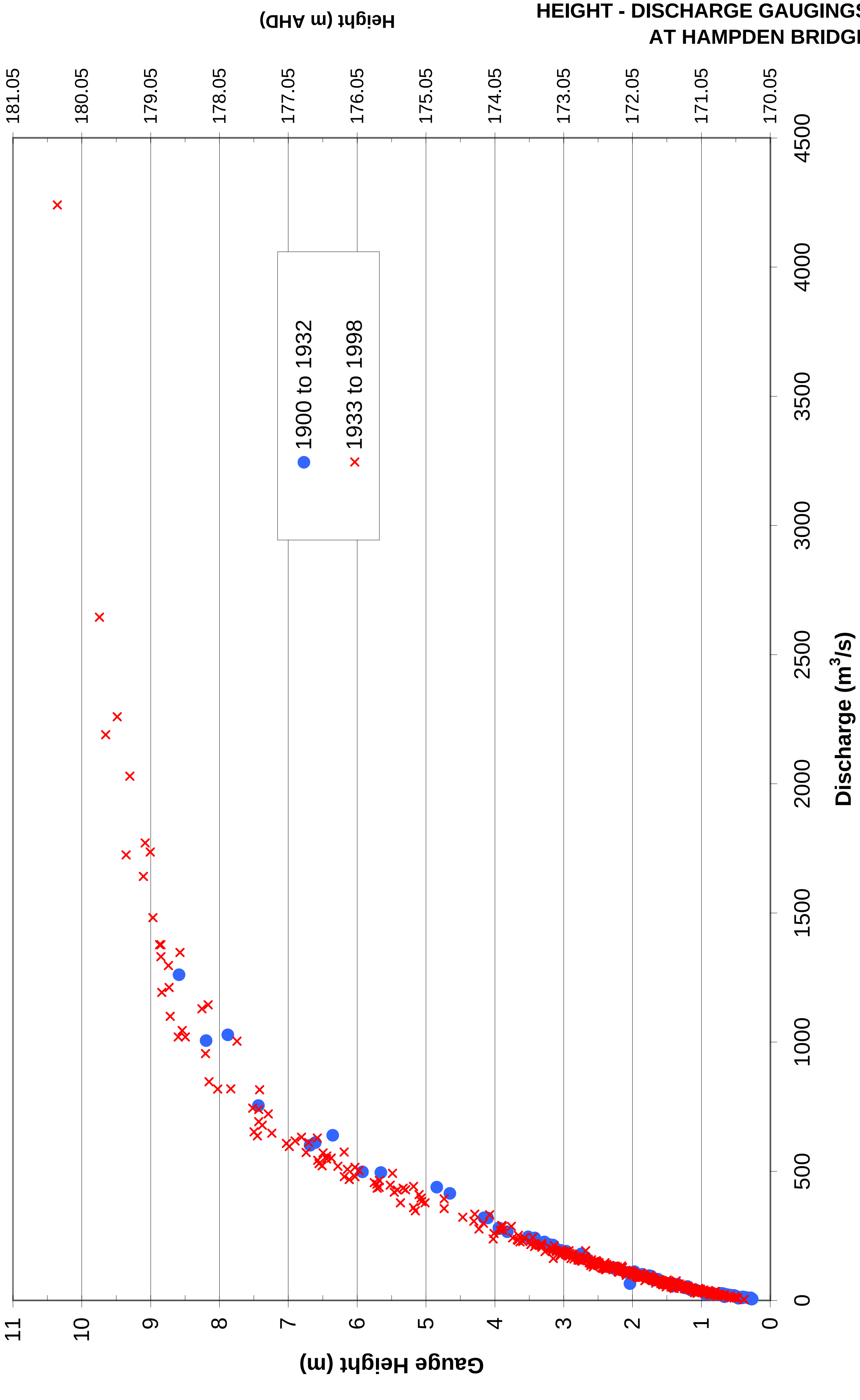
GRAPH 1

DISCHARGE GAUGINGS
AT HAMPDEN BRIDGE (1900 to 1998)



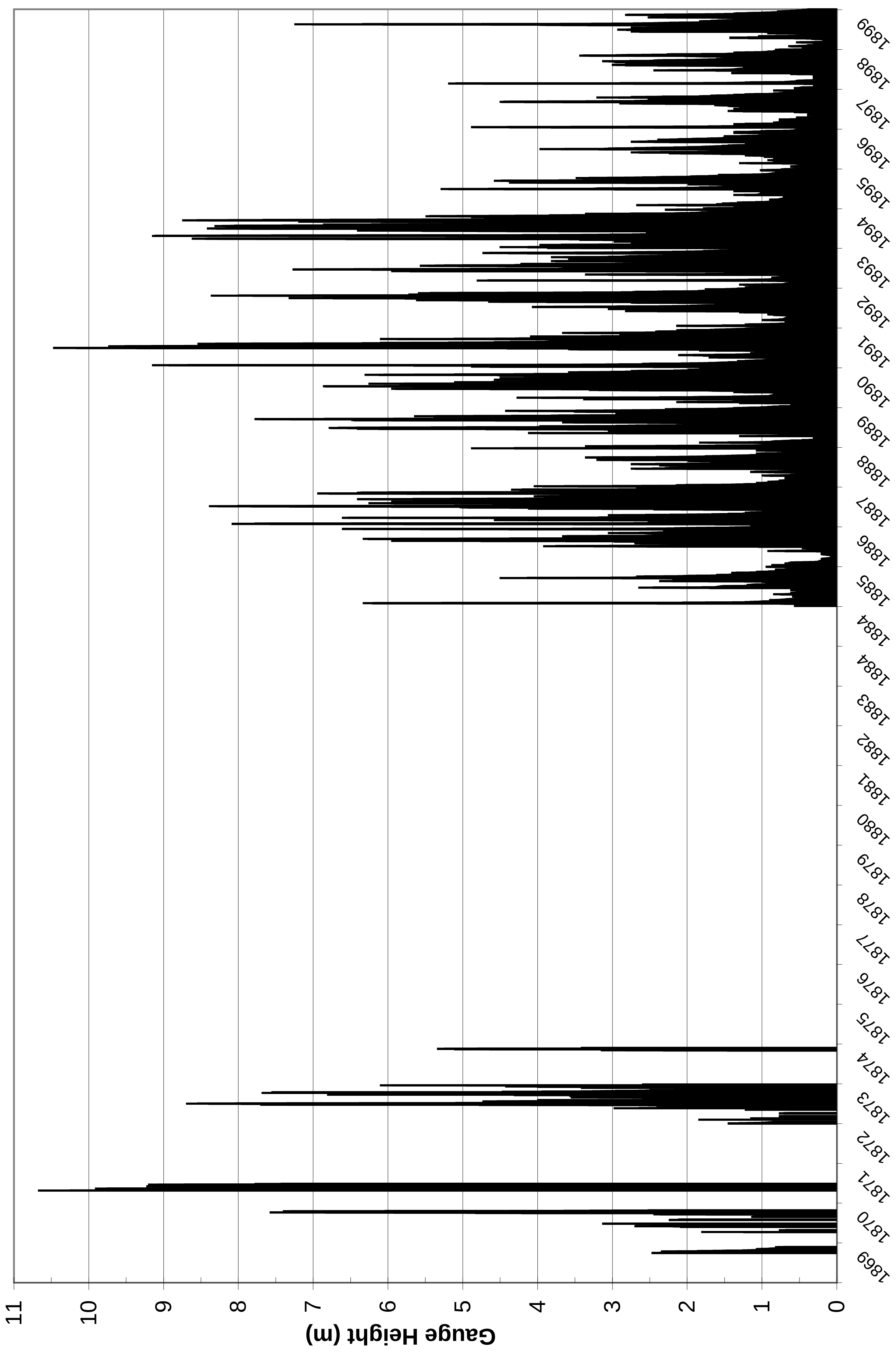
GRAPH 2

HEIGHT - DISCHARGE GAUGINGS AT HAMPDEN BRIDGE



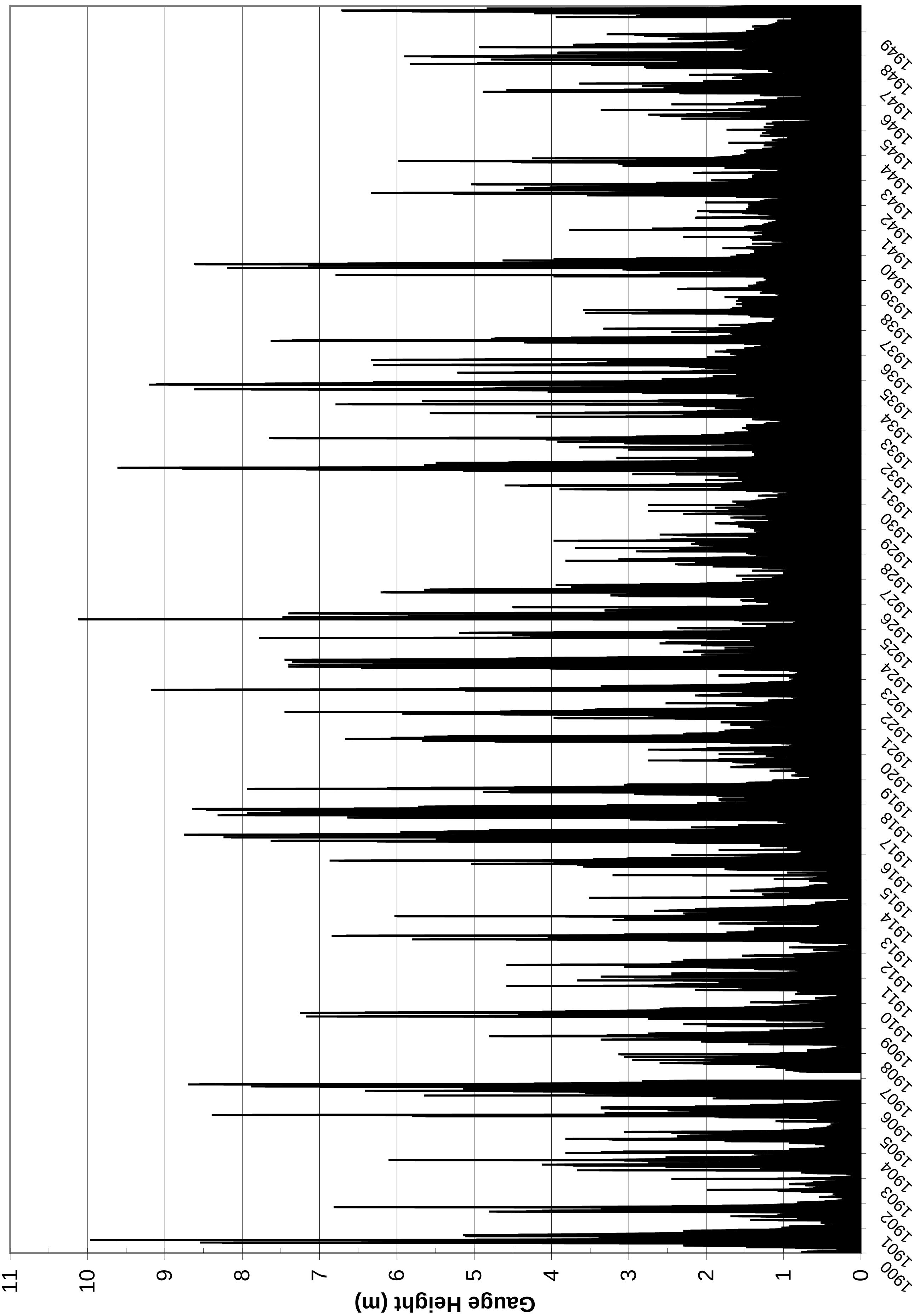
GRAPH 3

DAILY PEAKS AT HAMPDEN BRIDGE (1868 to 1899)

