BOMBALA COUNCIL

BOMBALA FLOOD STUDY AND OVERLAND FLOWS INVESTIGATION

Issue No. 3
DECEMBER 2010

WorleyParsons
consulting practices

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FOREWORD

The State Government's Flood Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Government's Floodplain Development Manual.

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 Local Government in the discharge of their floodplain management responsibilities.

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

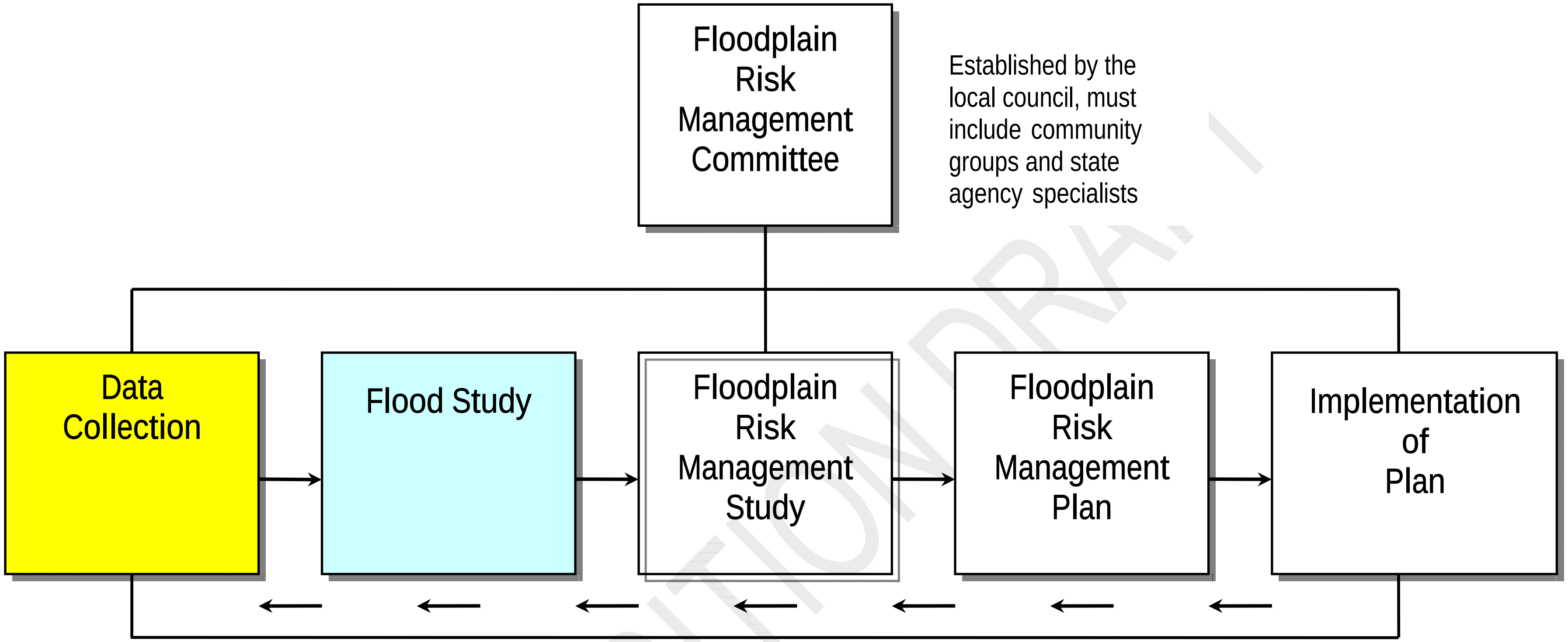
STAGES OF FLOODPLAIN MANAGEMENT

	Stage	Description
1	Flood Study	Determines the nature and extent of the flood problem.
2	Floodplain Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3	Floodplain Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4	Implementation of the Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

A detailed description of the inter-relationship between these stages is provided overleaf.

Bombala Council commenced this process in 2001, when it formed the Bombala Floodplain Management Committee. Council and the Committee, with the technical and financial support of the NSW Department of Environment, Climate Change & Water, have proceeded with the floodplain management process by commissioning this flood study.

The Bombala Flood Study and Overland Flows Investigation represents the first of the four stages. It has been prepared to assist Bombala Council and the local community to understand and define the existing flood behaviour and to establish the basis for the implementation of floodplain management measures.



Compilation of existing data and collection of additional data. Usually undertaken by consultants appointed by the council.	Defines the nature and extent of the flood problem, in technical rather than map form. Usually undertaken by consultants appointed by the council.	Determines options in consideration of social, ecological and economic factors relating to flood risk. Usually undertaken by consultants appointed by the council.	Preferred options publicly exhibited and subject to revision in light of responses. Formally approved by the council after public exhibition and any necessary revisions due to public comments.	Flood, response and property modification measures including mitigation works, planning controls, flood warnings, flood readiness and response plans, environmental rehabilitation, ongoing data collection and monitoring.

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Australia Height Datum (AHD)	National survey datum corresponding approximately to mean sea level
catchment	The catchment at a particular point is the area of land which drains to that point.
design floor level	The minimum *(lowest)* floor level specified for a building.
design flood	A hypothetical flood representing a specific likelihood of occurrence *(for example the 100 year or 1% annual exceedance probability flood)*. The design flood may comprise two or more single source dominated floods.
development	Existing or proposed works which may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in terms of volume over time. It is not the velocity of flow, which is a measure of how fast the water is moving. Rather, it is a measure of how much water is moving. Discharge and flow are interchangeable terms.
effective warning time	The available time that a community has from receiving a flood warning to when the flood reaches them.
flood	Above average river or creek flows which overtop banks and inundate floodplains.
flooding	The State Emergency Service uses the following definitions in flood warnings: ▪ Minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. ▪ Moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic bridges may be covered. ▪ Major flooding: extensive rural areas are flooded with properties, villages and towns isolated and/or appreciable urban areas flooded.
flood behaviour	The pattern/characteristics/nature of a flood. The flood behaviour is often presented in terms of the peak average velocity of floodwaters and the peak water level at a particular location.

flood awareness	An appreciation of the likely threats and consequences of flooding and an understanding of any flood warning and evacuation procedures. Communities with a high degree of flood awareness respond to flood warning promptly and efficiently, greatly reducing the potential for damage and loss of life and limb. Communities with a low degree of flood awareness may not fully appreciate the importance of flood warnings and flood preparedness and consequently suffer greater personal and economic losses.
flood frequency analysis	An analysis of historical flood records to determine estimates of design flood flows.
flood fringe	Land which may be affected by flooding but is not designated as a floodway or flood storage.
flood hazard	The potential threat to property or persons due to flooding.
flood level	The height or elevation of flood waters relative to a datum *(typically the Australian Height Datum)*. Also referred to as "stage".
floodplain	Land adjacent to a river or creek which is periodically inundated due to floods up to the Probable Maximum Flood event. Floodplains are a natural formation created by the deposition of sediment during floods.
flood planning levels (FPL)	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPL's may be appropriate for different categories of land-use and for emergency services planning. The concept of FPL's supersedes the "standard flood event" referred to in the 1986 edition of the *'Floodplain Development Manual'*. FPL's do not define the extent of flood prone land, and floodplain management plans must always consider that there is flood prone land above the area defined by an adopted FPL.
flood proofing	Measures taken to improve or modify the design, construction and alteration of buildings to minimise or eliminate flood damages and threats to life and limb.
floodplain management	The coordinated management of the risks associated with human activities that occur on the floodplain.
flood source	The source of the flood waters. In this study Bombala River is the primary source of floodwaters at Bombala. These floodwaters originate as runoff from the catchment which is concentrated in the Bombala River channel.

floodplain management standard	A set of conditions and policies which define the benchmark from which floodplain management options are compared and assessed.
flood storages	Floodplain areas which are important for the temporary storage of flood waters during a flood.
freeboard	A factor of safety usually expressed as a height above the flood standard. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
high hazard	Danger to life and limb; evacuation difficult; potential for structural damage, high social disruption and economic losses.
historical flood	A flood which has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
low hazard	Flood depths and velocities are sufficiently low that people and their possessions can be evacuated.
management plan	A clear and concise document, normally containing diagrams and maps, describing a series of actions which will allow an area to be managed in a co-ordinated manner to achieve defined objectives.
peak flood level, flow or velocity	The maximum flood level, flow or velocity occurring during a flood event.
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
runoff	The amount of rainfall from a catchment which actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
velocity	The speed at which the flood waters are moving. Typically, modelled velocities in a river or creek are quoted as the depth and width averaged velocity, ie. the average velocity across the whole river or creek section.

EXECUTIVE SUMMARY

History of Flooding at Bombala

Bombala is located on the Bombala River about 80 kilometres south of Cooma. The town is located downstream of the confluence of the Bombala and Coolumbooka Rivers (*refer* **Figure 1**), which collectively drain a catchment area of 537 km^2.

Major flooding at Bombala has occurred on a number of occasions over the last 70 years. The most severe floods occurred in 1971, 1952, 1983, 1978 and 1934. The 1971 flood was the largest, with floodwaters entering 16 houses and at least 6 commercial premises. A peak flood level of 703.1 mAHD was recorded at the old Forbes Street road bridge crossing of the Bombala River. This corresponds to a water depth of 400 mm over the existing Forbes Street bridge deck.

The 1971 flood is regarded as the most severe flood in recent times. The flood occurred primarily in response to extended rainfall over the Coolumbooka River catchment. The heavy rains began on the 6th February, and caused flooding throughout Bombala Shire. The rainfall gauge at Cathcart recorded 377 mm for the 24 hours to 9 am on the 7th February, and a further 149 mm for the 24 hours to 9 am on the following day. Similar rainfall was recorded at gauges further up the Coolumbooka River catchment. Substantial rainfall was also recorded within the Upper Bombala River catchment, but the magnitude was less than for the Coolumbooka River catchment.

As a result of the continued heavy rain, water levels in Bombala River rose and overtopped the banks. Floodwaters entered the town in the middle of the night of the 7th February. The extent of flooding is believed to have been exacerbated by local catchment runoff caused by a local storm burst to the south of the town centre. The flood caused significant damage to houses and businesses along Therry and Maybe Streets. The Forbes Street bridge (*which was reconstructed in 1996*) and public amenities situated within parklands along the northern banks of the river were also damaged.

Available data indicates that the February 1971 flood was of a similar magnitude to the predicted 100 year recurrence flood for Bombala.

Flood Behaviour

The Bombala River is a tributary of the Delegate River, which joins the Snowy River near Tombong. The Snowy River drains to the Tasman Sea at Orbost, which is located along the north-eastern coast of Victoria. The area of the Bombala River catchment downstream to the town of Bombala, is about 540 km^2.

The Bombala River rises in the coastal range near Brown Mountain (*elevation 1240 m above sea level*). It follows a southerly path being joined by the Undowah River at Bibbenluke, and the Coolumbooka River just upstream of the town of Bombala. The Undowah River drains the western part of the catchment, whereas the Coolumbooka River drains the eastern section of the catchment (*refer* **Figure 5**).

In major storms and periods of prolonged heavy rainfall, runoff from the catchment is concentrated along these tributaries. Available data indicates that in most major historical floods (*such as the 1971 flood*), the Coolumbooka River contributed most of the flow at Bombala. Notwithstanding, records for the 1983 flood indicate that there was only a minor contribution from the Coolumbooka River catchment, and that the flows in the Upper Bombala River catchment were the highest on record.

The available data indicates that floodwaters enter the town by overtopping the banks of the river and inundating low lying areas of parkland adjacent to the Forbes Street bridge. As floodwaters rise, water depths increase and floodwaters extend in a southerly direction, progressively inundating Therry and Maybe Streets, as well as the northern ends of Forbes, Caveat and Young Streets.

Study Findings

Computer models were developed as part of this study to investigate and quantify flood behaviour at Bombala. The models were used to determine peak discharges from the catchment and to establish design flood levels for major events such as the 100 year recurrence flood.

A plot of the water surface profiles generated from the modelling for a range of floods is provided in **Figure 13**. A plot of the recorded water surface profile for the 1971 flood is also included. This indicates that the 1971 flood was not as severe as current estimates for the predicted 100 year recurrence flood.

Plots of the predicted extent of inundation in the 20 and 100 year recurrence floods are provided in **Figures 14** and **15** respectively. The flood extent maps indicate that floodwaters will extend into the rear of properties that front Maybe Street in events as frequent as the 20 year recurrence flood. The peak level of the 20 year recurrence flood at the Forbes Street bridge is predicted to be about 1.6 metres lower than for the 100 year recurrence event and about 1.2 metres lower than the recorded peak level for the 1971 flood.

An analysis of floods rarer than the 100 year recurrence flood was also undertaken. The peak flow for the Probable Maximum Flood (*PMF*) was determined and was simulated within the two-dimensional hydrodynamic model developed for the study. This is regarded as the largest flood that could conceivably occur at Bombala. The modelling showed that extensive areas of the town would be inundated in a flood of the magnitude of the PMF (*refer* **Figure 16**).

The following are a selection of key findings from the study:

(1) In a 100 year recurrence flood, the Bombala River catchment has a critical storm duration of 36 hours. That is, a design storm with a 36 hour duration will generate the highest peak 100 year recurrence discharge at Bombala.

(2) The 36 hour duration 100 year recurrence design storm has an average rainfall intensity of 7.6 mm/hr. Hence, in the design storm a total of 273.6 mm of rainfall is estimated to fall across the catchment.

    Rainfall gauges within the Coolumbooka River catchment at Cathcart recorded rainfall of up to 375 mm over a 24 hour period during the 1971 storm. However, rainfall in the western part of the catchment draining to the Undowah and upper Bombala Rivers was substantially less (*typically 120 mm over the same 24 hour period*).

(3) The probable maximum precipitation for the Bombala River catchment is estimated to be 400 mm (*based on a 6 hour storm duration*). Simulation of the PMP event over the catchment results in a peak discharge at Bombala of about 7,000 m^3/s. In contrast the 100 year recurrence design storm discharge at Bombala is estimated to be 1,770 m^3/s.

(4) The hydraulics of flood behaviour was modelled using a two-dimensional hydrodynamic model extending through the town area from Cunningham's Bridge to "The Falls".

The model was developed from 20 cross-sections of the river channel and its floodplain, and extensive topographic survey data. This data was used to generate a digital elevation model of the floodplain and areas of the town.

The model was used to generate peak flood levels and flow velocities for a range of flood frequencies. The modelling showed that peak flood levels recorded in the 1971 flood are marginally lower than predicted peak water levels for the 100 year recurrence flood.

The peak flow at Bombala during the 1971 flood was determined to be 1670 m^3/s. In comparison, the predicted 100 year recurrence flood discharge determined by rainfall run-off modelling is estimated to be 1770 m^3/s.

(5) Flooding in the town appears to be exacerbated by the constriction in the channel / floodway downstream of Bright Street (*refer* **Figure 1**). In major floods, floodwaters "back-up" above Bright Street, leading to more rapid inundation of the town. Water surface profiles shown in **Figure 13** confirm this, showing a sudden increase in water surface gradient downstream of Bright Street.

(6) The Overland Flows Investigation established that Trouble Spots 1 and 3 are the location of the most significant problem for run-off in the village area. These trouble spots are locations where the results of hydraulic modelling predict stormwater will enter premises during the 20 year recurrence flood event.

(7) The results of modelling the sub-surface drainage lines established that the lines have very limited capacity. The existing capacity of the system is estimated to be less than the 5 year ARI storm event.

Recommendations

Investigations completed for this Flood Study and Overland Flows Investigation indicate that flooding of the Bombala River has the potential to cause damage to public and private property at Bombala. In moderate to severe storms, floodwaters peak in the town less than 20 hours after the rainfall commences. Although floodwater depths are not excessive and people can evacuate to higher ground, flooding during major events will result in substantial public and private losses.

The investigations also show that large areas of Bombala would be inundated in the probable maximum flood (*refer* **Figure 16**). Although a flood of this magnitude is extremely rare, the NSW Government's *Flood Prone Lands Policy* places a duty of care on Council to consider such an event.

For these reasons, it is recommended that Council proceed with the preparation of a Floodplain Risk Management Study and Plan for Bombala.

In the context of the results determined for the Flood Study, it is recommended that the Floodplain Risk Management Study consider the following:

- The potential for a reduction in flood damages by the construction of a low level levee at the rear of properties that front the northern side of Maybe Street.
- The construction of a flood storage system on the Bombala River.
- Other levee alignments targeted towards affording additional protection to existing development and identifying options to facilitate future development, in accordance with Bombala's projected housing needs.
- The potential to manage overland flows through construction of flood retarding basins at strategic locations in the village area
- The *Flood Planning Level* for the town, which would set the constraints for development such as floor levels for residential dwellings.
- Options for development of a flood warning system for Bombala.
- Protocols for flood emergency response for Bombala, including flood evacuation measures, flood damage minimisation strategies, and options for community awareness of the potential risk.
- Review to existing protocols for maintaining the stormwater drainage system in Bombala.

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1 INTRODUCTION

Bombala is located on the Bombala River about 80 kilometres south of Cooma. The town is located downstream of the confluence of the Bombala and Coolumbooka Rivers (*refer* **Figure 1**), which collectively drain a catchment area of 537 km^2.

Bombala has experienced major floods in the past, most notably in 1971, 1952 and 1983. As a consequence of these experiences, Council has adopted a policy of restricting development in low lying areas that are potentially vulnerable to flooding.

Nonetheless, current predictions of the extent of inundation in the 100 year recurrence flood indicate that most businesses on the northern or river side of the main street of Bombala (*ie., Maybe Street*) would experience inundation. Residential dwellings in Caveat, Young and Therry Streets would also be flood affected. Hence, there is an existing flood problem that needs to be addressed.

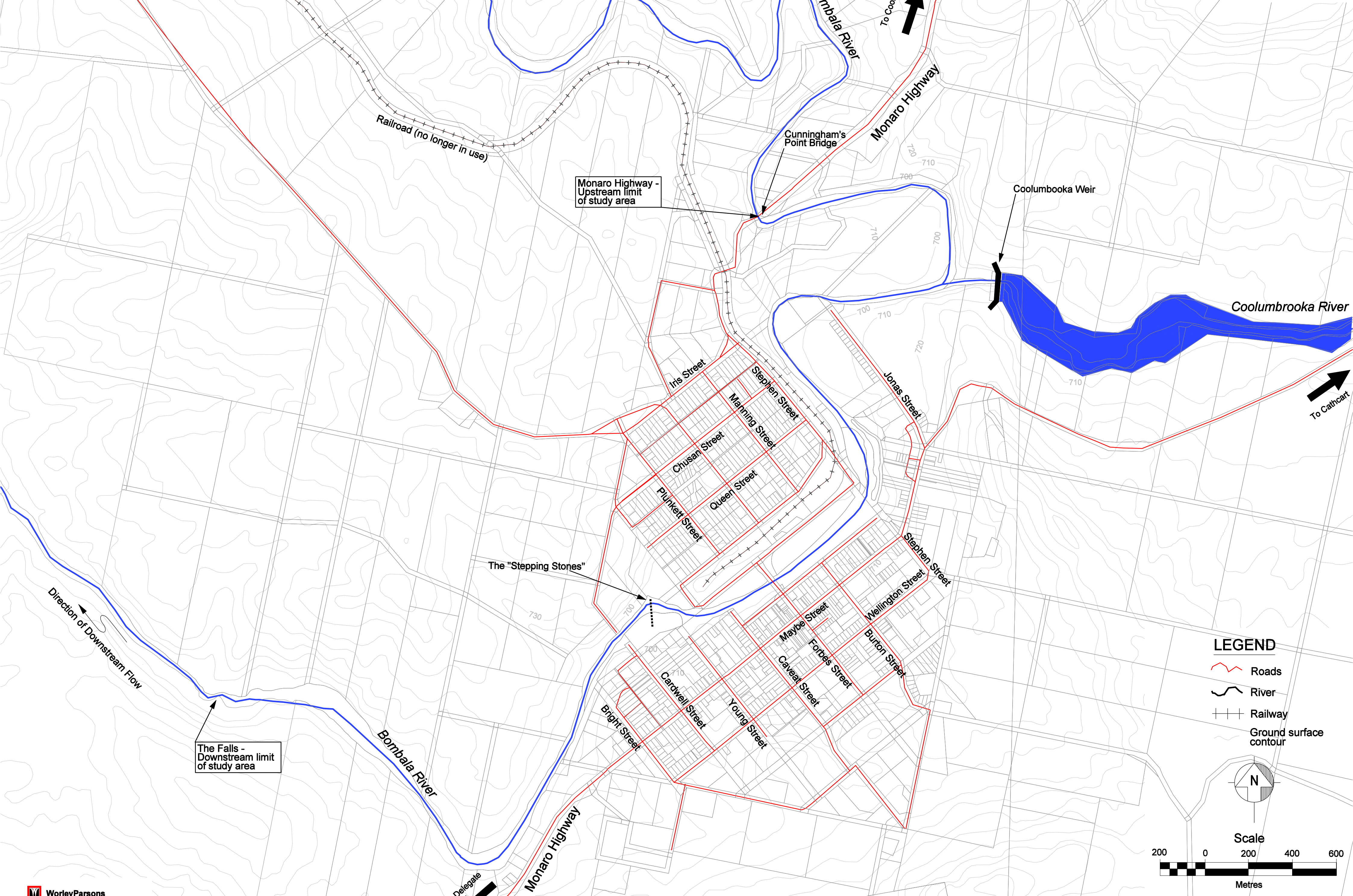
Bombala has a population of about 1500. However, it is anticipated that the imminent approval of a new softwood mill on the fringe of the town will result in a projected increase in the population to 1,700. There is insufficient available housing stock within the town to accommodate such a large increase in base population. Hence, there is likely to be an increase in demand for housing and in the number of development applications for land rezoning, subdivisions and dwelling construction.

Most of the additional development is to occur within the existing town boundaries (*pers comm Grantley Ingram*). As Council is aware of the potential for some areas within the town boundaries to be inundated in major floods, it is keen to further investigate the flood problem so that more informed planning decisions can be made in assessing the likely increase in development applications.

Accordingly, Council wishes to prepare a Floodplain Management Plan for Bombala that addresses the range of existing, future and continuing flood problems. This is to be undertaken in accordance with the NSW Government's *Flood Prone Land Policy*, as detailed in the *'Floodplain Development Manual'* (*2005*).

The findings of the <u>Flood Study and Overland Flows Investigation</u> are documented in this report. The study area for this Flood Study, which includes the Bombala River downstream of Cunningham's Point Bridge, is shown in **Figure 1**. The objective of this Flood Study phase of the project is to define flood behaviour within the study area, including flood levels and hazards for a range of design flood events. This provides baseline flood conditions which are required so that Council and the Floodplain Management Committee can make informed management decisions and assess potential impacts associated with proposed floodplain management measures.

FIGURE 1



BOMBALA TOWNSHIP & STUDY AREA

2 HISTORY OF FLOODING

2.1 MAJOR FLOODS SINCE EUROPEAN SETTLEMENT

Flooding in Bombala has occurred on numerous occasions since European settlement of the area in the 1830s. In the majority of these floods, floodwaters have been contained within the river channel. However, in the larger events, floodwaters have overtopped the river banks and caused inundation of areas of the adjacent floodplain and threatened residential and commercial areas in the centre of the town.

The largest floods since European settlement occurred in February 1971, June 1952 and March 1983. The 1987 Bombala Flood Study identified eight major flood events in the town's history dating from 1871. These events occurred in 1871, 1873, 1919, 1934, 1952, 1971, 1978 and 1983. The largest of these was the February 1971 flood event which inundated several residences and businesses in the town. A summary of the major floods recorded at Bombala since European settlement is provided in **Table 1**. The floods have been ranked according to their severity.

A flood warning gauge was installed in the town in 1978 but prior to this time records of flood events in Bombala were obtained from newspaper reports, the RTA and the State Rail Authority.

Table 1 MAJOR FLOOD EVENTS RECORDED AT BOMBALA

SEVERITY RANKING	DATE OF FLOOD
1	February 1971
2	June 1952
3	March 1983
4	June 1978
5	March 1950
6	January 1934
7	June 1991
8	June 1956
9	June 1975
10	October 1959

2.2 DESCRIPTION OF SIGNIFICANT FLOOD EVENTS

2.2.1 1971 Flood

The most severe flood recorded in the town of Bombala was the February 1971 flood which inundated 16 houses and at least 6 businesses. This flood is the highest on record with levels taken at the time correlating approximately to the 1 in 100 year event as calculated in the 1987 flood study. Flood levels were surveyed by Council from a debris line left behind from the flooding and levels were also surveyed during the 1987 study after interviews with residents who were present at the time of the 1971 flood. Apart from the damage to residences and businesses, this flood caused significant damage to the town bridge and recreation amenities adjacent to the river.

Historical flood marks recorded from the 1971 flood event at Bombala are shown on **Figure 2**.

2.2.2 1978 Flood

The 1978 flood event caused major flooding of the Coolumbooka River. A total of 125 mm was recorded in the 24 hour period on the 4th June 1978. Minor flooding had also taken place on the 2nd June 1978. This meant that the catchment was saturated and level in the river already raised.

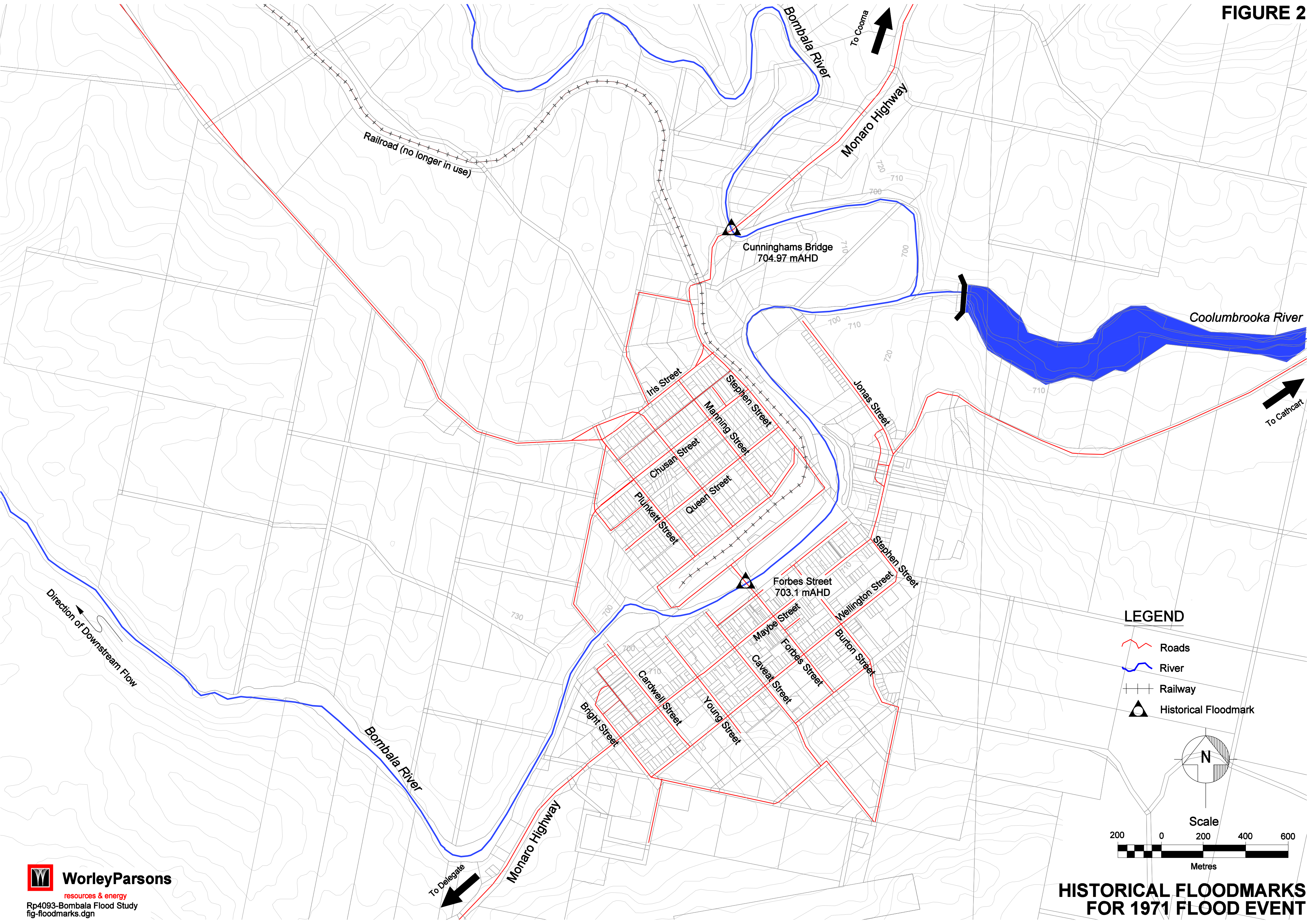
Data collected from the 1978 flood event has been used to verify the results of hydrologic modelling.

2.2.3 1983 Flood

Anecdotal observations and rainfall data indicate that the March 1983 flood event is the considered to be the flood of record for the upper Bombala River catchment.

Floodmarks from the March 1983 event were surveyed by the Department of Water Resources. However, details from the survey were unable to be recovered as part of this Study.

FIGURE 2



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HISTORICAL FLOODMARKS FOR 1971 FLOOD EVENT

3 STUDY METHODOLOGY

3.1 GENERAL

Floodplain management in New South Wales generally follows guidelines established in the government's *'Floodplain Development Manual'* (*2005*). This document outlines the steps involved in the floodplain management process and the activities required to be undertaken to successfully develop a floodplain management plan for flood affected regions.

The *'Floodplain Development Manual'* states that the implementation of the State Government's *Flood Prone Land Policy* requires a floodplain management plan that ensures:

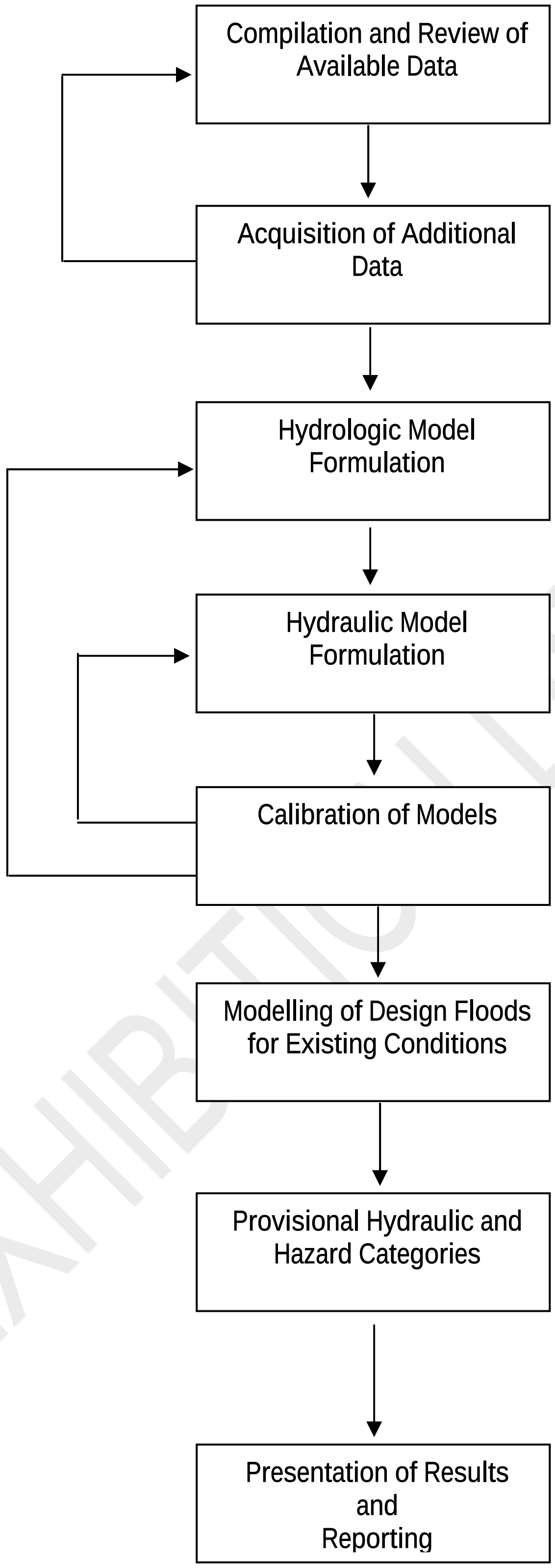
- the use of flood liable land is planned and managed in a manner compatible with the assessed frequency and severity of flooding;
- flood liable lands are managed having regard to social, economic and ecological costs and benefits, to individuals as well as to the community;
- floodplain management matters are dealt with having regard to community safety, health and welfare requirements;
- information on the nature of possible future flooding to the public;
- all reasonable measures are taken to alleviate the hazard and damage potential resulting from development on floodplains;
- there is no significant growth in hazard and damage potential resulting from new development on floodplains; and,
- appropriate and effective flood warning systems exist, and emergency services are available for future flooding.

One of the key steps involved in formulating a floodplain management plan is the recognition, definition and quantification of the principal factors associated with flooding. This information is presented in a Flood Study, which becomes a baseline document summarising flood related data that can be used to resolve floodplain management issues.

The aim of the Flood Study is to produce information on flood flows, velocities, levels and flood extents, for a range of flood events under existing floodplain and catchment conditions, and to highlight those areas where the greatest flood damage is likely to occur.

In particular, the study aims to characterise flood behaviour in the Bombala River catchment as it affects on the township of Bombala. This work includes an examination and analysis of the hydrologic characteristics of the catchments of the Bombala River and a detailed hydraulic study of floodwater movement.

The flow chart shown below outlines the key steps and the sequence of work undertaken.


Compilation and Review of Available Data
Acquisition of Additional Data
Hydrologic Model Formulation
Hydraulic Model Formulation
Calibration of Models
Modelling of Design Floods for Existing Conditions
Provisional Hydraulic and Hazard Categories
Presentation of Results and Reporting

3.2 ADOPTED APPROACH

The general approach and methodology employed to achieve the study objectives involved:

- compilation and review of available information, including previously completed flood studies, streamflow gauge records, rainfall records, topographic mapping of the floodplain, hydrographic surveys of the creek channel and details of bridge crossings;
- site inspections to establish catchment roughness, slope, and land-use, and to identify additional survey needs and critical hydraulic controls such as bridges and weirs;
- the collection of historical flood information, including records of peak flood levels for historical floods (*such as occurred in 1971, 1978 and 1983*);
- the development of a computer based hydrologic model to simulate the transfer of rainfall into runoff and its concentration in streams during the peak of a flood;
- the development of a computer based hydraulic model to simulate the movement of floodwaters through the “town reaches” of the floodplain between the Cunninghams Point Bridge and “The Falls”;
- calibration and verification of the models;
- the determination of peak water levels and flow velocities at selected locations along the Bombala River between Cunninghams Point Bridge and “The Falls”, for predicted 1 in 200, 1 in 100, 1 in 20 and 1 in 5 year average recurrence interval events (*ARI*) and the Probable Maximum Flood (*PMF*); and,
- an assessment of critical areas of the floodplain and stream channel system, and the development of recommendations for inclusion within the floodplain management plan.

Accordingly, linked hydrologic and hydraulic numerical computer models were developed and applied to the Bombala River catchment.

3.3 COMPUTER MODELS

Computer models are the most reliable, cost-effective tools available to simulate flood behaviour in rivers and streams. Two types of computer models were developed as part of the flood study for use in assessing and quantifying flooding characteristics within the Bombala River catchment. These were:

- a hydrologic model, extending over the entire catchment area (*refer* **Figure 6**); and,
- a hydraulic model, extending downstream from the Cunninghams Point Bridge crossing of the Bombala River to “The Falls”.

The hydrologic model simulates catchment rainfall-runoff processes, producing river flows which can be used in the hydraulic model.

The hydraulic model simulates the flow behaviour during flooding of the river and their floodplains, producing flood levels, flow discharges and flow velocities at selected points of interest.

Information on the topography and characteristics of the catchments, and the rivers and their floodplains, is built into the models. For each historic flood, data on rainfall, flood levels and river flows can be used to simulate and validate (*calibrate and verify*) the flood models.

The models produce as output, flood levels, flows (*discharges*) and flow velocities.

Development of the computer models involves:

- discretisation of the catchment, river, floodplain, etc. (*see discussion below*);
- incorporation of physical characteristics (*catchment areas, river cross-sections, etc.*);
- setting up of hydrologic and hydraulic databases (*rainfall, river flows, flood levels*) for historic events;
- calibration to one or more historic floods (*calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values*);
- verification to one or more other historic floods (*verification is a check on the model's performance without adjustment of parameters*).

Once model development is complete, it may then be used for:

- establishing design flood conditions;
- setting flood standards for planning, so that future land-use is controlled to minimise potential losses/damage due to flooding; and
- modelling "what-if" management options to assess the hydraulic impacts (*ie., changes to a bridge structure to reduce upstream bridge afflux, or the potential benefits of constructing a levee*).

The last two of these bullet points are typically undertaken as part of a floodplain management study, which is the third stage in the floodplain management process discussed in the Foreword.

3.3.1 Hydrologic (Catchment Runoff) Model

The hydrologic model simulates the rate of storm runoff from the catchment.

The amount of runoff from rainfall, and the attenuation of the flood wave as it travels down a creek or river, is dependent on catchment characteristics such as slope, area, and vegetation. Storage areas also influence the runoff process, and can be incorporated within the hydrologic model.

3.3.2 Hydraulic Model

The output from the hydrologic model is a series of flow hydrographs (*define the rate of rise and egress of flood flows*) at selected locations such as at the boundaries of the hydraulic model (*eg., at the Cunningham's Point bridge crossing of the Bombala River*). These hydrographs are used by the hydraulic model to simulate the passage of floodwaters through the town reaches of the river and over the adjacent floodplains. The definition of flood levels and flood extents in these areas is of most use because they are the areas of the catchment where the most intense development has taken place (*ie., in the town itself*), and therefore, are areas where flood damages are likely to be the highest. Furthermore, these areas are the areas most likely to be subject to any future urban, industrial or commercial development.

The hydraulic model simulates the movement of the flood wave through the river, and its floodplain. In effect, a hydraulic model is developed to reflect the topography of the river and floodplain land surface, and simulates the movement of floodwaters across this surface.