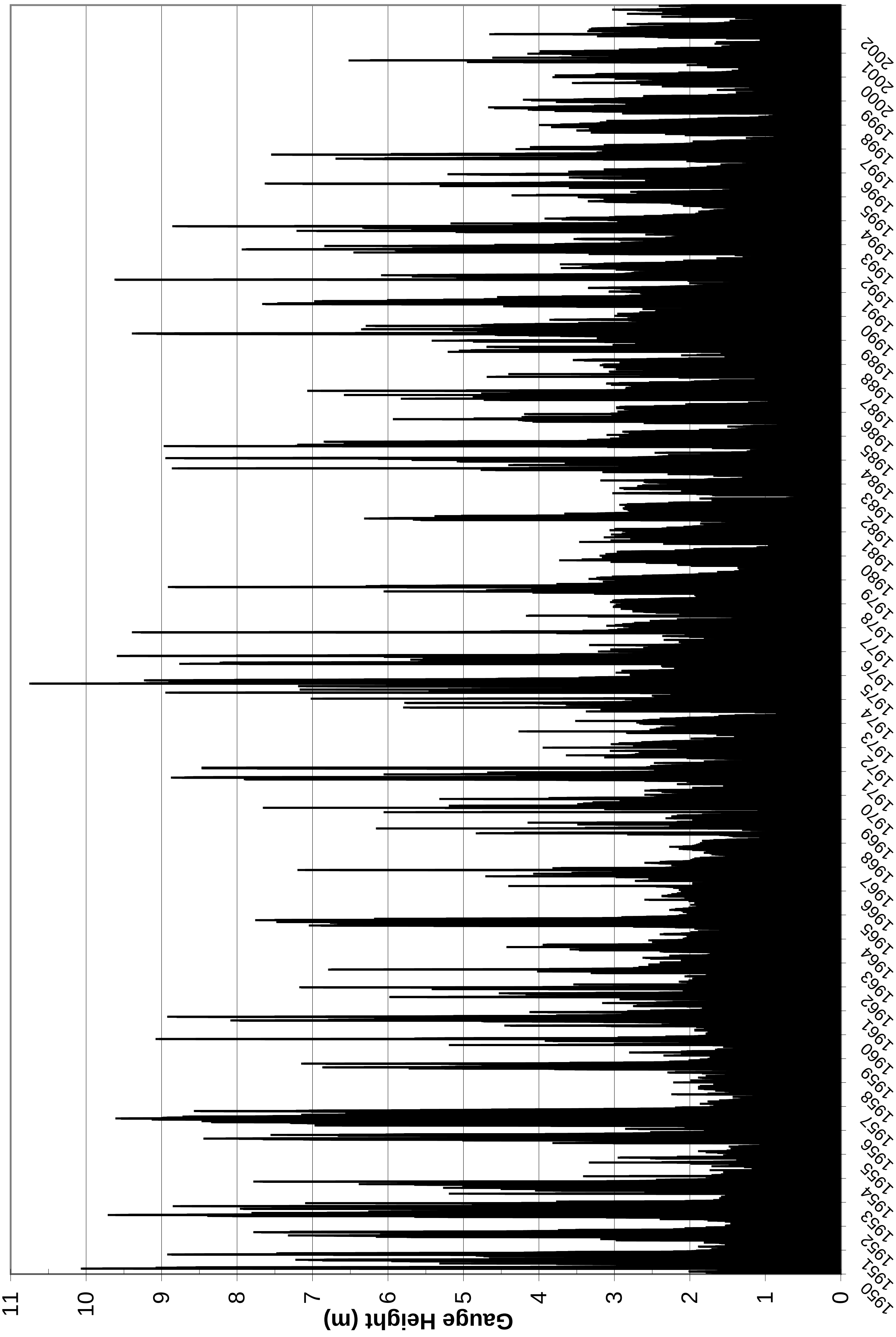


GRAPH 4

DAILY PEAKS AT HAMPDEN BRIDGE (1900 to 1949)

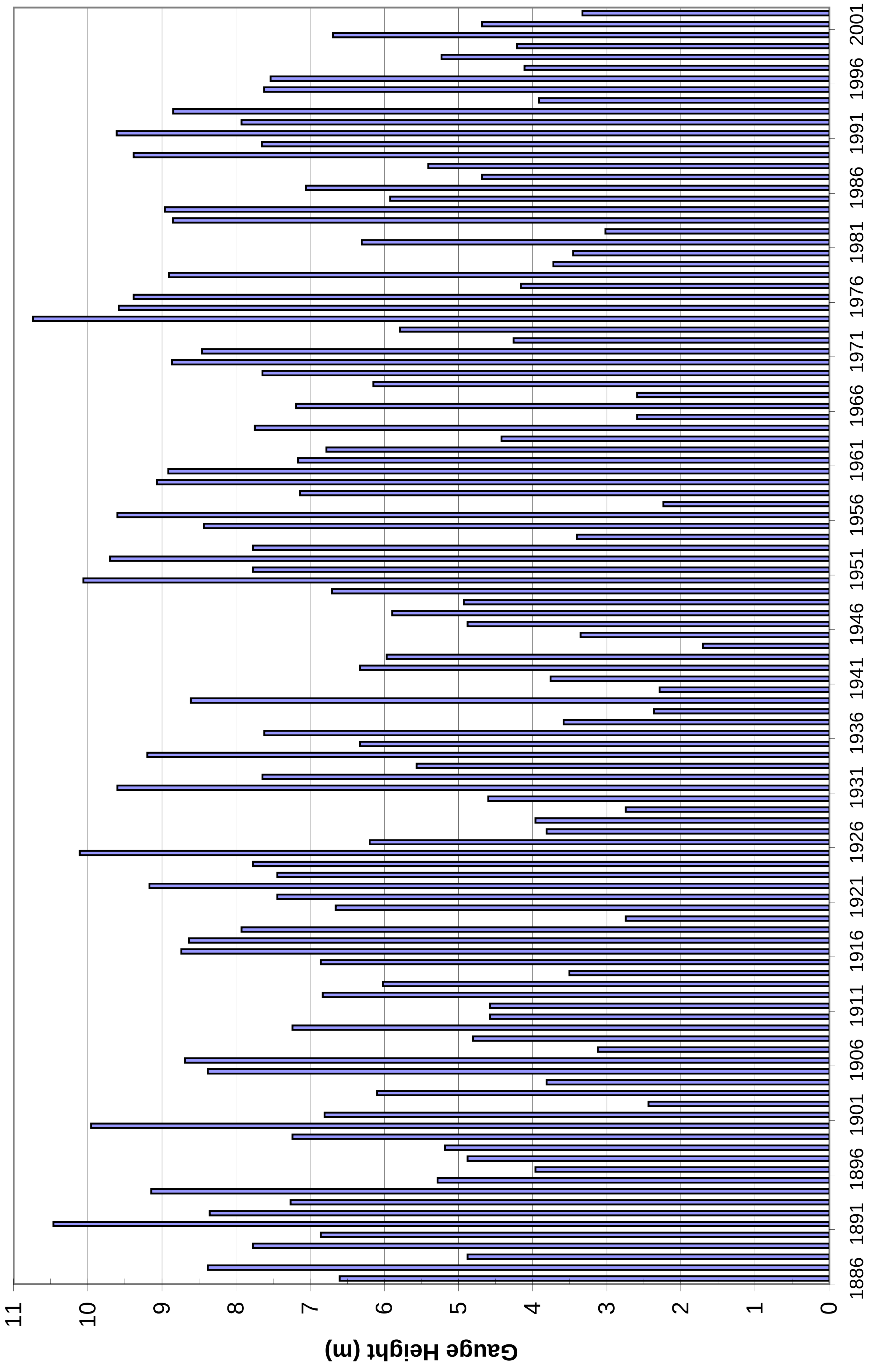


GRAPH 5
DAILY PEAKS AT HAMPDEN BRIDGE (1950 to 2002)



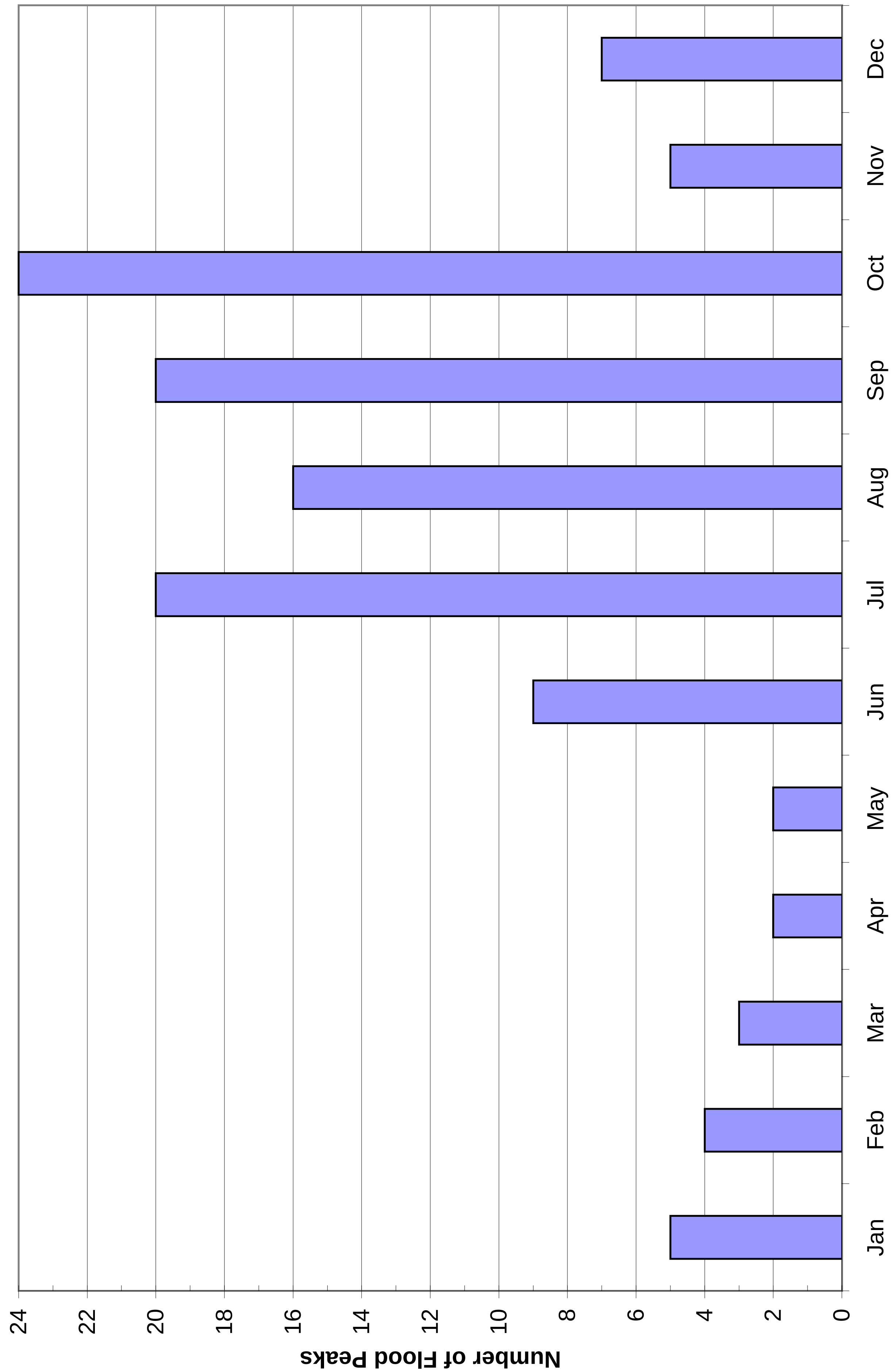
GRAPH 6

ANNUAL FLOOD PEAKS AT HAMPDEN BRIDGE (1886 to 2002)



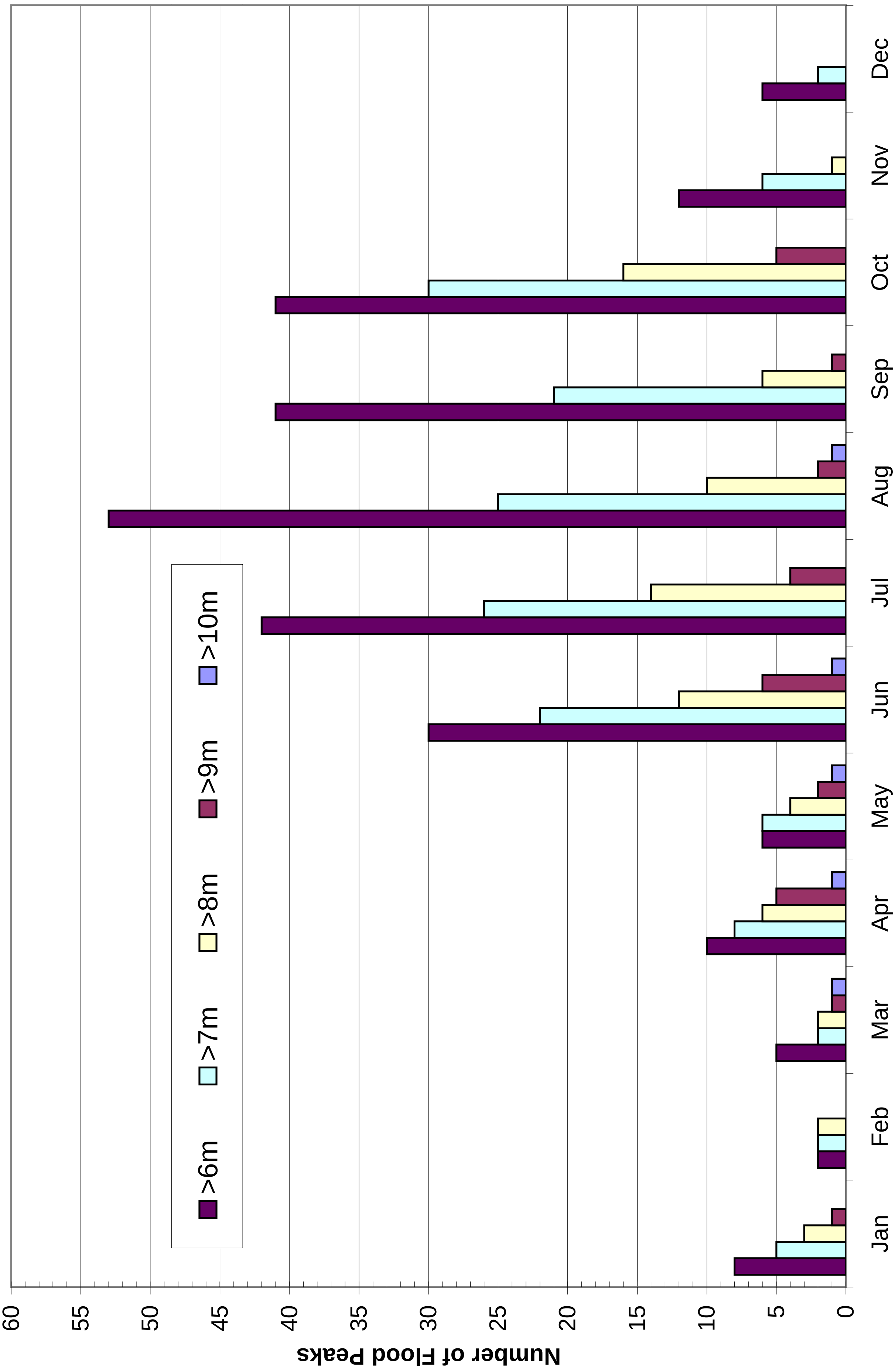
GRAPH 7

MONTH OF ANNUAL FLOOD PEAKS



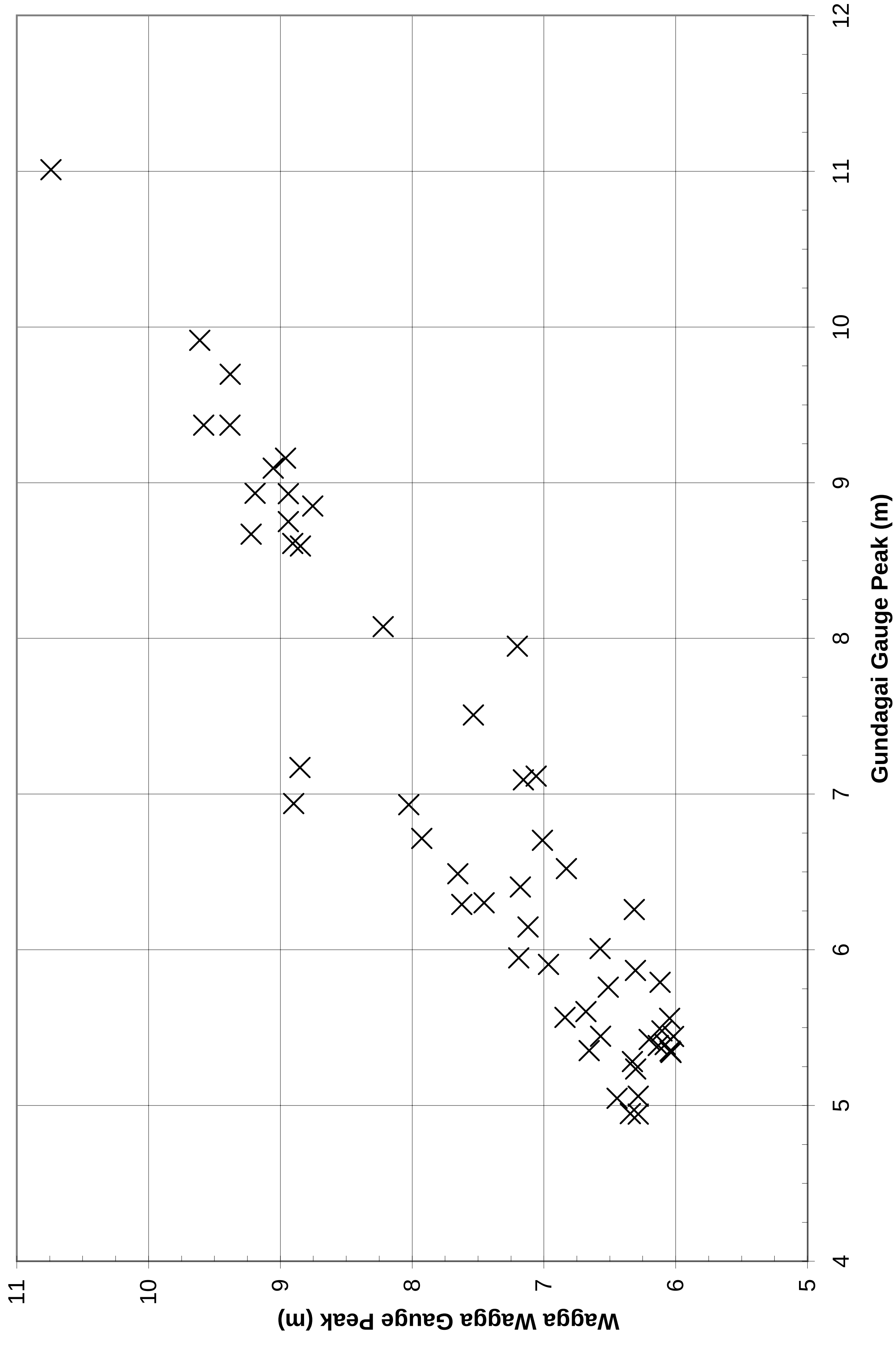
GRAPH 8

MONTH OF LARGE FLOOD PEAKS



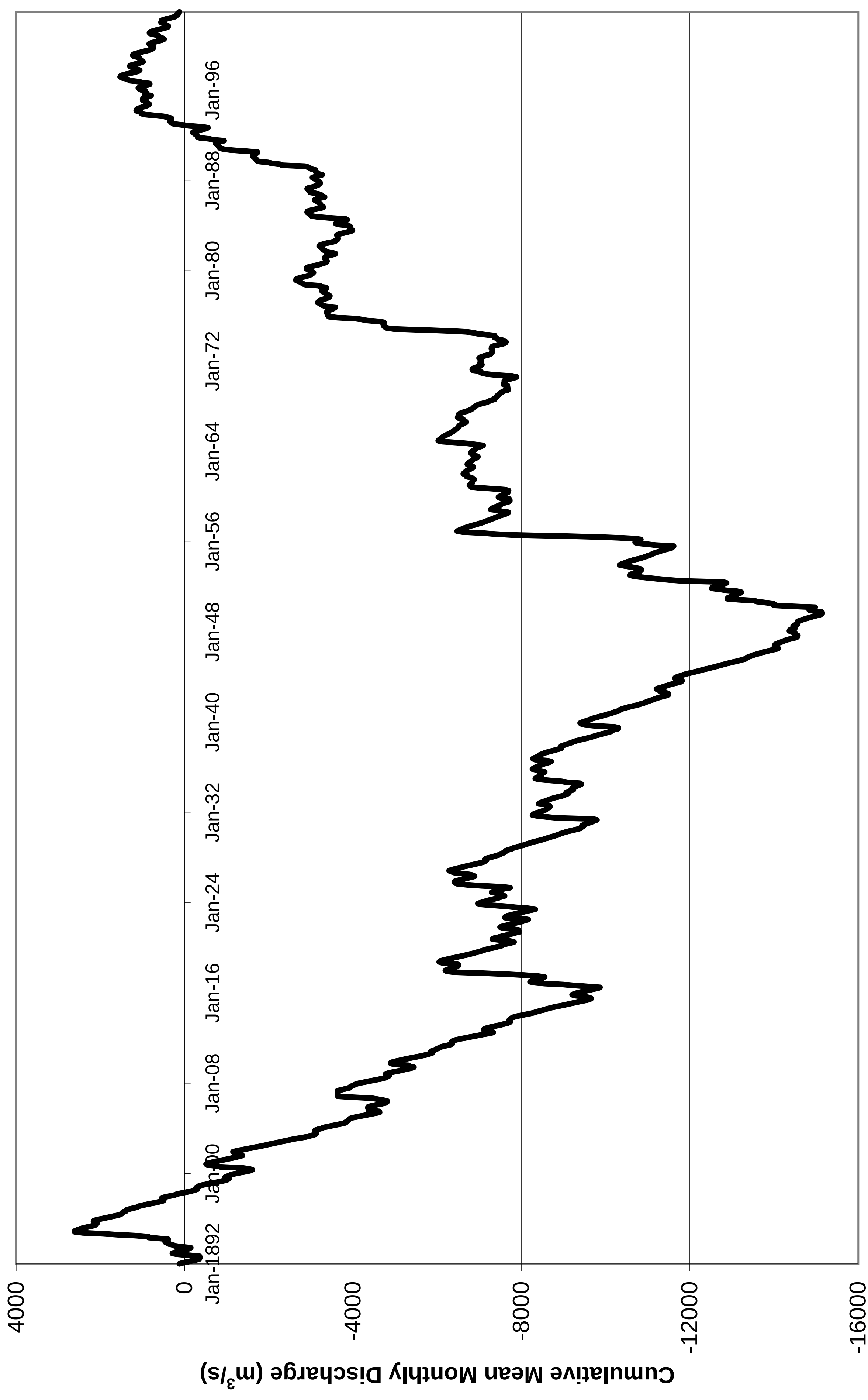
GRAPH 9

WAGGA WAGGA v GUNDAGAI
FLOOD PEAKS (1973 to 1997)