The hydraulic model incorporates channel shape, roughness, structures such as bridges and levees, and historical flood data. It can be used to replicate historical floods and to predict peak levels, velocities and hazards for some hypothetical flood that has a particular probability of occurring.

4 REVIEW OF AVAILABLE DATA

4.1 AVAILABLE DATA

A number of searches of Council records were undertaken during the course of the study to uncover as much flood related data as possible. A limited amount of background information was collected from Council held reports, and some topographic mapping was uncovered from Council' plan cabinets. Requests for relevant flood related data were also lodged with the NSW Department of Environment, Climate Change & Water, as well as with other government agencies such the State Rail Authority (*SRA*) and the Roads & Traffic Authority (*RTA*).

All of the data supplied was combined with information gathered from field visits (*including additional survey gathered for the computer modelling*), and is compiled in appendices within this report.

4.2 PREVIOUS INVESTIGATIONS

4.2.1 '*Bombala Flood Study Report*' (*1987*) prepared by the Department of Water Resources.

Synopsis

This report is based on flood investigations carried out under the 1977 flood policy which set the 1 in 100 year ARI flood as the flood standard for flood liable land through out New South Wales.

It is intended as an interim data source to assist councils in undertaking floodplain management responsibilities until such time as sufficient information is available to enable council to determine the final flood standard under the 1984 flood policy.

The report provides 1 in 100 and 1 in 20 year ARI flood levels for the town of Bombala taking into account the combined effects of the Bombala and Coolumbooka Rivers.

The flood levels are based on the results of HEC 2 modelling using flood frequency analysis carried out with data from 2 gauging stations in the vicinity of Bombala. One at the Falls, approximately 4 km downstream of Bombala and one at the Forbes Street Bridge in Bombala.

Items of Relevance to the Flood Study

Salient points include:

- River levels recorded since 1957 at " the falls" gauging station located 4kms downstream of Bombala
- Levels also recorded at Wellesly Gauging station on the Little Plains River, adjacent to the Bombala River Catchment and of similar size, since 1941.

- A flood warning gauge was installed at the Forbes Street Bridge in 1978. A graphical correlation was established between the gauging station and the town bridge based on recent large flood events and used to transpose flood levels from the gauging station to the bridge. This provided an annual series of flood levels at the bridge dating from 1941 onwards.
- The rating curve was obtained by assuming that the discharge at both stations was the same, as the difference in catchment area between the bridge and the gauging station downstream is only 1%. There are indications in the study that the rating curve underestimates discharges in high flow situations. High flow gaugings are carried out at the bridge where the mean velocity for the highest gauging was recorded as 2.5m/s. However, numerical water surface analysis with the rating table discharge indicates a mean velocity for the highest gauging of 1.8m/s in the main channel for a flood higher than the highest gauged flood at the bridge.
- The model was calibrated against the 1971 flood using flood marks obtained from residents who witnessed the 1971 flood.
- A flood frequency analysis was carried out on the partial series from 1870 to 1940 for which information on large floods was obtained from newspapers and various other media. This was used to determine the low frequency flood levels at the bridge
- According to the analysis carried out the 1971 flood was only marginally higher than the estimated 1 in 100 year ARI flood level.
- The HEC 2 model was calibrated to the 1971 flood and used as a basis for determination of the 1 in 100 year ARI flood and the 1 in 20 year ARI flood
- On average the floodway limits for the 1 in 100 year event were about 210m wide. Floodway limits for the 1 in 20 year event were about 30m less than for the 1 in 100 year event
- Hazard mapping was carried out based on velocities determined from discharges obtained from the rating curve determined earlier in the study. The velocities used are lower than expected, probably because the discharges in the rating curve are lower than expected
- 1971 was the highest flood on record. 16 houses and 6 businesses were damaged. The town bridge was also damaged.
- The study identifies further data collection tasksto be carried out and prioritises these tasks.
- A preliminary assessment of mitigation options is provided although no detailed economic evaluation of the costs and benefits of each option was carried out.

4.2.2 'Flood Study Reference Plan - HEC-2 Model cross section mapping' (1986) prepared by DWR

Synopsis

- Plan comprises locations of 14 cross-sections extending from Monaro highway Bridge crossing downstream to Joseph Street/Bright Street

Items of Relevance to the Flood Study

Salient points include:

- Additional survey gathered by Williams and Lightfoot only extends downstream to Young Street therefore cross-sections 1, 2 and 3 would need to be added to cross-sections surveyed by Williams and Lightfoot to extend the cross-sectional data downstream to council's specified "end of model area"
- There are also 3-4 sections from the 1987 HEC-RAS model that could be added to the Williams and Lightfoot data to extend the survey dataset upstream to the Monaro Bridge crossing
- HEC 3.0 or HEC RAS model could be developed from a combination of existing study cross sections and an additional 5 cross section s downstream of the current DWR survey.

5 FLOOD FREQUENCY ANALYSIS

5.1 GENERAL

Flood frequency analysis enables the magnitude of floods of a selected probability of exceedance to be estimated by the statistical analysis of recorded floods. The probability of exceedance is usually defined as the annual exceedance probability (*AEP*).

This section describes the definition of design flood peak discharges at Bombala for a range of AEP's by using flood frequency analysis. Development of the design values is outlined in **Sections 5.2** to **5.8**. The results of the FFA are summarised in **Section 5.9** (*refer* **Table 9**).

Methods for flood frequency analysis have been developed that allow a probability distribution to be fitted mathematically to observed data. This enables flood magnitudes of required probabilities to be calculated. The procedures are outlined in *Australian Rainfall and Runoff* in its 1987 single document format (Institution of Engineers, 1987) and the revised separate-book format (Institution of Engineers, 1998), in Chapter 10 and Book IV respectively. The procudres remain unchanged between the two publications. The publication will be abbreviated hence as ARR98.

The procedures apply primarily to peak discharges at a site, and generally should not be applied to peak water levels (*stages*). This is because the distribution of water level at a site can include discontinuities due to sudden changes in cross-sectional area as discharges increase. Furthermore, the relationship between flood stage and discharge may vary throughout the period of record. Discharge, and not stage, is therefore the variable that can be considered to be drawn randomly from a well-behaved statistical distribution, and is thus suitable for flood frequency analysis (*see ARR98*).

5.2 CHOICE OF SERIES

Flood frequency analysis can be based on either an *annual* or a *partial* series. The annual series is the most common analysis method and was chosen in this study.

The annual series approach uses the maximum instantaneous discharge in each year of record. The year may be a calendar year, or if there is seasonality in flow, a water year (*commencing at the end of the low flow period*). For *N* years of data there will be *N* values in the annual flood series.

A partial series analysis uses discharges for all floods above a specified minimum discharge, irrespective of the number that occur in a given year (*although the events should be independent*). There may be more than one flood in the analysed record for some years and none for others.

Either approach is acceptable, but can result in a different flood frequency distribution. ARR98 suggests a general preference for the annual series if floods rarer than the 10% AEP are of primary interest. This is because annual and partial series analyses give similar results in this probability range, and the annual series also has the advantages of likely independence of annual peaks (*this can be checked by examination of the record at the end of each year*), unambiguous extraction of records, and conformity of the annual flood frequency distribution to many theoretical distributions.

In this study, floods rarer than the 10% AEP are indeed of primary interest, so given the advantages listed above, the annual series approach was chosen.

Probability can also be expressed as the average recurrence interval (ARI). For an annual series, the ARI is the reciprocal of the AEP. For example, the 20% AEP flood has an ARI of 5 years, and the 1% AEP flood has an ARI of 100 years. This simple relationship does not apply for partial series, although it is a good approximation for probabilities less (*rarer*) than the 10% AEP.

5.3 AVAILABLE DATA

In flood frequency analysis, a longer record length gives a higher expected accuracy of flood estimates. A longer record also reduces the need for large extrapolations in the analysis to obtain discharges for rarer probability floods such as the 1% AEP.

A streamflow gauge has been operating in Bombala since 1951. Recordings commenced at the Bombala River at The Falls station (*4km downstream of the town of Bombala*), continuing until 1995. The gauge was relocated to the Bombala River at Bombala Town site in 1995, where recordings have persisted to the present.

A gauge also operated nearby, at the Coolumbooka River near Bombala, from 1966 to 1982. The Coolumbooka River joins with the Bombala River just upstream of Bombala.

A summary of the available relevant streamflow data at and near Bombala is given in **Table 2**, **Table 3** and **Table 4**. Data was considered to be relevant if it could potentially be used to extend the Bombala River at The Falls record back before commencement of recording in 1951, or if it could be used to fill in gaps in the record for Bombala (*at both stations that have operated in the town*).

The data extracted for each station was the instantaneous maximum *monthly* flow. Monthly, rather than annual, data was extracted as it allowed for correlation between gauges. If annual data was extracted it would not be possible to assume the flood peaks resulted from the same storm, and the physical basis for the correlation would be lost. Monthly data also has the advantage that gaps in the data set can be easily identified and analysed. With these advantages, it is also relatively simple to ultimately convert monthly peaks to annual peaks.

The instantaneous maximum monthly flows obtained for the Bombala River at The Falls extended from June 1951 to August 1995 inclusive, a total of 531 possible monthly values. During this period there were only 12 gaps in the monthly data, namely July 1959 to October 1959, August 1973 to December 1973, and July 1984 to September 1984. There were thus a total of 519 recorded monthly values.

The instantaneous maximum monthly flows obtained for the Bombala River at Bombala Town extended from November 1995 to April 2001 inclusive, a total of 66 possible monthly values. During this period there were no gaps in the monthly data. There were thus a total of 585 recorded monthly values in the combined Bombala River record using The Falls and Bombala Town stations, from June 1951 to April 2001 inclusive. In the combined record there was also a gap from September 1995 to October November 1995 inclusive, representing the transition period between the two stations. There was thus a total of 14 gaps in the monthly data over the recording period at Bombala.

Regression relationships between the available instantaneous maximum monthly flows at Bombala River at The Falls and all other stations were determined. The coefficient of determination, r^2, of each of these linear relations is shown in **Table 2**, **Table 3** and **Table 4**.

In statistics, r^2 is a measure of the strength of the linear association between two variables, where a value of 1 indicates a perfect correlation and a value of 0 indicates no correlation. Mathematically, r^2 expresses the proportion of the total variation in the values of the ordinate (y) that can be accounted for by a linear relationship with the values of the random abscissa (x). Thus an r^2 value of 0.89 means that 89% of the variation in y values is explained by a linear relationship with x.

In ARR98 an approximate recommended criterion for deciding whether the regression should be used is that the correlation coefficient exceeds 0.85, where r^2 is defined as the square of the correlation coefficient. Thus, according to ARR98, r^2 should approximately exceed 0.72.

In Australia there are 244 drainage basins (*catchments*) within 12 drainage divisions. Most of NSW is covered by 2 drainage divisions, the Southeast Coast Drainage Division (*east of the Great Dividing Range*) and the expansive Murray-Darling Drainage Division (*west of the Great Dividing Range*).

To facilitate the identification of gauging stations in Australia, and the orderly publication of gauging data, the "National Gauging Numbering System" was developed. Under this system each gauging station within Australia is assigned a unique six digit number. The first of the six numbers represents the drainage division, the next two the drainage basin (*catchment*) and the last three the station within the drainage basin. Bombala is located in the Snowy River catchment (*Basin 22*), within the Southeast Coast Drainage Division (*Division 2*), hence the station numbers at this location are prefixed by 222.

The stations investigated within the Snowy River catchment are shown in **Table 2**. In **Table 3**, the stations investigated in the adjacent north-eastern and eastern catchments are listed, namely the Tuross River (*Basin 18*) and Bega River (*Basin 19*) catchments. In **Table 4**, the stations investigated in the adjacent south-eastern and northern catchments are listed, namely the Towamba River (*Basin 20*), NSW portion of East Gippsland (*Basin 21*) and Murrumbidgee River (*Basin 10*) catchments.

Note that all basins are within the Southeast Coast Drainage Division (*Division 2*) except for the Murrumbidgee River (*Basin 10*), which is in the Murray-Darling Drainage Division (*Division 4*). There were no relevant stations within the NSW portion of the Upper Murray catchment (*Basin 1, Division 4*) to the west of Bombala, although some investigation of the data at the Murray River at Bringenbrong Bridge site (*401549*) was made.

There was also data available for stations in the Victorian portions of a number of the catchments investigated. This included the Snowy River (*20 sites*), East Gippsland (*18 sites*) and Upper Murray (*44 sites*) basins. It was considered to be beyond the scope of this investigation to analyse this data further.

Note that the "Years of Obtained Record", listed in the following tables, represents the annual coverage of the data from the first available record to the last available record. It does not take account of any gaps in the data.

Table 2 RELEVANT STREAMFLOW DATA AVAILABLE NEAR BOMBALA WITHIN NSW SNOWY RIVER CATCHMENT

STATION NAME	STATION NO.	YEARS OF OBTAINED RECORD	CORRELATION TO BOMBALA RIVER AT THE FALLS (R^2)
Bombala River at The Falls	222009	1951 – 1995	-
Bombala River at Bombala Town	222019	1995 – 2001	-
Coolumbooka River near Bombala	222012	1966 – 1982	0.96
Maclaughlin River at Dalgety Road	222001	1954 – 1977	0.65
Delegate River at Meads	222003	1941 – 1959	0.15
Little Plains River at Wellesley (Rowes)	222004	1941 – 1999	0.49
Eucumbene River at Providence No. 1	222005	1947 – 1955	0.40
Snowy River at Dalgety	222006	1949 – 1997	0.23
Wullwye Creek at Woolway	222007	1949 – 1999	0.35
Delegate River at Quidong	222008	1951 – 1999	0.43
Bobundara Creek at Dalgety Road	222010	1965 – 1982	0.50
Cambalong Creek at Gunning Grach	222011	1965 – 1982	0.80
Snowy River at Burnt Hut Crossing	222013	1975 – 1985	0.83
Delegate River at Delegate	222014	1975 – 1984	0.41
Jacobs River at Jacobs Ladder	222015	1975 – 1999	0.38
Pinch River at The Barry Way	222016	1975 – 1999	0.18
Maclaughlin River at The Hut	222017	1978 – 1999	0.50
Mowamba River @ Dalgety Road (Glenrock)	222506	1947 – 1966	0.05

Table 3 RELEVANT STREAMFLOW DATA AVAILABLE NEAR BOMBALA, IN ADJACENT NORTH-EASTERN AND EASTERN CATCHMENTS

STATION NAME	Station No.	Years of Obtained Record	Correlation to Bombala River at The Falls (r^2)
Tuross River at Tuross Vale	218001	1948 – 1999	0.66
Tuross River at Belowra	218002	1954 – 1984	0.54
Yowrie River at Yowrie	218003	1958 – 1984	0.57
Tuross River at Wattlegrove	218004	1959 – 1960	0.52
Tuross River D/S Wadbilliga River Junction	218005	1964 – 1999	0.74
Wandella Creek at Wandella	218006	1966 – 1985	0.74
Wadbilliga River at Wadbilliga	218007	1974 – 1999	0.71
Tuross River at Eurobodalla	218008	1977 – 1999	0.56
Rutherford Creek at Brown Mountain	219001	1924 – 1999	0.67
Bemboka River at Morans Crossing	219003	1943 – 1999	0.69
Tantawangalo Creek at Tantawangalo School	219004	1943 – 1974	0.64
Georges Creek at Steeple Flat (Cochrane Dam)	219005	1948 – 1953	0.99[1]
Tantawangalo Creek at Tantawangalo Mountain (Dam)	219006	1951 – 1999	0.68
Brogo River at Brogo	219007	1954 – 1959	0.81
Nunnock River at Brown Mountain (Dam Site)	219008	1954 – 1963	0.54
Yankeys Creek D/S Bega Swamps	219009	1954 – 1964	0.27
Bonar Creek at Brown Mountain (U/S Diversion Weir)	219010	1954 – 1974	0.14
Candelo Creek at Heffernans (Near Yurammie)	219011	1960 – 1962	0.31
Devils Creek Near Tantawangalo(Main Road Bridge)	219012	1969 – 1978	0.53
Brogo River at North Brogo	219013	1961 - 1999	0.71
Candelo Creek at Yurammie No.3	219014	1963 – 1978	0.67
Nutleys Creek near Bermagui	219015	1965 – 1989	0.51
Narira River at Cobargo	219016	1965 – 1999	0.73
Double Creek near Brogo	219017	1966 – 1999	0.54
Murrah River at Quaama	219018	1966 – 1999	0.73
Tantawangalo Creek at Kameruka	219019	1966 – 1978	0.78
Sandy Creek at Mogilla	219020	1966 – 1985	0.78
Bemboka River at Bemboka	219021	1966 – 1983	0.71
Tantawangalo Creek at Candelo Dam Site	219022	1971 – 1999	0.70
House Creek at Brogo North	219023	1972 – 1975	0.76[1]
Brogo River at Angledale	219025	1976 – 1999	0.57
Bega River at Warraguburra	219026	1977 – 1979	0.89[1]
Tantawangalo Creek at Tantawangalo	219028	1974 – 1978	0.93[1]

1. Insufficient number of values for a valid correlation

Table 4 RELEVANT STREAMFLOW DATA AVAILABLE NEAR BOMBALA, IN ADJACENT SOUTH-EASTERN AND NORTHERN CATCHMENTS

STATION NAME	STATION NO.	YEARS OF OBTAINED RECORD	CORRELATION TO BOMBALA RIVER AT THE FALLS (R^2)
Towamba River at New Buildings Bridge	220001	1954 – 1981	0.72
Stockyard Creek at Rocky Hall (Whitbys)	220002	1960 – 1985	0.57
Pambula River at Lochiel	220003	1966 – 1999	0.54
Towamba River at Towamba	220004	1970 – 1999	0.82
Merimbula Creek at Merimbula	220005	1979 – 1999	0.53
Merrica River at Nadgee Causeway	220006	1984 – 1999	0.31
Wallagaraugh River at Princes Highway	221002	1971 – 1999	0.56
Genoa River at Bondi	221003	1971 – 1989	0.78
Imlay Creek at Imlay Road Bridge	221010	1981 – 1999	0.35
Murrumbidgee River @ Mittagang Crossing	410033	1926 – 1999	0.40
Numeralla River @ Numeralla School	410062	1948 – 1954	0.75
Rock Flat Creek @ near Bunyan (Rosebrook)	410063	1948 – 1984	0.38
Cooma Creek @ Cooma No.1	410064	1948 – 1956	0.13
Big Badja River @ Numeralla (Goodwins)	410067	1951 – 1984	0.43
Kybeyan River @ Kybeyan	410075	1954 – 1985	0.63
Cooma Creek @ Cooma No.2 (The Grange)	410081	1957 – 1998	0.24
Numeralla River @ Montagu	410100	1968 – 1980	0.73
Numeralla River @ Numeralla Dam Site	410105	1971 – 1982	0.79

As shown in **Table 2**, **Table 3** and **Table 4**, the stations with the best (*and valid*) correlations to Bombala River at the Falls were the Coolumbooka River near Bombala (*222012*), Snowy River at Burnt Hut Crossing (*222013*), Towamba River at Towamba (*220004*), Brogo River at Brogo (*219007*), and Cambalong Creek at Gunning Grach (*222011*).

5.4 DATA VALIDITY

Data for this study was generally extracted from *Pinneena* (*Department of Land and Water Conservation, 1999*). Springall (*2001*) also provided instantaneous maximum monthly flows at Bombala River at Bombala Town for November 1995 to April 2001. The *Pinneena* data for this station ended in May 1999.

It was assumed that the discharges provided for this station and the other stations listed in **Section 5.3** had been determined from reliable rating curves for each gauge. As a check, flow "Quality Codes" were analysed in the data set, with those identified as the worst of the recorded level and rating table "Quality Codes" that generated the flows.

This investigation was limited, as the majority of the data had not been quality coded. The Bombala River at The Falls gauge generally had no quality codes for March 1966 to January 1989. Otherwise, the Bombala River at The Falls data was generally coded as of poor quality prior to 1966, and fair quality after 1989. The Bombala River at Bombala Town record was generally coded as good. Further discussion of quality codes for other gauges is given in **Section 5.5**.

For flood frequency analysis to be valid, catchment and meteorological conditions should not have significantly changed during the period of record. If conditions have changed, it cannot be considered that the data constitutes a random sample of independent values from a homogeneous population. Potential catchment changes include variations in land use (*for example vegetation clearing and agricultural development*), and construction of dams and other storages. Potential meteorological changes include climate change due to the greenhouse effect and changes in rainfalls with Pacific and Indian Ocean sea surface temperature anomalies (*El Nino*).

The Department of Water Resources (1987) claimed that there had been no significant changes to the catchment or Bombala River channel during the period of flood recordings, and therefore considered the record was homogeneous. This has also been assumed in this study.

Although there are major storages within the Snowy River catchment, such as Lake Eucumbene and Jindabyne Reservoir, these do not influence the flow at Bombala. The Bombala River and Coolumbooka River do not contain major storages or other flow regulating structures.

Climate change and sea surface temperature anomalies have implications on flood frequency analysis that are currently not fully understood. Kuczera (2001) has reported evidence that flood frequency distributions appear to change with climate state in NSW. Some distributions prior to 1945 are noticeably gentler than post 1945 distributions.

It has been suggested that this change in distributions is related to significant and lasting shifts in Pacific and Indian Ocean sea surface temperature anomalies between 1945 and 1950, which are probably associated with the higher rainfalls experienced in eastern Australia after 1945 (Kuczera, 2001). This observation, and the potential for altered rainfalls and storm patterns with greenhouse-induced climate change, challenges the fundamental assumption in flood frequency analysis that the flood risk does not change over time. At this stage it is noted in our study, but until further research is generated on this issue the assumption that we have a homogeneous flood data set remains.

5.5 EXTENSION AND FILLING OF BOMBALA RECORD

The Bombala record of instantaneous maximum monthly flows commenced in June 1951. Given the good correlation between Bombala and adjacent gauges with records that commenced prior to 1951, it is possible to validly extend the Bombala record. In the same manner, it is also possible to use the developed correlations to fill the gaps in the Bombala record.

Filling gaps in the Bombala River at the Falls monthly record data set (*refer* **Section 5.3**), by correlation to other stations was significant to the development of an annual series. This was because the monthly flow data used to correlate produced the highest flow for the annual series. This is strong evidence that the gaps occurred in large floods, perhaps due to equipment failure. A summary of the Stations used to extend and fill the Bombala record of instantaneous maximum monthly flows is given in **Table 5**.

Table 5 ADJACENT STATIONS USED TO EXTEND AND FILL THE BOMBALA FLOW RECORD

YEAR	STATION NAME	STATION NO.	BASIS
1924-1925	Rutherford Creek at Brown Mountain	219001	Fair r^2, only station available
1926-1947	Murrumbidgee River @ Mittagang Crossing	410033	Generally conservative
1948-1950	Numeralla River @ Numeralla School	410062	Best r^2; generally conservative
1959	Brogo River at Brogo	219007	Best r^2; most conservative
1973	Coolumbooka River near Bombala	222012	Outstanding r^2
1984	Snowy River at Burnt Hut Crossing	222013	Best r^2; most conservative
1995	Murrumbidgee River @ Mittagang Crossing	410033	Conservative

The decision to use the Murrumbidgee River @ Mittagang Crossing station to extend monthly data at Bombala between 1926 to 1947 record was based on a significant amount of analysis. Although the r^2 of this station's correlation to Bombala River at The Falls was poor, it was found that it generally produced the highest discharges for the annual series for this period, based on the 18 stations analysed. It was considered that conservatism rather than correlation was more important, with the Murrumbidgee River @ Mittagang Crossing station ultimately chosen since:

- the Bombala record suffered from poor quality data (*refer* **Section 5.4**);
- there were no other stations with substantially better correlations;
- the Murrumbidgee River @ Mittagang Crossing station had a complete data coverage from 1926 to 1999, of reasonable to good quality (*see below*);
- there was a physical basis to the correlation – higher flows at the Murrumbidgee River @ Mittagang Crossing station were generally reflected in higher flows at Bombala.

To obtain a single record for Bombala at the Bombala River at Bombala Town gauge, it was assumed that the flow at Bombala River at The Falls was identical to the flow at Bombala Town. This is a realistic assumption as the catchment areas at these two locations are within 1% (Department of Water Resources, 1987). It is also conservative as it more likely that the flows at The Falls would exceed those at Bombala Town, as the former is downstream.

The resulting record consisted of 925 monthly values, from May 1924 to April 2001.

Note that the "Quality Codes" of the data used to extend and fill the Bombala record were:

- undetermined for Rutherford Creek at Brown Mountain and Brogo River at Brogo;
- "fair" up to 1976, and "good" thereafter for Murrumbidgee River @ Mittagang Crossing;
- generally undetermined or "poor" to "fair" for Numeralla River @ Numeralla School ("good" from 1990);
- "fair" to "good" for Coolumbooka River near Bombala;
- generally "fair" for Snowy River at Burnt Hut Crossing.

5.6 ANNUAL SERIES

As stated in **Section 5.2**, it is possible to develop an annual series using either a calendar year or water year. At Bombala (*The Falls and Bombala Town combined from 1951-2001*), the month with the highest flood peak (*on average*) is June, with the minimum occurring in January. This is also the case considering the entire extended record from 1924 to 2001. The average monthly flows directly measured at Bombala and determined by correlation and extension are listed in **Table 6** and shown in **Figure 3**.

Table 6 AVERAGE MONTHLY FLOWS DIRECTLY MEASURED AT BOMBALA (1951-2001), AND FOR THE EXTENDED RECORD (1924-2001)

MONTH	AVERAGE MONTHLY FLOW (m^3/s)	
	1951-2001	1924-2001
January	9	35
February	52	53
March	73	71
April	43	55
May	86	71
June	135	120
July	104	106
August	56	90
September	36	57
October	68	74
November	69	66
December	35	38

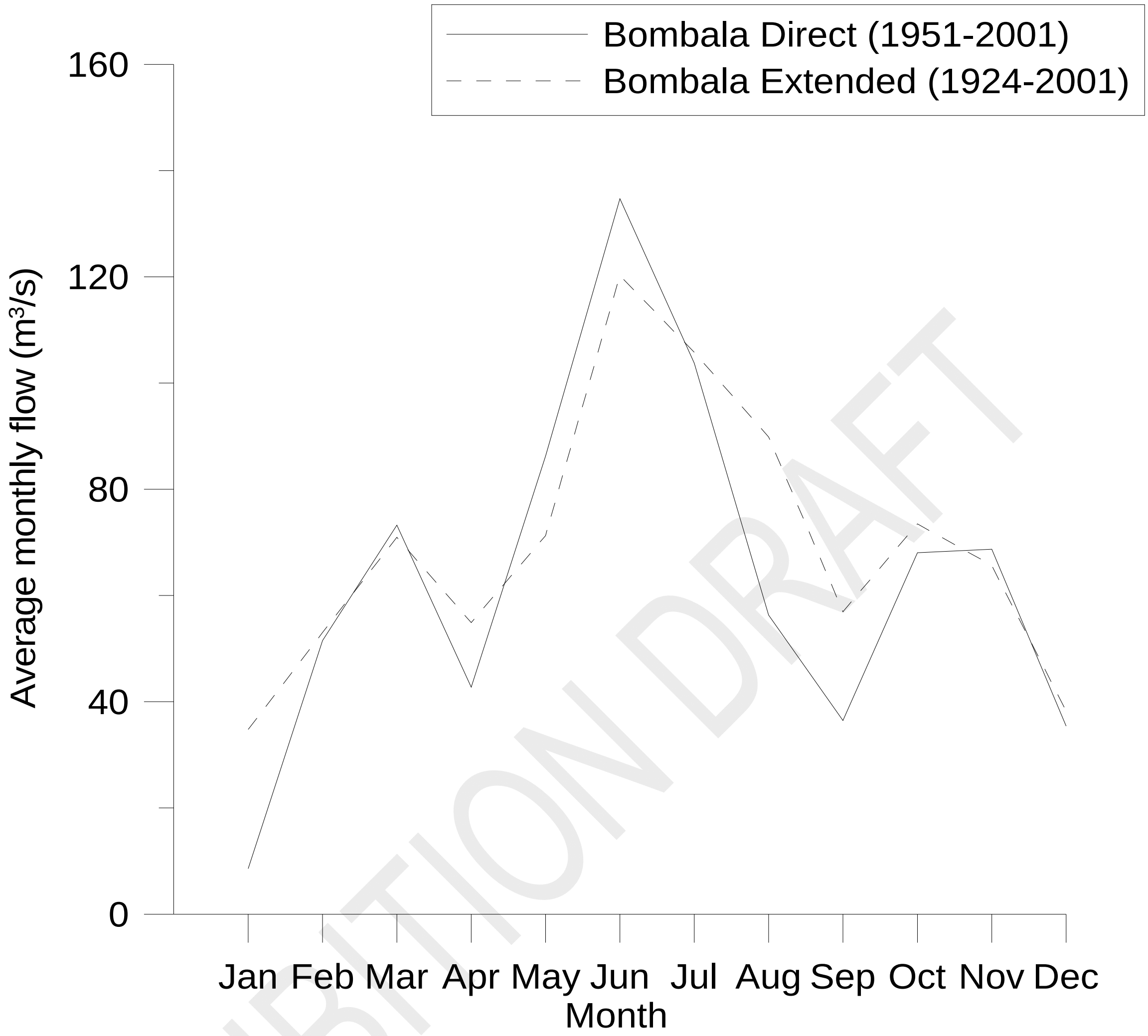


Figure 3 AVERAGE MONTHLY FLOWS DIRECTLY MEASURED AT BOMBALA (1951-2001), AND FOR THE EXTENDED RECORD (1924-2001)

Although average winter flows are generally higher and summer flows are generally lower, there is not a consistent pattern throughout the year. For example, March, August and November flows are relatively similar. The use of water year was therefore not attempted. However, it can be expected that the series developed using either a calendar or water year would be virtually identical.

In **Figure 3**, the average monthly flows for the direct record show the same general trends as the record extended by correlation. This provides further validity for the correlations adopted to fill and extend the data set.

The calendar year annual series, of 77 years duration, is shown in **Table 7**. The incomplete year of 2001 (*4 months*) was combined with the incomplete year of 1924 (*8 months*) as a complete year 1924 in the series. Incorporation of the 2001 monthly data into 1924 did not alter the annual series value for 1924. Note that the series is based on correlation with adjacent gauges for 1924 to 1950, 1959, 1973, 1984 and 1995 as described in **Section 5.5**.

Table 7 ANNUAL SERIES FOR BOMBALA RIVER AT BOMBALA TOWN, 1924-2000

YEAR	PEAK DISCHARGE (m^3/s)	RANK	YEAR	PEAK DISCHARGE (m^3/s)	RANK
1924	58	63	1963	610	18
1925	97	55	1964	553	20
1926	165	50	1965	10	73
1927	96	56	1966	486	26
1928	96	56	1967	290	38
1929	182	45	1968	3	77
1930	240	42	1969	393	31
1931	521	22	1970	537	21
1932	429	28	1971	1670	1
1933	150	52	1972	8	75
1934	1080	6	1973	406	30
1935	823	11	1974	726	15
1936	243	41	1975	867	9
1937	166	49	1976	625	17
1938	59	62	1977	25	67
1939	277	39	1978	1227	4
1940	140	53	1979	411	29
1941	135	54	1980	67	61
1942	521	23	1981	206	44
1943	179	46	1982	11	71
1944	90	59	1983	1239	3
1945	358	32	1984	323	35
1946	675	16	1985	819	12
1947	171	47	1986	10	74
1948	338	33	1987	20	70
1949	150	51	1988	764	14
1950	1130	5	1989	308	36
1951	276	40	1990	493	24
1952	1364	2	1991	928	7
1953	576	19	1992	292	37
1954	45	64	1993	25	69
1955	94	58	1994	10	72
1956	876	8	1995	170	48
1957	488	25	1996	27	66
1958	7	76	1997	478	27
1959	859	10	1998	88	60
1960	785	13	1999	25	68
1961	328	34	2000	29	65
1962	237	43			

The top 20 ranked annual floods are listed in **Table 8**. Again note that the ranked annual series is based on correlation with adjacent gauges for 1924 to 1950, 1959, 1973, 1984 and 1995 as described in **Section 5.5**.

Table 8 TOP 20 RANKED ANNUAL FLOODS AT BOMBALA, 1924-2000

RANK	YEAR	PEAK DISCHARGE (m^3/s)
1	1971	1670
2	1952	1364
3	1983	1239
4	1978	1227
5	1950	1130
6	1934	1080
7	1991	928
8	1956	876
9	1975	867
10	1959	859
11	1935	823
12	1985	819
13	1960	785
14	1988	764
15	1974	726
16	1946	675
17	1976	625
18	1963	610
19	1953	576
20	1964	553

It can be seen that the period from 1971 to 1978 had particularly significant flooding, with five of these eight years ranked in the top 20 floods. Furthermore, the (*February*) 1971 flood had the highest ranking, and was the highest actually recorded at the Bombala gauge.

Most the top 20 ranked floods were during the period of recording at Bombala (*1951-2000*). Only 4 annual floods in the top 20 were prior to 1951. This is further evidence of the post-1945 increase in rainfall in NSW as described in **Section 5.4**. It also indicates that the extension of the Bombala record is less critical in terms of the low (*rare*) end of the flood frequency distribution.

5.7 FLOOD FREQUENCY DISTRIBUTION (BASED ON ARR98)

In flood frequency analysis, discharges in the series are plotted on a frequency diagram. This has discharge as the ordinate (*linear or log scale*), plotted against AEP or ARI as the abscissa (*probability scale*). For the abscissa (*x axis*), Normal, Exponential or Gumbel (*Extreme Value Type I*) probability scales are most commonly used, corresponding to the commercially available graph papers of these types. The type of plot chosen is generally a convenience, and also allows the presentation of data in such a way that deviations from the distribution assumed by the axes can be judged.

Each discharge in the annual series was given a "plotting position" (*PP*), that is, an AEP for plotting purposes, using the recommended formula in ARR98, namely:

$$PP = \frac{m - 0.4}{N + 0.2}$$

where *m* is the rank in the flood series (*the highest flood in the series having rank m = 1, refer* **Table 7**) and *N* is the number of years of record (*in this case 77 years*). Note that the plotting position is <u>not</u> an estimate of the AEP of a particular plotted discharge; the AEP is derived from the fitted distribution (*see below*). The plotting position is only useful for graphical presentation.

ARR98 (*non-prescriptively*) recommends fitting a log Pearson III distribution for an annual series. The methodology presented in ARR98 is based on the method of moments, preserving the moments of the logarithms of flows. The log Pearson III distribution fitted to the annual series presented in **Table 7** and plotted on log normal probability scales is given in **Figure 4A**.

Note that the observed data was tested for outliers, which are values that depart significantly from the trend of the remaining data. According to the tests given in ARR98, neither high nor low outliers were present.

Confidence limits are also shown in **Figure 4A**. Confidence intervals give the range within which the actual population is expected to lie with a selected level of probability. Confidence limits enclose the confidence interval (*see ARR98*). The wider a confidence interval is, the more confident we can be that the given interval contains the unknown parameter. The 95% and 5% confidence limits are given in **Figure 4A**, enclosing a 90% confidence interval. That is, there is a 90% probability that the true (*not observed*) discharge lies within the confidence limits shown.

Adjustment for expected probability was also attempted as per ARR98, with the expected probability curve shown in **Figure 4A**. In terms of exceedance probabilities, expected probability is defined as the average of the true exceedance probabilities of an infinite number of magnitudes that might be determined in the same manner from random samples of the same size derived from the same parent population (*ARR98*). The adjustment for expected probability can be carried out for each sample frequency by increasing the AEP of each discharge (*usually resulting in a shift to the left if higher frequencies are plotted nearer to the origin*), or by increasing the discharge at each AEP. In either case the effect is to move the sample frequency curve upwards, giving more conservative estimates.

ARR98 recommends consideration of the use of expected probability in a number of situations, including where:

- risk or frequency of exceedance is of primary importance, and it is desired that the actual frequency of exceedance will equal the design frequency,
- design for sites where underestimated frequency of surcharging carries large penalties, such as would occur with overtopping of a levee.

These aspects are indeed applicable here and it was thus recommended that expected probability estimates are used to determine design floods for this study. This is further supported by Kuczera (*1999*), who recommends the use of expected probability even more strongly than ARR98, stating that "in flood frequency applications where the design flood is required to have a specified exceedance probability, expected probability should be used".

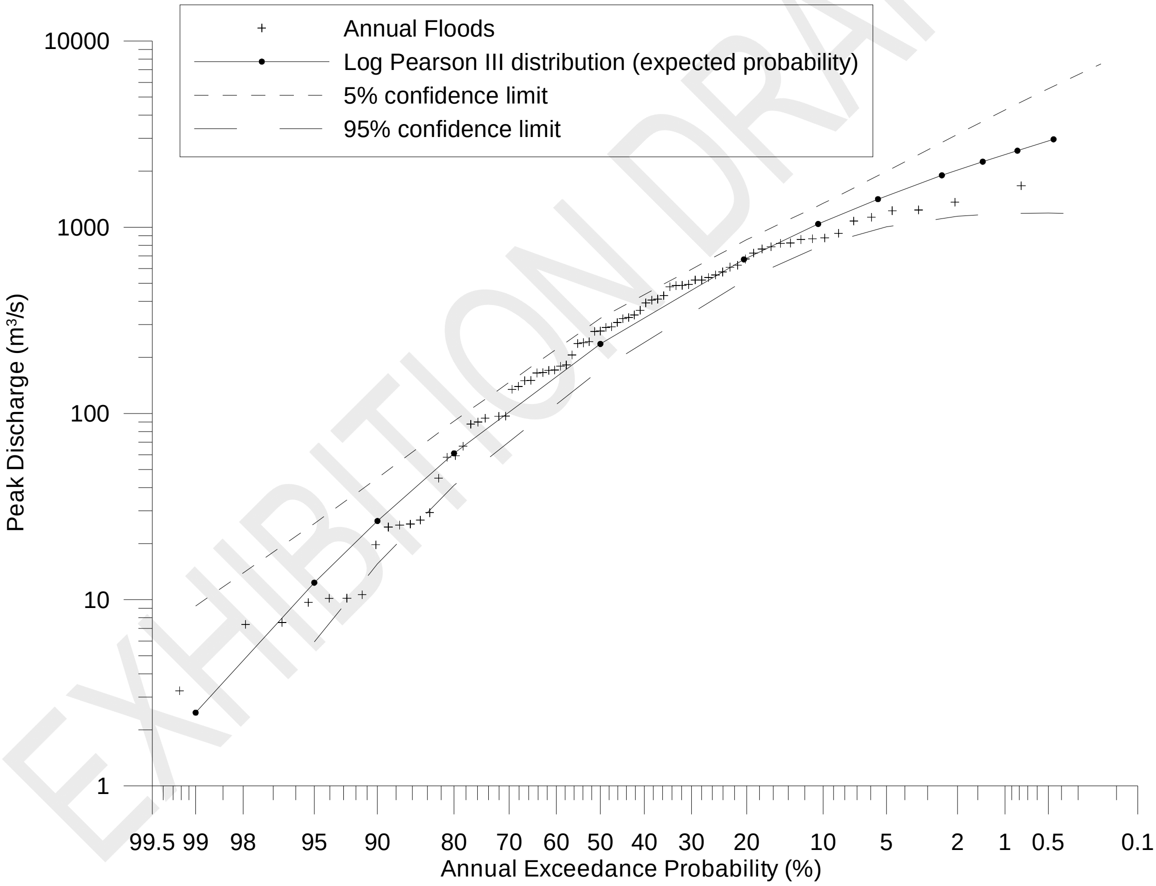


Figure 4A: Log Pearson III frequency distribution for Bombala, based on ARR98

It can be seen that the fitted Log Pearson III distribution generally fits the recorded annual floods reasonably, although it must be understood that it is not a regression relationship. The observed floods also generally lie within the 90% confidence interval of the fitted distribution. In the region of particular interest, between the 20% and 1% AEP, the fit was higher than the recorded annual floods, and therefore conservative.

Note that ARR98 recommends avoiding large extrapolations in flood frequency analysis. For important work, ARR suggests the largest flood that should be estimated is the 1% AEP flood, with a maximum limit under any circumstances of the 0.2% AEP.

5.8 ALTERNATIVE FLOOD FREQUENCY DISTRIBUTIONS

Major modifications to the ARR98 flood frequency procedures have been proposed. The revision team for this section (*Book IV, Section 2*) is headed by George Kuczera (*Department of Civil, Surveying and Environmental Engineering, University of Newcastle*) and QJ Wang (*Institute of Sustainable Agriculture, Department of Natural Resources and Environment, Victoria*).

The procedures have not been formalised, and are unlikely to be published before 2005. However, techniques are available to allow assessment of some of the proposed methods.

The proposals include more emphasis on the range of available probability distributions, such as the generalised extreme value (*GEV*) probability distribution. In addition, the proposed changes involve replacement of log moments (*which are biased and can overestimate the importance of small discharges*) with L and LH moments. There are various methods, both numerical and graphical, for estimating the parameters of a probability distribution, that is, to fit a distribution to data. Numerical techniques include the method of moments, maximum likelihood estimation (*MLE*), and least squares. L and LH (*probability-weighted*) moments are linear combinations of ranked observations.

The L and LH moments approach is proposed for use with gauged data only. It is alternatively proposed to apply Monte Carlo Bayesian methods in cases involving combinations of gauged and historic (*censored*) data, where expected probability floods are required, and where rating curve errors need to be allowed for. Bayesian inference (Gelman et al, 1995) works for any probability model. The Bayesian approach infers a posterior distribution which is a probability distribution that describes what is known about the true parameters given the data and the assumed model. The posterior quantifies parameter uncertainty explicitly.

George Kuczera has developed the FLIKE software package which can be used to apply the new Bayesian procedures. A number of distributions can be fitted using the package, including the Generalised Extreme Value (GEV), Generalised Pareto, Gumbel (*Extreme Value Type I*), two parameter log-normal and log Pearson III.

The FLIKE procedures were tested on the 1924-2000 annual series of floods at Bombala. The log-Pearson III and Generalised Pareto expected probability distributions provided the best fits to the data, as shown in **Figure 4B**. These distributions are given along with the results presented in **Figure 4A** using the ARR98 method.

Both of the fitted distributions matched the recorded annual floods well, and are similar over the mid-range of probabilities (*AEP's between 50% and 10%*). Differences for frequent events (*over 90% AEP*) are of no consequence. For AEP's less (*rarer*) than 10%, the log-Pearson III more closely matched the recorded floods, with the Generalised Pareto predicting the largest discharges. The Generalised Pareto discharges also increased relatively more rapidly at the tail (*rare events*).

For the log-Pearson III distribution, it can be seen that the distribution predicted by FLIKE (*Bayesian method*) is an improvement, in terms of being closer to the recorded floods for rare events, on the ARR98 method in this case. The FLIKE values are less conservative than ARR98 for rarer floods, but still sit above the recorded values.

The FLIKE log-Pearson III distribution was adopted for use in this study. This was chosen as it provided the best match to the recorded floods and was a more modern approach than ARR98. It was considered that use of the Generalised Pareto distribution would be overly conservative for this study. However, given the inherent risks in extrapolating beyond the 1% AEP, the use of the Generalised Pareto distribution could be considered for other investigations. The adopted design floods are listed in the following Section.

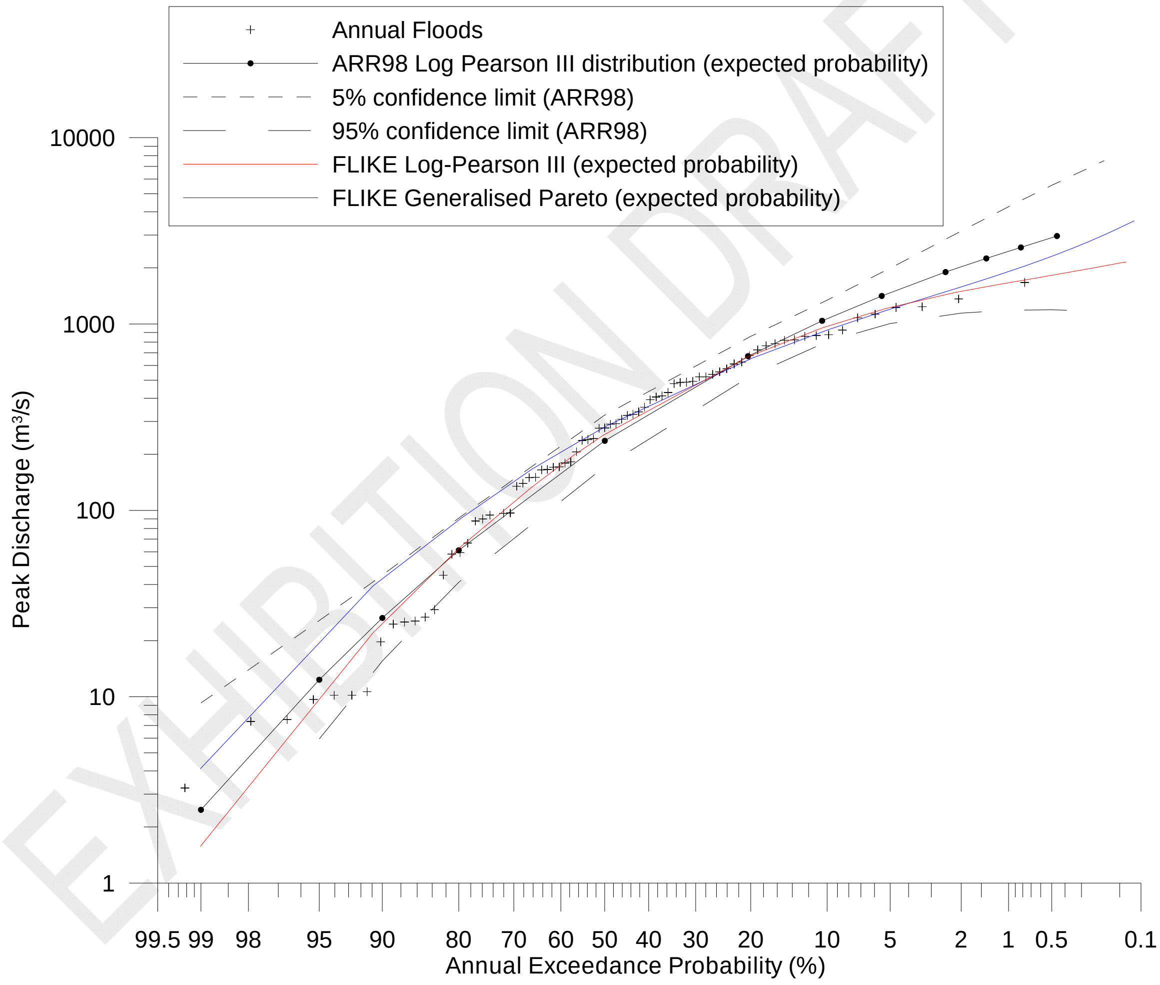


Figure 4B: Log Pearson III and Generalised Pareto distributions for Bombala, based on FLIKE

5.9 ADOPTED DESIGN FLOODS

Based on the log-Pearson III expected probability distribution, derived using the FLIKE flood frequency analysis package (see **Figure 4B**), the design floods adopted for the 20, 10, 5, 2, 1, 0.5 and 0.2% AEP's are listed in **Table 9**.

Table 9 ESTIMATED DESIGN PEAK FLOOD DISCHARGES AT BOMBALA

AEP (%)	ARI (years)	DESIGN PEAK DISCHARGE (m^3/s)
20	5	680
10	10	970
5	20	1230
2	50	1500
1	100	1670
0.5	200	1830
0.2	500	2050

As stated in **Section 5.7**, note that ARR98 recommends avoiding large extrapolations in flood frequency analysis. For important work, ARR suggests the largest flood that should be estimated is the 1% AEP flood, with a maximum limit under any circumstances of the 0.2% AEP.

Based on the adopted distribution, the 1971 flood at Bombala has an AEP of approximately 1% (*1 in 100 years*).

5.10 COMPARISON OF ADOPTED FLOODS WITH PREVIOUS ESTIMATES

The Department of Water Resources (1987) attempted a flood frequency analysis at Bombala. This was based on 35 years of direct records, from 1951 to 1985, at Bombala River at The Falls. The record was also derived from a correlation to the Little Plains River at Wellesley (*Rowes*) station, which extended the record back to 1941. Overall, the annual series was thus developed using 45 years of record from 1941 to 1985.

Based on the correlations developed in this study (*refer* **Section 5.5**), the use of the Little Plains River at Wellesley (*Rowes*) station is difficult to justify. This is because in the correlation with Bombala River at The Falls it had an r^2 value of only 0.49, and also commencement of recording at the station was later than other stations with more appropriate records.

Unfortunately the Department of Water Resources (*1987*) flood frequency analysis was based on water levels (*stages*), rather than discharges. As stated in **Section 5.1**, flood frequency analysis generally should not be applied to peak water levels, as the water level distribution can include discontinuities (*eg as floodwaters go overbank, a small increase in discharge can cause negligible increases in water level*), and the stage-discharge relationship can vary with time.

The reasons given for use of levels were twofold. Firstly, it was to allow inclusion of historical flood levels (*presumably unrated*), recorded prior to 1941, in the analysis. Secondly, it was to avoid rating curve inaccuracies at the Bombala River at The Falls gauge, at which it has been postulated that the rating underestimates discharges in the high flow range.

The recorded and extended data at Bombala River at The Falls, which is 4km downstream of Bombala, was transferred to the Bombala town bridge site using a graphical correlation between levels at the two sites, based on flood levels observed during large floods, probably in 1971 and 1983 (*no further details were given*). The Bombala town bridge site is presumably at the location of the current Bombala River at Bombala Town gauge, which is on the upstream side of the bridge. Discharges at The Falls and Bombala Town were assumed to be the same given that catchment areas only differed by 1%.

The flood frequency analysis was based on the combination of the annual series from 1941 to 1985 already described, as well as a partial series analysis from 1870 to 1985. The partial series allowed the inclusion of flood levels recorded prior to 1941 as discussed above. Four floods were included prior to 1941, in 1871, 1873, 1919 and 1934. The partial series was based on the 8 levels recorded at or above 8.56m on the gauge (*701.36m AHD*) at Bombala bridge, which included the four floods described prior to 1941, and floods in 1952, 1971, 1978 and 1983. Note that the annual series had the four floods that were included in the partial series removed.

To combine the partial series and annual series frequency distributions into a contiguous 116 year flood frequency distribution from 1870 to 1985, the ranking of the flood events was modified using the procedure of Benson (1950).

The Department of Water Resources (1987) did not fit a probability distribution to the historical floods, but a third degree polynomial equation. The resulting estimated flood elevations are given in **Table 10**.

Table 10 FLOOD LEVEL PROBABILITIES ADOPTED BY THE DEPARTMENT OF WATER RESOURCES (1987) AT BOMBALA

AEP (%)	ARI (years)	DESIGN FLOOD PEAK ELEVATION (m AHD)
10	10	700.6
5	20	701.8
2	50	702.7
1	100	703.0

The peak discharge for these design flood events were determined by the Department of Water Resources (1987) by applying the statistical flood levels to the rating curve adopted at the town bridge gauge.

This required extrapolation of the rating curve to determine the discharges for large events such as the 1971 flood. The slope-area method was used to estimate discharges at large water levels. This uses measured water levels along a stream to determine water surface slope. At a particular cross section (*with the area and hydraulic radius known for a given water level*), assuming a particular roughness, the discharge can then be determined from Manning's or Chezy's equation. However, the discharges were not reported. The estimated discharges, based on the rating curve used by the Department of Water Resources (*1987*), are given in **Table 11**, compared to the values adopted in this study.

Table 11 COMPARISON OF FLOOD FREQUENCY ANALYSES AT BOMBALA

AEP (%)	DESIGN PEAK DISCHARGE (m^3/s)	
	Bombala Flood Study (2010)	Department Of Water Resources (1987)
20	680	
10	970	930
5	1230	1170
2	1500	1300
1	1670	1350
0.5	1830	
0.2	2050	

The values adopted in this study are considered to be more reliable, and are also more conservative.

6 HYDROLOGIC MODEL

6.1 HYDROLOGIC MODEL DEVELOPMENT

The Runoff Analysis and Flow Training Simulation (*RAFTS-XP*) software package was employed to quantify flood discharges from the Bombala River catchment. The overall catchment draining to the Bombala River is shown in **Figure 5**. RAFTS-XP is a deterministic runoff routing model that simulates catchment runoff processes. It is recognised in *'Australian Rainfall and Runoff – A Guideline to Flood Estimation' (1987)*, as one of the available tools for use in flood routing within Australian catchments.

RAFTS-XP was chosen for this investigation because it has the following attributes:

- it can account for spatial and temporal variations in storm rainfalls across a catchment;
- it can accommodate variations in catchment characteristics;
- it can be used to estimate discharge hydrographs at any location within a catchment; and,
- it has been widely used across eastern NSW and therefore, where suitable calibration data is not available, the results from modelling of other similar catchments can be used as a guide in the determination of model parameters.

The RAFTS-XP model was developed using the physical characteristics of the catchment including catchment area, slope, percentage impervious area and vegetation. It was used to estimate sub-catchment runoff peaks and to generate discharge hydrographs for tributary inflows to the Bombala River at Bombala. These tributary inflows form the upstream boundary conditions for the proposed hydraulic model.

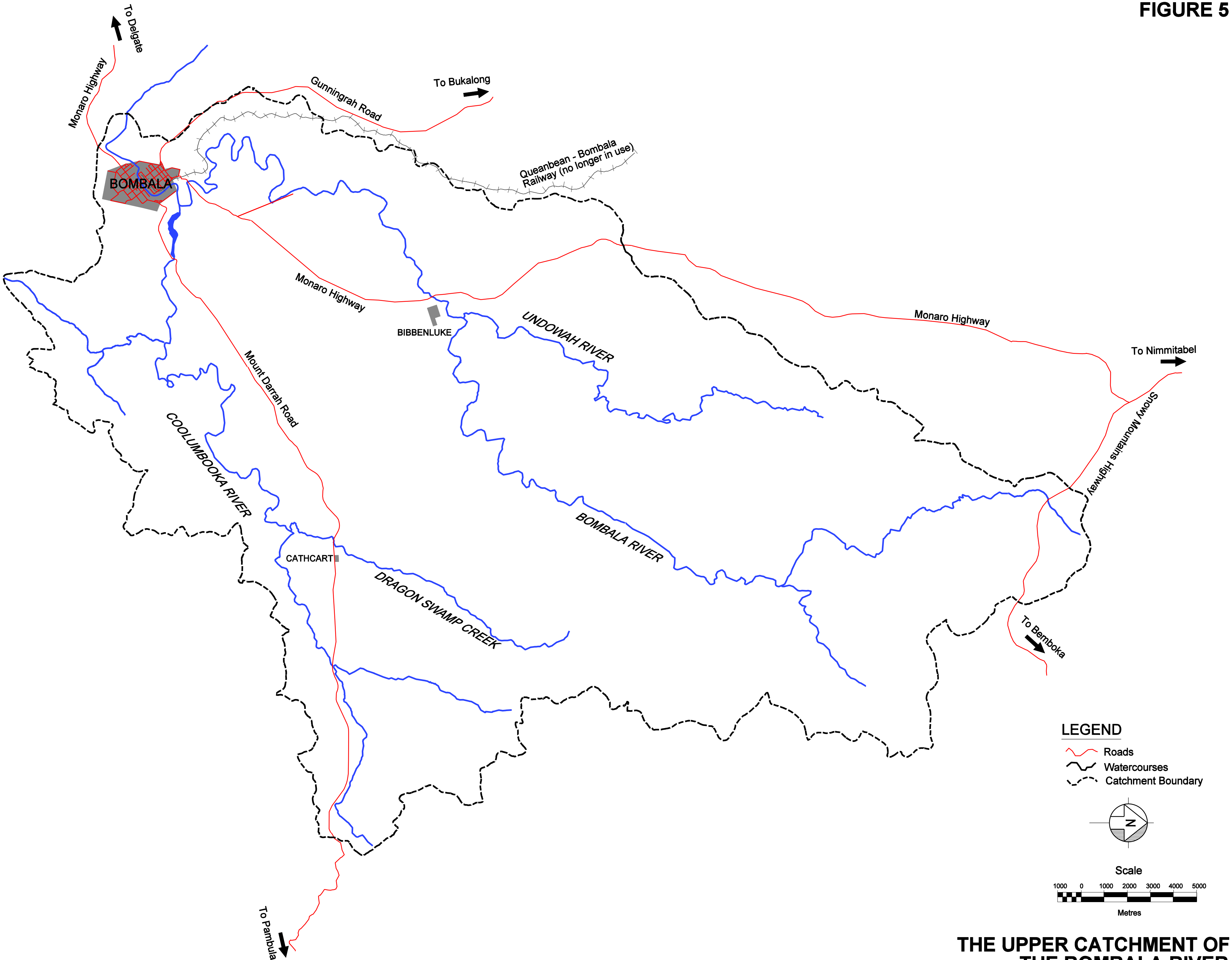
6.1.1 Sub-catchment Details

The Bombala and Coolumbooka River catchments were divided into sub-catchments differentiated on the basis of the alignment of major tributary flow paths and watershed boundaries, as well as the homogeneity of land-use, vegetation, and ground slope. Parameters such as catchment area, slope, and percentage impervious area were established from the available data and assigned to each sub-catchment. Catchment break-up was also designed so that the downstream points of sub-catchments draining to the lower potion of the catchment coincided with the likely location of inflow points for the proposed hydraulic model.

The adopted catchment break-up and model layout is shown in **Figure 6**.

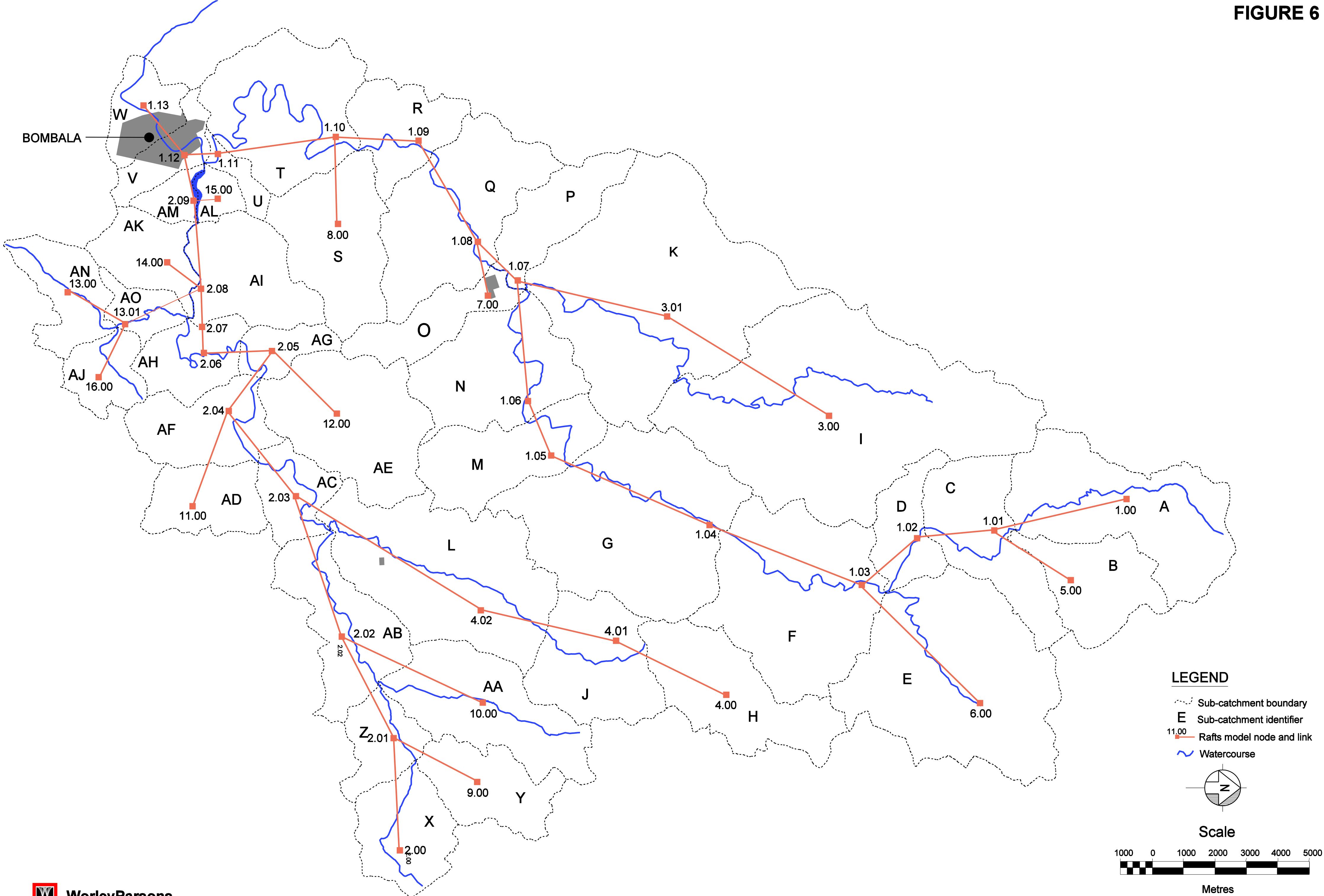
The RAFTS model was set-up using a range of characteristic catchment parameters including sub-catchment area, vectored average slope, roughness, and initial and continuing rainfall losses. A summary of adopted sub-catchment parameters is provided in **Appendix A**.

FIGURE 5



THE UPPER CATCHMENT OF THE BOMBALA RIVER

FIGURE 6



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RAFTS HYDROLOGIC MODEL LAYOUT

6.1.2 Rainfall Loss Model

In a typical storm event, not all of the rainfall that falls onto the catchment is converted to runoff. Depending on the prevailing “wetness conditions” of the catchment at the commencement of the storm (*ie., antecedent wetness conditions*), some of the rainfall may be lost to the groundwater system through infiltration into the soil, or may be intercepted by vegetation and stored. This component of the overall rainfall is considered to be “lost” from the system and does not contribute to the estimated catchment runoff.

To account for rainfall losses of this nature, a rainfall loss model can be included within the RAFTS-XP model. For this study, the *Initial-Continuing Loss Model* was used to simulate rainfall losses across the catchment. This model assumes that a specified amount of rainfall (*eg., 10 mm*) is lost from the system in the initial stages of the storm being considered (*initial loss)*, and that further losses occur at a specified rate per hour (*eg., 5 mm/hr*). These further losses are referred to as continuing losses which aim to account for infiltration and interception by vegetation once the catchment is saturated. These rainfall losses are effectively deducted from the total rainfall over the catchment, thereby leaving the remaining rainfall to be distributed through the watershed as runoff.

As no definitive loss rate data is available for the Bombala River catchment, rainfall loss rates used in the modelling were based on recommendations outlined in the RAFTS User Manual and documented in ‘*Australian Rainfall and Runoff*’ (*1987*). Sensitivity analyses were also undertaken to ensure that the adopted values provided reliable estimates of peak flood discharges.

6.1.3 Adopted Model Structure

The RAFTS model was developed using the catchment subdivision identified from consideration of the Conceptual Model of Hydrologic Processes. The adopted model structure is represented by the nodal-link arrangement shown in **Figure 6**. As discussed, a summary of the adopted sub-catchment and model link parameters is provided in **Appendix A**.

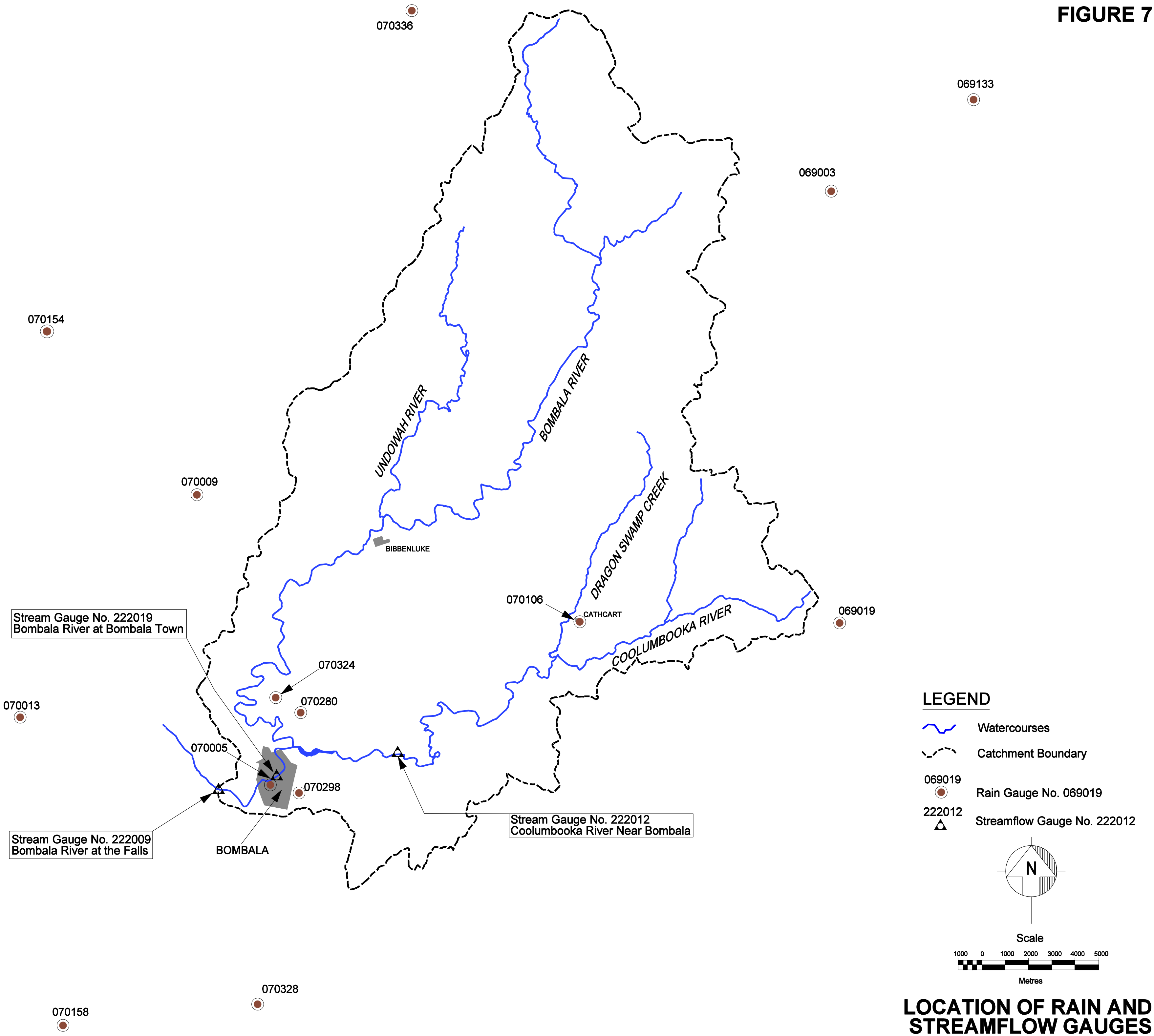
6.2 MODEL CALIBRATION

Flood routing models such as RAFTS should be calibrated and verified using rainfall and streamflow data from specific flood events. Rainfall records from a major storm that caused flooding, are input into the model to reflect the variability of rainfall over the catchment through the course of the storm.

For model calibration, the rainfall excess is routed through the model and discharge hydrographs are determined at locations where streamflow records for the flood corresponding to the storm, have been gathered. Calibration is completed by modifying model parameters to achieve the best match between recorded and model generated discharge hydrographs.

The location of streamflow and rain gauges located within the Bombala River catchment is shown in **Figure 7**. **Figure 7** also includes a number of rain gauges located adjacent to the extent of the Bombala River catchment.

FIGURE 7



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LOCATION OF RAIN AND STREAMFLOW GAUGES

Accordingly the model was calibrated to the storm event that occurred on the 6th of February 1971. As outlined in Section 5, the 1971 flood event corresponded approximately to a 100 year ARI flood event. This flood caused significant damage with floodwaters entering at least 16 houses and 6 businesses within the Bombala township.

The calibration of the RAFTS model was verified by referring to the flood event that occurred on the 3rd of June 1978. Rainfall data from the 1978 event, which corresponds approximately to a 20 year flood event, was placed in the RAFTS model. The model was re-run and the discharge hydrographs generated were compared to those obtained from the Bombala and Coolumbooka River gauging stations

6.2.1 Rainfall Data

Continuous rainfall data for specific storms is required for the calibration and verification of hydrologic computer models. As discussed in **Section 3.4.3**, there are no pluviometers located within the Bombala River catchment, nor are there any in nearby catchments. Proper calibration of hydrologic models without pluviograph records is generally fraught with difficulties and inaccuracies. This is because the variation in rainfall intensity over the duration of the storm event and catchment needs to be estimated.

However, depending on the duration of the historical storm event, it is possible to use daily read rainfall (*ie., the amount of rainfall falling over a 24 hour period*), to carry out a "pseudo" calibration of the hydrologic model. The distribution of the total rainfall over each time period (*e.g every hour*) can then be estimated based on standard storm durations and temporal patterns outlined in *'Australian Rainfall and Runoff'* (*1987*).

Around 250mm of rainfall was recorded at Rain Gauge No. 07005 (*refer* **Figure 7**), located in the Lower Bombala catchment over a 24 hour period for the 6th February 1971 storm. During the same period, a total of 378mm was recorded at Rain Gauge No. 070106, which is located in the Coolumbooka catchment. A comparatively large 192mm of rainfall fell on the nearby Bemboka catchment. A significant amount of rainfall was recorded in the previous 24 hours on each catchment.

It is noted that the 24 hour rainfall volume suggests the event was <u>slightly rarer</u> than the 100 year ARI rainfall storm , when compared to IFD data provided in **Appendix B**.

Around 84mm of rainfall fell on the Lower Bombala catchment over a 24 hour period during the storm that occurred on the 3rd of June 1978. A total of 129mm fell on the Coolumbooka catchment during the same period. Significant rainfall also fell on each catchment before and after the main rainfall events.

Recorded rainfall at the above gauges for the month of the 1971 and 1978 storm events is provided at **Appendix C**.

6.2.2 Streamflow Records

Streamflow data is generated from rating curves for gauging stations that are usually located along streams and rivers. A time series record of flood level over the duration of the flood is generated at the gauging station and the corresponding rating table is used to generate a discharge hydrograph. The discharge hydrograph provides a measure of the rate of flow at any particular time during the flood.

As discussed in **Section 3.4.3**, streamflow gauges are located on the Coolumbooka River, and Bombala River. Discharge hydrographs are available for both gauging stations for the 1971 and 1978 storm events.

The 1971 flood event provided a peak discharge of 1,670 m^3/s at 1:30am on the 6th of February on the Bombala River. The peak discharge at the Coolumbooka River gauge of 723 m^3/s occurred at 11:00pm on the 5th of February 1971.

The 1978 flood event provided a peak discharge of 1,227 m^3/s at 12:10pm on the 3rd of June on the Bombala River. The peak discharge at the Coolumbooka River gauge of 723 m^3/s occurred at 11:00am on the 3rd of June 1978.

6.2.3 1971 Flood Simulation

Once the RAFTS hydrologic model was established, calibration was attempted using rainfall and discharge hydrograph data from the 1971 storm event. Historical daily read rainfall data, supplied from the Monaro Division of the State Forests of New South Wales, was placed in the RAFTS model. The discharge hydrographs generated by RAFTS were then compared with the historical discharge hydrographs from the Bombala and Coolumbooka River gauging stations.

It is our understanding that there have been no rainfall-runoff models developed for the Bombala River catchment. Therefore, initial loss rates were applied from anecdotal reports of catchment wetness. Continuing loss rates were then adjusted to replicate the historical discharge hydrographs obtained from the gauging stations, while keeping in mind the topography and vegetation distribution throughout the catchment. For example, catchments with a high vegetation density would tend to intercept more runoff and would therefore have a larger loss rate.

While a close correlation between hydrographs is desired, an exact agreement cannot be expected nor justified. This is due to several parameters within the RAFTS model being estimated. An emphasis was placed on obtaining similar peak discharges at the same time. An attempt was also made at calibrating the model so that it delivered approximately the same volumes of water (*represented by the area under the hydrograph*) during the historical storm event.

If the peak discharges occur at a similar time this will indicate the lag times and estimated storm duration are accurate. If the area under each discharge hydrograph are similar this will indicate that the loss rates are accurate as a similar amount of runoff is being generated by the hydrologic model.

As there is no indication as to the duration of the 1971 storm, several storm durations were trialled. It was found that a 48 hour storm duration and design temporal pattern provided the "best fit" to the historical discharge hydrographs.

Link lag times were determined based on assuming an average velocity of 2.5m/s in accordance with mean values determined by Department of Water Resources (*1987*) for the 1978 flood event. It was assumed that the majority of the catchment was pervious. An impervious area of 5% of the catchment area was provided to account for impervious areas such as rocks, roads and concrete.

The results of the calibration for the 1971 storm event are presented in **Figure 8**. Three different rainfall intensities were distributed over the catchment; one for the upper Bombala catchment, one for the lower Bombala catchment and one for the Coolumbooka catchment. An initial loss of 10mm was applied to all sub-catchments as similar amounts of rainfall had fallen on each prior to the commencement of the major storm event. A continuing loss rate of 5mm/hour was found to provide reasonable results when applied to the lower Bombala catchment.

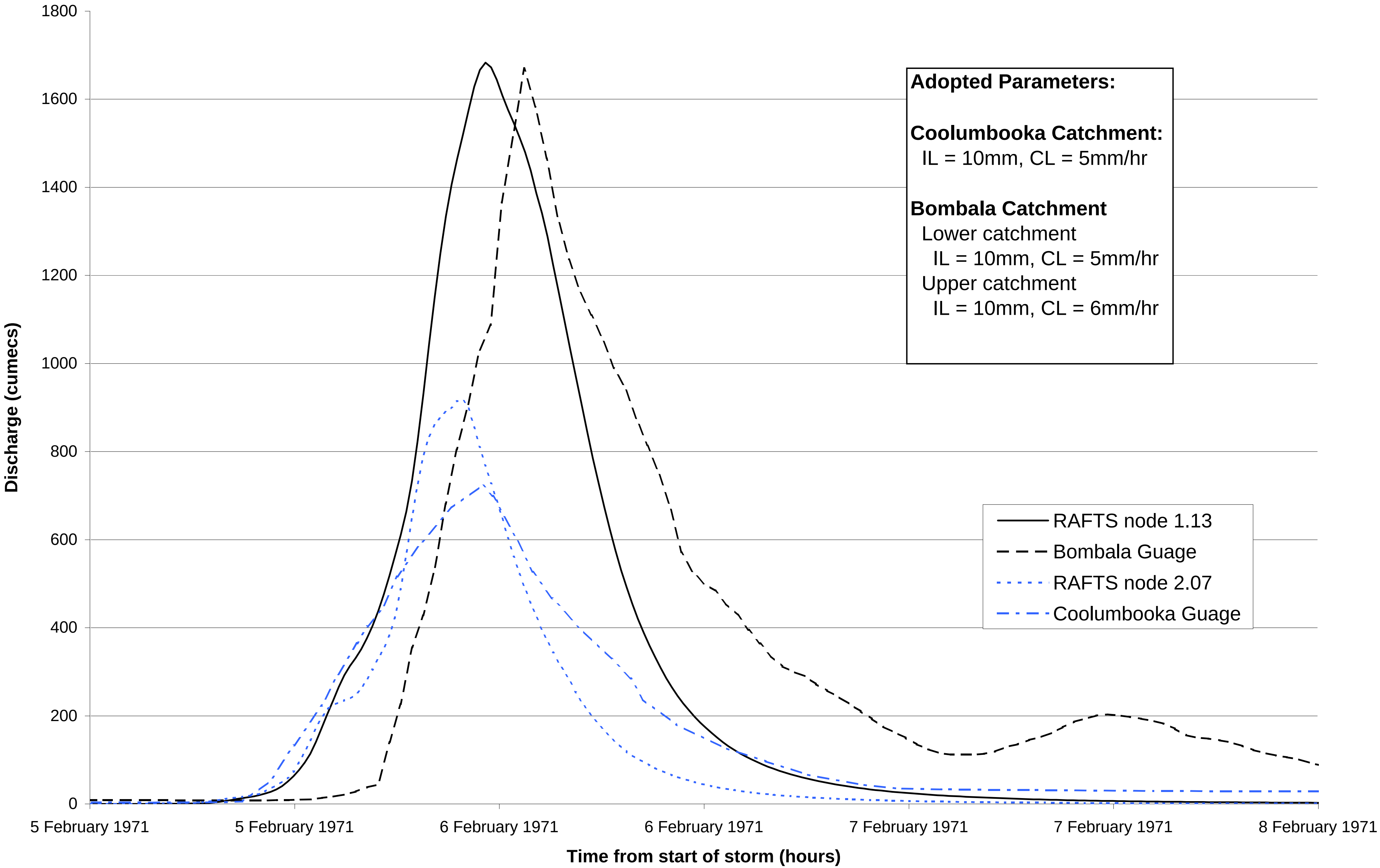
A slightly higher loss rate of 6mm/hour was applied to the upper Bombala and Coolumbooka catchments due to the higher vegetation density. These loss rates are within acceptable bounds provided in the RAFTS User Manual and documented in *'Australian Rainfall and Runoff'* (*1987*). The adopted initial and continuing loss rates are summarised in **Table 12**.