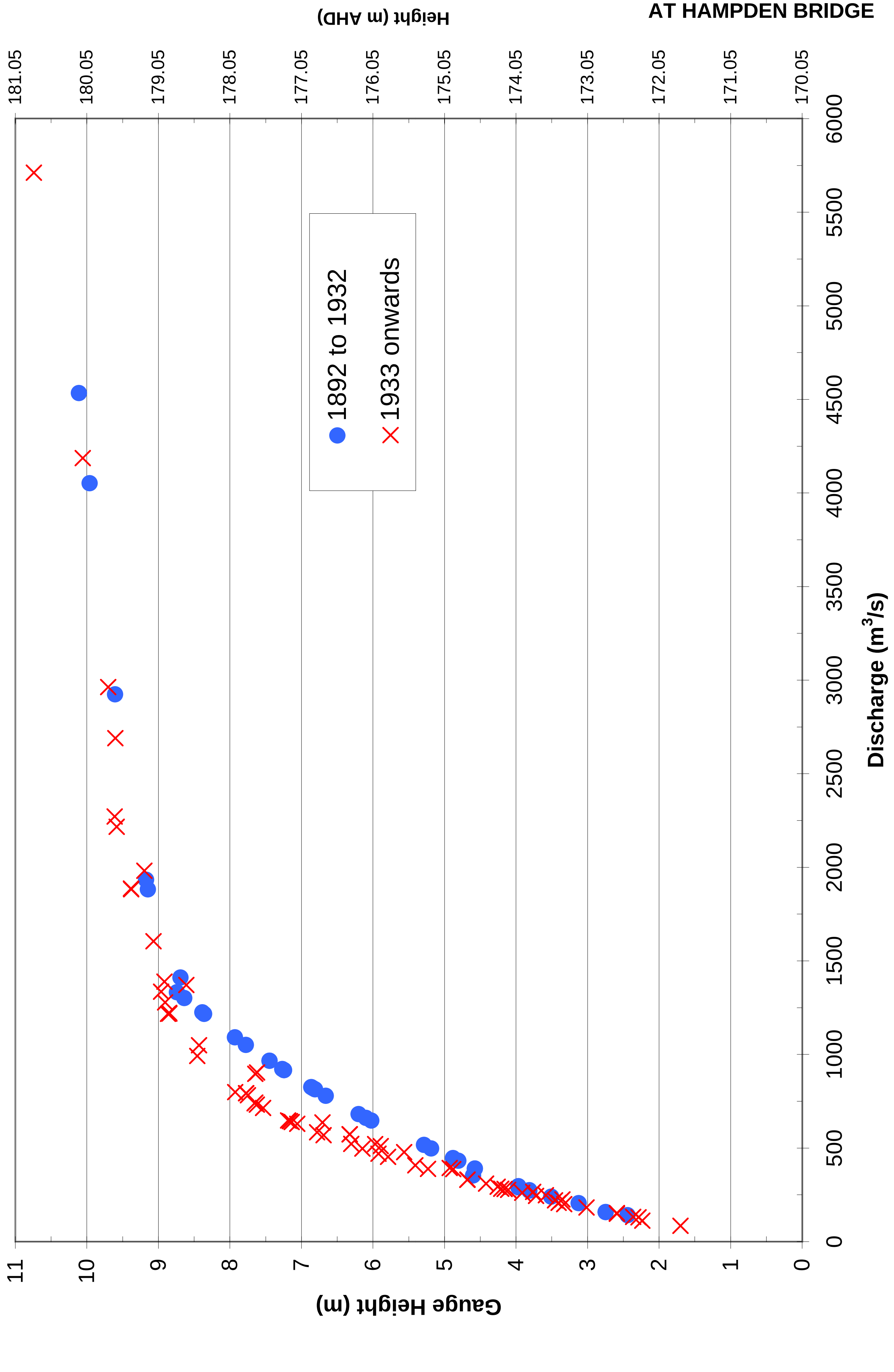
GRAPH 10

CUMULATIVE MONTHLY DISCHARGES
SURPLUS/DEFICIT CURVE



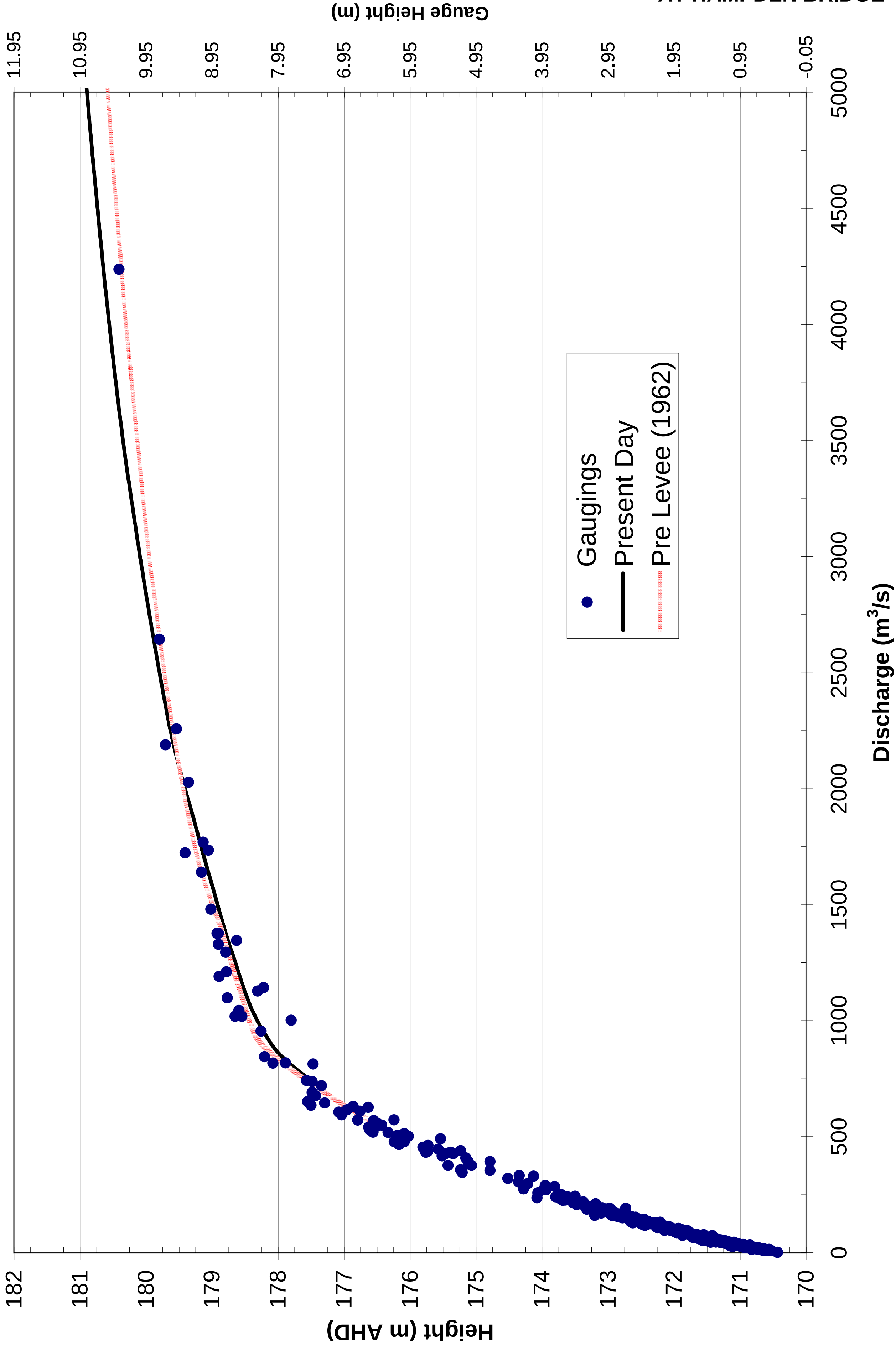
GRAPH 11

RATING OF ANNUAL PEAK DISCHARGES AT HAMPDEN BRIDGE



GRAPH 12

MODELLED RATING CURVES AT HAMPDEN BRIDGE



APPENDIX A: HISTORICAL FLOOD HEIGHT DATA

List of Floods at Wagga Wagga of 28ft. and over from 1838 to 1960

COMPILED BY R. J. E. GORMLY
OF 30 BOBBIN HEAD ROAD
PYMBLE

Date	ft.	ins.	Date	ft.	ins.
ept. 25: 1844	29	2	Jan. 24: 1887	28	2
ct. 16: 1844	32	2	July 7: 1887	28	0
ugust: 1845	30	9	Jan. 20: 1891	30	4
uly 20. 1847	30	1	June 29 1891	34	5
ug. 20: 1851	31	3	July 13: 1891	31	9
une 26: 1852	35	0	Mar. 28: 1894	28	4
uly 3: 1853	31	2	Apr. 23: 1894	29	9
uly 14: 1853	36	2½	Sept 12: 1894	28	9
ugust: 1856	28	2	May 31: 1900	28	1
ctober: 1857	28	5	July 8: 1900	32	9
une: 1860	28	3	Oct. 6: 1906	29	2
une 15: 1864	29	6	Oct. 9: 1916	28	11
une 20: 1864	29	6	Oct. 8: 1917	28	1½
uly 19: 1864	30	4	Oct. 23: 1917	28	3
une 23: 1867	31	6	July 31: 1922	30	1
uly 31: 1867	31	10	May 29: 1925	33	3
ct. 8: 1867	31	1½	June 13: 1931	28	9
ct. 18: 1869	29	10	June 26: 1931	31	8
pr. 27: 1870	35	0	January: 1934	30	0
ay 15: 1870	33	1	August: 1934	28	3
une 5: 1870	30	3	October: 1934	30	0
une 21: 1870	30	3	Aug. 26: 1939	28	3
uly 13: 1870	29	6	Mar. 24: 1950	33	0
uly 27: 1870	29	8	October: 1950	28	7
ug. 10: 1870	29	6	June 19: 1952	32	1½
pt. 11: 1870	30	1	June 15: 1956	29	11
ov. 1: 1870	30	0	June 29: 1956	31	5
une 9: 1871	29	5	July 13: 1956	29	5
uly 3: 1872	28	7	July 28: 1956	28	7
ov. 6: 1873	29	6	Sept. 29: 1960	29	6
[illegible] 20: [illegible]	30	8			

61 Floods at Wagga Wagga

NOTES BY R. J. E. GORMLY

My mother's parents, Mr. and Mrs. Joseph Cox were pioneer settlers on the Murrumbidgee River in 1838. And my father's parents, Mr. and Mrs. Patrick Gormly settled on that river in 1844. Thus, I have taken much trouble in compiling my list of floods on that river.

If I have missed some floods I express my regret. But I can assure readers of my list, that those sixty-one floods have not been easy to find. In The Mitchell Library I have received great kindness and attention from the staff during my twenty-one years of research work.

I started to seek information about the floods at Wagga away back in the 1890's, when I owned land in the flood area. Then, when I first became an alderman at Wagga in 1900, it was my duty to learn about floods from the early settlers.

Later on when I subdivided by Foxborough Hall Estate of forty acres at Wagga into building lots, I endeavoured to induce people to avoid building on land subject to flood danger.

I have estimated the heights of the early floods with so much care that I could give details as to how my estimates were made. My knowledge of the old buildings in Wagga has been a great help to me.

The highest flood at Wagga was on 14th July, 1853, when the river reached a height of 36 feet 2½ inches at 2 a.m. On two other occasions there were floods of 35 feet. The first one having occurred on 26th June, 1852 and the other was on 27th April, 1870.

To avoid confusion I have avoided giving the river heights for Gundagai. There zero on the river gauge was raised two feet in 1892, and on 27th March, 1916 zero on that gauge was lowered two and a half feet.

At Wagga the official river gauge is on the river bridge and it has no ups and downs since it was originally fixed in about the year 1862. However, one newspaper at Wagga for some years took the river heights from an unofficial gauge fixed to a growing gum tree. The gum tree gauge could be seen in flood time without having to use a rowing boat. But the gauge was not reliable. It had its ups and its downs. The gum tree is still alive but the newspaper referred to has been out of circulation for many years.

A flood of 28 feet at Wagga is not only a matter of serious concern for the local residents, but such a flood hampers much of the huge amount of traffic over the Murrumbidgee River. If another wet year like the year 1870 came along it would create an enormous lot of trouble to many people.

Forty-four of the sixty-one floods mentioned in my list have occurred since I was born at Wagga on 12th June, 1868. Thus, I can claim to have had a personal knowledge of many of those floods.

My grandparents Patrick and Mary Gormly and three of their children were drowned at Gundagai on 25th June, 1852 in the big flood, when about one hundred persons lost their lives.

R. J. E. GORMLY

20th October, 1960.