Table 12 ADOPTED LOSS RATES FOR RAFTS HYDROLOGIC MODEL

CATCHMENT	LOSS RATES	
	INITIAL LOSS (mm)	CONTINUING LOSS (mm/hour)
Upper Bombala	10	6
Lower Bombala	10	5
Coolumbooka	10	6

With reference to **Figure 8**, the RAFTS model has provided a peak discharge of 1,682 m^3/s which compares favourably with the historical peak discharge of 1,670 m^3/s on the Bombala River. The RAFTS model, however, has produced a higher peak discharge of 915 m^3/s on the Coolumbooka River which is significantly higher than the historical discharge of 723 m^3/s.

The discharge hydrograph generated by RAFTS for the Bombala River provides a similar shape and volume to that of the historical hydrograph, although the peak discharge is slightly delayed. It is believed that this is a result of the storm duration adopted. A slightly better fit could be provided by adopting a storm duration slightly less than 48 hours, however there are no standard storm durations or temporal patterns that fit this criteria.



CALIBRATION OF RAFTS MODEL TO 1971 FLOOD

Although the peak discharge and hydrograph shape generated by RAFTS for the Coolumbooka catchment differ from that of the historical hydrograph, the area under each hydrograph is similar indicating the loss rates are appropriate. The difference in discharges and hydrographs could again be attributed to different storm durations. The difference could also be attributed to a "backwater effect" from the Coolumbooka Weir.

6.2.4 1978 Flood Simulation

After a reasonable agreement was obtained from the RAFTS model for the 1971 flood event, the model was verified by comparing results for the 1978 flood event. The 1978 flood event approximately corresponds to a 20 year recurrence flood event.

Exactly the same catchment parameters and loss rates that were adopted for the 1971 simulation were applied for the 1978 event. Only the rainfall distribution was varied in accordance with daily read rainfall data for the 1978 event supplied by the Monaro Division of the State Forests of New South Wales. This rainfall data is presented in **Appendix C**.

Due to the fact no pluviographs are located within or adjacent to the Bombala River catchment, the storm duration and variation in rainfall intensity over the storm duration needed to be estimated. Again it was found that a 48 hour standard storm duration and temporal pattern provided the most accurate fit to historical discharge hydrographs.

The discharge hydrographs generated by RAFTS for the 1978 flood event are provided in **Figure 9**. The historical discharge hydrographs for the Bombala and Coolumbooka River are also superimposed.
It should be noted that although the historical hydrographs consist of dual peaks, the RAFTS model was only compared to the second, larger peak when establishing the storm durations.

With reference to **Figure 9**, the RAFTS model produces a peak discharge of 1,115 m^3/s which is slightly less than the peak historical discharge of 1,227m^3/s. The RAFTS model also produces a smaller discharge of 370m^3/s for the Coolumbooka catchment. This compares to the historical peak discharge of 479 m^3/s.

The general shapes of the hydrographs generated by RAFTS compare favourably to the historical hydrographs, although RAFTS generates a smaller volume of runoff for both the Bombala and Coolumbooka catchments. The differences could be attributed to a non-standard storm duration and temporal pattern applying. There could also be a difference in the loss rates associated with slight changes to the catchment between 1971 and 1978.

To assess the likely impact of variation in catchment loss rates on hydrologic results, a sensitivity analysis was performed. The sensitivity analysis is presented in the following section.

FIGURE 9

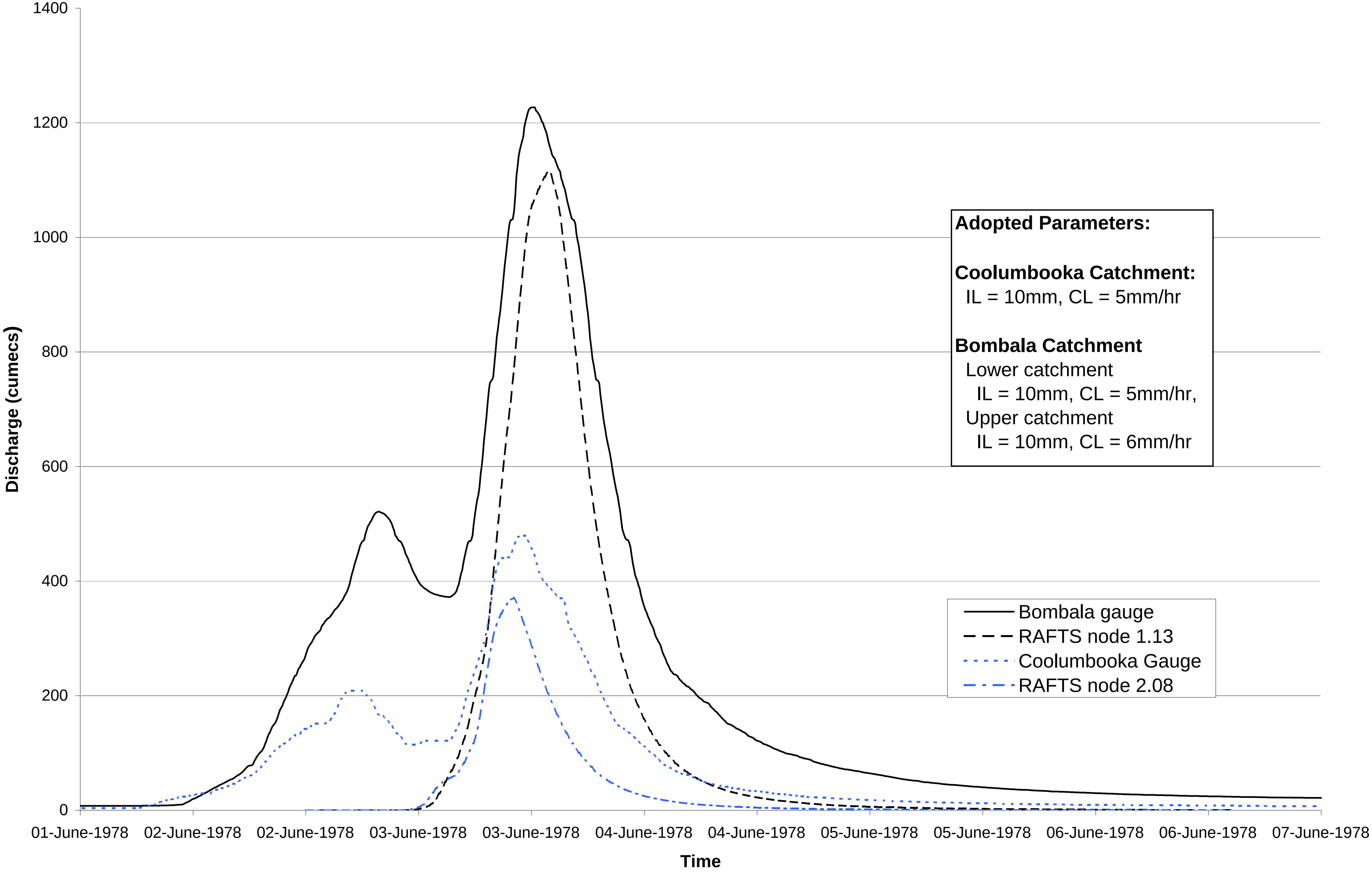


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Figure 9 - 1978 RAFTS calibration

VERIFICATION OF RAFTS MODEL TO 1978 FLOOD EVENT

6.3 SENSITIVITY ANALYSIS

In the absence of reliable historical rainfall data for model calibration, an assessment was made of the sensitivity of predicted discharges to catchment wetness conditions and variations in vegetation density. Details of the sensitivity analysis are provided in the following sections.

6.3.1 Catchment Wetness

The degree of catchment wetness prior to a storm is important as it determines the extent to which rainfall can infiltrate the soil surface. The groundwater systems of catchments which are saturated prior to a major storm, will have less capacity to absorb rainfall. Therefore, under wet antecedent (*ie., prior to a storm*) conditions, there will be less "loss" of rainfall to the groundwater systems, and consequently more runoff. Hence, high or saturated antecedent wetness conditions, will generally cause the highest flood discharges.

An assessment of the sensitivity of predicted model discharges to catchment wetness can be made based on variations to sub-catchment rainfall loss rates. Based on field observations of catchment condition, the limited literature on hydrologic model loss rates, and the calibration performed in the previous section, it was decided that the representative loss rates for the RAFTS model sub-catchments should be:

In order to confirm the suitability of these loss rates, an assessment of the sensitivity of the model to variability in initial loss rates across the catchment was made. The assessment was based on a comparison of modelled discharges along the major tributaries within the catchment for the 1971 flood event for a wet and dry catchment scenario. The adopted losses for each model run and a comparison of resultant peak discharges at selected locations are listed in **Table 13**.

The results in **Table 13** show that a reduction in the adopted loss rates to reflect saturated catchment conditions resulted in no change in the 1971 peak discharge. Similarly, increasing the loss rates to model a storm occurring on a dry catchment, had no effect on the peak discharge

Hence, it could be concluded that the initial rainfall loss rates adopted in the model have no significant impact on peak flood discharge estimates for the Bombala River at Bombala.

Table 13 MODEL SENSITIVITY TO VARIATION IN CATCHMENT WETNESS

RAFTS MODEL SUB-CATCHMENT IDENTIFIER	RAFTS MODEL NODE AT DOWNSTREAM END OF CATCHMENT	PEAK DISCHARGE (m^3/s)		
		Adopted Design Losses (*IL=10, CL=5/6*)	Wet Catchment Conditions (*IL=5, CL=5/6*)	Dry Catchment Conditions (*IL=15, CL=5/6*)
A	1.00	77	77	77
C	1.01	171	171	171
D	1.02	196	196	196
F	1.03	367	367	367
G	1.04	445	445	445
M	1.05	468	468	468
N	1.06	521	521	521
P	1.07	765	765	765
Q	1.08	812	812	812
R	1.09	822	822	822
T	1.10	869	869	869
U	1.11	870	870	870
V	1.12	1680	1680	1680
W	1.13	1683	1683	1683
Z	2.01	67	67	67
AB	2.02	170	170	170
AC	2.03	329	329	329
AF	2.04	595	595	595
AG	2.05	689	689	689
AH	2.06	788	788	788
AI	2.08	820	820	820
AM	2.09	820	820	820

6.3.2 Variation in Catchment Vegetation Distribution

The Bombala and Coolumbooka River catchments cover a large geographic area and are subject to large variations in vegetation distribution. Sensitivity runs were carried out to assess the impact of variations to the vegetation density conditions. Continuing rainfall losses were varied to reflect the two most extreme vegetation density conditions; viz:

- the occurrence of the 1971 storm over the catchment with a uniformly sparse vegetation distribution; and,
- the occurrence of the 1971 storm over the catchment with a uniformly dense vegetation distribution.

The dense vegetation distribution will have the ability to intercept more runoff and will therefore produce a higher continuing loss rate than the sparse vegetation distribution.

The results of these model simulations are presented in **Table 14**.

The results show that by increasing the loss rates to reflect dense vegetation across the catchment, the peak 1971 storm discharge at Bombala township is decreased by approximately 20%. The results also show that by decreasing the rainfall loss to represent a sparse vegetation distribution, the peak 1971 storm discharge at Bombala could be increased by around 25%.

Based on this analysis it can be concluded that the continuing rainfall loss rates adopted in the hydrologic model can have a significant impact on flood discharge estimates for the Bombala River at Bombala.

Table 14 MODEL SENSITIVITY TO VARIATION IN CONTINUING LOSS RATES

RAFTS MODEL SUB-CATCHMENT IDENTIFIER	RAFTS MODEL NODE AT DOWNSTREAM END OF CATCHMENT	PEAK DISCHARGE (m^3/s)		
		Adopted Catchment Parameters (*IL=10, CL=5/6*)	Sparse Vegetation (*IL=10, CL=3)*	Dense Vegetation (*IL=10, CL=8*)
A	1.00	77	98	62
C	1.01	171	214	142
D	1.02	196	244	163
F	1.03	367	471	298
G	1.04	445	578	358
M	1.05	468	611	376
N	1.06	521	672	418
P	1.07	765	982	583
Q	1.08	812	1044	614
R	1.09	822	1057	620
T	1.10	869	1121	654
U	1.11	870	1123	655
V	1.12	1680	2102	1347
W	1.13	1683	2108	1349
Z	2.01	67	76	61
AB	2.02	170	195	155
AC	2.03	329	383	296
AF	2.04	595	704	518
AG	2.05	689	813	602
AH	2.06	788	931	691
AI	2.08	820	968	720
AM	2.09	820	968	720

6.3.3 Conclusion

Based on the sensitivity analyses completed on the RAFTS hydrologic model, it is apparent that peak discharge estimates generated by the model, are particularly sensitive to variations in continuing rainfall loss rates. These variations reflect the capacity of the vegetation to intercept runoff.

However, the two scenarios presented in the sensitivity analysis can be considered to represent extreme conditions, and therefore may be regarded as providing the upper and lower bound estimates of possible peak discharges for the 1971 storm event. For them to occur, there would need to be uniform vegetation distribution (*either dense or sparse*) across the catchment, which is unlikely.

As the results for the sensitivity analyses show that the “design” rainfall loss rate provide median estimates of the peak discharge (*relative to the upper and lower bound values*), it was concluded that the “design” sub-catchment parameters presented in **Table 12** are appropriate. These parameters were adopted for subsequent design flood simulations.

7 HYDRAULIC MODEL

7.1 GENERAL

The RMA-2 (*Resource Management Associates, USA*) suite of software was employed to simulate flood behaviour along the Bombala River in the immediate vicinity of Bombala. RMA-2 is a fully two dimensional finite element model developed by Resource Management Associates of the USA and Prof. Ian King of the University of California at Davis.

RMA-2 was chosen for this investigation over other modelling techniques because it has the following attributes:

- RMA-2 is a fully two dimensional finite element model, hence it allows for overland flow to be modelled within the floodplain;
- it uses finite element methods to solve 2D depth averaged equations for turbulent energy losses, friction losses and horizontal momentum transfer, and as such offers significant benefits over the more traditional finite difference techniques;
- it uses a variable grid geometry employing elements with irregular and curved boundaries which can be modified as required without the need for regeneration of the entire grid, this enables any shaped boundary to be modelled exactly;
- it permits the simulation of systems that flood and dry during the analysis period.

The RMA-2 model developed for this study was used to simulate the passage of floodwaters through the township and thereby predicting flooding characteristics such as flood levels and flow velocities.

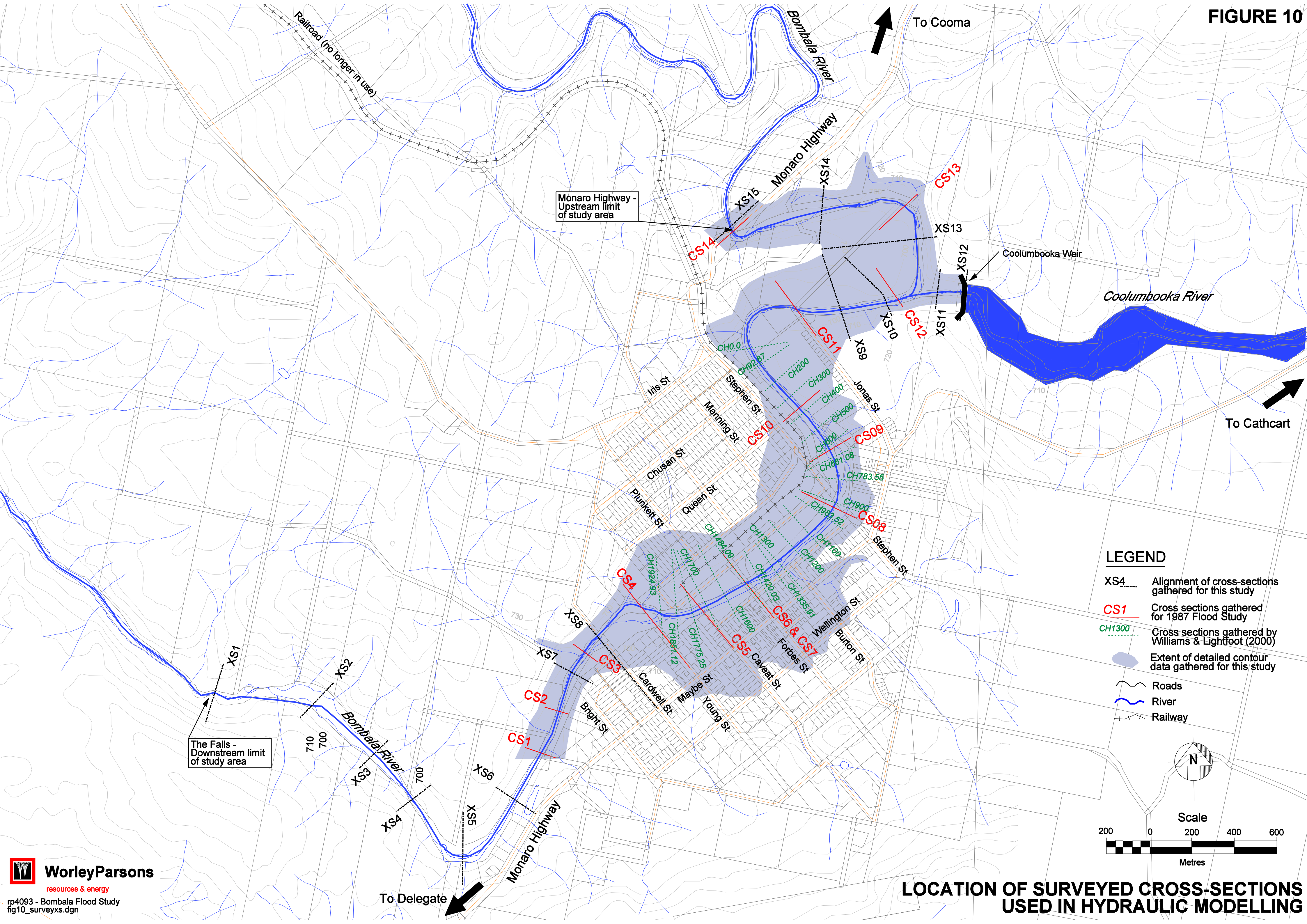
7.2 MODEL DEVELOPMENT

In order to develop a RMA-2 model capable of simulating flood behaviour within the study area additional topographic and hydrographic definition of the Bombala and Coolumbooka River channels and floodplain was required. Consulting Surveyors and Environmental Engineers, Williams & Lightfoot, were engaged to gather the additional survey data necessary for the hydraulic model.

To provide the necessary definition of the Bombala and Coolumbooka River channels and adjacent floodplain, 15 cross-sections were required to be taken across the floodplain extending from the Cunninghams Point Bridge crossing of the Bombala River to downstream at The Falls (*refer* **Figure 10**). Plots of these cross-sections are provided in **Appendix D**. In addition, the 14 cross-sections that were surveyed as part of the *1987 Flood Study,* were also used to define cross-section and floodplain elevations within the RMA-2 hydraulic model.

Details of the bridge structures within the floodplain were also required. There are two bridges within this reach of the Bombala River being the Cunninghams Point (Monaro Highway) Bridge crossing and the Forbes Street Bridge crossing within the Bombala township. Plots of each of the bridges showing levels and major dimensions are provided within **Appendix D**.

FIGURE 10



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LOCATION OF SURVEYED CROSS-SECTIONS USED IN HYDRAULIC MODELLING

7.2.1 Network Development

The RMA-2 model network extended over the Bombala River channel and floodplain between the Cunninghams Point Bridge (*XS15*) crossing at the upstream end to around 4km downstream of the village in an area known as “The Falls” (*XS 1*). The confluence between the Bombala and Coolumbooka Rivers was also modelled by extending the Coolumbooka River up to the Coolumbooka Weir. The higher topography on the north western and south eastern side of the Bombala River floodplain defined the lateral extent of the model network

An approximation consisting of 4 rectangular finite elements were used to define the Bombala and Coolumbooka River channels. This approximation was checked to ensure that the conveyance of the channel was not compromised by using this approach. The size and location of floodplain finite elements were determined based on the definition required within the model and the topography of the floodplain. The finite element grid was aligned with the cross-sections taken along the creek to enable flood heights and velocities to be related back to the location of these cross-sections.

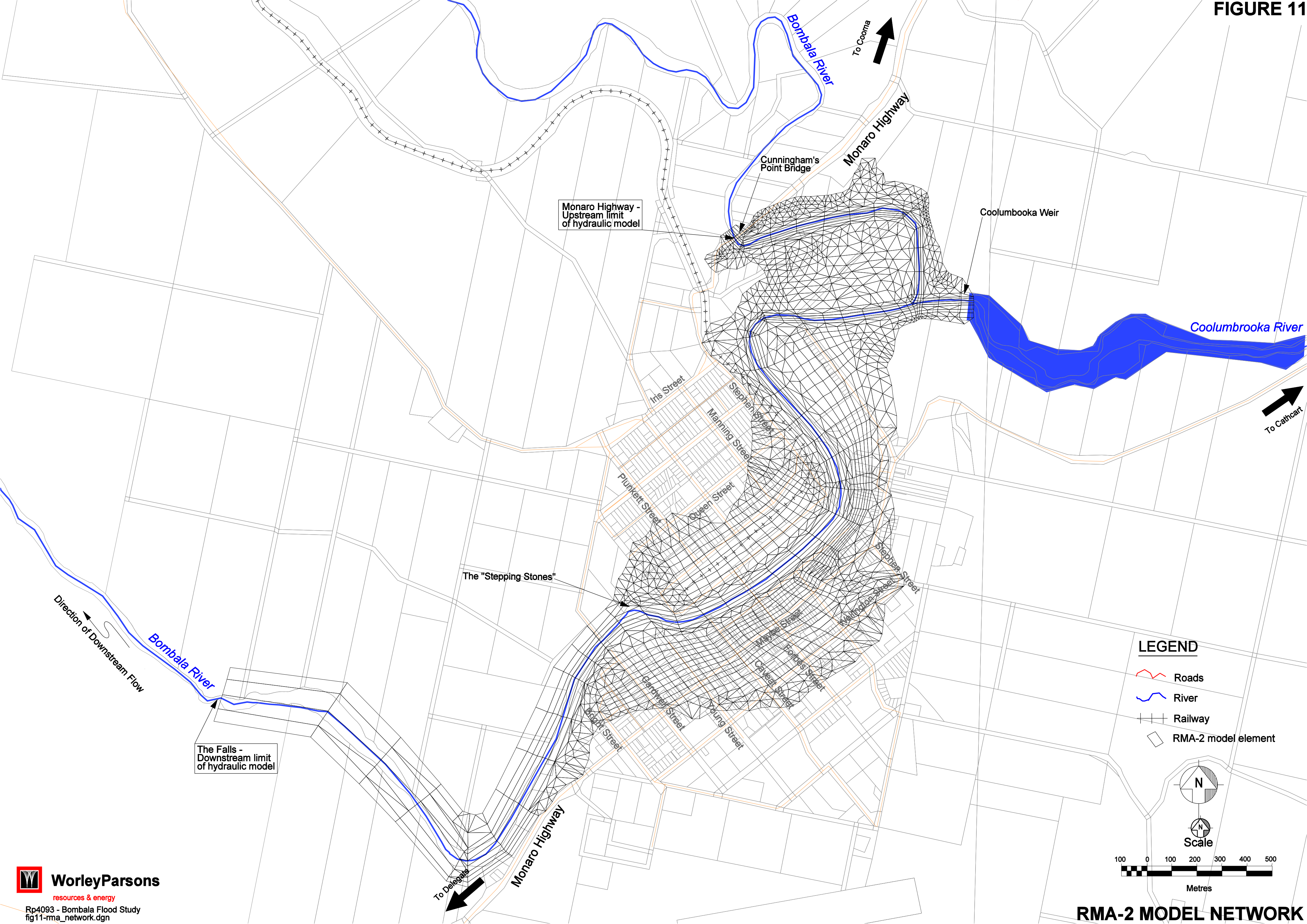
The layout of the RMA-2 hydraulic model mesh is provided in **Figure 11**.

7.2.2 Channel and Floodplain Roughnesses

Main channel and overbank roughnesses were determined for the study area from aerial and cross-section photograph analysis and field observations of channel and floodplain vegetation density. The adopted Manning’s “n” roughness values were determined by comparing vegetation density and soil types observed in the field, with standard photographic records of stream and floodplain condition for which Manning’s “n” values are documented in the literature.

The roughnesses adopted for the Bombala River RMA-2 model are listed in **Table 15** based on cross-sections surveyed for the study.

FIGURE 11



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RMA-2 MODEL NETWORK

Table 15 RMA-2 MODEL MANNINGS "n" VALUES

MODEL CROSS-SECTION No	MANNING'S 'n'			MODEL CROSS-SECTION No.	MANNING'S 'n'		
	Left Overbank	Main Channel	Right Overbank		Left Overbank	Main Channel	Right Overbank
XS 15	0.065	0.035	0.065	CS 6	0.055	0.035	0.065
CS 14	0.065	0.035	0.065	CS 5	0.055	0.035	0.055
XS 14	0.065	0.035	0.065	CS 4	0.055	0.035	0.055
CS 13	0.065	0.035	0.065	XS 8	0.065	0.035	0.055
XS 13	0.065	0.035	0.065	CS 3	0.065	0.035	0.055
XS 12	0.065	0.035	0.065	XS 7	0.065	0.035	0.065
XS 11	0.065	0.035	0.065	CS 2	0.065	0.035	0.065
CS 12	0.065	0.035	0.065	CS 1	0.065	0.035	0.065
XS 10	0.065	0.035	0.065	XS 6	0.065	0.035	0.065
XS 9	0.065	0.035	0.065	XS 5	0.065	0.035	0.065
CS 11	0.065	0.035	0.065	XS 4	0.065	0.035	0.065
CS 10	0.065	0.035	0.065	XS 3	0.065	0.035	0.065
CS 9	0.055	0.035	0.065	XS 2	0.065	0.035	0.065
CS 8	0.055	0.035	0.065	XS 1	0.065	0.035	0.065

7.2.3 Boundary Conditions

Proper inclusion of boundary conditions within a hydraulic model is very important for a successful application of the modelling technique. To start the hydraulic model the initial and boundary conditions within the model must be specified. Initial conditions are the depth and flow conditions the model starts a simulation with, while the boundary conditions simulate the physical boundaries of the model area as well as model inflows and outflows. Upstream Boundary conditions are the flow conditions coming into the model such as hydrographs generated by a hydrologic model while downstream boundary conditions are the depth and flow conditions at the downstream or outflow point of the model such as normal or critical depth conditions.

Upstream Boundary Conditions

As discussed in **Sections 3** and **4**, the upstream boundary conditions for the hydraulic model are provided by the discharge hydrographs generated from the RAFTS rainfall runoff model.

Therefore, the RAFTS hydrologic model was structured to ensure discharge hydrographs were generated at the location of these inflows. The RAFTS model nodes corresponding to these inflows are shown in **Figure 6**. Descriptions of these locations are provided in **Table 16**.

Table 16 UPSTREAM BOUNDARY CONDITIONS FOR HYDRAULIC MODEL

TRIBUTARY	LOCATION	RAFTS MODEL NODE REFERENCE
Bombala River	Upstream extent of hydraulic model located at the Cunninghams Point Bridge crossing of the Bombala River	1.11
Coolumbooka River	At model cross-section XS12 downstream of the Coolumbooka Weir	2.09

Downstream Boundary Conditions

There are no hydraulic controls such as weirs or dams, downstream of Bombala, that could cause floodwaters to "back-up" and influence flood levels through the town. Although the absence of a weir structure downstream of the town eliminates the complication of backwater effects, it does reduce the potential for a reliable estimate of the peak water level for a particular flood at the downstream end of the model. In order to model flood behaviour through the town, it is necessary to have a reliable estimate of peak water level at the downstream end of the model.

However, from field observations and a review of the topographic mapping, an area where the floodplain narrows was identified downstream of Bombala at a location known as "*The Falls*". In the absence of hydraulic controls such as weirs or bridges, an area where the width of the floodplain is relatively narrow and the potential floodplain extent is well defined (*by rising topography on the fringes*), can be used to estimate peak water levels.

Accordingly, a cross-section was gathered across the full width of the floodplain in the vicinity of "*The Falls"*. The cross-section is referred to as XS1 and its location is shown in **Figure 10**. The RMA-2 hydraulic model was developed with this cross-section as the site of the downstream boundary condition. The downstream boundary condition was assumed to be a gradually varying water level that varied with increasing flood discharge. This varying tailwater condition was determined by applying the HEC-RAS model that was originally developed for the Bombala Flood Study Report (*Department of Water Resources, 1987*) and the flood discharges generated from the RAFTS model for each flood frequency (*ie., 1, 2, 5, 10, 20, 50 and 100% AEP*). A subcritical flow regime was assumed in the calculation of the varying tailwater levels which is consistent with the characteristics of flow in relatively flat river systems.

7.3 MODEL CALIBRATION

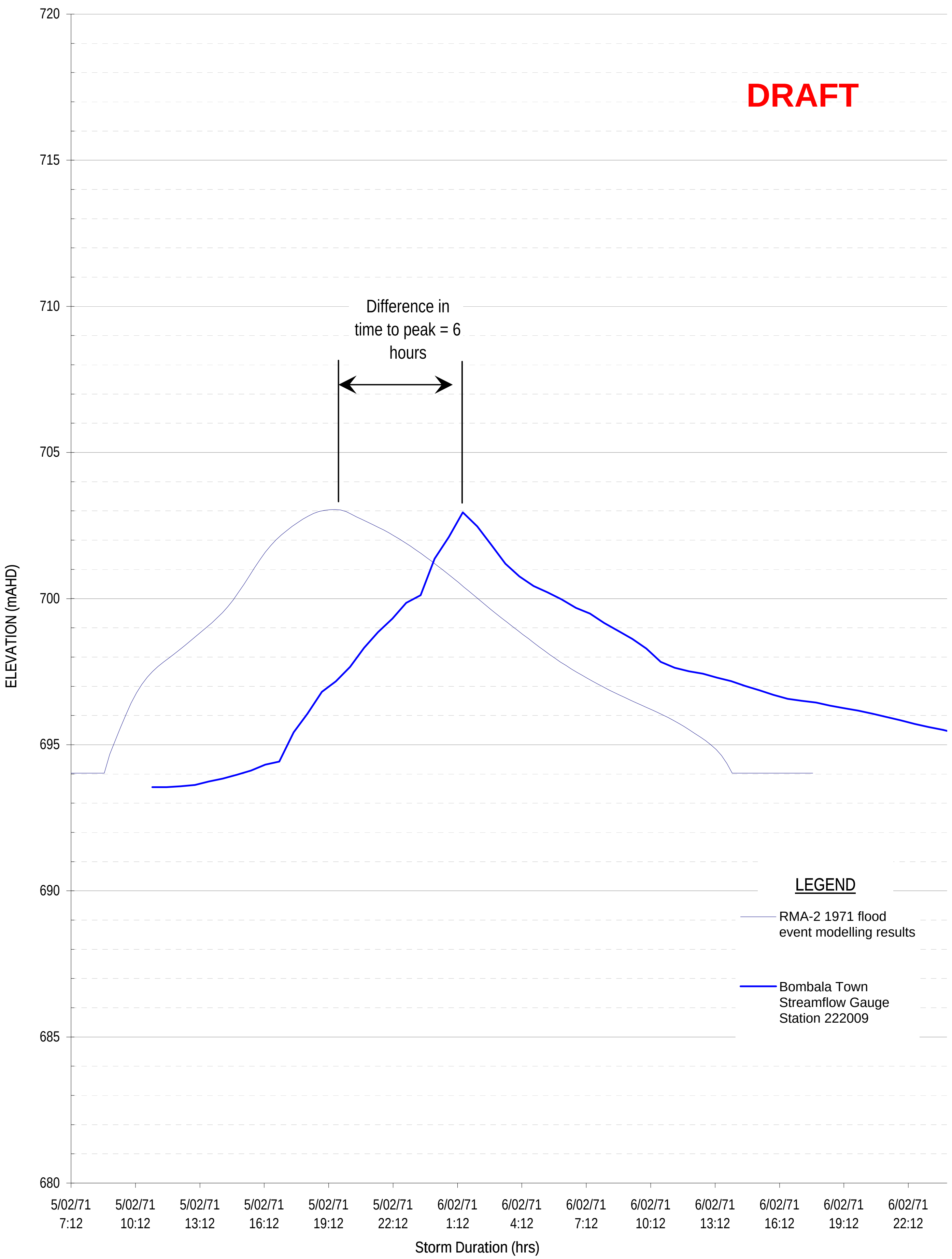
As discussed in **Section 3**, streamflow records exist for the gauging stations located on the Bombala and Coolumbooka Rivers at Bombala for floods such as the 1971, 1978 and 1983 events. Although the absence of pluviographs within the Bombala River catchment meant that only a pseudo-calibration of the hydrologic model was possible, the RAFTS model was able to replicate the peak discharges accurately particularly for the 1971 flood event.

Records of flood heights through the town area have been compiled for the 1971 and 1983 floods . Therefore, the hydraulic model can be calibrated by attempting to "match" recorded or observed peak flood levels to the flood levels generated by the hydraulic model.

The RMA-2 model was used to simulate the 1971 flood event, since this represents the flood of record at the town and is close the 100 year ARI flood. The stage hydrograph generated for the 1971 flood was extracted from the results of the flood modelling. The results of the modelling were compared with the historical stage data collected at the Bombala streamflow gauge (*No. 222009*).

The comparison suggests that the RMA-2 flood model predicts the peak to arrive some 6 hours before the peak recorded at the Bombala town streamflow gauge. The difference between the timing of the two peaks can be attributed to assumptions made regarding rainfall hyetographs when using the RAFTS model to generate inflow hydrographs for the 1971 flood (*refer* **Figure 8**).

The two stage hydrographs are compared in **Figure 12**.



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COMPARISON BETWEEN RECORDED STAGE HYDROGRAPH AT FORBES STREET BRIDGE AND RMA-2 MODELLING RESULTS FOR 1971 FLOOD EVENT

8 DESIGN FLOOD ESTIMATION

8.1 HYDROLOGY

8.1.1 Design Simulations

The RAFTS model described in **Section 5**, was used to simulate runoff from the catchment for design storm conditions. The design storm conditions were based on rainfall intensities and temporal patterns for the study area, which were derived using standard procedures outlined in *'Australian Rainfall and Runoff – A Guide to Flood Estimation' (1987)* (*ARR87*). The design storm rainfall data was generated by applying the principles of rainfall intensity estimation described in Chapter 2 of ARR87. Intensity-frequency-duration data for Bombala were developed using these procedures and are enclosed in **Appendix B**.

Design temporal patterns outlined in ARR87 for the Bombala region were also adopted. These temporal patterns specify the distribution of the rainfall over the duration of the design storms.

A range of storm durations were considered and modelled to establish the critical storm duration for the catchment. The critical storm duration was assumed to correspond to the maximum peak discharge at Bombala as generated using the RAFTS model.

A critical storm duration of 36 hours was determined for the Bombala River catchment.

Peak discharges and hydrographs were generated throughout the catchment for a range of flood frequencies using the critical storm duration of 36 hours and the corresponding rainfall intensities and design temporal patterns. In accordance with the study brief, these flood frequencies included the 0.5, 1, 2, 5 and 20% annual exceedance probability (*AEP*) events, as well as the Probable Maximum Flood (*PMF*).

8.1.2 Hydrologic Modelling Results

Peak Discharges

Peak tributary catchment discharges determined using the RAFTS hydrologic model are listed in **Table 17**. The peak discharges are referenced to the RAFTS model node identifiers, which can be located in **Figure 6**. For example, the peak discharge in Bombala River at Bombala, corresponds to the listed discharges in **Table 17** for RAFTS model node number 1.13. As shown in **Figure 6**, this peak discharge is for all catchment runoff draining to the Bombala River at this particular location.

In addition, RAFTS modelling results are enclosed in **Appendix E**.

Table 17 PEAK FLOWS FOR BOMBALA RIVER SUB-CATCHMENTS BASED ON 36 HOUR CRITICAL STORM DURATION

SUB-CATCHMENT	RAFTS MODEL NODE NUMBER	PEAK DISCHARGE					
		0.2% AEP	0.5% AEP	1% AEP	2% AEP	5% AEP	20% AEP
A	1.00	156	127	106	77	62	34
C	1.01	329	269	228	167	136	77
D	1.02	376	307	260	191	156	89
F	1.03	755	611	510	372	299	166
G	1.04	923	744	619	460	366	201
M	1.05	968	781	650	488	390	215
N	1.06	1,033	837	700	535	426	239
P	1.07	1,651	1,310	1,078	886	704	397
Q	1.08	1,679	1,333	1,097	898	714	404
R	1.09	1,790	1,430	1,180	959	761	437
T	1.10	1,791	1,430	1,181	960	761	437
X	2.00	69	56	48	35	29	16
Z	2.01	175	143	122	89	72	41
AB	2.02	351	283	236	171	135	75
AC	2.03	714	574	479	355	281	158
AF	2.04	802	645	539	406	321	179
AG	2.05	886	715	599	461	366	206
AH	2.06	912	737	617	479	381	215
AI	2.08	912	737	617	479	381	215
AM	2.09	1,101	882	741	561	447	254
U	1.11	2,639	2,128	1,770	1,444	1,142	657
V	1.12	2,641	2,129	1,771	1,447	1,144	658
W	1.13	2,641	2,129	1,771	1,447	1,144	658

The results show that the peak 1% AEP flood discharge for the Bombala River at Bombala is 1,771 m^3/s. In contrast, the 20% AEP event (*or 1 in 5 year recurrence event*), only has a peak discharge of 658 m^3/s.

8.1.3 Comparison between RAFTS and FFA RESULTS

Two independent analysis methods have been applied to define the peak discharge at Bombala across a range of design flood events. The first method, referred to as Flood Frequency Analysis (*FFA*) is discussed in **Chapter 5** The second method is the hydrologic modelling undertaken using the XP-RAFTS software and is discussed in **Chapter 6**.

The peak discharge predicted by the two methods across a range of design storm events is presented in **Table 18**. The predicted difference in peak flow between the two methods is included in the table.

Table 18 FLOOD FREQUENCY ANALYSIS AND XP-RAFTS COMPARISON

AEP (%)	DESIGN PEAK DISCHARGE (m^3/s)		DIFFERENCE: FLIKE LPIII – XP-RAFTS PEAK DISCHARGE (m^3/s)	DIFFERENCE IN PEAK DISCHARGE AS A % OF FLIKE LPIII FFA
	FLIKE LPIII FFA	XP-RAFTS Modelling		
20	680	658	-22	3.2%
5	1,230	1,144	-86	7.0%
2	1,500	1,447	-53	3.5%
1	1,670	1,771	101	6.0%
0.5	1,830	2,129	299	16.3%
0.2	2,050	2,641	591	28.8%

The results presented in **Table 18** suggest that reasonable correlation has been achieved between the two methods for the range of floods up to and including the 1% AEP event. However, the peak discharge predicted by the two methods begins to diverge significantly for the 0.5% and 0.2% AEP flood events. The reasons for the difference between peak flows is addressed in the following sections. The discussion has been separated into events up to the 1%AEP storm and for events rarer than the 1% AEP flood.

Discussion of Results for Events up to and including the 1% AEP flood

Rainfall Run-off modelling operates on the assumption that an AEP rainfall event is expected to generate the equivalent AEP run-off.

It is standard practice to calibrate rainfall run-off models to recorded historical storm event(s). This involves using the rainfall run-off model to simulate the historical rainfall data and varying model parameters to reproduce the streamflow hydrograph recorded at a gauging station.

There is the potential that calibration of the rainfall-run-off model to historical storm event, may result in some divergence in the predicted peak discharge for design storm events between the two methods.

The RAFTS model was calibrated to the 1971 flood event. The calibration process is described in **Section 6.2**. Daily read rainfall data for the 1971 event was extracted from two rain gauges, one located in Bombala Town (*070005*) and the other in the upper Coolumbooka River catchment at Cathcart (*070106*). Significant variation (*i.e. in excess of 100 mm during the 24 hour period*) existed between the rainfall recorded at the Bombala and Cathcart gauges for the 1971 storm event.

It is noted that the Bombala River catchment flowing to Bombala covers a relatively large area (*over 500 km^2*). Some variation in recorded rainfall is to be expected. In this regard, the IFD data generated for Bombala and Cathcart noticeable variation does exist in the design rainfall events (*refer* **Appendix B**).

Since recorded rainfall varied across the catchment, the process used to calibrate the model could not reproduce the assumption that the Annual Exceedance Probability of Rainfall and Run-off is the same. This is considered to account for some of the variation between the peak flows predicted by the FFA and rainfall runoff methods during the 1% AEP event.

A further reason for the difference results from the calibration storm not representing the critical storm for the catchment.

As discussed in **Chapter 6**, only daily read rainfall data was available to calibrate the rainfall run-off model to the 1971 storm event. Accordingly, various storm durations were trialled in the RAFTS model for the 1971 storm. A 48 hour duration storm event was determined to generate the best "fit" between the hydrograph generated by the RAFTS model at Bombala and Coolumbooka and the historical recorded streamflow hydrographs.

However, subsequent modelling of design storm events in the rainfall run-off model established the 36 hour duration rainfall event to be the critical storm event for the catchment. The critical storm is referred to as the rainfall duration for a storm event which produces the largest peak discharge at the study area.

Therefore, although the 1971 storm represented the 1% AEP flood, the rainfall duration event adopted for modelling purposes didn't represent the critical storm for the Bombala River catchment.

The findings discussed above suggest that the assumption that an AEP rainfall event generates an equivalent AEP run-off event in a rainfall run-off model could potentially be revised with the following qualifiers:

- This will hold true where the storm used to calibrate the rainfall run-off model represents the critical storm event for the catchment; and,
- where uniformity between the Annual Exceedance Probability of historical rainfall and run-off methods occur.

It is also noted that the predicted peak discharge for the XP-RAFTS model for the 20%, 5% and 2% AEP events is less than the FFA's predicted peak discharge. Conversely, the predicted peak discharge from the XP-RAFTS model is slightly higher than the FFA for the 1% AEP event.

This is understood to result from the initial and continuing losses adopted from the calibration, which is understood to have a more significant impact on events more frequent than the flood used to calibrate the model.

Nonetheless, the peak discharge generated by the FFA and rainfall run-off methods are believed to correlate adequately. A comparison between the design and historical storm events shown in **Figure 4B**, suggests the peak flow predicted by the rainfall run-off model fall within the variation between the FFA curve and the historical flood data.

The RAFTS model is considered to be an appropriate representation of the hydrological mechanisms of the Bombala River Catchment. Calibration of the model to a historical flood event is considered the most reliable method to define the catchment parameters.

An alternative approach which would reflect the stated assumption involves using the rainfall-runoff model to simulate the 100 year ARI rainfall event and calibrating the model to the predicted FFA 1% AEP peak flow. The calibrated model could then be used to simulate the 1971 flood and establish the peak flow. This latter method would rely on probabilistic rainfall data and statistical analysis of streamflow. In addition, the method would afford no means to verify other hydrologic parameters such as the total volume of flow and hydrograph shape.

Discussion of Peak Discharge Predictions for Events rarer than 1%AEP flood

The peak discharge determined by the FFA and rainfall-runoff methods for the 0.5% and 0.2% AEP flood events are presented in **Table 18**. The results indicate that the two methods predict significantly different flows.

Flood Frequency Analysis procedures are detailed in *'Australian Rainfall & Runoff* (*1998*) *Book IV Section 2 – Flood Frequency Analysis'*. Book IV identifies some of the limits associated with the FFA method. In particular, Section 2.4.4 of Book IV recommends significant caution be exercised when extrapolating to larger flood events such as the 0.5% and 0.2% AEP events.

AR&R Book III, *'Choice of flood estimation method'* outlines a numerical approach to determining the flood event at which rainfall run-off methods are preferable to FFA. This is described in Section 2.6.4. This method considers the length of record which the FFA was derived from and the characteristics of the data set.

Through application of the method described in Section 2.6.4 , it was determined that a rainfall-run-off modelling approach is the preferred method for any AEP event rarer than approximately 120 years. Therefore, the rainfall runoff method is the preferred method for determining the 0.5% and 0.2% peak discharges.

Nonetheless, the correlation achieved between the peak discharge generated by FFA and rainfall-run-off models is considered reasonable, given the margin of error which enters either method for events rarer than the 1% AEP flood. Were either of the 0.5% or 0.2% flood events to be used for design, the decision regarding each flood event would depend on the consequences of failure.

8.2 HYDRAULIC MODELLING

8.2.1 Design Simulations

The RMA-2 two-dimensional hydrodynamic model of the Bombala River was used to simulate flood behaviour through the Bombala Township for the design 0.5, 1, 2, 5, and 20% AEP events, and the probable maximum flood (*PMF*). The model was also used to simulate the 1971 historical flood.

Upstream boundary conditions were defined by inflow hydrographs developed using the RAFTS hydrologic model (*refer* **Section 6.2.2**). For example, the design 1% AEP flood discharge hydrographs for tributary inflows were extracted from the RAFTS model output and used to define the rate of flow into the area covered by the hydraulic model.

The downstream boundary condition was based on the stage hydrographs developed according to the methodology described in **Section 6.2.2**.

8.2.2 Results

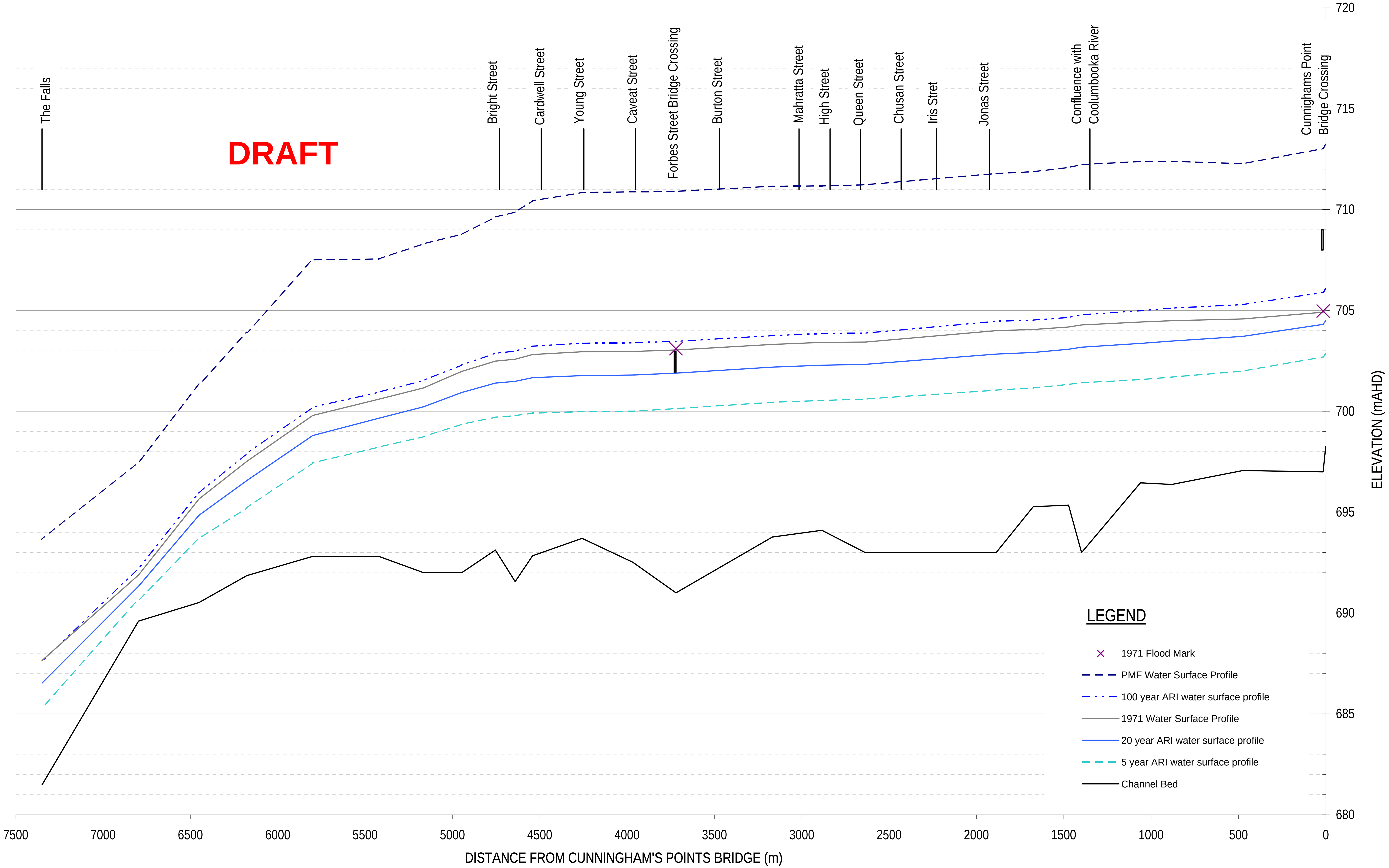
The hydraulic modelling provided design floodwater levels and mean channel and overbank velocities at each model cross-section, for each of the flood frequencies considered. The resulting flood profiles along Bombala River are presented in **Figure 13**. A summary of flood levels for all flood frequencies considered in the study is provided in **Table 19**. An expanded summary of the RMA-2 hydrodynamic modelling results including velocity is enclosed in **Appendix F**.

Discussion

The hydraulic modelling results for the 1% AEP event show that within the centre of the Bombala township, near the Forbes Street Bridge crossing, floodwaters would extend into Maybe St. Floodwaters would reach depths of approximately 0.4 metres at the centre of the Maybe and Forbes Street intersection. Downstream of the township, floodwaters would be confined within the main river channel.

The flood profile, shown in **Figure 13**, is a ‘good fit’ to 1971 known flood marks. The 1971 event is approximately equivalent to the 1% AEP event. The modelled design affluxes across the bridges are supported by the 1974 floodmarks. Flood mapping of the predicted extent of the 5% and 1% AEP flood events are outlined in **Figure 14** and **Figure 15**.

FIGURE 13



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rp4093 - Bombala River Flood Study
Water Surface Profile-Bombala River.xls

WATER SURFACE PROFILES FOR BOMBALA RIVER FROM RMA-2 MODEL RESULTS

FIGURE 14

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Rp4093 - Bombala Flood Study
Fig13_20yr_extent.dgn

PREDICTED EXTENT OF INUNDATION DURING 20 YEAR RECURRENCE EVENT

FIGURE 15

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Fig14_100yr_extent.dgn

PREDICTED EXTENT OF INUNDATION DURING 100 YEAR RECURRENCE EVENT

Table 19 PREDICTED DESIGN FLOODWATER LEVELS FOR BOMBALA RIVER

LOCATION (*refer* Figure 10)	RMA-2 MODEL CROSS-SECTION	WATER SURFACE ELEVATION (mAHD)				
		PMF	200YR ARI	100YR ARI	20YR ARI	5YR ARI
Cunnighams Point Bridge	XS 15	713.1	706.9	706.0	704.5	702.8
	CS 14	712.9	706.7	705.9	704.3	702.7
	XS 14	712.3	706.1	705.3	703.7	702.0
	CS 13	712.4	706.0	705.1	703.5	701.7
	XS 13	712.4	705.8	705.0	703.4	701.6
Coolumbooka Weir	XS 12	712.4	705.9	705.0	703.4	701.6
	XS 11	712.3	705.8	704.9	703.3	701.5
Confluence of Bombala and Coolumbooka Rivers	CS 12	712.2	705.6	704.8	703.2	701.4
	XS 10	712.1	705.5	704.7	703.1	701.3
	XS 9	711.9	705.4	704.5	702.9	701.2
	CS 11	711.8	705.3	704.5	702.8	701.1
Queen Street	CS 10	711.2	704.7	703.9	702.3	700.6
High Street	CS 9	711.2	704.7	703.8	702.3	700.5
	CS 8	711.2	704.6	703.7	702.2	700.5
Forbes Street Bridge	CS 6	710.9	704.3	703.5	701.9	700.1
Caveat Street	CS 5	710.9	704.3	703.4	701.8	700.0
Young Street	CS 4	710.8	704.2	703.4	701.8	700.0
Cardwell Street	XS 8	710.5	704.1	703.2	701.7	699.9
	CS 3	709.9	703.8	703.0	701.5	699.8
Bright Street	XS 7	709.7	703.7	702.9	701.4	699.7
	CS 2	708.8	703.0	702.3	700.9	699.4
Sewage Treatment Plant	CS 1	708.3	702.2	701.5	700.2	698.7
	XS 6	707.6	701.7	701.0	699.7	698.2
	XS 5	707.3	700.9	700.1	698.7	697.4
	XS 4	703.9	698.7	697.9	696.6	695.2
	XS 3	701.3	696.6	696.0	694.9	693.7
	XS 2	697.5	692.8	692.3	691.3	690.7
"*The Falls*"	XS 1	693.9	688.4	687.8	686.6	685.3

8.2.3 Probable Maximum Flood

The probable maximum flood (*PMF*) is the largest flood that could conceivably occur at a particular location. It is often referred to as a "flood of biblical proportion". Although floods of this magnitude are extreme, they provide important criteria for consideration in the management of the residual flood hazard. For example, the PMF should be considered when identifying the location of resources that are critical during floods, such as telephone exchanges, police stations and hospitals.

In recognition of these factors, investigations were undertaken to assess the magnitude of the PMF and its potential impact on Bombala Township.

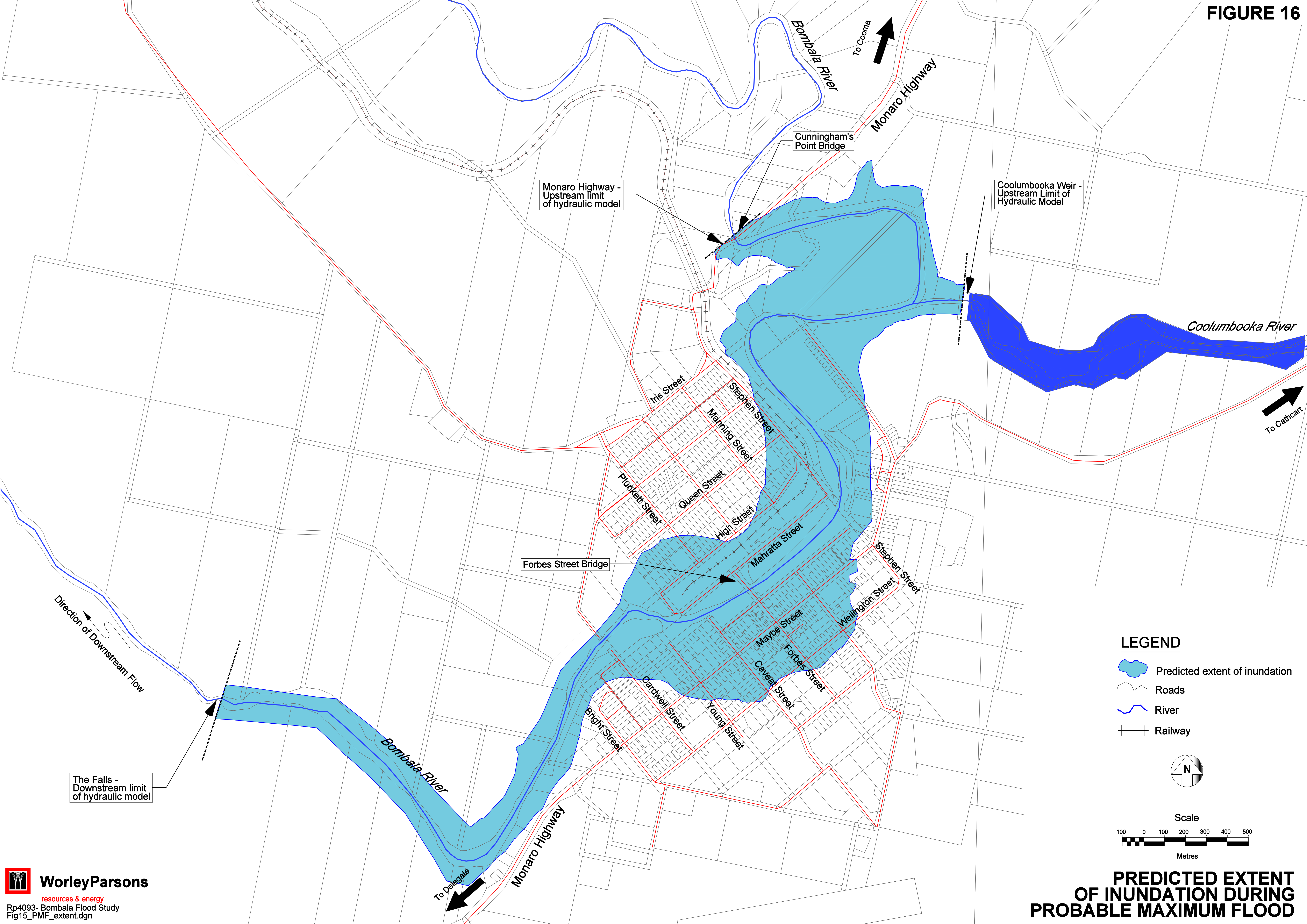
Probable Maximum Precipitation

Estimates of the probable maximum flood should be based on the probable maximum precipitation (*PMP*). The PMP is defined as the greatest depth of precipitation that is meteorologically possible for a given duration at a specific location. Procedures for estimation of the PMP are outlined in a document published by the Bureau of Meteorology, which is titled, *'Bulletin 53 - The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method'*(*1994*). These procedures were applied to the Bombala River catchment to derive the PMP for Bombala.

The PMP was incorporated in RAFTS and used to simulate PMF inflows for the Bombala River catchment. The results of this simulation were extracted from RAFTS and incorporated within the RMA-2 model inputs. This was then used to simulate the PMF flood event.

The predicted extent of the PMF flood event is outlined in **Figure 16**. The predicted peak flood level along the Bombala River are summarised in **Table 19**.

FIGURE 16



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PREDICTED EXTENT OF INUNDATION DURING PROBABLE MAXIMUM FLOOD

9 VILLAGE OVERLAND FLOW INVESTIGATION

9.1 INTRODUCTION

A number of locations within the village area of Bombala have been observed to become inundated by stormwater during times of high intensity local catchment rainfall. This is understood to result from the concentration of stormwater run-off along overland flow paths. Inundation of dwellings, properties and roads are affected by the stormwater run-off.

The Bombala River RMA-2 flood model was developed to define the characteristics of catchment-wide river flood events at Bombala. The RMA model is not intended to assess stormwater run-off in the village area. Accordingly, the extent of stormwater inundation in the village area was not defined by the Bombala River RMA-2 flood modelling.

The Bombala Floodplain Management Committee decided that overland flows within the village area should be assessed as an extension to work being undertaken for the Bombala Flood Study. Accordingly, the scope of the study was extended to analyse stormwater run-off and ponding within the Bombala township. This extension is referred to as the "Village Overland Flow Investigation" (*VOFI*).

The following terminology has been adopted for the VOFI, to distinguish between different types of flooding:

- "*Stormwater*" refers to run-off generated within the Bombala village area, being assessed for the VOFI; and,
- "*Flooding*" refers to catchment wide flooding of the Bombala River, as defined by the RMA-2 flood modelling results.

It was necessary to undertake additional hydrologic investigation for the VOFI. The additional hydrological investigation included Bombala village area sub-catchment definition which facilitated the development of a RAFTS model for the village. The RAFTS model was used to simulate a range of design storm events. Details of the hydrologic investigations undertaken for the village area are provided in **Section 9.2**.

A summary of the existing issues surrounding stormwater run-off and ponding within the Bombala village area was provided by Bombala Shire Council. This has been included at **Appendix G**. The summary identified existing overland flow paths as well as locations where run-off causes inundation of dwellings, property or roads. These locations are referred to as "*Trouble Spots*". The trouble spots are described in **Section 9.3**.

Details of the model development for each of the sites is outlined in **Section 9.4**. The results of the modelling are documented in **Section 9.5**. Preliminary recommendations targeted towards reducing the impact of stormwater run-off and ponding within the village area are provided in **Section 9.6**.

9.2 LOCAL CATCHMENT HYDROLOGY

Previously, a hydrologic model was developed using RAFTS for the Bombala River Flood Study (*refer* **Chapter 6**). However, this model was developed to define run-off from the whole Bombala River catchment upstream of Bombala. As a result, the model had insufficient detail for the requirements of the VOFI and additional hydrologic modelling was required.

The additional hydrologic modelling involved dividing the village area at Bombala into a number of separate sub-catchments.. Existing contour information, survey data, aerial photography and the information gathered during the site visit were used to identify the local catchment areas and develop a hydrologic model of the Bombala village area.

The adopted catchment areas for Bombala village are outlined in **Figure 17**. Between one and three nodes have been used for each sub-catchment area to account for variation in slope which is typical of many of the areas.. Key inputs for the hydrologic mode including sub-catchment areas, slopes and the percentage impervious is provided in **Appendix H**.

The hydrologic model developed for the Bombala village was used to simulate the 20, 100 and 200 year recurrence storm events. The 90 minute duration storm event was determined to be the critical storm event for the catchment areas. The peak discharge values for the 20, 100 and 200 year recurrence storm events at each of the nodes included in the hydrologic model are summarised in **Table 20**.

Table 20 peak flood discharge ESTIMATES for KEY ARI EVENTS

CATCHMENT IDENTIFIER	RAFTS Model Node	LOCATION DESCRIPTION	PEAK FLOOD DISCHARGE (m^3/s)		
			20 yr ARI	100 yr ARI	200 yr ARI
A_u	1.00	Corner of Cardwell St & Wellington St	9.1	13.7	16.2
A_l	1.01	Young St @ Bombala River	12.6	18.6	21.9
B_u	2.00	Corner of Caveat & Mercy St	14.0	20.4	24.0
B_l	2.01	Caveat St @ Bombala River	17.2	25.0	29.2
C_u	3.00	Corner of Burton St. & Mercy St.	3.3	4.6	5.3
C_l	3.01	Corner of Therry St. & Forbes St.	9.9	13.4	15.4
D_u	4.00	Corner of Wellington St. & Burton St.	9.5	13.7	15.9
D_l	4.01	Burton St. near Maybe St.	10.0	14.3	16.4
E	4.02	End of Therry St.	29.2	43.7	51.5
F	5.00	Corner of Mahratta St. & Stephen St.	15.6	21.3	24.6
G_u	6.00	Corner of Plunkett St & Iris St.	0.7	0.9	1.0
G_l	6.01	Mort St.	12.2	16.8	19.4

FIGURE 17

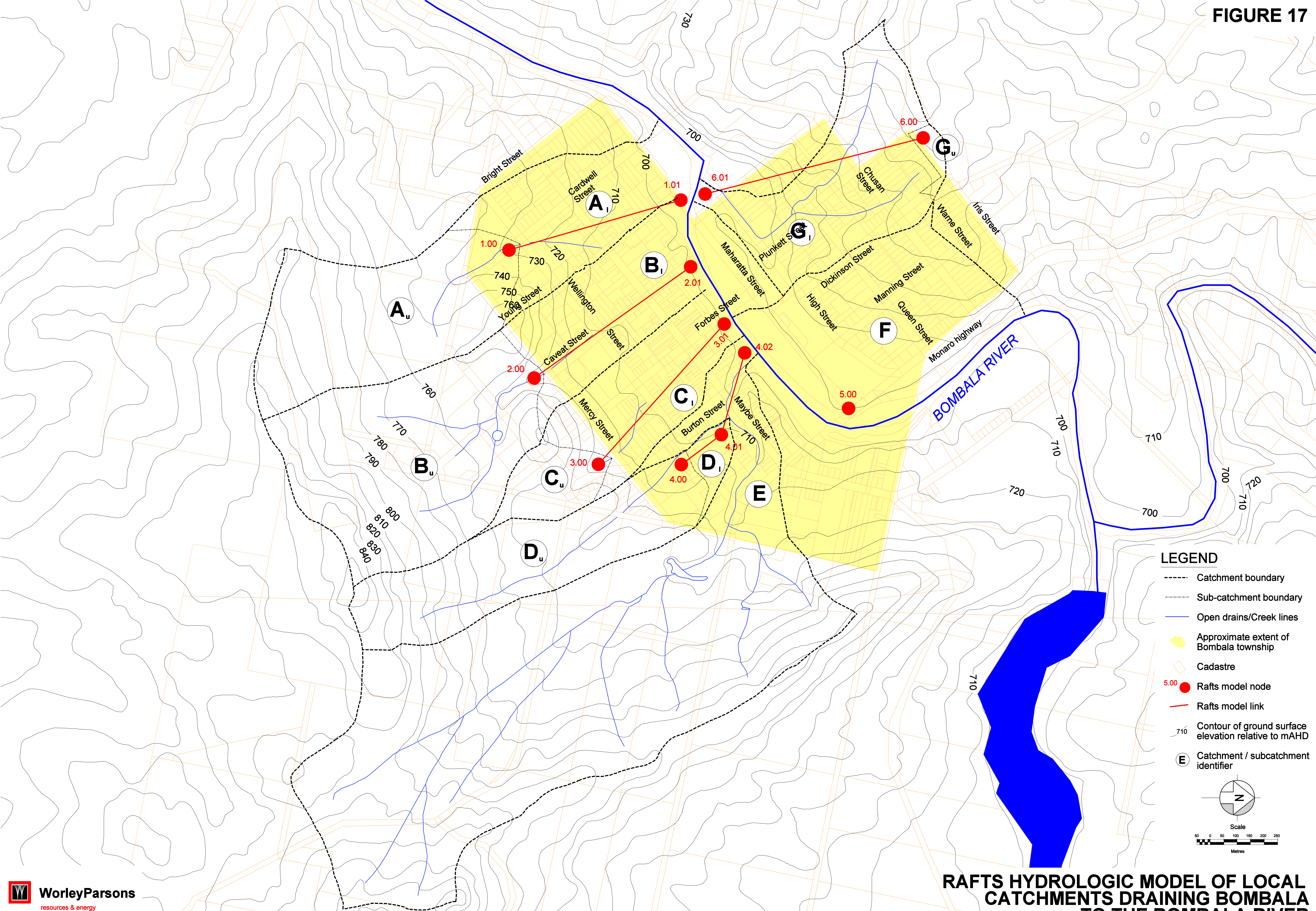

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fig14_VOFIraftsLayout

RAFTS HYDROLOGIC MODEL OF LOCAL CATCHMENTS DRAINING BOMBALA TO THE BOMBALA RIVER

9.3 DESCRIPTION OF TROUBLE SPOTS

A summary of locations where stormwater run-off and inundation has been an issue was provided by Bombala Shire Council. A total of twelve *Trouble spots* were identified within the village area. The *Trouble spots* are locations where stormwater run-off/ponding has been identified as an issue in the during previous storm events. Subsequent discussions with Council refined the original list of twelve Trouble spots was refined to ten Trouble spots. The location of the ten *Trouble spots* are identified on **Figure 18**. The original numbering provided by Council has been maintained.

The trouble spots can be defined according to three different categories, based on past observed flood impacts. These categories are as follows:

(i) Locations where stormwater flow or ponding of backwater results in water inundating dwellings, causing damage to property and presenting a hazard to people (*Trouble spots 1 and 3*).

(ii) Locations where stormwater discharges over the road and represents a hazard to motorists (*Trouble spots 6, 8, 9, 10*).

(iii) Locations where overland flow paths are located within or adjacent to private property boundaries resulting in nuisance flooding and potential damage to private property (*Trouble spots 2, 4, 6, 7 and 12*).

The above categorisation has assisted in prioritising the above sites during the hydraulic assessment.

In addition, a total of seven overland flow paths (*OFP*) have been identified within the village area that collect and discharge stormwater run-off. The indicative alignment of each overland flow paths is included in **Figure 18**.

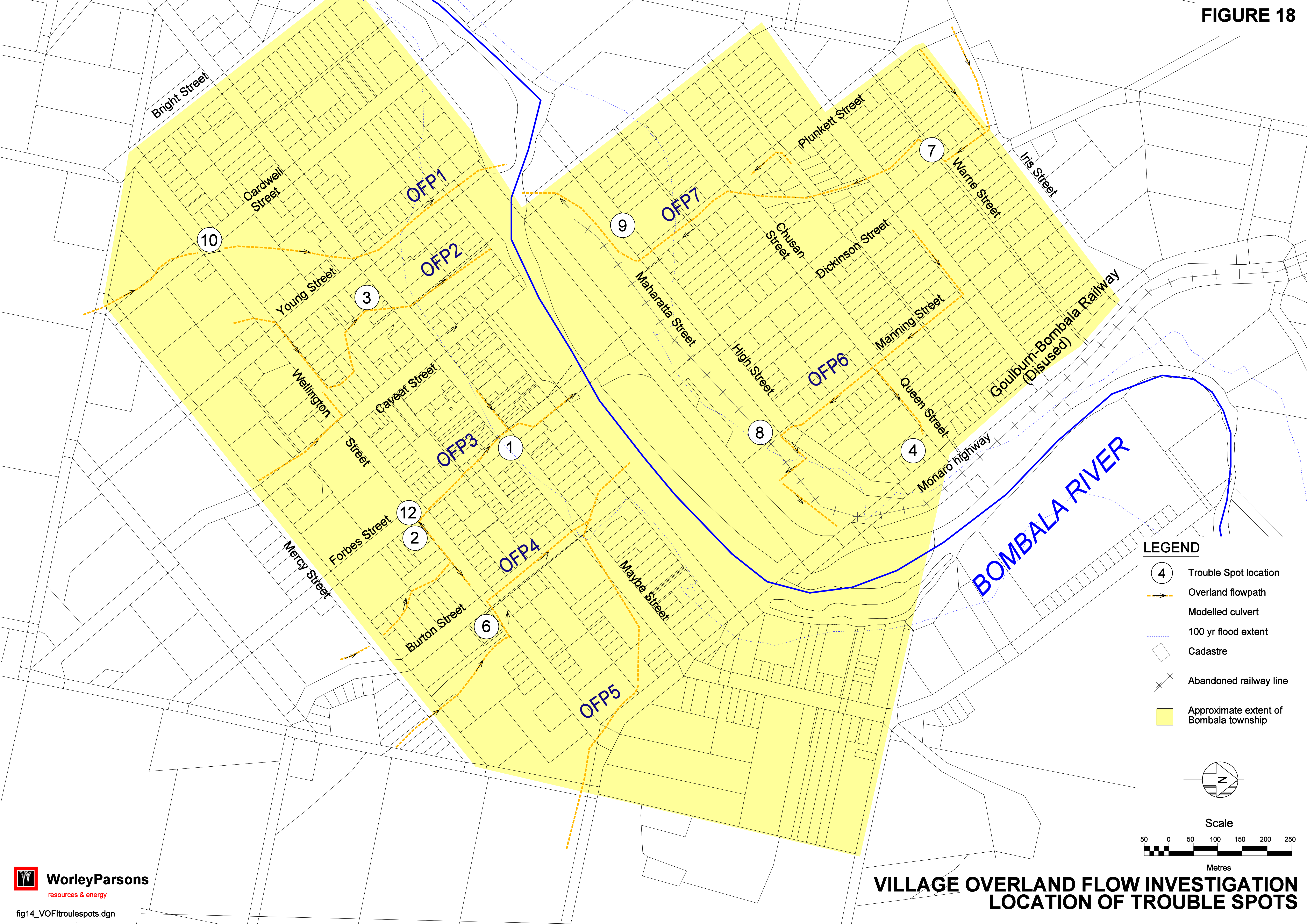
A brief description of the each of the sites is provided in the following sections. A qualitative assessment of the mechanisms which are understood to lead to inundation of the trouble spots has been included.

9.3.1 Trouble Spot 1: Forbes and Maybe Street Intersection

Trouble spot 1 is located at the intersection of Forbes and Maybe Street, on the southern side of the Bombala River. Forbes Street conveys the majority of run-off generated within Catchment C (*refer* **Section 9.2**) to the Bombala River. It is situated along the overland flow path identified as *OFP 3*.

The existing topography indicates that run-off flows north through the catchment and converges at the intersection of Forbes and Maybe Street. At this location, run-off is constricted due to development which has occurred along Maybe Street is concentrated along Forbes Street.

Consequently, stormwater builds up at the intersection, resulting in inundation of properties in the vicinity of the intersection. Water has been observed entering the premises of No. 79 Maybe Street. Stormwater also enters the cellar of the Imperial Hotel.



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VILLAGE OVERLAND FLOW INVESTIGATION
LOCATION OF TROUBLE SPOTS

In addition, the 100 year recurrence flood event of the Bombala River is predicted to extend as far as the intersection of Forbes and Maybe Street and is expected to further exacerbate the impact of stormwater run-off at *Trouble spot 1*.

Sub-surface drainage infrastructure is located on the south-western side of Forbes Street. The inlet to the drainage system is located on the southern corner of the Maybe Street. The sub-surface drain is a single 750 mm dia. pipeline for the majority of its length. The outlet of the drainage system is located at the bank of the Bombala River.

9.3.2 Trouble Spot 2: Wellington Street between Forbes and Burton Street

Run-off is generated from catchment C_u before being concentrated through the property of No. 8 Wellington Street. An open channel, which connects to a 375 mm dia. pipe culvert is located within the property. Once the capacity of the culvert is exceeded, water spills through the front yard and erodes the lawn and garden.

9.3.3 Trouble Spot 3: Maybe Street between Caveat and Young Streets

Run-off generated within catchment B collects along Caveat and Young Street and discharges into Wellington Street. Once in Wellington Street, run-off flows towards a low point located midway between Young Street and Caveat Street. A poorly defined overland flow path conveys run-off between Wellington and Maybe Street, identified as OFP2 (*refer* **Figure 18**).

OFP2 passes through the Toyota dealership (*154 Maybe Street*) and discharges across Maybe Street. At present, stormwater builds up on the southern side of Maybe Street and enters the workshop of the Toyota dealership.

Available survey indicates that the crest of Maybe Street is almost level with the floor of the Toyota dealership. In addition, the crest of Maybe Street is approximately 0.6 m above the northern side of Maybe Street. Accordingly, the crest of Maybe Street is understood to act as a critical hydraulic control for the peak water level at the Toyota dealership.

Once flow overtops the crest of Maybe Street, it discharges through the Bombala community centre property via a 10 metre wide grass strip located adjacent to the community centre building. Run-off has also been known to discharge through part of the Maneroo Motel property, although it is understood buildings are not inundated.

A sub-surface drainage system is located at *Trouble Spot 3*. The drainage system begins within the Toyota dealership property as a 525 mm dia. pipe. The pipe connects to the inlet structure located on Maybe Street outside the Toyota dealership. A 900x650 mm box culvert conveys flow beneath Maybe Street. On reaching the northern side of Maybe Street, the drainage line transitions to a 1300x600 mm box culvert which subsequently connects to a 900 mm dia. pipe before discharging at the bank of the Bombala River.