List of 61 Floods at Wagga Wagga of 28ft. and over from 1838 to 1960

To Alderman W. P. Brennan
Wagga Wagga
Seasons Greetings from
R. J. E. Gormly 16-12-1960

COMPILED BY R. J. E. GORMLY
OF 30 BOBBIN HEAD ROAD
PYMBLE

20TH OCTOBER, 1960

BF SHORT
WWC

A BUREAU OF METEOROLOGY

FLOOD FORECASTING

SYSTEM

TABLE 1

MURRUMBIDGEE RIVER AT GUNDAGAI

RECORDED FLOODS 23 FEET AND OVER

YEAR	DATE	PEAK RECORDED HEIGHT Ft. Ins.
1852	26th June	40 - 6
1853	3rd July	41 - 4
1870	26th April	40 - 6
1879	18th September	36 - 0
1887	24th January	28 - 3
	27th January	26 - 0
	21st March	23 - 0
	6th July	27 - 4
1889	11th September	25 - 0
1891	18th January	34 - 0
	28th June	38 - 0
	12th July	34 - 6
	29th July	25 - 4
	4th August	28 - 6
1892	26th September	29 - 0
	19th October	28 - 3
1894	26th March	27 - 6
	21st April	30 - 6
	27th June	26 - 3
	20th July	25 - 4
	10/11th September	27 - 0
1899	14th August	25 - 6
1900	29th May	29 - 0
	6th July	38 - 6
1905	12th July	27 - 11
1906	6th October	28 - 6
1909	25th June	23 - 6
1916	11th July	23 - 3
	28th/29th August	26 - 6
	6th October	29 - 0
1917	20th July	24 - 3
	6th October	26 - 3
	22nd October	26 - 6
1918	10th August	23 - 3
1921	11th September	24 - 0
1922	30th July	31 - 0
1924	27th August	24 - 10
1925	28th May	37 - 0
	22nd June	23 - 3
1931	29th May	24 - 6
	12th June	28 - 6
	21st June	23 - 6
	25th June	32 - 9½
1932	1st September	25 - 0
1934	17th August	28 - 0
	26th/27th October	31 - 4
1939	24th August	27 - 4
1950	23rd March	34 - 5
	4th April	29 - 0
	9th April	26 - 9
	22nd October	28 - 6
	11th November	23 - 0
1951	27th September	23 - 6
1952	31st May) 2nd June)	25 - 0
	8th June	26 - 3
	18th June	33 - 3
	19th September	24 - 0
	29th October	28 - 9½

TABLE 1 (CONT.)

MURRUMBIDGEE RIVER AT GUNDAGAI

RECORDED FLOODS 23 FEET AND OVER

YEAR	DATE	PEAK RECORDED HEIGHT FT. INS.
1955	17th August	23 - 0
	26th August	26 - 3
	22nd October	24 - 0
1956	4th May	25 - 0
	15th May	24 - 6
	12th June	29 - 2
	30th June	31 - 1½
	8th July	28 - 4
	27th July	26 - 10
	20th October	25 - 4¾
1959	23rd October	32 - 10
1960	3rd August	24 - 1
	27th September	26 - 1
1961	19th December	24 - 11½
1966	13th November	23 - 8
1970	28th August	24 - 6
	25th September	28 - 0
	28th September	26 - 9
1971	12th February	29 - 0

TABLE 2

MURRUMBIDGEE RIVER AT WAGGA

RECORDED FLOODS 27 FEET AND OVER

YEAR	DATE	PEAK RECORDED HEIGHT Ft. Ins.
1844		36 - 0
1852	25th June	35 - 0
1853	July	35 - 9
1867	July	30 - 7
1869	July	29 - 10
1870	April	35 - 0
	May	32 - 6
	June	30 - 3
1878	November	29 - 6
1879	20th September	30 - 8
1887	8th July	27 - 6
1891	20th January	30 - 4
	29th June	34 - 4
	13th July	31 - 9
	6th August	28 - 0
1892	20th October	27 - 4½
1894	28th March	28 - 3
	23rd April	30 - 1
	29th June	27 - 7
	21st July	27 - 3
	12th September	28 - 8
1900	31st May	28 - 0
	7th July	32 - 9
1905	14th July	27 - 6
1906	6th October	29 - 2
1916	31st August	27 - 0
1916	9th October	28 - 9
1917	21st July	27 - 3
	23rd August	28 - 0
	8th October	27 - 3
	24th October	27 - 11
1922	31st July	30 - 1
1925	30th May	32 - 4
1931	13th June	28 - 9
	26th June	31 - 8
1934	18th August	28 - 0
	28th October	30 - 0
1939	26th August	28 - 3
1950	25th March	33 - 3
	6th April	29 - 9
	24th October	29 - 3
1952	3rd June	27 - 6
	19th June	32 - 1½
	9th June	27 - 6
	31st October	29 - 0
1955	29th August	27 - 8
1956	5th May	27 - 3
	19th May	27 - 9
	16th June	29 - 11
	29th June	31 - 6
	10th July	29 - 6
	20th July	28 - 2
	28th July	28 - 7
	21st October	28 - 1
1959	24th October	30 - 0
1960	28th September	29 - 3
	26th September	29 - 1
1970	1st October	28 - 8
1971	14th February	27 - 9

TABLE 3

MURRUMBIDGEE RIVER AT NARRANDERA

RECORDED FLOODS 22 FEET AND OVER

YEAR	DATE	PEAK RECORDED HEIGHT Ft. Ins.
1891	1st July	28 - 10
1892	1st November	25 - 4
1893	23rd June	23 - 3
1894	27th April	25 - 4
	26th/27th July	25 - 6
	17th September	25 - 7
1900	5th June	24 - 0
	10th July	27 - 3
1905	18th July	24 - 1
1906	6th July	22 - 1
	18/19th September	23 - 11
	11th October	25 - 8
1909	21st August	22 - 3
1916	18th July	22 - 8½
	14th October	25 - 9
1917	28th August	24 - 9
	28th October	25 - 6
1918	17th August	23 - 4½
1921	18th September	22 - 3
1922	5th August	26 - 0
1923	11th July	22 - 11
	9th August	23 - 8½
	15th September	23 - 0½
	22nd October	22 - 9
1924	4th September	22 - 3
1925	2nd June	27 - 0
1926	7th August	25 - 0
1931	29th June	28 - 8
1932	9th September	23 - 5
1936	11th August	23 - 9½
1939	8th July	24 - 0
	30th August	25 - 9½
1950	27th March	28 - 6¼
	10th April	26 - 6
	30/31st July	22 - 1
	11/12th August	23 - 5½
	29th October	26 - 2
1951	16th August	23 - 6
	5th October	24 - 1
1952	22nd June	28 - 6½
	16th August	22 - 8
	26th September	24 - 8
	5th November	25 - 8
1953	15th November	22 - 1
1955	2nd September	25 - 3
1956	24th March	22 - 4½
	29th April	23 - 8
	25th May	25 - 8
	19th June	26 - 6½
	3rd July	28 - 6½
	1st August	26 - 2
	1st September	23 - 10
	26th October	25 - 10
	1st November	24 - 1
1958	20th October	22 - 3
1959	31st October	24 - 2½
1960	9th August	24 - 7
	3rd October	25 - 11
1964	31st July	22 - 10½
	20th September	23 - 6
	18th October	24 - 4
1970	6th September	23 - 2

TABLE 4

KNOWN FLOODS IN MURRUMBIDGEE RIVER BASIN

12/4/1832	Murrumbidgee reported in flood, covering most of the extensive neighbouring plains.
Nov. 1844	Murrumbidgee in flood: Gundagai 4 feet under water.
25/6/1852	Murrumbidgee in high flood; surrounding country at Gundagai inundated; township swept away, and 89 out of population of 250 perished.
3-13/7/1853	Murrumbidgee in high flood; considerable damage at Gundagai; on 13th, South Wagga under water.
23/6/1867	Disastrous floods in the Hunter, Hawkesbury, Murrumbidgee and other rivers.
7/7/1875	Rivers Bogan, Lachlan and Murrumbidgee in flood, and country around Warren, Canonbar, Nyngan, Nevertire and Wagga submerged.
7/2/1878	Floods covered railway line between Cootamundra and Murrumburrah; traffic suspended several days.
4/11/1878	Murrumbidgee in flood and at Gundagai 25ft. above summer level; all flats submerged. On 5th flood waters in main street of Wagga. Yass and Tumut Rivers, Billabong Creek (highest on record) in flood; bridges, crops, fencing, stock swept away.
20-26/1/1891	Murrumbidgee in flood; water through main street of Wagga. Reached Narrandera 24th; flats inundated and considerable damage; water at greatest height 28ft. 4in. on 26th.
27-29/6/1891	Flood at Queanbeyan; worst within memory; water over bridge, houses swept away. Murrumbidgee in high flood; very little below level of 1852 flood at Cavan. Wagga reached 34ft. 4in. within 8in. of 1870 flood; great damage to property, and great loss of stock. At Kimo, highest flood for 21 years.
25/9/1892	Murrumbidgee in high flood at Gobarralong, Gundagai, Gundaroo and Wantabadgery; flats inundated.
22/3/1894	Murrumbidgee in flood at Narrandera.
30/3/1894	Murrumbidgee covered flats at Narrandera.
28/5/1900	Yass River, all creeks in Upper Lachlan and Murrumbidgee in high flood. Cooma Creek overflowed; bridges and fences washed away.
4/7/1900	Murrumbidgee River in strong flood at Cavan, Tarcutta and Tarsus.
23/4/1903	Local flooding at Cootamundra; £10,000 damage, Murrumbidgee in flood at Gundagai and Temora; roads, fencing, bridges destroyed; Tumut railway suffered serious damage.
13/7/1903	Murrumbidgee at Rosedale greatest height for 10 years; quickly subsided.
2-3/7/1906	Tumut River in high flood, water 4ft. over main road between Gundagai and Wagro-gobilly; fences and bridges swept away. Water to great height Upper Murrumbidgee.
10-11/9/1906	Tumut River in flood; all flats in lower reaches inundated.

TABLE 4 (cont.)

KNOWN FLOODS IN MURRUMBIDGEE RIVER BASIN

5-6/10/1906	Murray and Murrumbidgee Rivers in flood. Parts of Narrandera, Wagga, Albury and Wodonga submerged. Crops and vegetable gardens swept away.
14/1/1907	Upper tributaries of Murrumbidgee in flood at Cooma; loss of life and destruction of stock.
28/2/1916	Local flooding at Queanbeyan, damage to residences and bridges.
28-29/8/1916	Macquarie, Murrumbidgee, Yass, Tumut, Lachlan and Burrowa Rivers in flood; places affected were Orton Park (houses flooded, stock drowned, crops and fencing damaged), Cowra (lowlands submerged), Forbes and Burrowa (traffic suspended); the bridge at Lower Tarcutta was washed away.
29-30/7/1922	Murrumbidgee River in flood; Burrinjuck Dam flooded. Places affected were Cooma (highest flood on record), Gundagai (highest for 22 years, miles of fencing swept away, some houses inundated) Wagga (28ft. 2in. above summer level, residents of Canvas Town rescued by boat), Tarcutta (earthworks caved in and bridge abutment wahsed away and township flooded). Several bridges damaged.
5/8/1922	Murrumbidgee River in flood; at Narrandera reached 26ft.; broke through bank of irrigation canal at Bundidgarie.
8/8/1922	Murrumbidgee in flood at Wagga; great damage to houses and gardens, railway bridges swept away.
14/1/1925	Albury and Tarcutta flooded after severe storms; crops destroyed, homes and property, roads and bridges damaged.
20/5/1925	Murrumbidgee in highest flood for 34 years. Two people were drowned at Nangus, two at Gundagai, one at Canberra. Places affected were Gundagai (immense damage), Jugiong (township isolated), Burrinjuck (great damage). Yass River caused people to vacate homes; water over bridge at Goodhope and house washed away. Greatest flood on record at Molonglo; families washed out, water up to ceilings, bridges damaged.
28/5/1925	Floods in Canberra - Yass area. At Queanbeyan, greatest on record; houses flooded, roads blocked, two men drowned. Canberra isolated. Yass flooded, great damage.
30/5/1925	Murrumbidgee in flood at Wagga, with extreme damage and further loss of life; highest for 34 years; business quarters flooded and stock drowned. Regarded as most devastating in history - over 1000 buildings affected, and damage in town and district set at £1,000,000.
1/6/1925	Murrumbidgee in flood at Gundagai, maize crops submerged, stock lost, fences damaged, and two men drowned.
2/6/1925	Murrumbidgee in flood at Narrandera; all lowlands inundated.
6/6/1926	Serious floods at Junee; immense damage.
23/6/1926	Local flooding at Wagga; miles of country flooded, cultivation damaged.
14-16/2/1928	Heavy rain in Riverina caused rail washaways; bridge collapsed at Marinna; damage to railway very great in Coolamon - Narrandera district; three men drowned between Junee and Illabo.
27-28/12/1929	Floods in Cootamundra - Temora district. At Cootamundra lowlands inundated and rail washaways; Stockinbingal, rail washaways; Springdale, homes and Post Office invaded, crops destroyed