9.3.4 Trouble Spot 4: Queen Street near Monaro Highway

Run-off enters the intersection of Manning Street and Queen Street from the upper portion of catchment F. At the intersection the flow divides between Manning Street and Queen Street.

Grassed swales are located on either side of Queen Street for a certain distance down from Manning Street, however neither continues as far as the Monaro Highway. Twin 600 mm pipe culverts are located on the northern side of Queen Street discharge run-off from Queen Street beneath the Monaro highway.

The existing run-off issue at *Trouble spot 4* is caused by run-off discharging down Queen Street, overtopping the gutter on the southern side of the street near the intersection of Queen Street and Monaro Highway and discharging through properties located on the corner of Queen Street and the Monaro Highway.

9.3.5 Trouble Spot 6: Burton Street above Wellington Street

Run-off is conveyed along the rear of properties situated on Burton Street to the south of the Wellington Street intersection via the overland flow path identified as OFP4. At present run-off impedes upon the backyards of properties on the eastern side of Burton Street located near the intersection with Wellington Street.

At the intersection of Wellington Street and Burton Street, the channel joins to a recently installed pipe drainage line. The subsurface drainage line running down the eastern side of Burton Street is approximately 180 m in length. At the upstream end, the drainage line consists of a 1880 mm x 650 mm box culvert section which connects to a 1350 mm diameter pipe. The culvert discharges to an unnamed tributary which flows to the Bombala River. Flow in excess of the capacity of the drainage line is conveyed along Burton Street.

9.3.6 Trouble Spot 7: Dickinson & Warne Street

Iris Street is located at the very northern edge of the Bombala village area in sub-catchment G_u. A proportion of the flow from Iris Street drains into Dickinson Street with some being diverted along Warne Street and the overland flow path identified as OFP7.

Run-off has been observed inundating several front yards of properties along Dickinson Street between Iris and Warne Street along with some properties on Warne Street.

9.3.7 Trouble Spot 8: Manning and High Street Intersection

As discussed above (*refer* **Section 9.3.4**) run-off from the upper part of catchment F divides at the intersection of Manning and Queen Street. A portion of the run-off drains down Queen Street while the remaining flow discharges down Manning Street.

The grade of Manning street between Queen and High Street is hydraulically steep (*8% grade*). However, the grade flattens out at High Street. No sub-surface drainage infrastructure is located at the intersection of Manning Street and High Street. During times of high intensity storm events, run-off inundates the intersection of Manning and High Street. It is understood to present a hazard to motorists.

9.3.8 Trouble Spot 9: Plunkett and High Street Intersection

The overland flow path identified as OFP7 conveys generated by catchment G. The intersection of High Street and Plunkett Street is located near the base of OFP 7.

Twin 650 x 450 mm box culverts, approximately 16 metres in length have been installed at the intersection of Plunkett and High Street. During high intensity storm events, the culvert capacity is exceeded and run-off inundates the road.

9.3.9 Trouble Spot 10: Cardwell and Wellington Street Intersection

Runoff is conveyed to the intersection of Cardwell Street and Wellington Street via the overland flow path identified as OFP1. An existing 1050 mm dia. culvert is located at the intersection. On the downhill side of the intersection, run-off discharges through an undeveloped block of land.

During high intensity storm events, run-off overtops the road once the culvert's capacity is exceeded.

9.3.10 Trouble Spot 12: Wellington Street near Forbes Street

Stormwater has been observed to pond along Wellington Street near the intersection with Forbes Street, which is attributed to the very flat grade along Wellington Street.

It is understood that the ponded water does not represent a critical motoring hazard, nor does result in inundation of dwellings.

9.4 MODEL DEVELOPMENT

It was initially assumed that hydraulic models would be developed for the seven overland flow paths identified within the village area. Additionally, investigation of two sub-surface drainage systems was proposed for the VOFI.

The following is noted in regards to the VOFI investigation:

- For a number of different sections in the village area, the existing overland flow path is ill defined and has the potential to extend across a wide area, commonly referred to as “sheet” flow. In areas where sheet flow occurs, defining the flow extent is somewhat redundant.
- Additionally, sections of sheet flow often occur in combination with steep terrain. A wide channel area located on a steep slope creates hydraulic conditions where the predicted flow is very sensitive to small changes in depth.
- The extent of survey required to undertake the full analysis of the seven overland flow paths would prove expensive and the cost difficult to justify given the above characteristics of run-off in parts of the village area.
- The issues surrounding stormwater inundation in the village area are primarily restricted to the Trouble Spots identified. For much of the length of the overland flow paths, stormwater run-off is not considered to be a critical issue.

Therefore, it was decided that the VOFI would primarily focus on specific sections along the overland flow paths where run-off and inundation have been identified as an issue. A meeting with Mr Grantley Ingram at Bombala Council Chambers on 29th April 2009 assisted in defining the locations considered critical to the village overland flow investigation.

Accordingly, the additional survey data collected for the village overland flow investigation has primarily focussed on those location where inundation has been noted as an issue previously. The additional survey data collected is included for reference in **Appendix I**.

In addition, the results of the hydraulic modelling included in **Section 9.5** correspond to the trouble spots within the overland flow paths.

Notwithstanding, an inspection of each of the overland flow paths was undertaken to define key run-off characteristics and hydraulic controls.

9.4.1 Hydraulic Model Development

Three different options have been utilised for the development of the hydraulic models at each of the Trouble Spots. The three options are as follows:

- *HEC-RAS*: The *HEC-RAS* modelling software package was developed for modelling open channel scenarios such as rivers, creeks and channels. In addition, it facilitates analysis of other structures including culverts and bridges. HEC-RAS has been used to model situations where a reasonably well defined overland flow path exists.

- *DRAINS*: The *DRAINS* modelling software package allows analysis of sub-surface drainage systems. For the village overland flow investigation, the DRAINS software has been employed at two locations where significant sub-surface drainage infrastructure is located. In addition, DRAINS was used to confirm the capacity of a number of isolated culvert systems.
- Modelling has also been undertaken using standard hydraulic modelling procedures, including the following scenarios:
  - Determining culvert capacity;
  - Assessing free discharging broad crested weir scenarios (*e.g. road embankments*); and,
  - Normal depth calculations for open channels.

Each of the Trouble Spots was reviewed to determine the most suitable hydraulic model for the site.

9.4.2 Scenarios Analysed

The hydraulic models developed for each site have been used to simulate the peak discharge generated by three recurrence storm events, namely the 20, 100 and 200 year recurrence storm events. The peak discharge value at each of the sites investigated has been extracted from the relevant RAFTS model node. is provided in **Section 9.3**.

For the Trouble Spots where hydraulics is affected by flooding of the Bombala River, the recurrence storm events have been simulated in combination with two separate river level conditions. The first river level corresponds to the peak of the five year recurrence flood event in the Bombala River. This combination represents a minor catchment wide storm event occurring concurrently with each of the local catchment storms being assessed.

The second river level condition examined corresponds to the peak 100 year flood level in the Bombala River. It is noted that the 20 year local storm event was not modelled concurrently with the 100 year flood level. This is because a 100 year flood level in the Bombala River presumes a 100 year storm event within the Bombala village area.

Additionally, if a site is completely inundated by the 100 year recurrence flood event of the Bombala River then the assessment has only been completed for the 5 year river level. Details of the predicted peak flood level for the two events at each of the Trouble spots is included in **Section 9.5**.

The predicted extent of the 100 year Bombala River flood events is outlined in **Figure 18**.

9.5 HYDRAULIC MODELLING

9.5.1 Trouble Spot 1: Forbes and Maybe Street Intersection

The capacity of the existing sub-surface drainage system as well as the predicted flow characteristics along Forbes Street was assessed at Trouble spot 1. *DRAINS* was used to assess the capacity of the sub-surface drainage infrastructure while the *HEC-RAS* modelling package was used to determine the impact of overland flooding.

The peak discharge for the recurrence storm events investigated were extracted from the RAFTS node 3.01. The peak flood levels at Forbes Street for the 5 and 100 year recurrence flood events are included in **Table 21**.

The results of the DRAINS modelling indicate that only a very small proportion of the total flow is captured and conveyed by the sub-surface drainage system. A summary of the sub-surface drainage system capacity for the scenarios analysed is provided in **Table 21**.

Table 21 FORBES STREET SUB-SURFACE DRAINAGE CAPACITY

BOMBALA RIVER FLOOD EVENT (ARI)	DESIGN STORM EVENT (ARI)	ASSUMED PEAK FLOOD DISCHARGE (m^3/s) (RAFTS node 3.01)	PREDICTED PEAK FLOW IN SUB-SURFACE DRAIN (m^3/s)	PREDICTED PEAK OVERLAND FLOW (m^3/s)
5 year TWL (700.12 mAHD)	20	9.9	1.5	8.4
	100	13.4	1.5	11.9
	200	15.4	1.5	13.9
100 year TWL 703.50 m AHD	100	13.4	0.1[1]	13.3
	200	15.4	0.1[1]	15.3

1. During the 100 year Bombala River flood event, the exit of the pipe system is inundated with water. Consequently a negligible quantity of flow is conveyed by the pipe system

The results of the overland flow investigation along Forbes Street are summarised in **Table 22**. The modelling results reported in **Table 22** correspond to a location on Forbes Street approximately aligned with the shop fronts located along the northern side of Maybe Street.

Table 22 FORBES STREET OVERLAND FLOW PATH RESULTS

BOMBALA RIVER FLOOD EVENT (ARI)	DESIGN STORM EVENT (ARI)	ASSUMED OVERLAND FLOW (m^3/s)	PREDICTED PEAK FLOOD LEVEL (mAHD)	MAXIMUM DEPTH (m)	PREDICTED PEAK VELOCITY (m/s)
5 year TWL (700.12 mAHD)	20	8.4	703	0.45	1.55
	100	11.9	703.06	0.51	1.75
	200	13.9	703.09	0.54	1.83
100 year TWL 703.50 m AHD	100	13.3	703.50[1]	0.94	0.76
	200	15.3	703.50[1]	0.94	0.87

The above results indicate that there is little difference in the peak flood level at the intersection of Forbes and Maybe Street. This is the result of a wide overland flow path, where small increases in depth will generate significant increases in the discharge.

Run-off has been observed entering the furniture store located on the corner of Forbes and Maybe Street. The floor level of the furniture store has been surveyed as 702.89 mAHD. This accords with the findings of the above assessment which indicate that the furniture store would currently be inundated by a 20 year flood event in combination with a 5 year river level condition.

9.5.2 Trouble Spot 3: Maybe Street between Caveat and Young Streets

Trouble spot 3 is located along OFP2. Hydraulic modelling was undertaken for the overland flow path and the sub-surface drainage system. DRAINS was used to model the sub-surface drainage system. The overland flow path was assessed via a series of normal depth and broad crested weir calculations.

The peak discharge for the range of storm events being investigated at Trouble spot 3 were extracted from RAFTS node 2.01 and the peak flood levels extracted from the Flood Study. Both the peak discharges and the flood levels are documented in **Table 23**.

The capacity of the existing sub-surface drainage system which runs between Maybe Street and the Bombala River at Trouble spot 3 is outlined in **Table 23**.

Table 23 MAYBE STREET SUB-SURFACE DRAINAGE CAPACITY

BOMBALA RIVER FLOOD EVENT (ARI)	DESIGN STORM EVENT (ARI)	ASSUMED PEAK FLOOD DISCHARGE (m^3/s) (RAFTS node 2.01)	CULVERT PEAK FLOW (m^3/s)	PEAK OVERLAND FLOW (m^3/s)
5 year TWL (700.00 mAHD)	20	17.2	1.2	16
	100	25.0	1.2	23.8
	200	29.2	1.2	28
100 year TWL (703.39 m AHD)	100	25.0	0.1[1]	24.9
	200	29.2	0.1[1]	29.1

1. During the 100 year Bombala River flood event, the exit of the pipe system is inundated with water. Consequently a negligible quantity of flow is conveyed by the pipe system

Hydraulic modelling was undertaken for OFP2 (*refer* **Figure 18**) between the southern side of Maybe Street (*i.e. outside the Toyota Dealership*) and the Bombala River. From this assessment peak flood levels, depths and flow velocities were determined at a series of locations.

The available survey data indicates that the crest of Maybe Street is approximately 600 mm above the northern gutter on Maybe Street. The difference in surface level is sufficient to ensure that the inundation due to run-off on the southern side of Maybe Street is controlled by the crest level of Maybe Street.

Consequently, the crest of Maybe Street is understood to act as a broad crested weir and control the peak flood level at Trouble spot 3. The predicted peak flood level and depth of inundation at Trouble spot 3 is outlined in **Table 24**.

The analysis indicates that the only difference in the peak flood level at Trouble spot 3 between the two Bombala River flood level cases examined is due to the predicted reduction in capacity of the pipe drainage system during the 100 year recurrence flood event. However, only a small proportion of the peak flow is conveyed by the sub-surface drainage system (*refer* **Table 23**) and as a consequence the difference in inundation levels has been found to be negligible.

The predicted depth of inundation of the Toyota dealership, based on surveyed floor levels is included in **Table 24**.

Table 24 PEAK FLOOD LEVELS AT TROUBLE SPOT 3

BOMBALA RIVER FLOOD EVENT (ARI)	DESIGN STORM EVENT (ARI)	PREDICTED OVERLAND FLOW (m^3/s)	WATER LEVEL SOUTHERN SIDE MAYBE STREET (mAHD)	DEPTH OF INUNDATION AT TOYOTA DEALERSHIP (m) (Floor RL = 704.09 mAHD)
5 year TWL: 700.00 mAHD	20	16	704.22	0.13
	100	23.8	704.27	0.18
	200	28	704.29	0.20
100 year TWL: 703.39 m AHD	100	24.9	704.27	0.18
	200	29.1	704.29	0.20

9.5.3 Trouble Spot 4: Queen Street near Monaro Highway

A HEC-RAS model was developed to assess flooding along OFP6 to quantify flood impacts at Trouble spot 4. At present, floodwaters inundate properties near the corner of Queen Street and the Monaro Highway. The HEC-RAS model was developed using the detailed survey data collected during 2009.

Trouble spot 4 is located within catchment F (*refer* **Figure 17**). The proportion of the catchment located above Queen Street equates to an area of approximately 16.6 ha. Run-off generated from this sub-catchment area will divide between Queen Street and Manning Street. Based on the site inspection and the available survey data, it is reasonable to assume that run-off from this sub-catchment area divides evenly between Queen Street and Manning Street. The peak run-off values, based on the above assumption corresponding to the 20, 100 and 200 year recurrence storm events, are summarised in **Table 25**.

Table 25 provides a summary of the results of hydraulic modelling along Queen Street. An estimate of the peak stormwater flow through Trouble Spot 4 is included. Since the site remains unaffected by flooding of the Bombala River up to and including the 100 year recurrence flood event one set of results for each event was sufficient.

Table 25 QUEEN STREET DRAINAGE CAPACITY

DESIGN STORM EVENT (ARI)	PEAK FLOW IN QUEEN STREET (m^3/s)	PEAK DISCHARGE THROUGH PROPERTIES (m^3/s)	CULVERT DISCHARGE (50% blocked) (m^3/s)
20 year	2.3	1.45	0.85
100 year	3.8	2.90	0.90
200 year	4.3	3.40	0.90

9.5.4 Trouble Spot 6: Burton Street above Wellington Street

An assessment was undertaken of the sub-surface drain which runs along the eastern side of Wellington Street located along OFP4. This assessment determined the inundation depth of the road at the intersection of Wellington and Burton Street.

The predicted peak run-off values were extracted from RAFTS node 4.01. The site remains free of backwater flooding from the Bombala River during the 100 year recurrence flood event.

A summary of key flood parameters is provided in **Table 26**.

Table 26 BURTON STREET CULVERT CAPACITY

DESIGN STORM EVENT (ARI)	PEAK DISCHARGE (m^3/s) (RAFTS node 4.01)	FLOW IN CULVERT (m^3/s)	OVERLAND FLOW (m^3/s)	DEPTH OF FLOW IN BURTON STREET	FLOW VELOCITY ALONG ROAD (m/s)
20	10.0	3.4	6.6	0.11	1.5
100	14.3	3.6	10.1	0.14	1.7
200	16.4	3.7	12.2	0.16	1.9

It was determined from the assessment that inundation of rear yards of properties along Burton Street should remain unaffected from the flood level at the intersection of Burton Street and Wellington Street.

Detailed survey wasn't collected in the vicinity of these yards. However, based on the existing terrain and predicted flow values, the flow depths are expected to be shallow. The flooding of the rear yards is a function of their proximity to a natural drainage channel.

9.5.5 Trouble Spot 8: Manning and High Street Intersection

The main issue surrounding floodwaters at High Street is caused by stormwater run-off from Manning Street.

The predicted peak depth of flow at the intersection of Manning and High Street was determined assuming a worst case scenario where the flow discharged down Manning Street remains concentrated while crossing High Street.

Peak flow data for the location was extracted from node 5.00, with the proportion of peak flow discharging down Queen Street subtracted (*refer* **Section 9.5.3**). This site remains unaffected by flooding of the Bombala River for events up to and including the 100 year ARI flood.

Table 27 below provides a summary of the key flood parameters at the intersection.

Table 27 FLOW CHARACTERISTICS AT HIGH AND MANNING STREET INTERSECTION

DESIGN STORM EVENT (ARI)	PEAK FLOW (m^3/s) (RAFTS node 5.00)	DEPTH OF FLOW ACROSS ROAD (m)	FLOW VELOCITY (m/s)
20	13.3	0.17	2.7
100	17.5	0.20	3.0
200	20.3	0.21	3.2

9.5.6 Trouble Spot 9: Plunkett & High Street Intersection

The slope and dimensions of Plunkett Street controls overland flow characteristics at the Plunkett and High Street intersection. Therefore, normal depth calculations were undertaken to determine the characteristics of flooding at the site.

Additionally, the capacity of the culverts at the intersection was undertaken based on standard culvert calculations.

The peak flow data for Trouble spot 9 was extracted from node 6.01. Trouble spot 9 is completely inundated during the 100 year recurrence flood event of the Bombala River. Accordingly only one set of results is provided.

A summary of the depth and velocity characteristics of the flow across the road is included in **Table 28**.

Table 28 FLOW CHARACTERISTICS PLUNKETT AND HIGH STREET INTERSECTION

DESIGN STORM EVENT (ARI)	PEAK DISCHARGE (m^3/s) (refer RAFTS node 6.01)	FLOW THROUGH CULVERT (m^3/s)	OVERLAND FLOW (m^3/s)	DEPTH OF FLOW ACROSS ROAD (m)	FLOW VELOCITY ACROSS ROAD (m/s)
20	12.2	1.6	10.6	0.11	3.1
100	16.8	1.7	15.1	0.14	3.57
200	19.4	1.7	17.7	0.16	3.8

9.5.7 Trouble Spot 10: Culvert at Corner of Cardwell & Wellington Streets

Trouble Spot 10 was modelled using standard culvert procedures and broad crested weir calculations.

Flow data used in the modelling was extracted from node 1.00. The site is unaffected by Bombala River flooding up to and including the 100 year recurrence flood event.

The predicted peak flow across the road and within the culverts is provided in **Table 29**, together with the predicted peak depth of inundation.

Table 29 WELLINGTON STREET FLOW CHARACTERISTICS

DESIGN STORM EVENT (ARI)	PEAK DISCHARGE (m^3/s) (RAFTS node 1.01)	CULVERT FLOW (m^3/s)	OVERLAND FLOW (m^3/s)	PREDICTED DEPTH OF FLOW ABOVE LOW POINT(m)
20	9.1	3.4	5.7	0.33
100	13.7	3.6	10.1	0.42
200	16.2	3.7	12.5	0.46

9.5.8 Other Trouble Spots (2, 7, 12)

The remaining Trouble spots are locations where nuisance run-off has been observed but do not result in damage to dwellings or inundation of the roads. A brief assessment is provided for each of the sites following.

Trouble Spot 2

Trouble spot 2 is located near the beginning of OFP3. The existing 375 mm dia. pipe culvert was assessed and determined to have negligible capacity (*i.e. 0.1* m^3/s) due to the small cross sectional area and flat grade of the culvert.

Consequently, run-off spills out of the drainage channel located within No.8 Wellington Street and discharges across through the front yard as “sheet flow” While it does not enter dwellings, it results in erosion of the front yard and garden.

Trouble Spot 7

Trouble spot 7 is located near the top of catchment F adjacent to the watershed of the Bombala village catchment area. Consequently, the peak run-off within the vicinity of Trouble spot 7 is expected to be minimal.

In this regard, results extracted from RAFTS node 6.00 provides some guidance as to the expected peak discharge at node 6.00. These results indicate that the peak discharge for the 200 year event is only 1 m^3/s. Based on an indicative assessment, the depth of flow is expected to be less than 100 mm.

Trouble Spot 12

No specific analysis has been undertaken for Trouble spot 12. The water which ponds during a storm event results from the very flat grade along Wellington Street. It is understood to be more a nuisance than an actual risk during storm events and survey information indicates the terrain is not sufficient for it to be either deep enough or fast enough to present as a hazard to traffic.

9.6 RECOMMENDATIONS

The following section focuses on two key aspects of reducing the impact of run-off during overland flows. These are improving maintenance of the existing system and recommendations to reduce the impact of run-off at specific sites.

9.6.1 Maintenance

During the site visit, it was noticed that a large proportion of the existing drainage infrastructure is blocked by debris. In some cases, 50% of the capacity of the pipe was blocked. Therefore, it is proposed that Council initiate a maintenance program to provide for the cleaning and removal of sediment from drainage infrastructure.

In addition to a regular maintenance program, the installation of sediment traps at strategic locations would reduce the frequency with which infrastructure needs to be maintained and increase the ease with which sediment can be removed.

9.6.2 Site Specific Recommendations

Trouble Spot 1 & Trouble Spot 3

These two sites are considered to be most critical as they are locations where local catchment storm events potentially result in stormwater entering dwellings and businesses.

Based on the experience of modelling the existing sub-surface drainage systems, it has been concluded that installing additional sub-surface drainage infrastructure will be of limited value in reducing inundation levels and is likely to require significant capital expenditure. Additionally, the capacity of any additional drainage infrastructure would remain negligible during major flood events in the Bombala River as a result of water "backing up".

It is recommended that the installation of stormwater detention basins at strategic locations along the respective overland flow paths be investigated. Aerial photography indicates there are a number of locations where a detention basin may be installed in the respective sub-catchments of trouble spots 1 & 3. The costs and benefits associated with any proposed detention basin(s) could be considered as an extension to the Bombala Floodplain Risk Management Study and Plan.

Trouble Spot 4

The installation of additional culverts, on the same side of Queen Street as where run-off discharge through properties may reduce the impact of floodwaters at these properties. Culverts are considered to represent an effective option for two reasons. Firstly, relatively small peak discharges are expected at the site. Secondly, the site remains unaffected by flooding of the Bombala River for events up to and including the 100 year flood event.

In addition, consideration should be given to extending the swale which runs down the southern side of Queen Street. A swale is located on this side of the street, however it terminates midway down Queen Street.

Other Locations

At present, the findings of the hydraulic investigation indicate that flooding during local storm events at other sites could be defined as nuisance flooding and only represents a low hazard to people. If necessary, signage could be installed to advise people of the danger of floodwater at particular sites.

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APPENDIX A
RAFTS MODEL INPUT PARAMETERS

TABLE A1 - ADOPTED SUB-CATCHMENT PARAMETERS FOR RAFTS MODEL OF BOMBALA RIVER

RAFTS MODEL SUB-CATCHMENT	RAFTS MODEL NODE AT DOWNSTREAM END OF CATCHMENT	AREA *(ha)*	WATERCOURSE LENGTH *(m)*	VECTOR AVERAGED SLOPE *(%)*	PERVIOUS 'n'	RAINFALL LOSSES		LAG TIME *(minutes)*
						Initial *(mm)*	Continuing *(mm/h)*	
A	1.00	2272	9471	4.0	0.1	10	6	28.6
B	5.00	1022	7600	4.4	0.1	10	6	28.6
C	1.01	1336	4296	4.9	0.1	10	6	17.6
D	1.02	655	2644	3.9	0.1	10	6	51.4
E	6.00	3328	6437	3.2	0.1	10	6	51.4
F	1.03	2673	7707	3.3	0.1	10	6	47.6
G	1.04	3255	7140	2.3	0.1	10	6	22.2
H	4.00	1529	7640	1.3	0.1	10	6	27.8
I	3.00	5079	12513	1.9	0.09	10	5	58.2
J	4.01	1372	4173	4.0	0.1	10	6	51.4
K	3.01	4282	8732	2.1	0.1	10	5	10.1
L	4.02	2754	9251	1.4	0.09	10	6	30.1
M	1.05	1271	3337	3.7	0.09	10	6	35.9
N	1.06	1631	6453	1.9	0.09	10	5	10.1
O	7.00	720	1814	1.8	0.07	10	5	29.2
P	1.07	867	1814	3.2	0.07	10	5	29.2
Q	1.08	2060	5262	2.7	0.07	10	5	21.6
R	1.09	870	3242	4.6	0.1	10	5	91.0
S	8.00	1498	7220	2.3	0.07	10	5	91.0
T	1.10	1911	13648	1.9	0.07	10	5	9.0
U	1.11	202	1354	4.0	0.06	10	5	16.8
V	1.12	473	2524	4.4	0.05	10	5	25.1
W	1.13	579	3758	3.0	0.05	10	5	0.0
X	2.00	962	5337	3.4	0.1	10	6	20.6
Y	9.00	924	5860	2.5	0.1	10	6	20.6
Z	2.01	593	3087	3.8	0.1	10	6	45.6
AA	10.00	1649	7518	2.0	0.1	10	6	38.0
AB	2.02	1270	6834	1.2	0.09	10	6	30.1
AC	2.03	600	5410	2.8	0.1	10	6	21.4
AD	11.00	764	5120	3.4	0.1	10	6	21.4
AE	12.00	1852	7680	2.6	0.07	10	6	12.0
AF	2.04	1001	3858	2.0	0.1	10	6	12.0
AG	2.05	386	2163	2.7	0.07	10	6	30.7
AH	2.06	707	5520	4.3	0.1	10	6	22.1
AI	2.08	1162	3984	2.9	0.07	10	6	15.0
AJ	16.00	529	3222	3.3	0.1	10	6	30.1
AO	13.01	349	2996	3.2	0.07	10	6	22.1
AN	13.00	759	4995	3.8	0.07	10	6	30.1
AK	14.00	702	3984	4.8	0.07	10	6	0.0
AL	15.00	215	2246	4.9	0.06	10	6	0.0
AM	2.09	248	2246	4.2	0.06	10	6	14.0

APPENDIX B

INTENSITY–FREQUENCY-DURATION DATA FOR BOMBALA AND CATHCART

TABLE B1 - BOMBALA IFD TABLE

IFD INTENSITY BASED ON AUSTRALIAN RAINFALL & RUNOFF 1987

Site Name: Bombala River Catchment, BOMBALA

IFD Table for Various ARIs and Durations

DURATION	AVERAGE RECURRENCE INTERVAL						
	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
6min	62	82	112	131	156	191	220
10	51	67	91	107	128	157	180
20	37	48.9	66	78	93	114	131
30	30.1	39.8	54	63	76	93	107
1.0 hr	20.5	27.1	36.8	43.1	51	63	73
2	13.8	18.2	24.5	28.6	34	41.5	47.5
3	11	14.4	19.3	22.4	26.5	32.2	36.8
6	7.33	9.59	12.7	14.7	17.3	20.9	23.8
12	4.91	6.41	8.39	9.65	11.3	13.6	15.4
24	3.39	4.39	5.63	6.39	7.42	8.82	9.93
36	2.71	3.49	4.41	4.98	5.75	6.78	7.6
48	2.29	2.94	3.69	4.13	4.75	5.58	6.23
72	1.78	2.27	2.81	3.12	3.57	4.16	4.61

Geographical factor for 6 min 2 yr storm = 4.23
Geographical factor for 6 min 50 yr storm = 15.6
Skewness = 0.22

2-year ARI,
1 hour intensity = 27.5
12 hour intensity = 6.5
72 hour intensity = 2.3

50-year ARI,
1 hour intensity = 60
12 hour intensity = 13
72 hour intensity = 4

TABLE B2 - CATHCART IFD TABLE

IFD INTENSITY BASED ON AUSTRALIAN RAINFALL & RUNOFF 1987

Site Name: Coolumbooka River Catchment, CATHCART

IFD Table for Various ARIs and Durations

DURATION	AVERAGE RECURRENCE INTERVAL						
	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
6min	63.4	84.1	115	135	162	199	230
10	51.9	68.9	94.4	111	133	164	189
20	37.5	49.8	68.5	80.9	97.1	120	138
30	30.5	40.5	55.8	65.9	79.1	97.7	113
1.0 hr	21	27.9	38.6	45.6	54.8	67.7	78.2
2	14.4	19.2	26.6	31.5	37.9	46.9	54.2
3	11.6	15.4	21.4	25.4	30.6	37.9	43.9
6	7.95	10.6	14.8	17.6	21.3	26.5	30.7
12	5.5	7.33	10.2	12.1	14.6	18.1	21
24	3.8	5.03	6.86	8.06	9.61	11.8	13.6
36	3.01	4.01	5.42	6.05	7.08	8.78	10.05
48	2.57	3.36	4.44	5.13	6.03	7.28	8.28
72	2	2.6	3.39	3.88	4.53	5.42	6.12

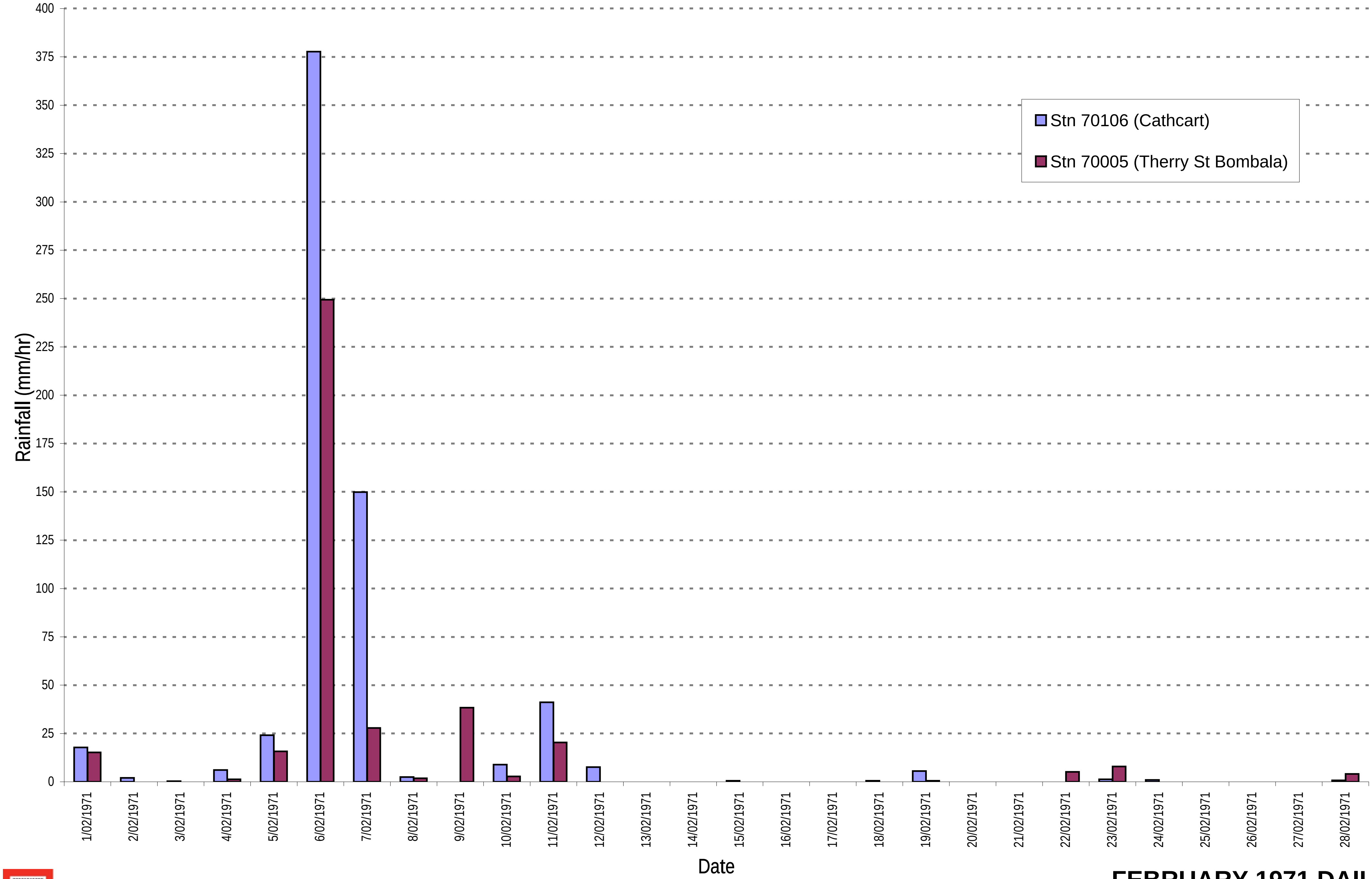
Geographical factor for 6 min 2 yr storm = 4.22
Geographical factor for 6 min 50 yr storm = 15.66
Skewness = 0.21

2-year ARI,
1 hour intensity = 28.13
12 hour intensity = 7.44
72 hour intensity = 2.64

50-year ARI,
1 hour intensity = 63.91
12 hour intensity = 17.33
72 hour intensity = 5.18