KNOWN FLOODS IN MURRUMBIDGEE RIVER BASIN

13/2/1930	Some severe flooding on south - west slopes. Places affected were Murrumburrah (biggest flood for 40 years, houses wrecked), Neville, Harden (scenes of desolation, thousands of pounds worth of damage), Junee (road for miles under 2 ft. of water), Cootamundra (communications interfered with), Frampton (dams burst, bridges submerged, country inundated).
27-30/5/1931	Murrumbidgee, Yass and Wollondilly Rivers in flood; places affected were Ganmain (large part of township under water, roads impassable, fences destroyed), Lockhart (town flooded, bridge covered), Burrowa (homes inundated), Gunning (damage to fencing and property), Yass (water 8ft. over Hardwicke Bridge, extensive washaways and landslips), Kippilan (water 6ft. over bridge), Goulburn (gardens inundated), Wagga (lowlands submerged), Gundagai (lowlands submerged, damage £7000); roads between Tumut, Gundagai and Adelong impassable.
28/5/1931	Molonglo River ih flood at Canberra; low level bridges under water; telegraphic communications interrupted.
11/6/1931	Tumut and tributaries in high flood; waters spread over large area with extensive loss of stock and crops. Roads impassable. One life lost. Railway dislocations.
12/6/1931	Bullenbong and Burkes Creeks caused flooding of Queanbeyan; homes vacated. Murrumbidgee in flood and Gundagai isolated; bridges washed away and roads impassable.
23-29/6/1931	Watercourses in Eastern Riverina in flood; many wheat crops completely covered; many roads impassable and damage to culverts, bridges and causeways; rail services disrupted by washaways and flooding; a man drowned in Billabong Creek. Flood greatest for 50 years on Tallangatta Creek, and Billabong Creek near Culcairn was 5ft. higher than record 1891 flood.
	Murrumbidgee in full flood. Gundagai (valley a huge lake, damage exceeded £60,000), Tarcutta (Homesteads flooded), Wagga(flats an inland sea, hundreds homeless, crops damaged), Narrandera (floods miles wide, damage to residences), Hay (water near 1925 flood level), Adelong (most serious flood for 50 years, approaches to bridge collapsed), Ariah Park (country under water), Leeton (many farms under water), Tumbarumba (river over top of two main bridges), Ganmain (Houses inundated), Coolamon (district flooded), Tumut (valley flooded and homes vacated), Grong Grong (country inundated, many sheep drowned).
8-9/1/1934	Murrumbidgee River in flood, lowlands in Riverina flooded. Places affected were Gundagai (flats inundated for miles), Wagga (agricultural lands submerged, sheep drowned, crops inundated), Albury (one-third or crops ruined), Belldale (fencing and 13 chains of railway washed away), Henty (stock drowned), Urangeline and Pleasant Hills (rail washaways) Urana (creek in flood, many sheep and one man drowned, homes vacated, thousands of acres flooded), Lockhart (roads, bridges and railway damaged), Narrandera and Grong Grong (rail washaways), and Boree Creek (police station flooded). Cooma (biggest flood since 1922, two bridges seriously damaged, homes flooded, and township cut off).
18/2/1934	Severe local flooding at Junee; damage estimated at thousands of pounds.
25-28/10/1934	Floods along southern slopes and some adjacent districts. Canberra (town isolated, roads submerged, railway damaged), Queanbeyan (main streets flooded, considerable damage), Wagga (tremendous damage, streets submerged, houses damaged).

TABLE 4 (cont.)

KNOWN FLOODS IN MURRUMBIDGEE RIVER BASIN

2/11/1934	Murrumbidgee River in flood at Narrandera; many pastures flooded.
22-23/10/1935	Flooding in south-east Riverina. Stock losses and other damage at Walla Walla, Albury, Balldale and Brocklesby; much country inundated.
4/8/1935	Floods on Murrumbidgee River. Main roads closed. Man drowned in Bald Blair Creek. Minor damage to property and some loss of stock.
17/3/1939	Eastern Riverina river systems in flood; rail traffic dislocated. Among places affected were Milbrulong (township half submerged), Ardlethan (isolated), Lockhart (homes flooded), Gundagai (one life lost), Cootamundra (bridges and culverts destroyed) and Wagga (bridges, roads and fencing damaged, homes flooded, many sheep drowned).
25/8/1939	Floods in Wagga district; several homes evacuated.
25/1/1941	Severe local flooding at Narrandera; some heavy damage.

APPENDIX B: FLOOD MODELLING AT OURA

APPENDIX B: DESIGN FLOOD PROFILES AT OURA

The quasi two-dimensional RUBICON hydraulic model set up for this Flood Study extends from Braehour to the Malebo Range at Kallewanda. In order to derive design flood levels for the village of Oura, upstream of Braehour, the HEC-RAS steady-state package was used.

B1. SURVEY

Four cross-sections of the floodplain in the vicinity of Oura were surveyed by Council in 2003. Four corresponding hydrosurvey sections of the Murrumbidgee River were also provided by Council. Details of the available survey data are shown on Figure B1. The existing cross-section at Braehour (Section x-1.12 of the RUBICON model layout - refer Figure 12) was utilised s the downstream boundary for the HEC-RAS model.

B2. BOUNDARY CONDITIONS

The peak height at Braehour obtained from the RUBICON model was adopted as the downstream boundary condition for the HEC-RAS model. The corresponding peak flow at Braehour was also adopted but with a 5% increase to allow for attenuation.

B3. CALIBRATION

The Manning's "n" roughness values used in the HEC-RAS model were adjusted within reasonable limits until the modelled peak height profile best fitted the observed flood heights available from the August 1974 event. The resulting peak height profile is shown on Figure B2.

B4. DESIGN EVENTS

The resulting peak height profiles for the design 1 in 10, 1 in 20, 1 in 50 and 1 in 100 ARI events as well as the PMF are shown on Figure B3.

Table B1: HEC-RAS Model Results

Location (1)	Peak Flood Level (mAHD)	Peak Flow (m3/s)			Peak Velocity (m/s)		
		Left overbank	Main Channel	Right Overbank	Left overbank	Main Channel	Right Overbank
10 year ARI							
x-section 1	185.6	886	1167	297	0.3	1.5	0.4
x-section 2	185.2	482	1688	180	0.3	1.3	0.3
x-section 3	184.6	759	1591	0	0.6	2.5	0.1
x-section 4	184.1	243	2075	32	0.6	2.0	0.3
20 year ARI							
x-section 1	186.7	1699	1336	465	0.4	1.6	0.4
x-section 2	186.2	902	2230	369	0.4	1.5	0.3
x-section 3	185.5	1403	2093	4	0.8	2.9	0.3
x-section 4	184.8	521	2847	132	0.8	2.5	0.5
50 year ARI							
x-section 1	188.1	3186	1652	762	0.5	1.7	0.5
x-section 2	187.5	1672	3051	877	0.6	1.8	0.5
x-section 3	186.8	2562	2829	209	1.1	3.4	0.4
x-section 4	185.8	1092	4124	384	0.9	3.2	0.8
100 year ARI							
x-section 1	189.1	4598	2051	1102	0.5	1.9	0.6
x-section 2	188.5	2457	3862	1431	0.7	2.0	0.6
x-section 3	187.7	3586	3420	744	1.3	3.7	0.6
x-section 4	186.6	2027	5006	716	1.2	3.5	0.8
Extreme							
x-section 1	196.3	26282	5558	5159	1.2	3.2	1.1
x-section 2	195.0	13568	13552	9881	1.7	4.3	1.6
x-section 3	193.4	15737	9677	11586	2.7	6.7	2.1
x-section 4	192.1	13633	11389	11978	2.4	5.1	2.0

1 - Refer Figure B1 for locations

FIGURE B1

OURA SURVEY DATA

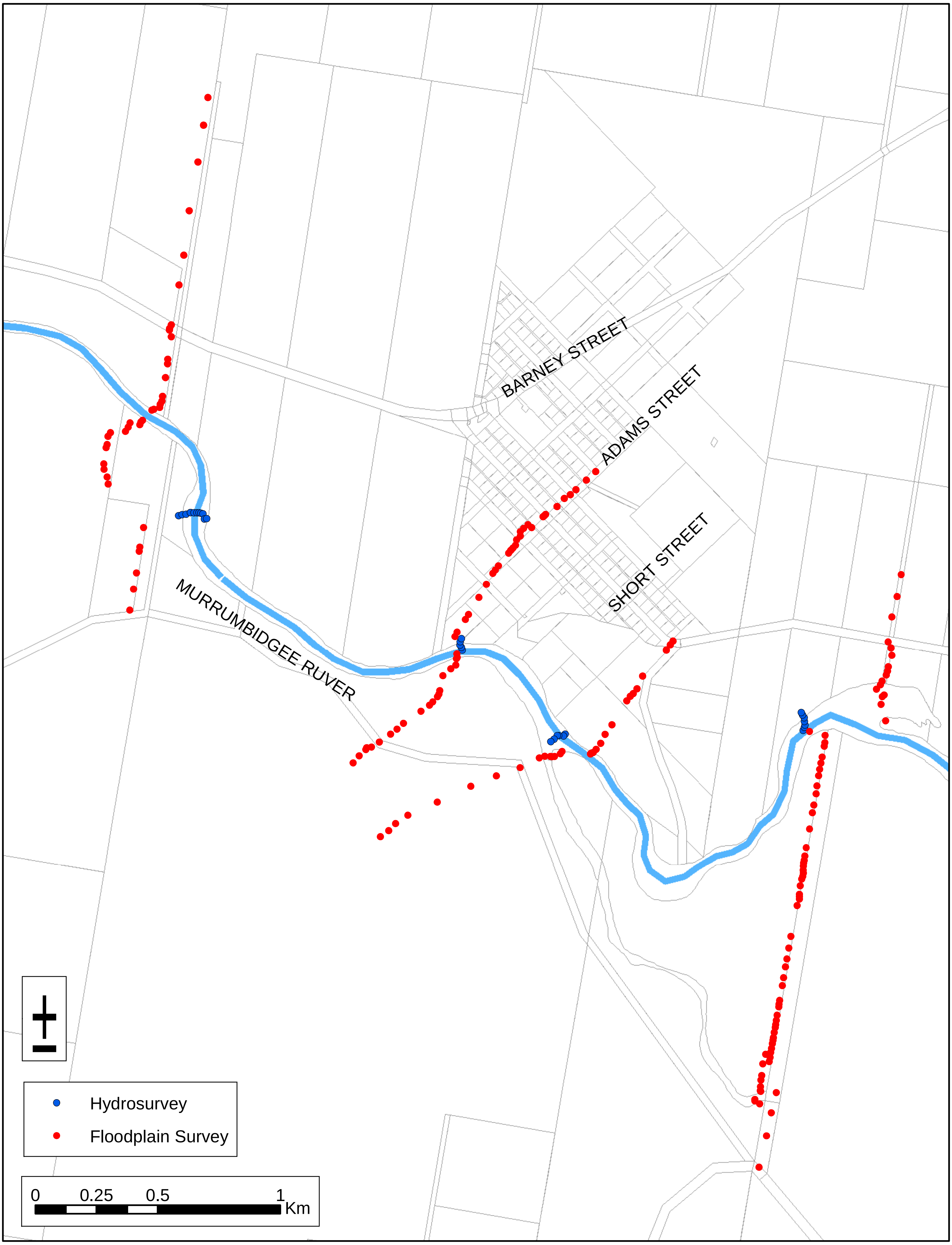


FIGURE B2
PEAK HEIGHT PROFILE
AUGUST 1974

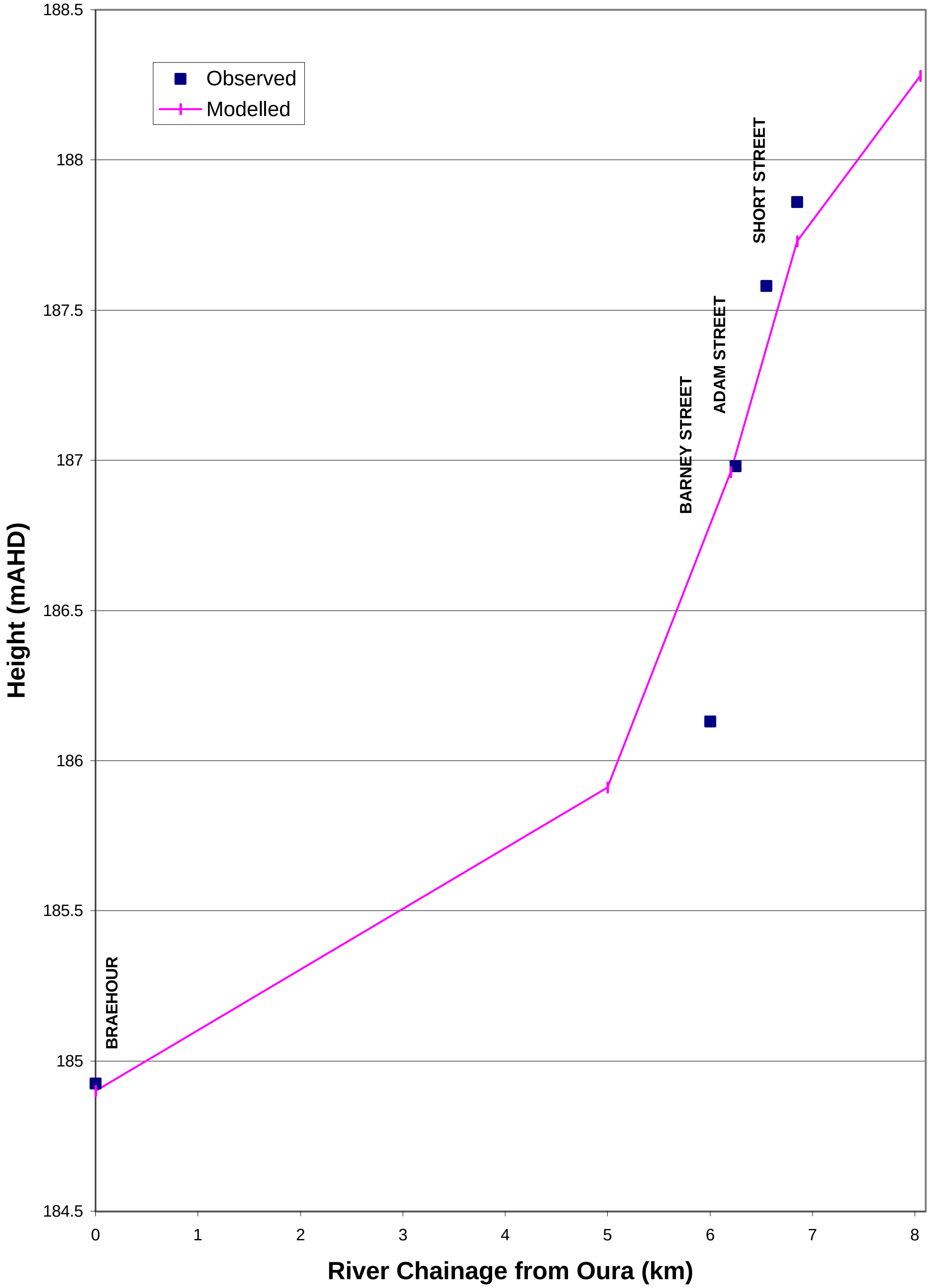
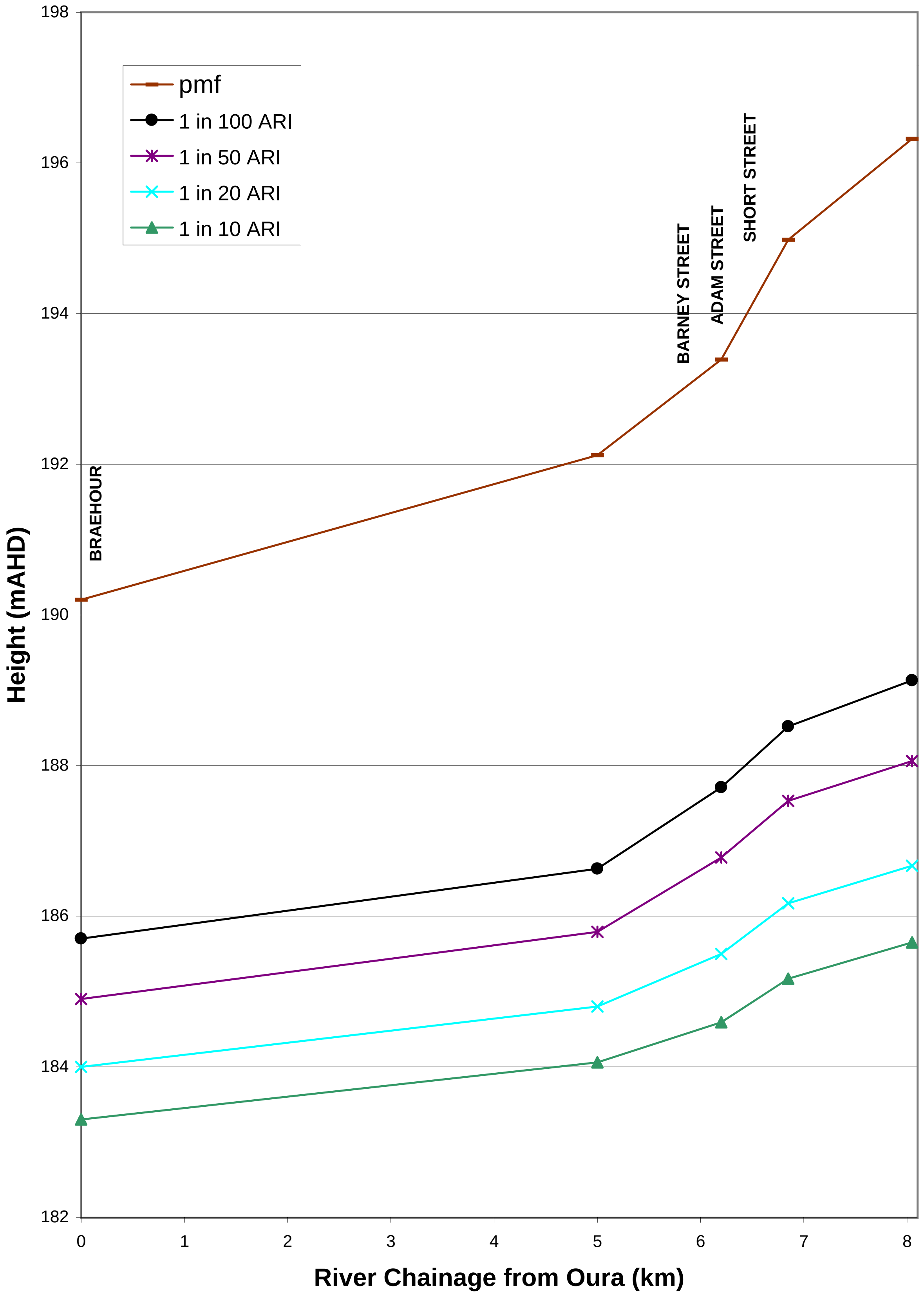


FIGURE B3

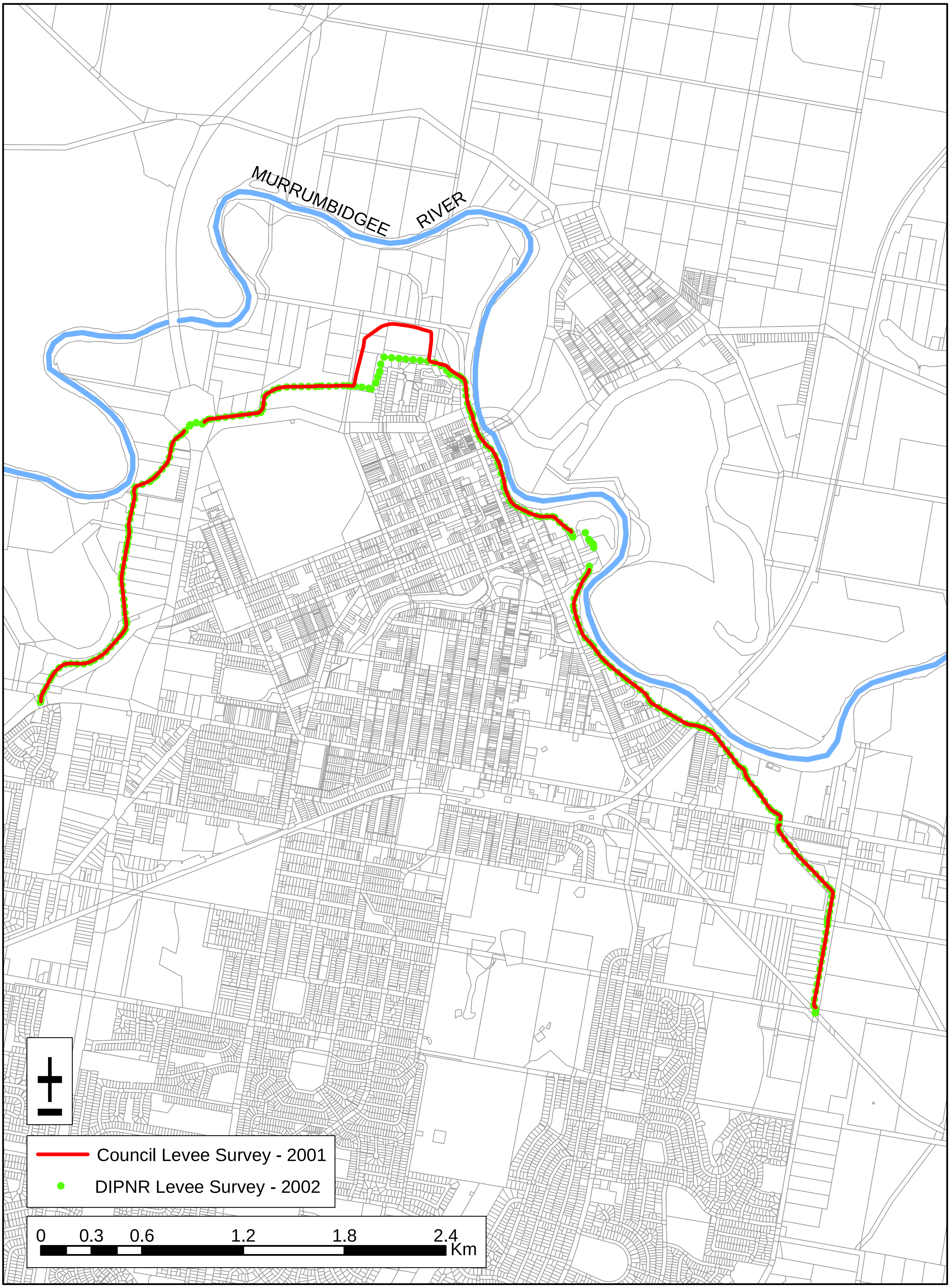
PEAK HEIGHT PROFILES
DESIGN FLOOD EVENTS