APPENDIX C
HISTORICAL RAINFALL DATA

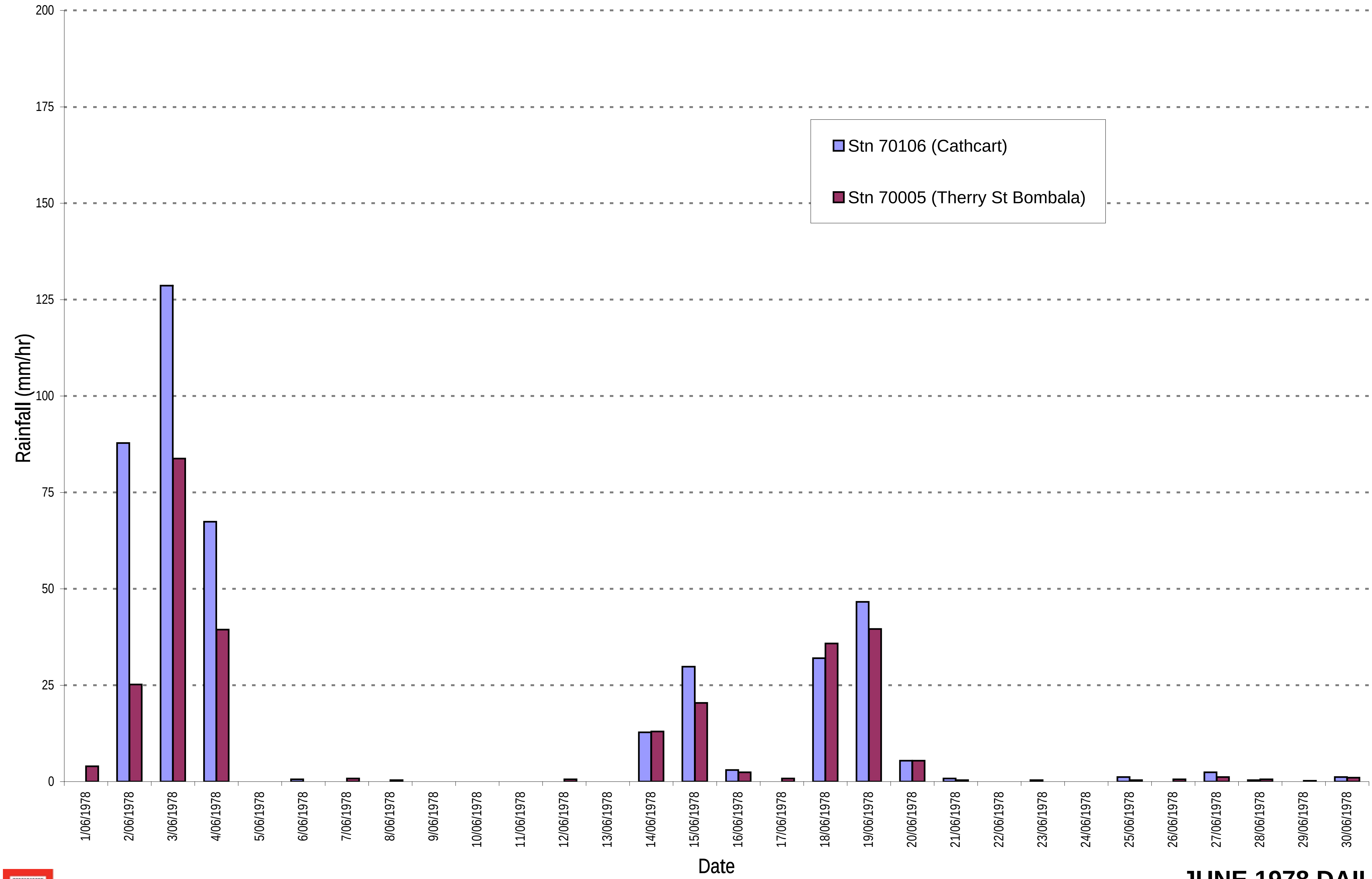
FIGURE C1



WorleyParsons
resources & energy

FEBRUARY 1971 DAILY READ RAINFALL HYETOGRAPHS

FIGURE C2

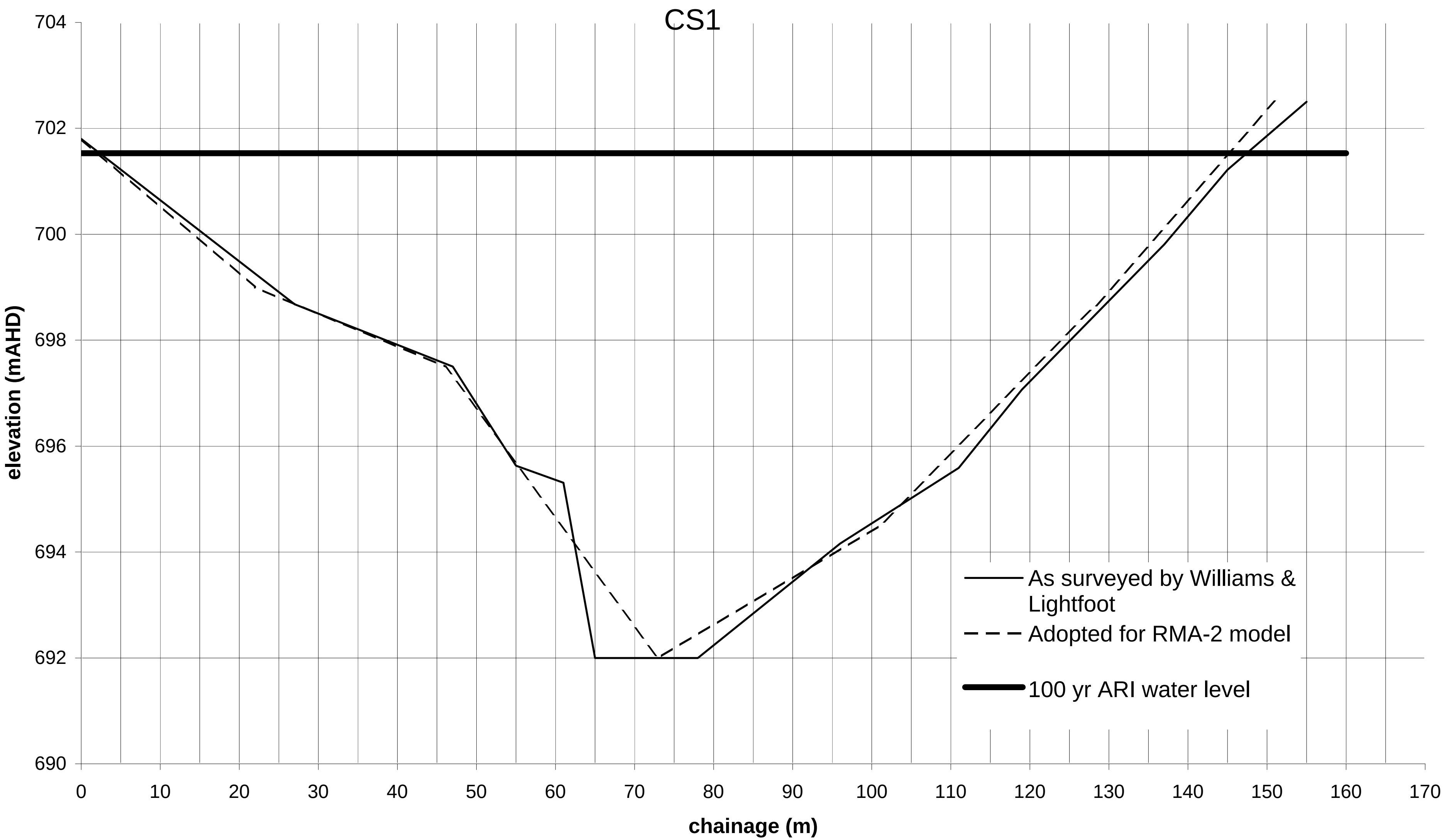


WorleyParsons
resources & energy

JUNE 1978 DAILY
READ RAINFALL HYETOGRAPHS

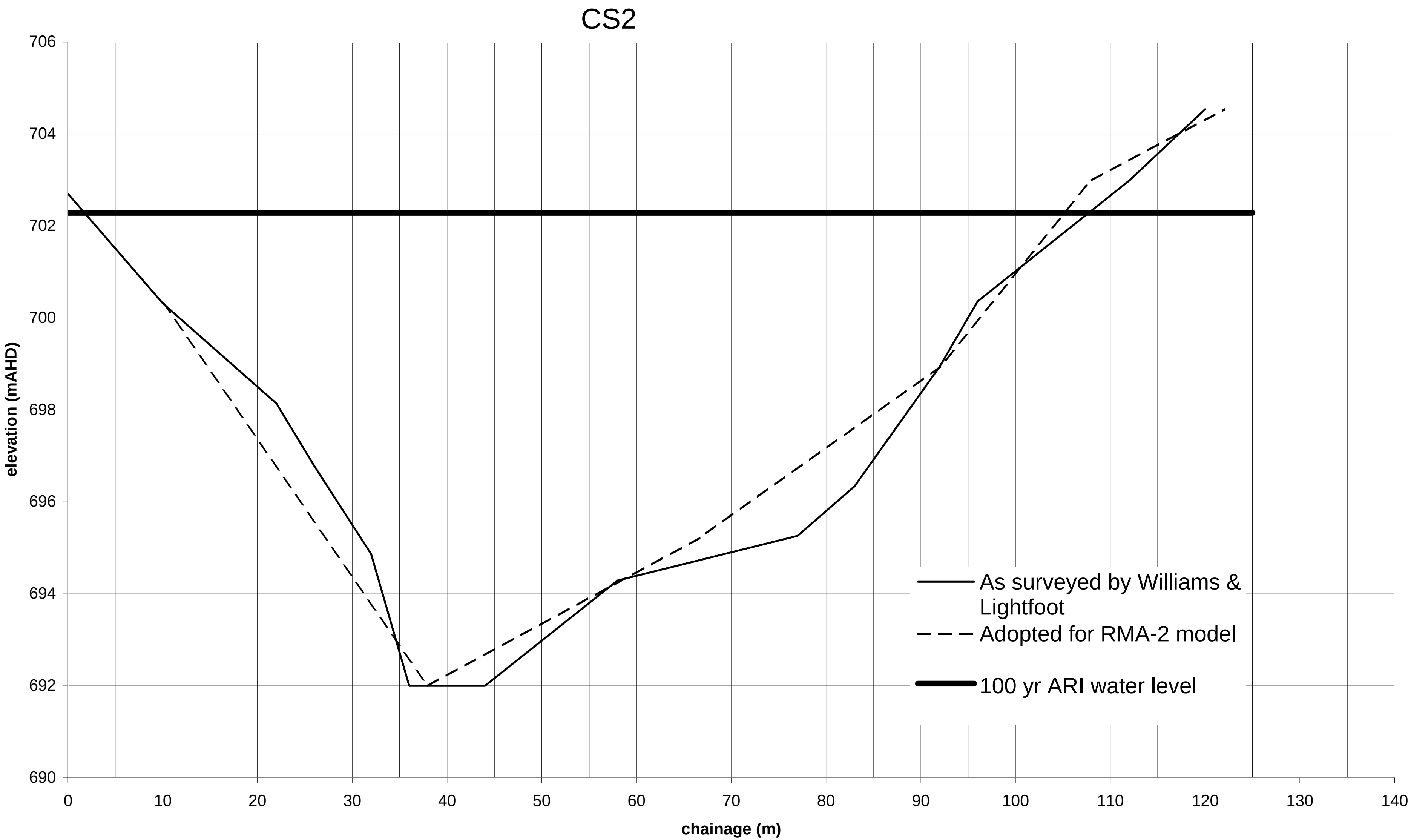
APPENDIX D

HYDRAULIC MODEL CROSS-SECTIONS

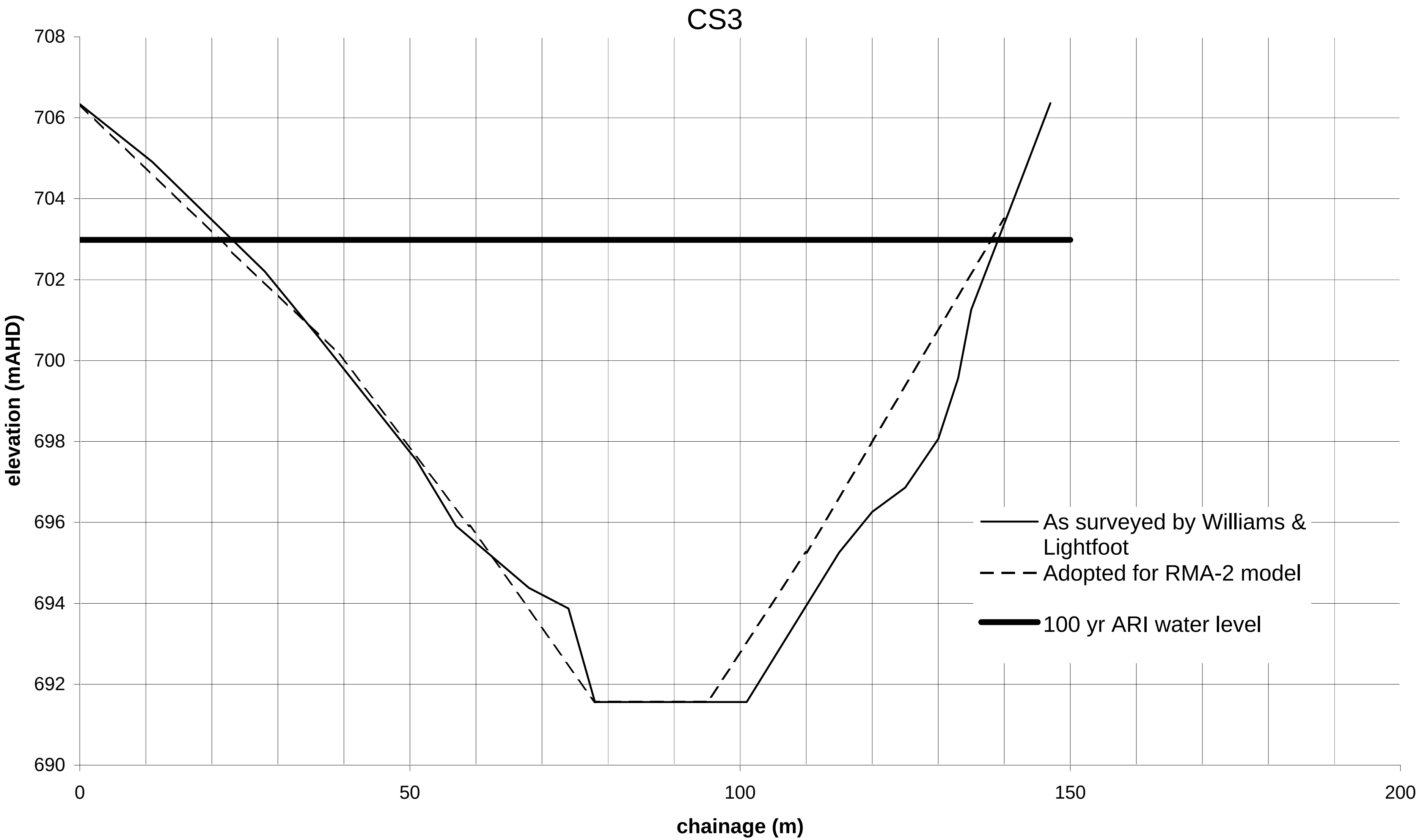


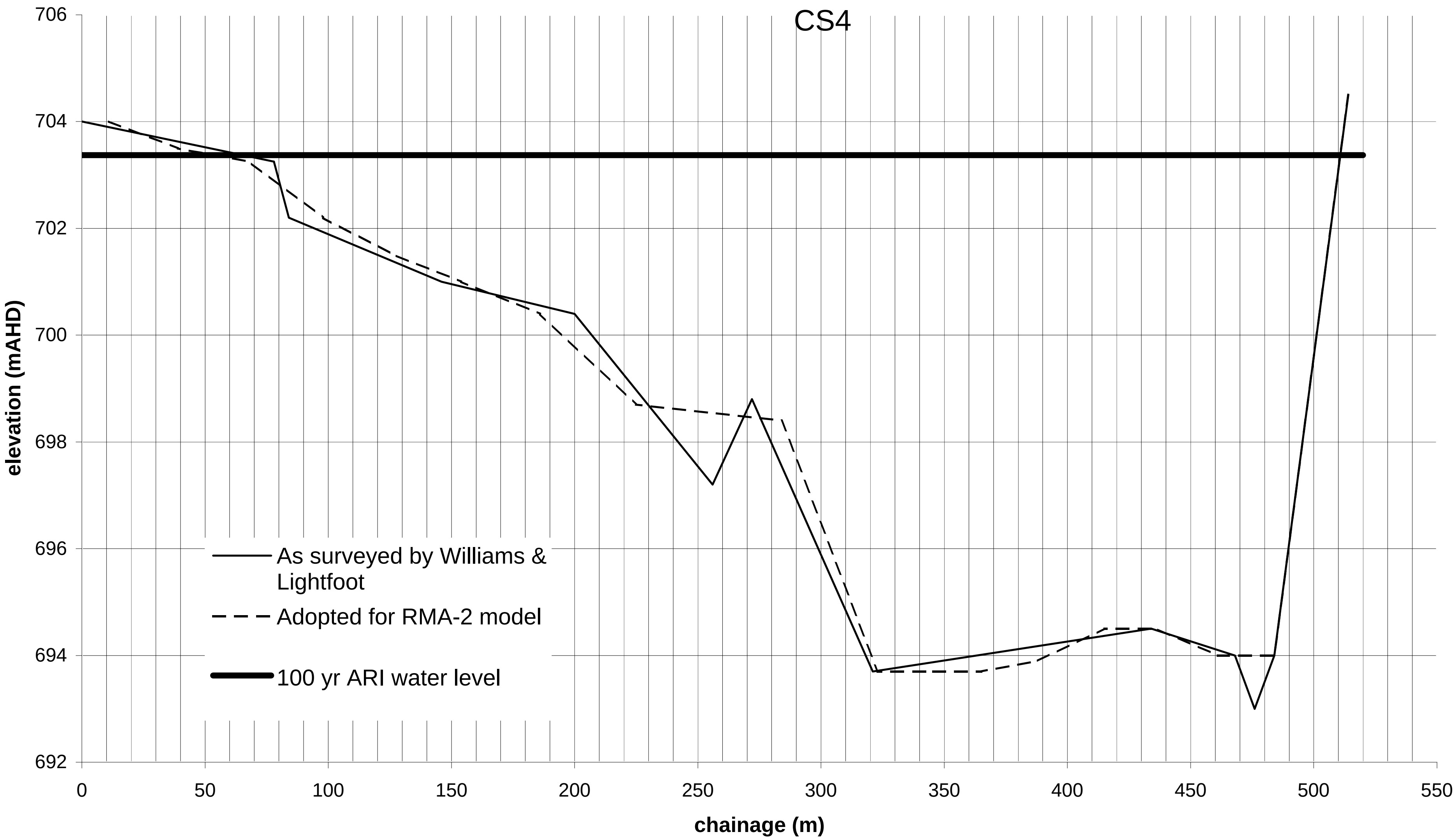
CS1
704
702
700
698
696
694
692
690
elevation (mAHD)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

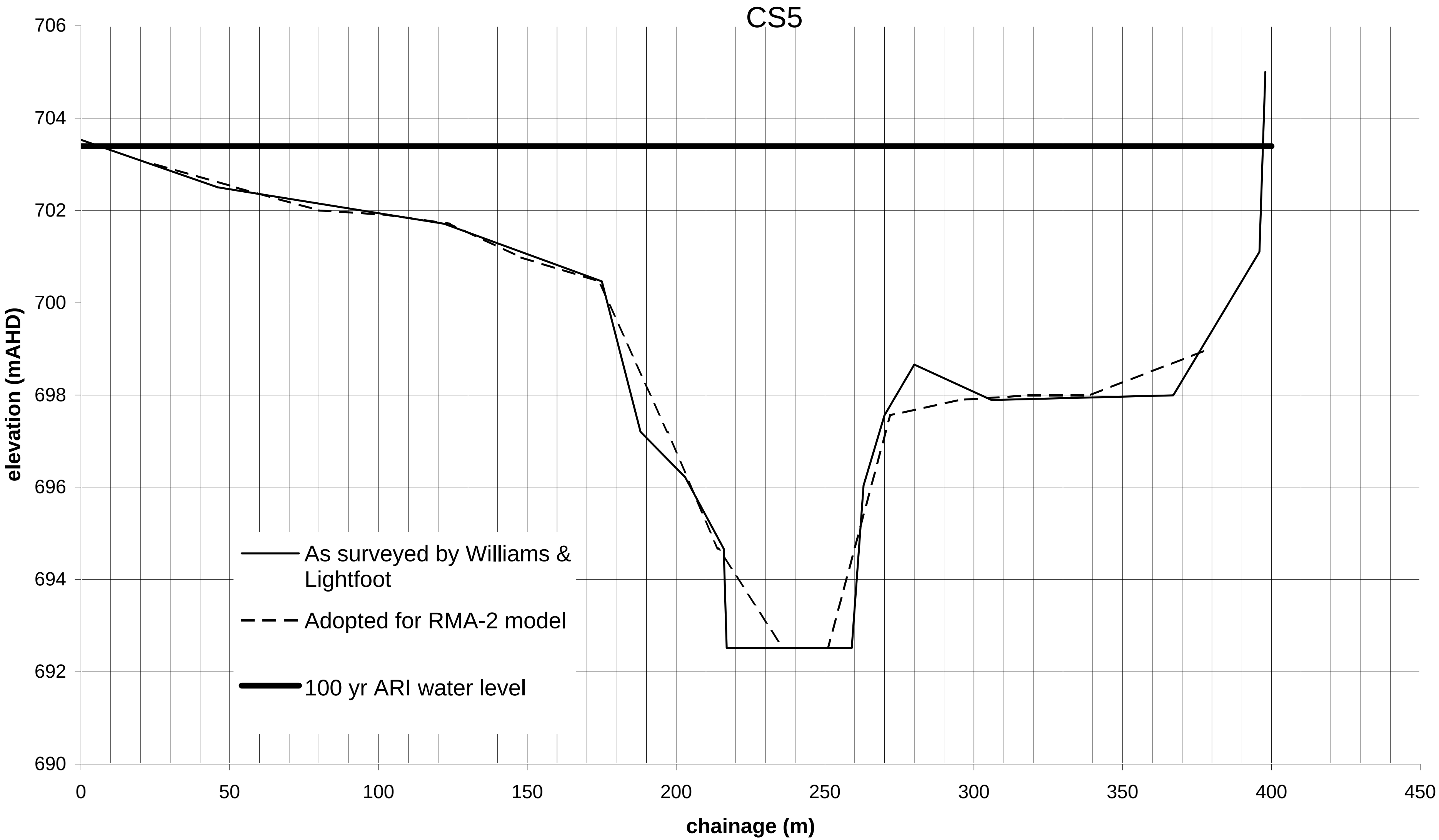
Appendix D

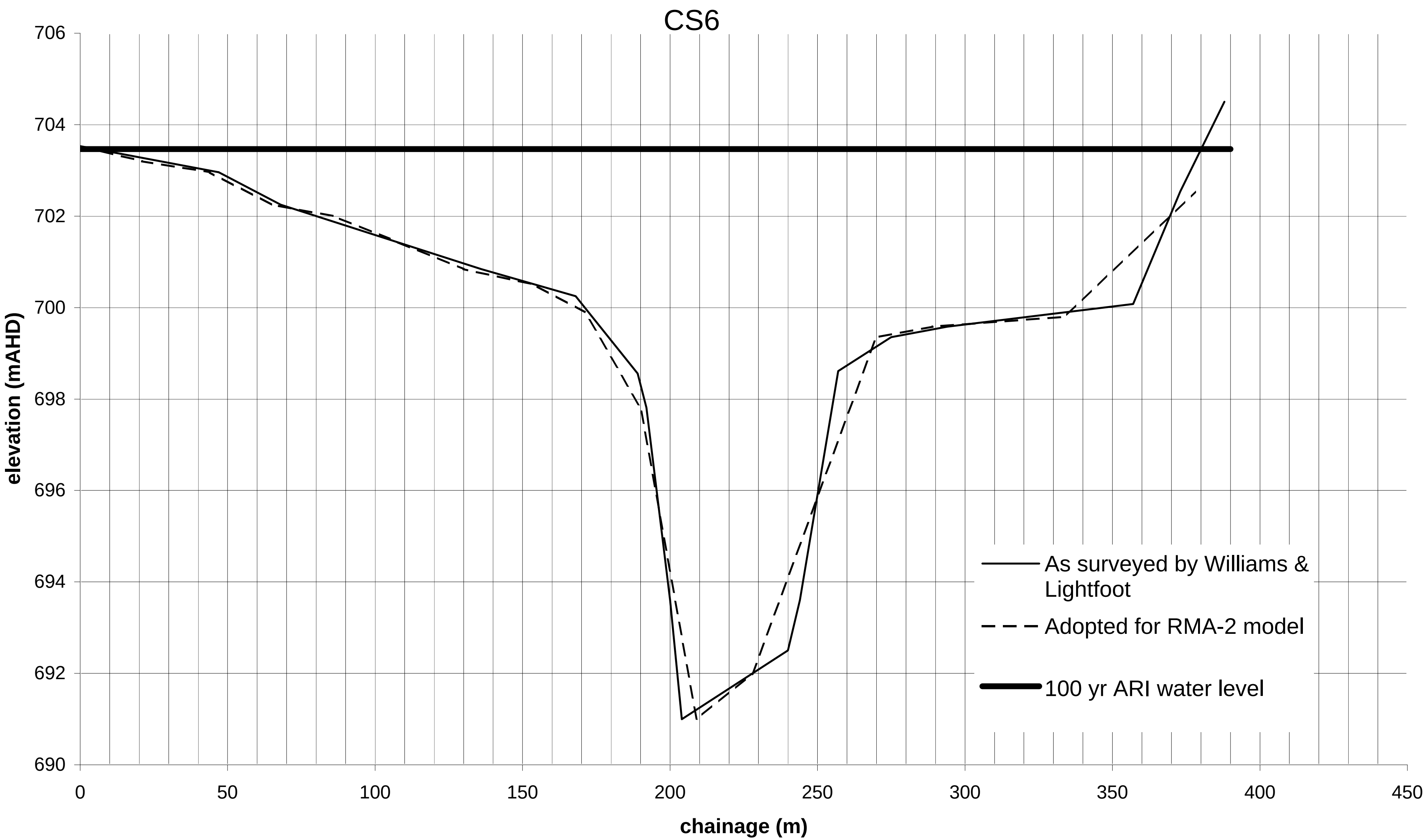


CS2
706
704
702
700
698
696
694
692
690
elevation (mAHD)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

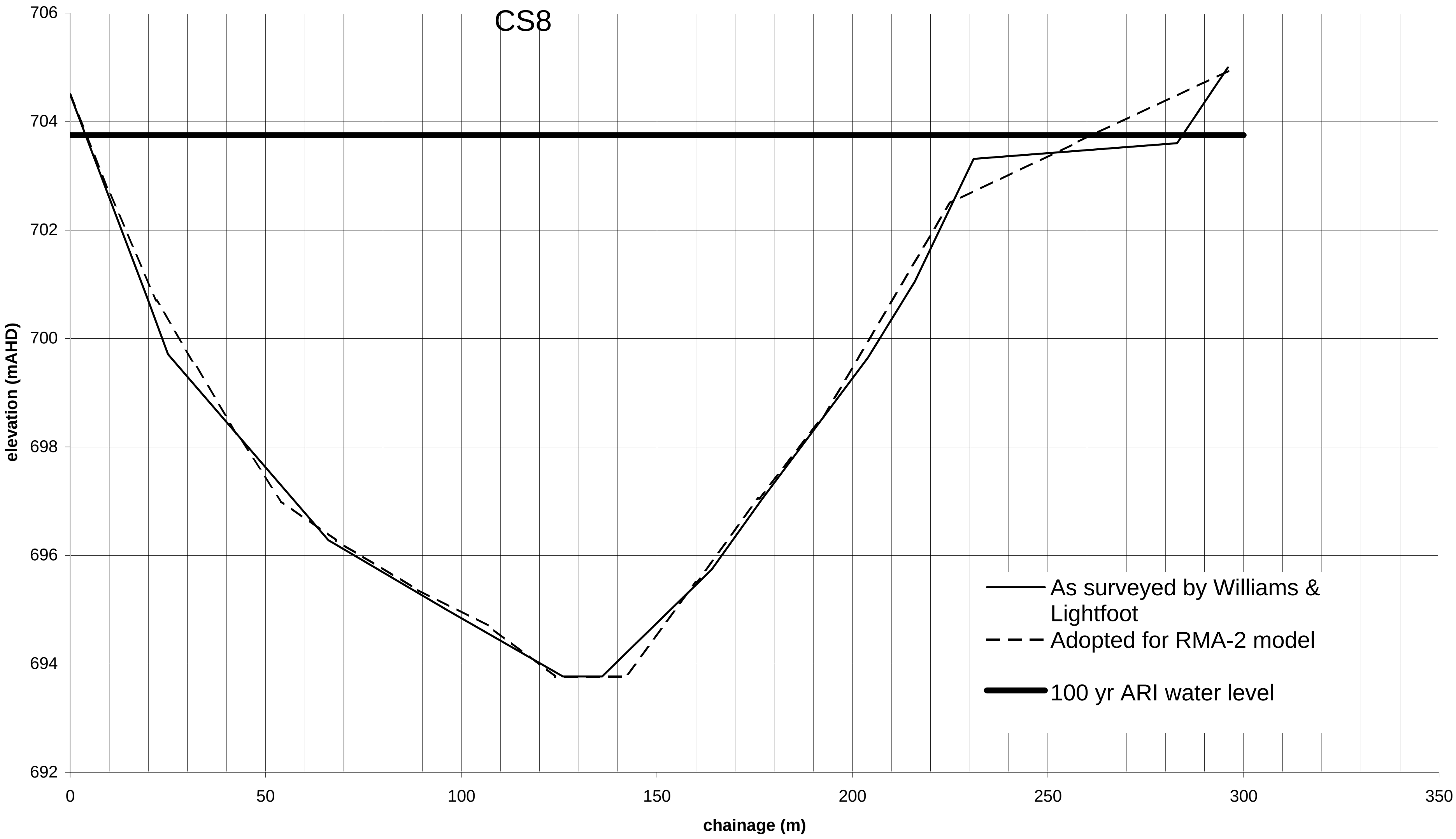

CS3
708
706
704
702
700
698
696
694
692
690
elevation (mAHD)
0
50
100
150
200
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

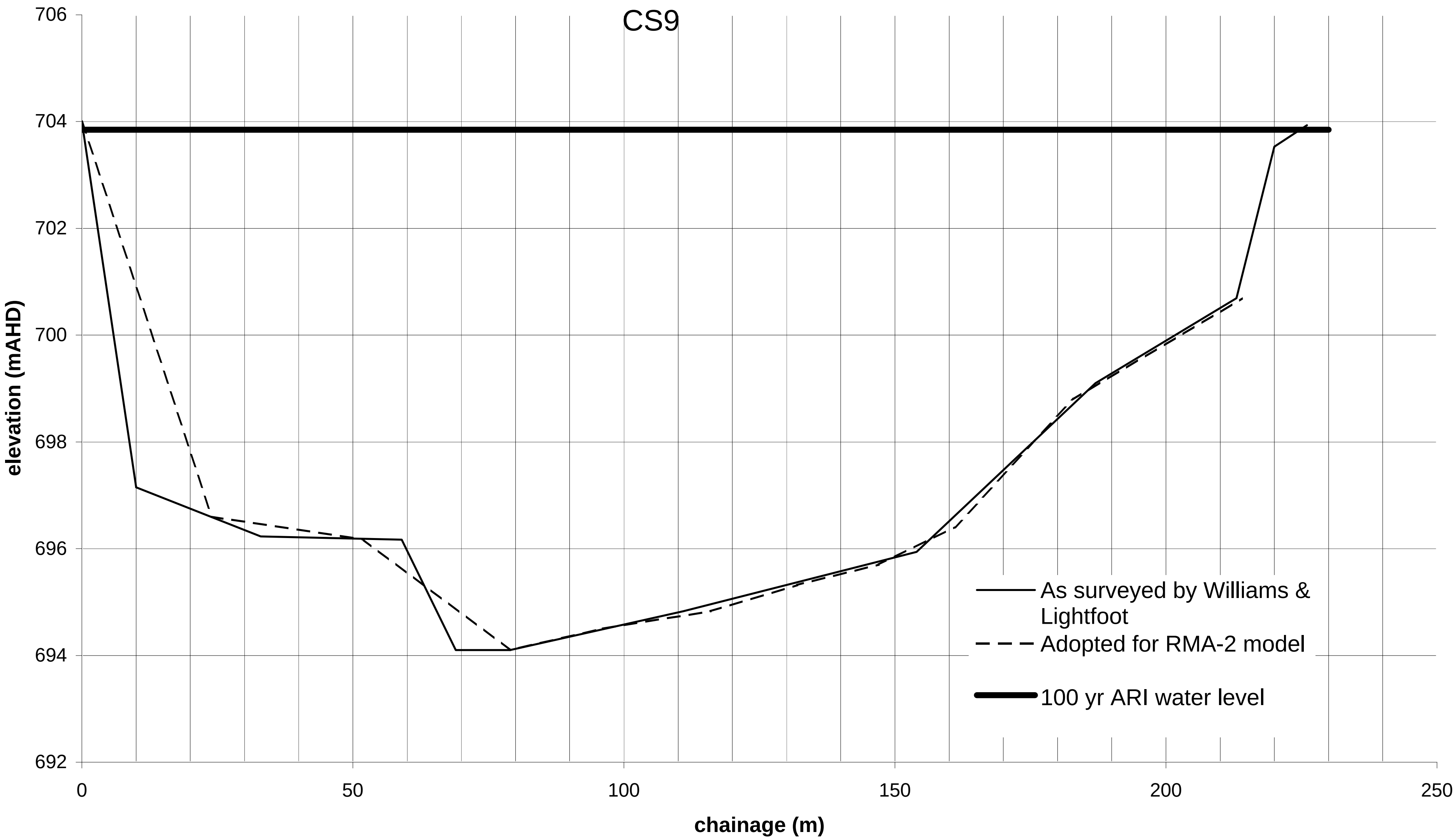

CS4
706
704
702
700
698
696
694
692
elevation (mAHD)
0
50
100
150
200
250
300
350
400
450
500
550
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

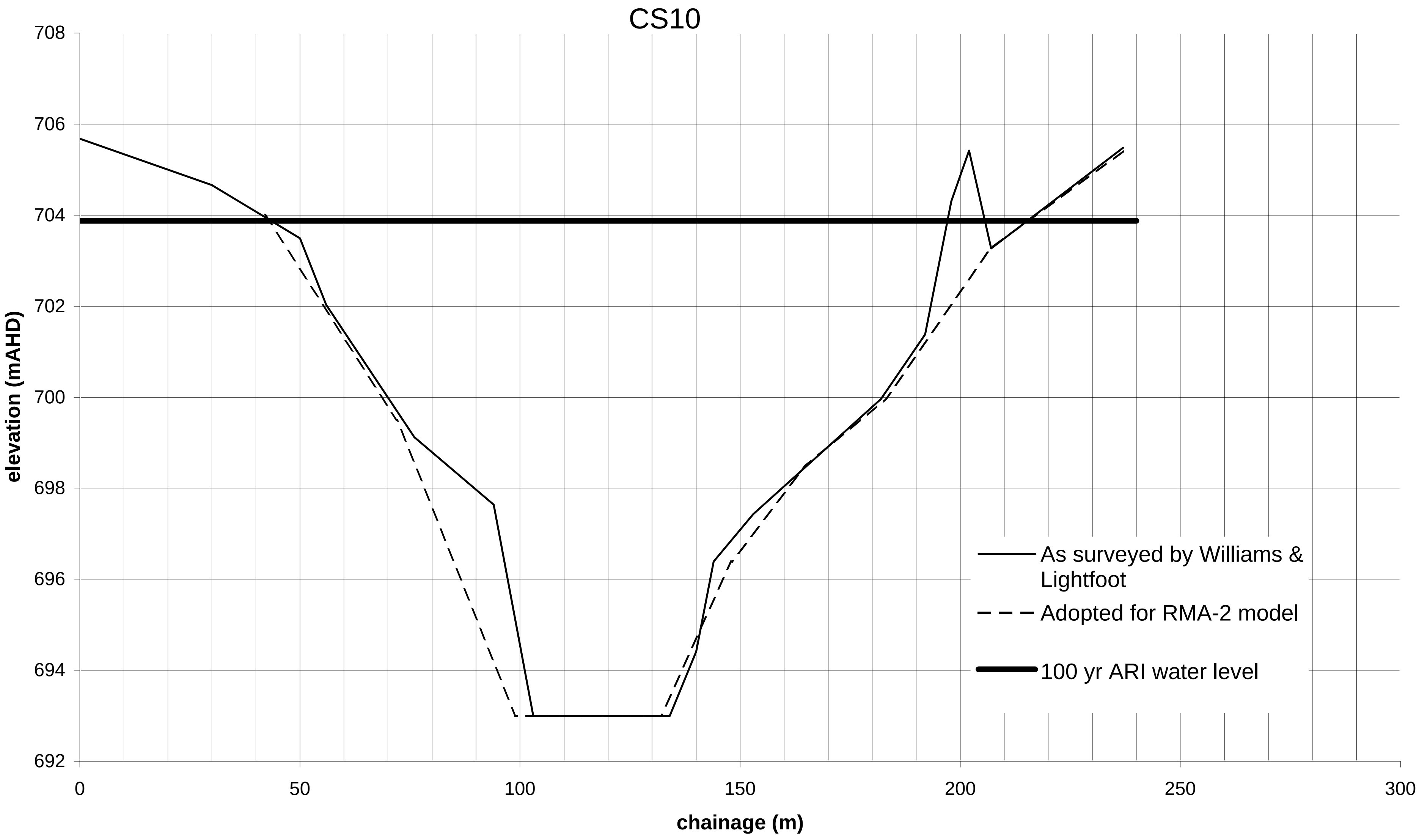

CS5
706
704
702
700
698
696
694
692
690
elevation (mAHD)
0
50
100
150
200
250
300
350
400
450
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

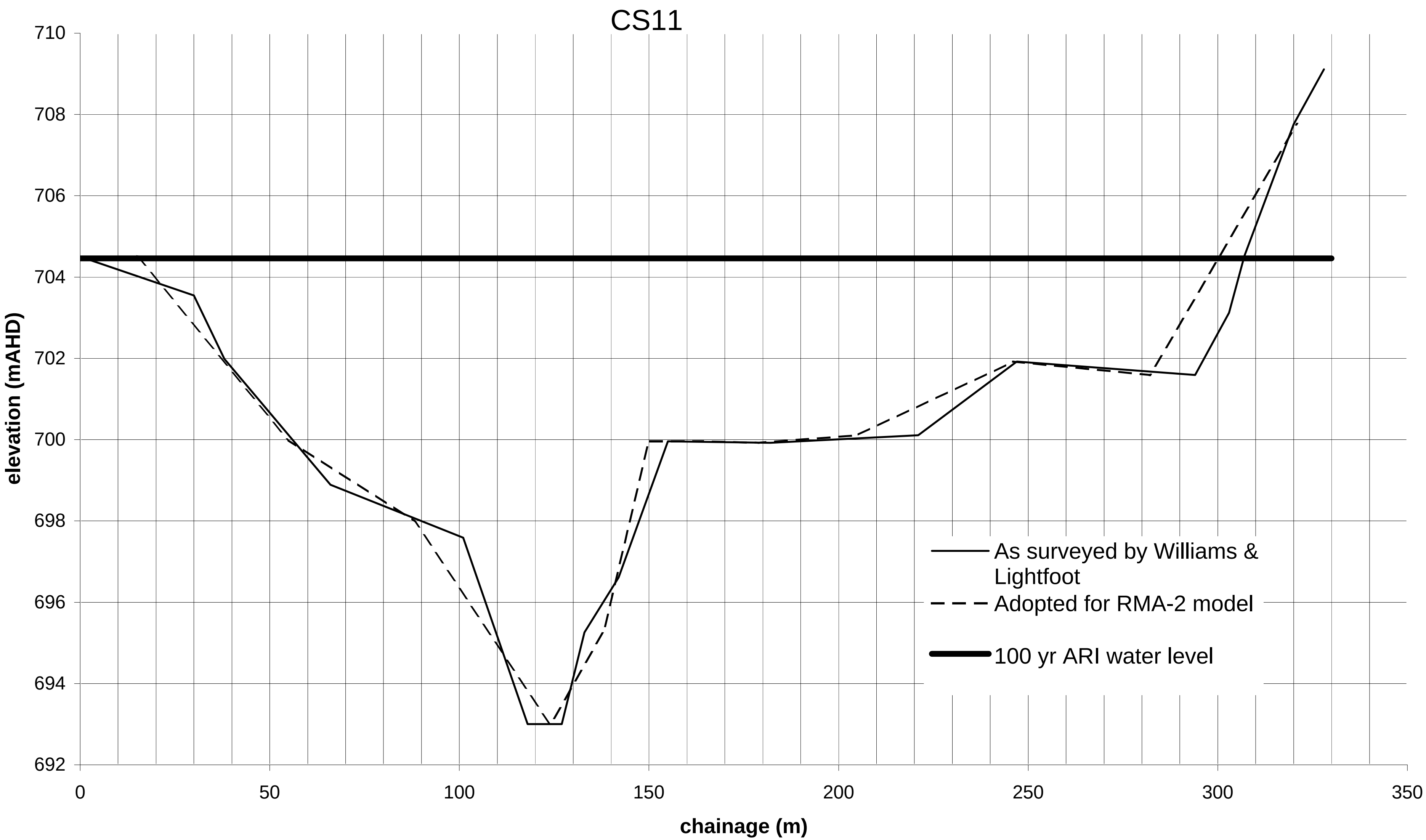


CS6
706
704
702
700
698
696
694
692
690
elevation (mAHD)
0
50
100
150
200
250
300
350
400
450
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