APPENDIX C: SURVEYED LEVEE ALIGNMENTS

FIGURE C1

SURVEYED LEVEE ALIGNMENTS



APPENDIX D: ADDITIONAL FLOOD FREQUENCY ANALYSES

FIGURE D1

GUMBEL DISTRIBUTION

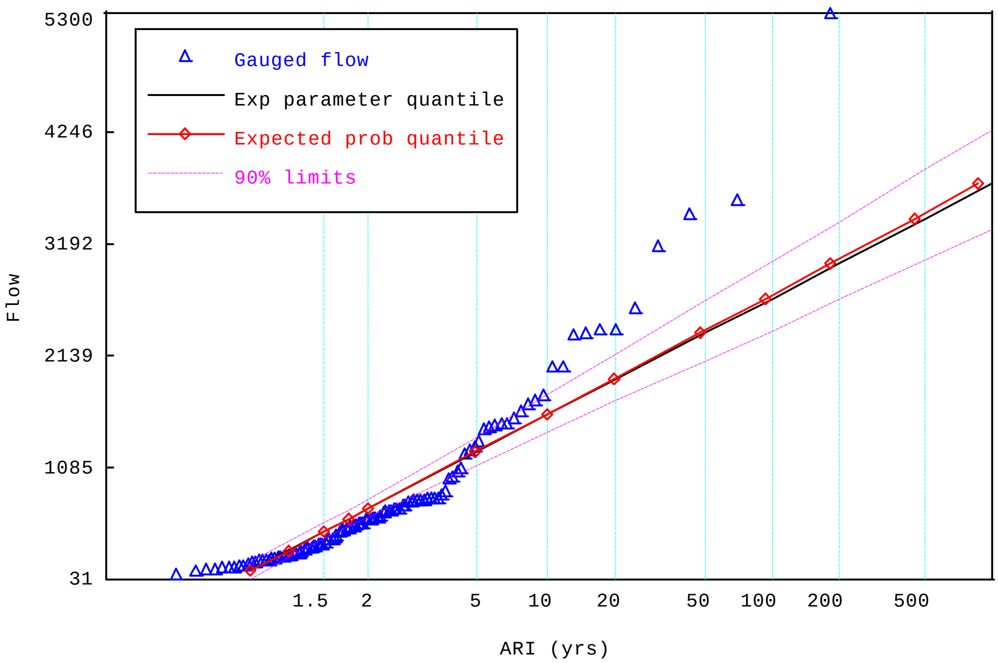
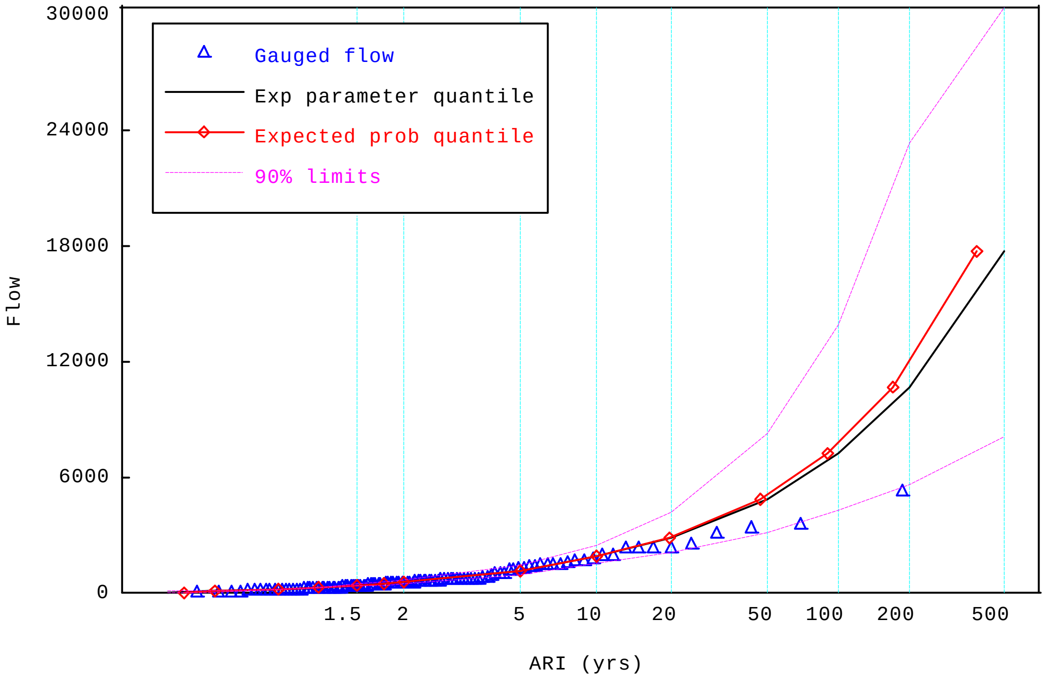


FIGURE D2

GENERALISED EXTREME VALUE (GEV)



APPENDIX E: INDICATIVE FLOOD HAZARD MAPPING

APPENDIX E: INDICATIVE FLOOD HAZARD MAPPING

Full hazard mapping of the floodplain would require a DTM to be developed requiring detailed survey of the whole floodplain. The large costs involved are not justified at this time. Instead indicative hazard mapping only is presented in Figures E1 and E2 for the PMF and the 1 in 100 ARI events. These figures show broad zones of hazard only - where a more definitive hazard category was required at a future date, e.g. for a proposed development, detailed survey could be collected at that time and the maps refined.

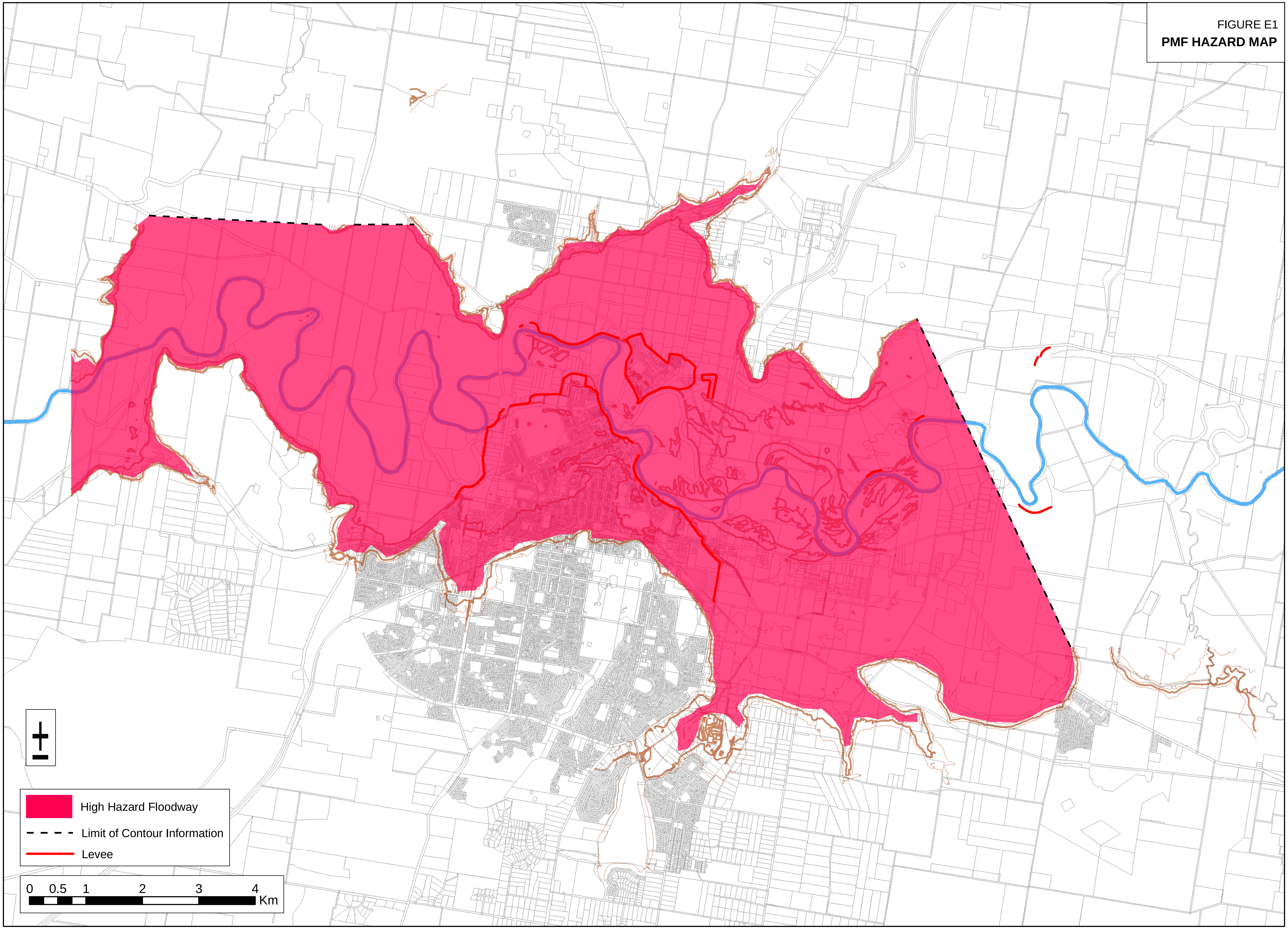


FIGURE E1
PMF HAZARD MAP
High Hazard Floodway
Limit of Contour Information
Levee
0
0.5
1
2
3
4
Km

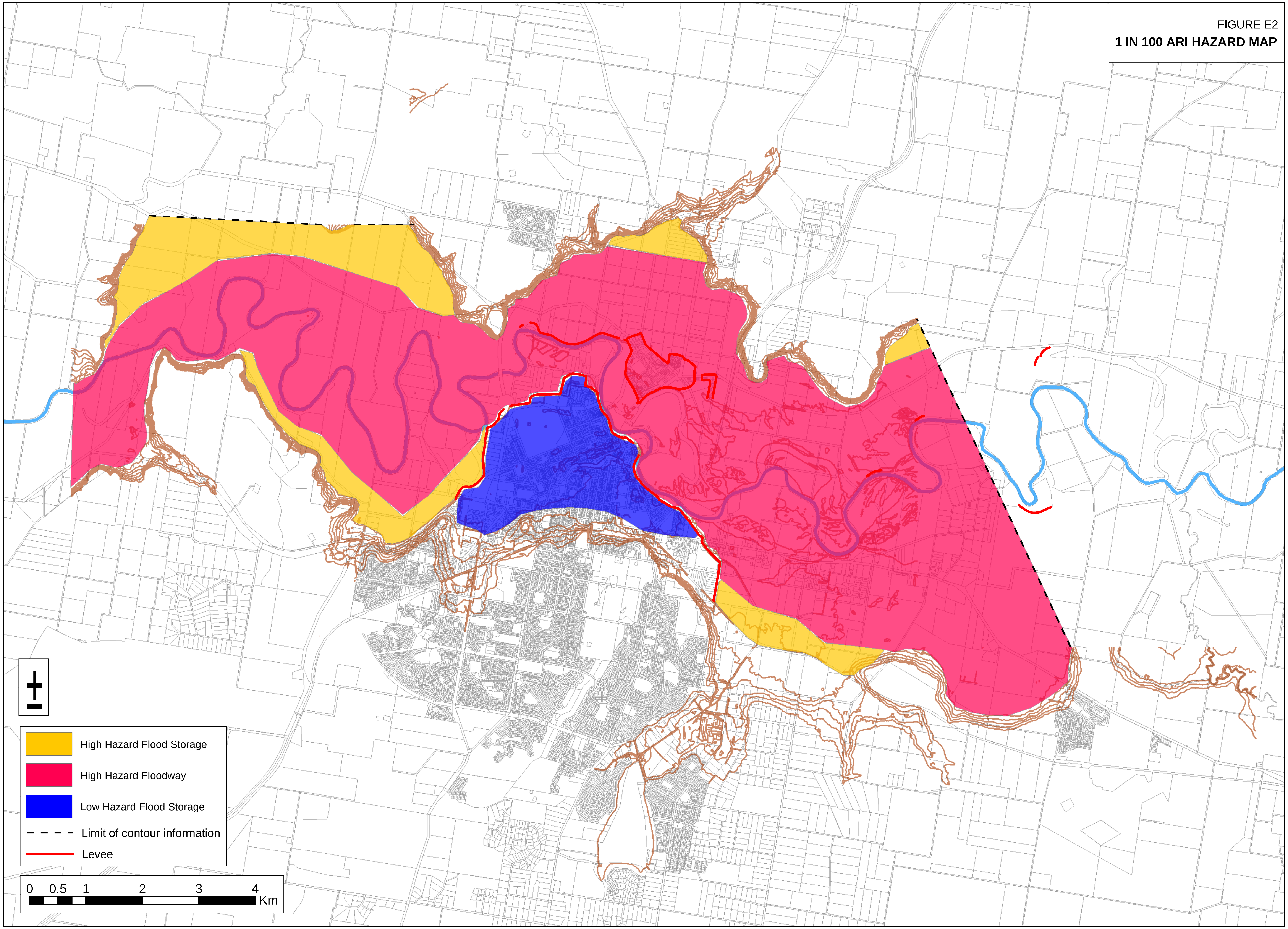


FIGURE E2
1 IN 100 ARI HAZARD MAP
High Hazard Flood Storage
High Hazard Floodway
Low Hazard Flood Storage
Limit of contour information
Levee
0 0.5 1 2 3 4
Km