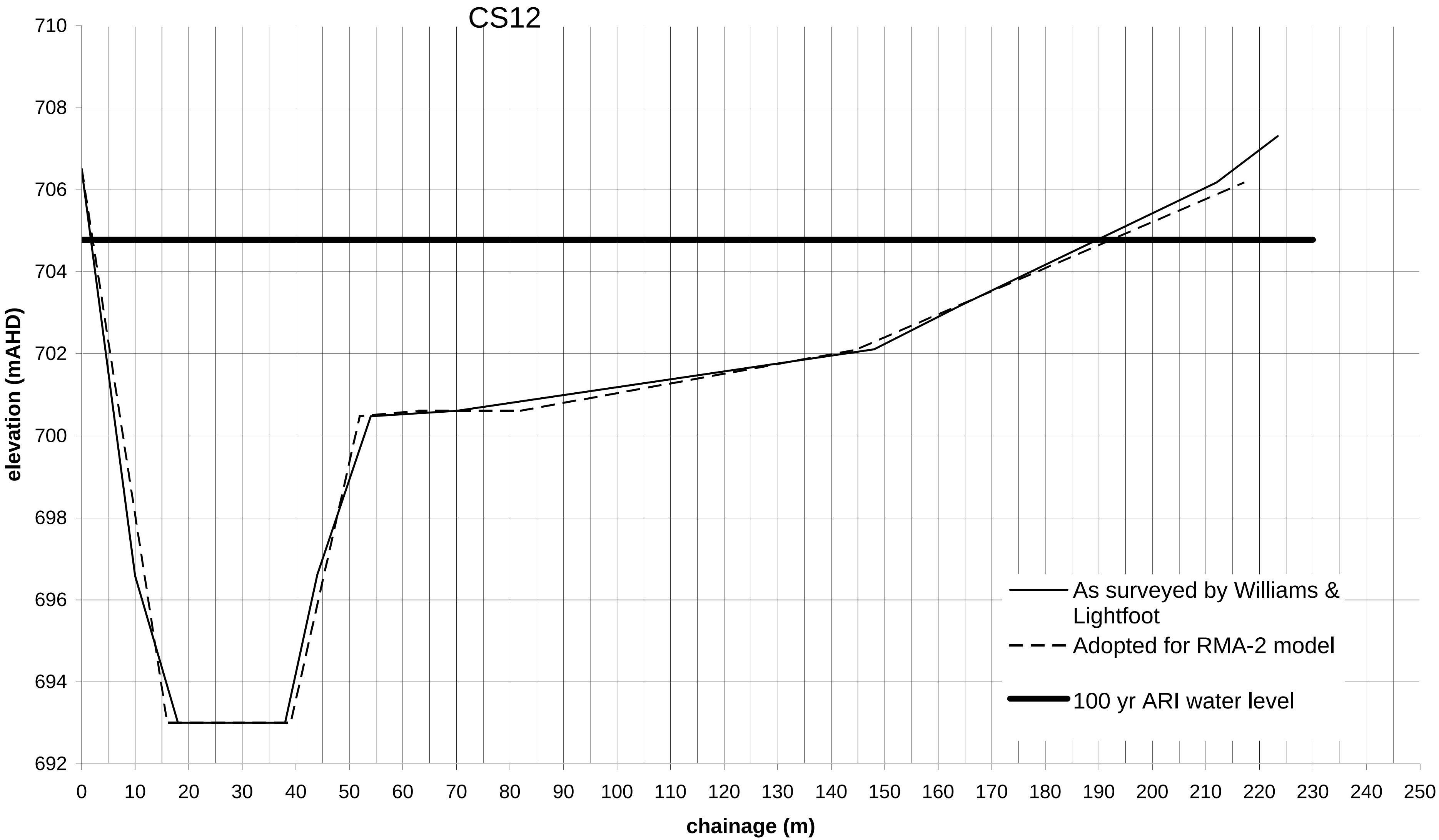

CS8
706
704
702
700
698
696
694
692
elevation (mAHD)
0
50
100
150
200
250
300
350
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

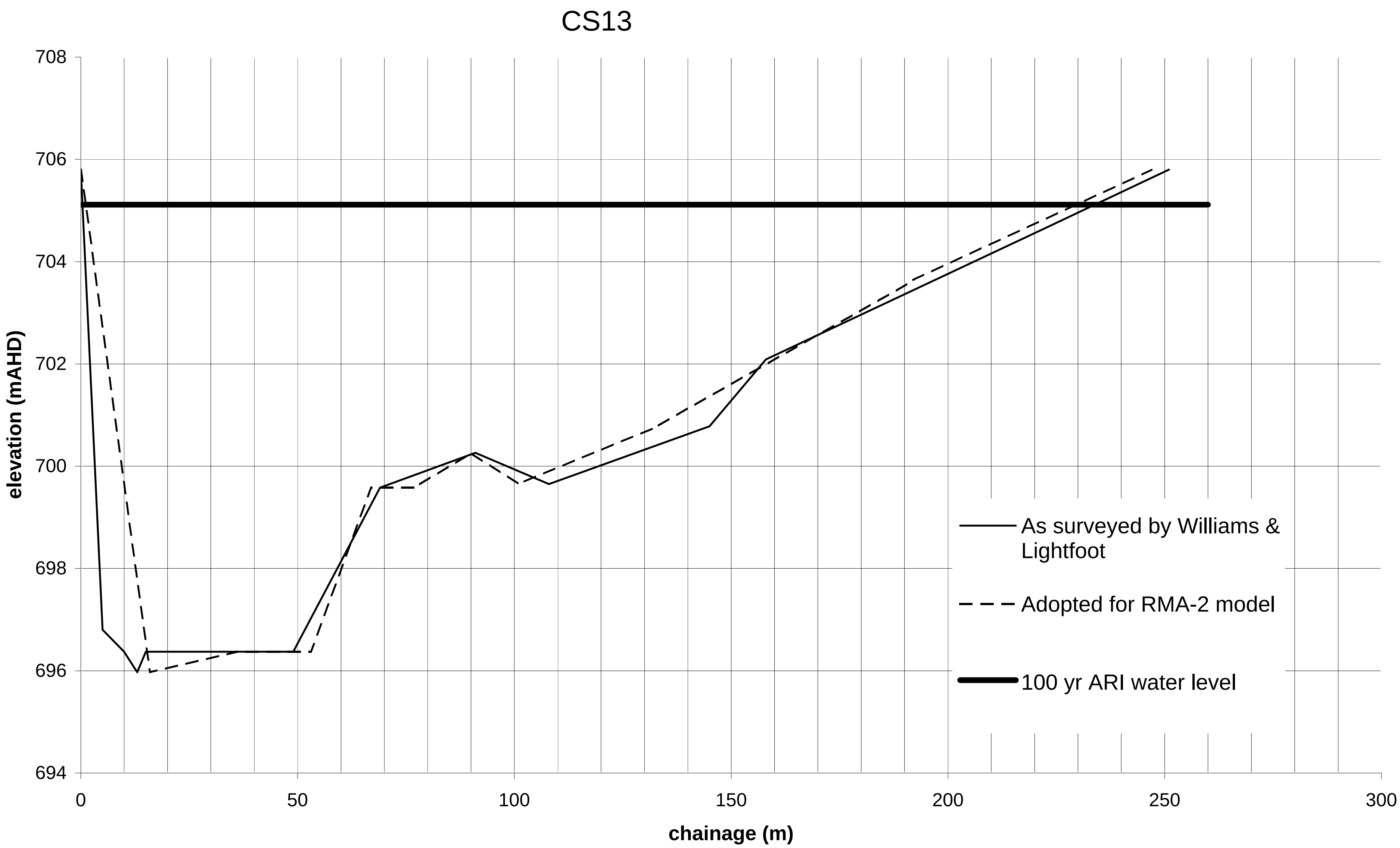

CS9
elevation (mAHD)
706
704
702
700
698
696
694
692
0
50
100
150
200
250
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


CS10
elevation (mAHD)
708
706
704
702
700
698
696
694
692
0
50
100
150
200
250
300
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level



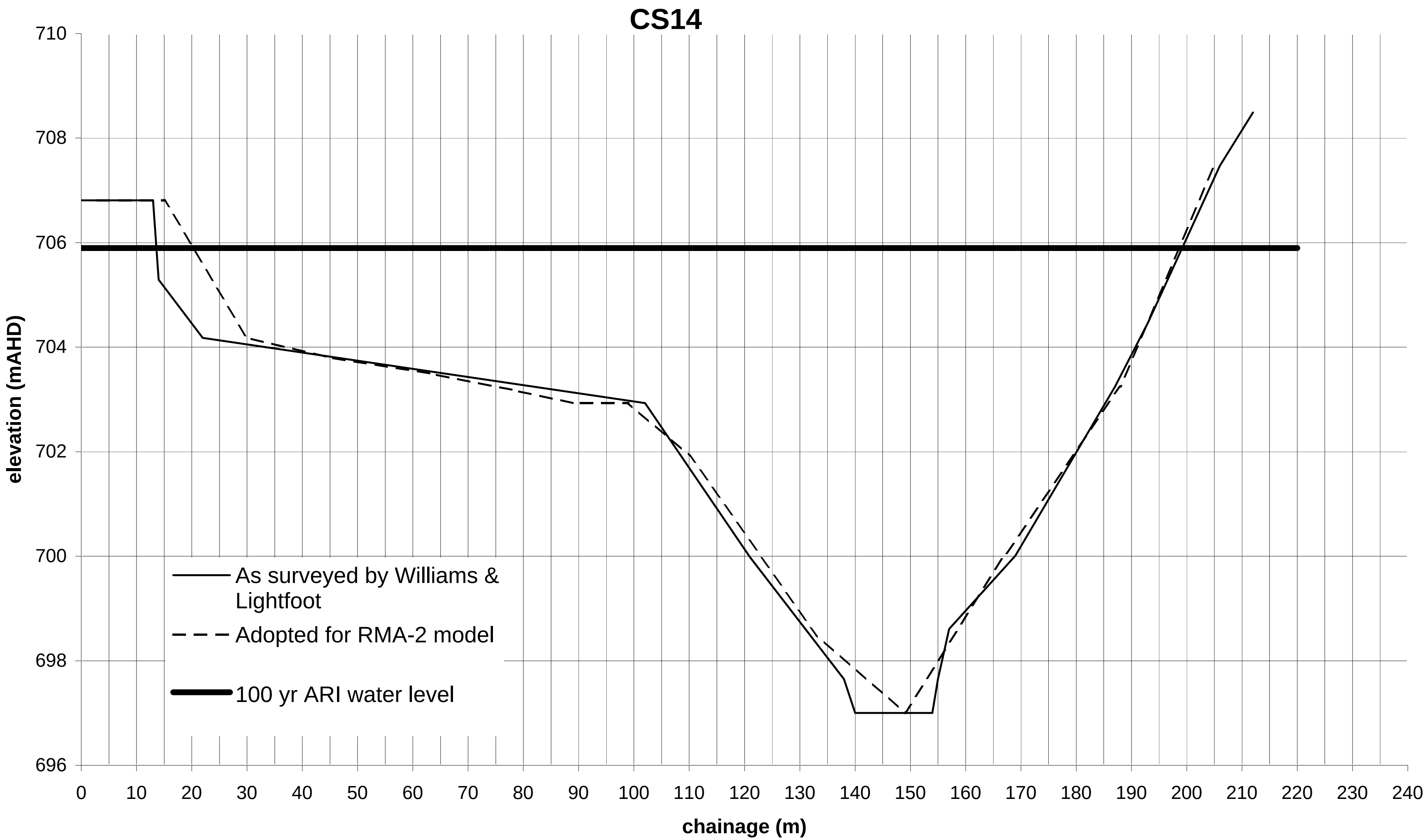
CS11
elevation (mAHD)
710
708
706
704
702
700
698
696
694
692
0
50
100
150
200
250
300
350
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

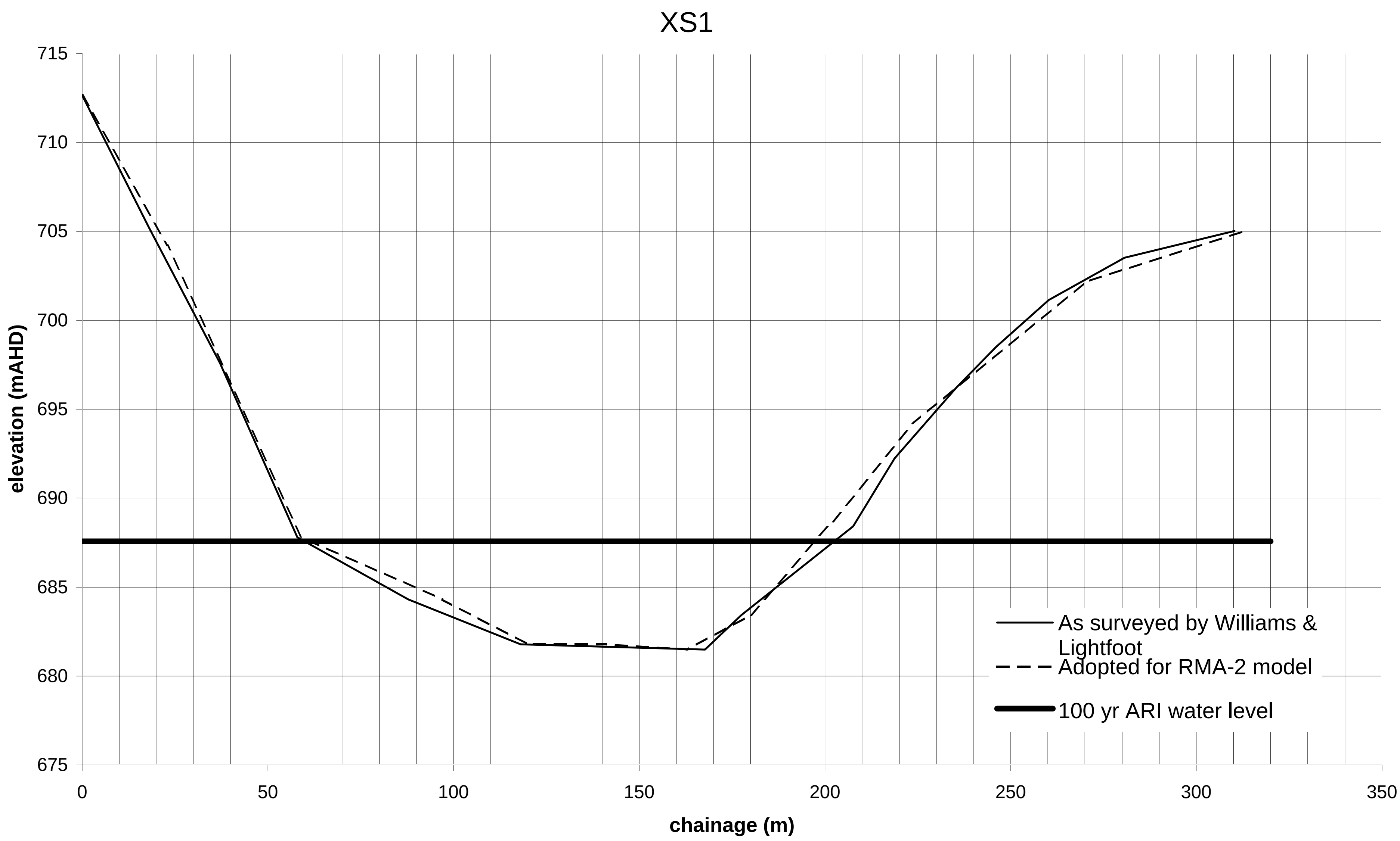

CS12
elevation (mAHD)
710
708
706
704
702
700
698
696
694
692
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level



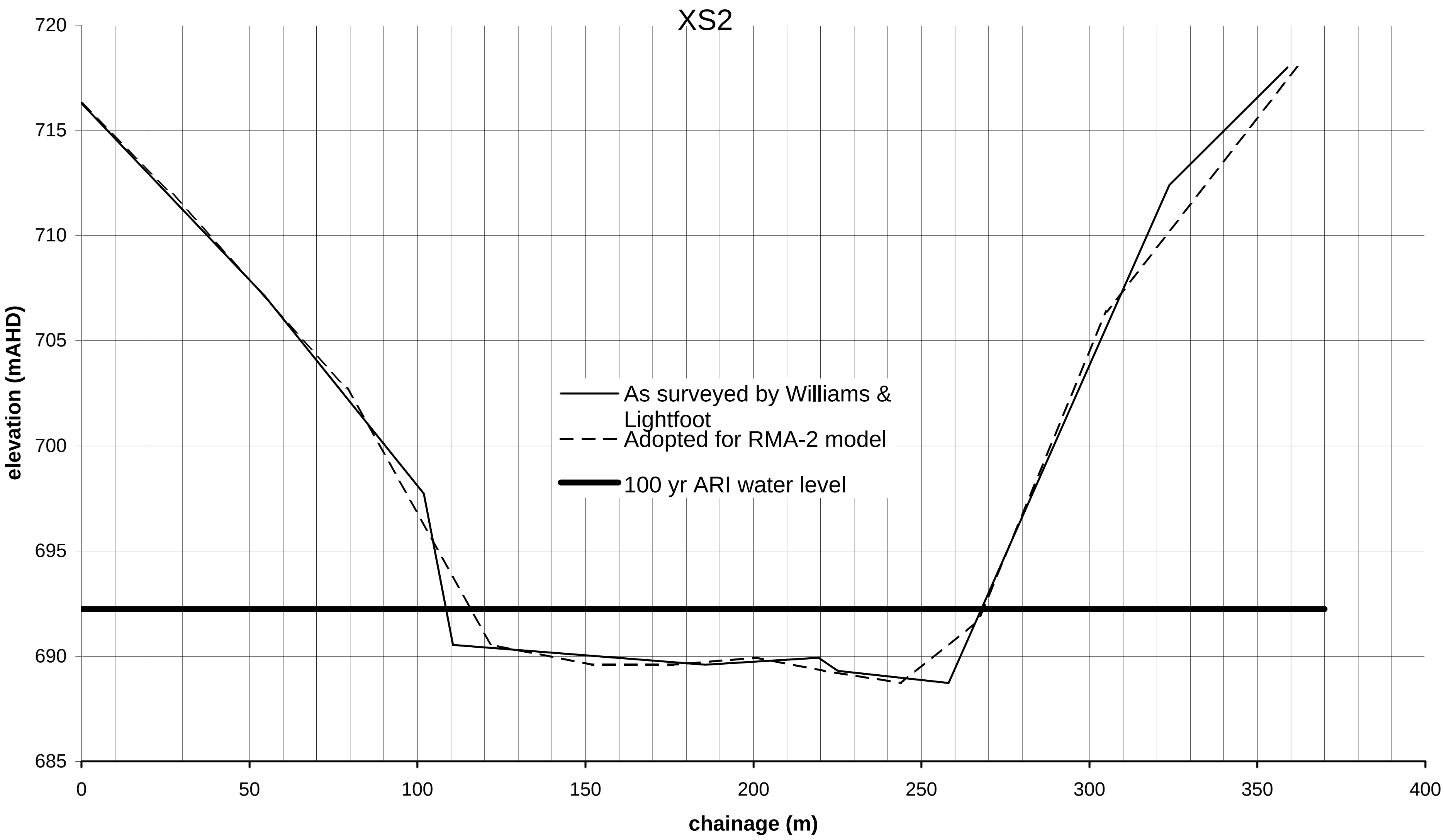
CS13
708
706
704
702
700
698
696
694
elevation (mAHD)
0
50
100
150
200
250
300
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

Appendix D

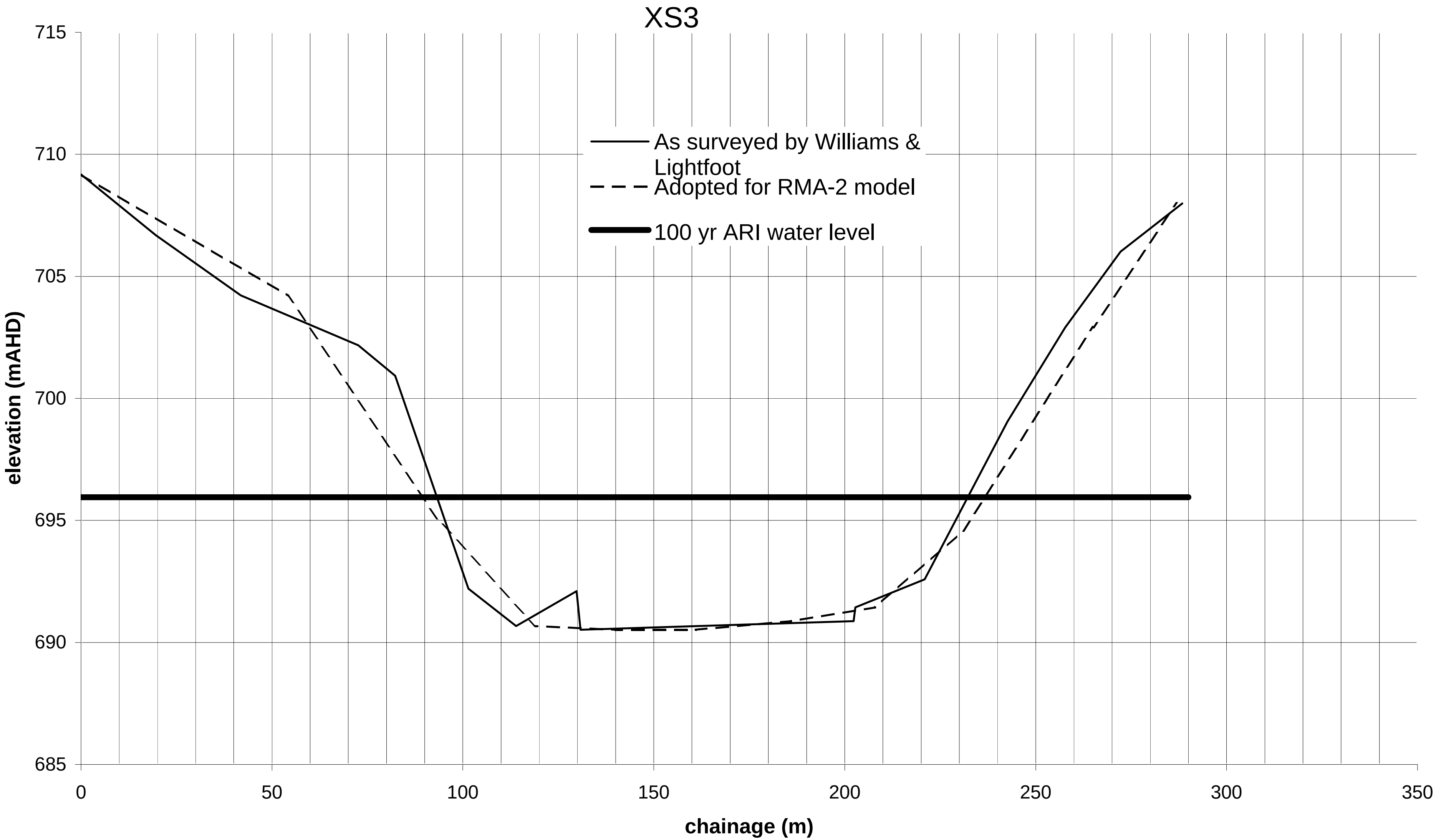

CS14
elevation (mAHD)
710
708
706
704
702
700
698
696
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

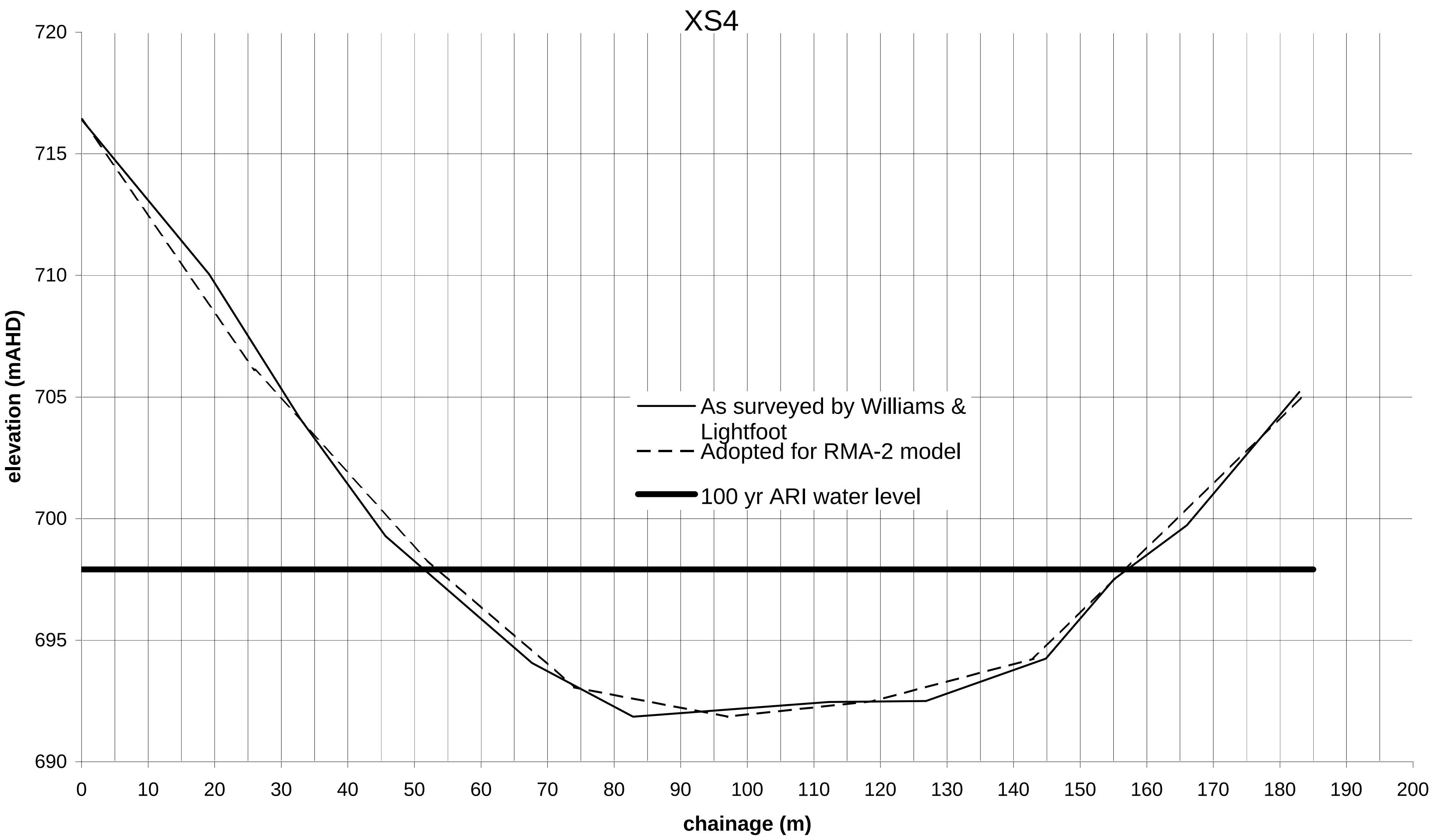

XS1
715
710
705
700
695
690
685
680
675
elevation (mAHD)
0
50
100
150
200
250
300
350
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

Appendix D

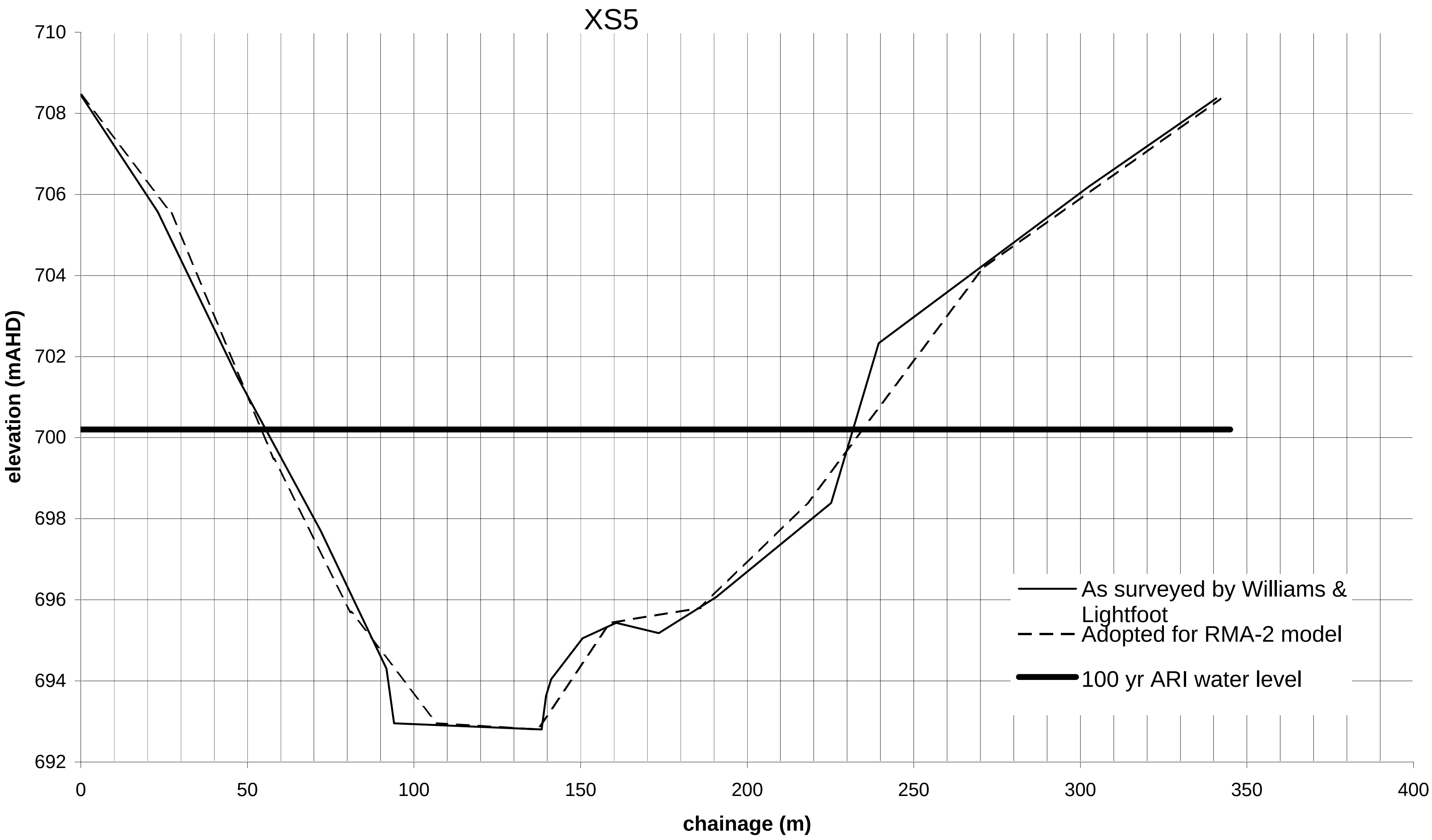


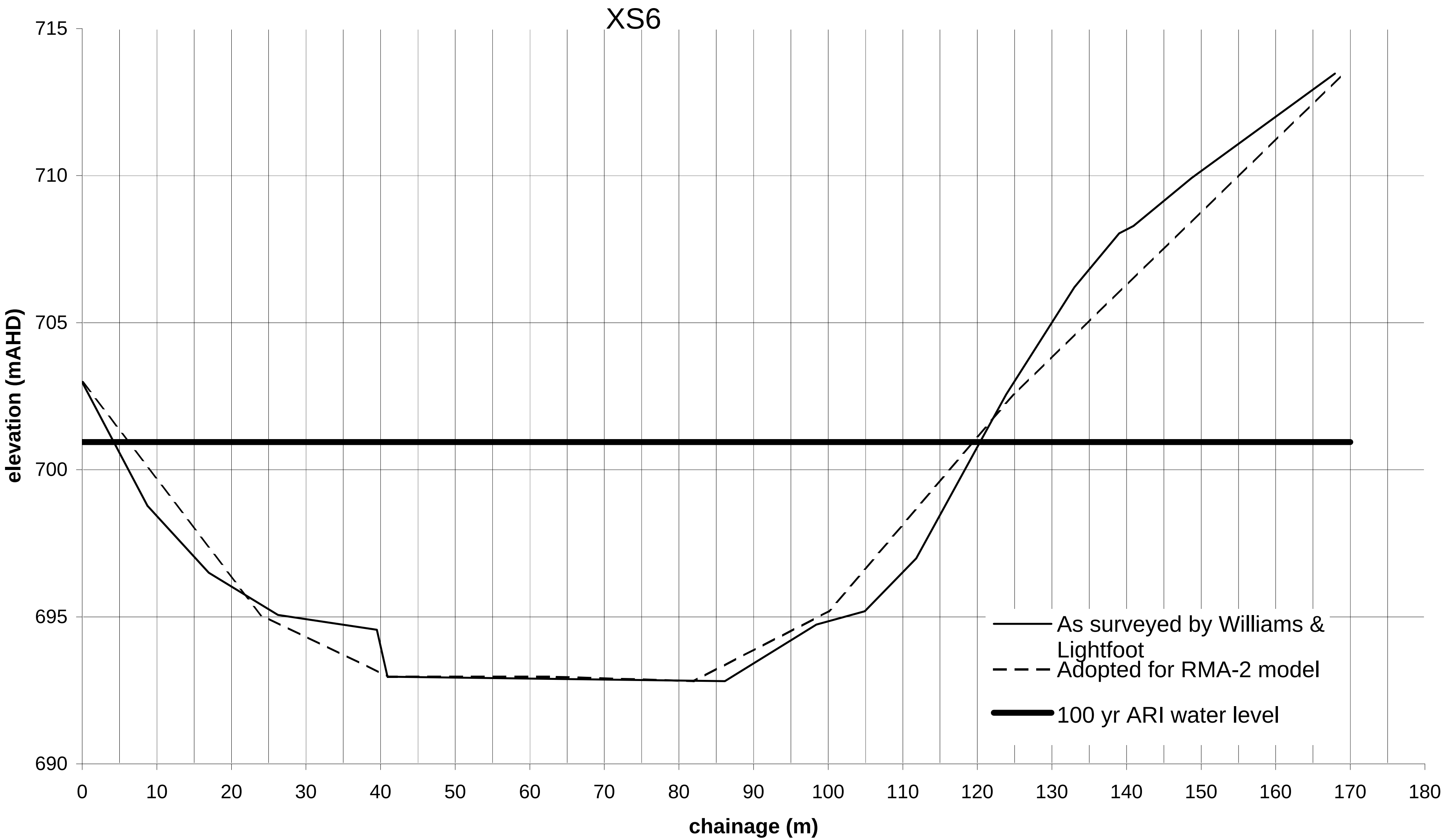
XS2
elevation (mAHD)
chainage (m)
720
715
710
705
700
695
690
685
0
50
100
150
200
250
300
350
400
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

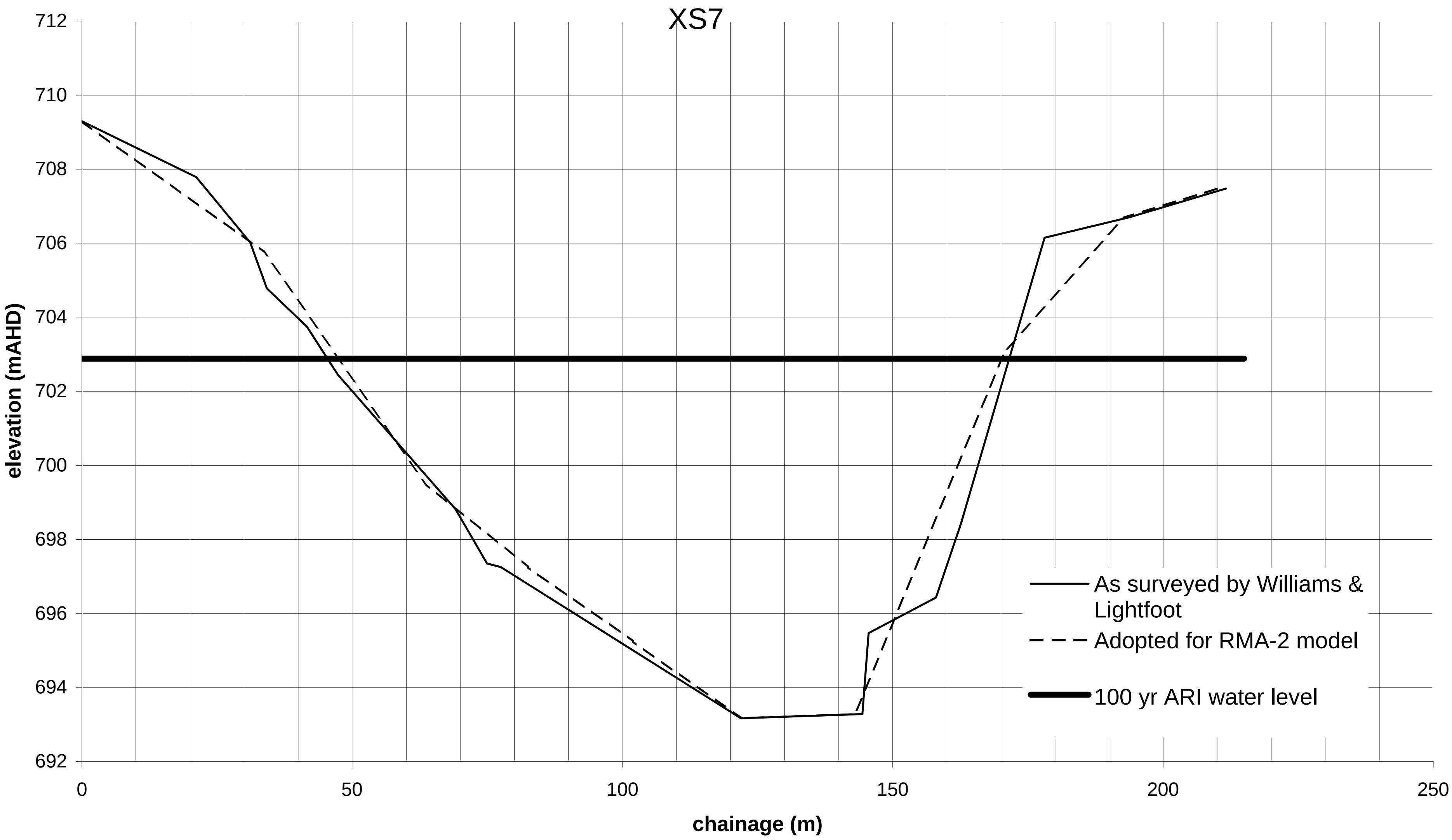

XS3
715
710
705
700
695
690
685
elevation (mAHD)
0
50
100
150
200
250
300
350
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

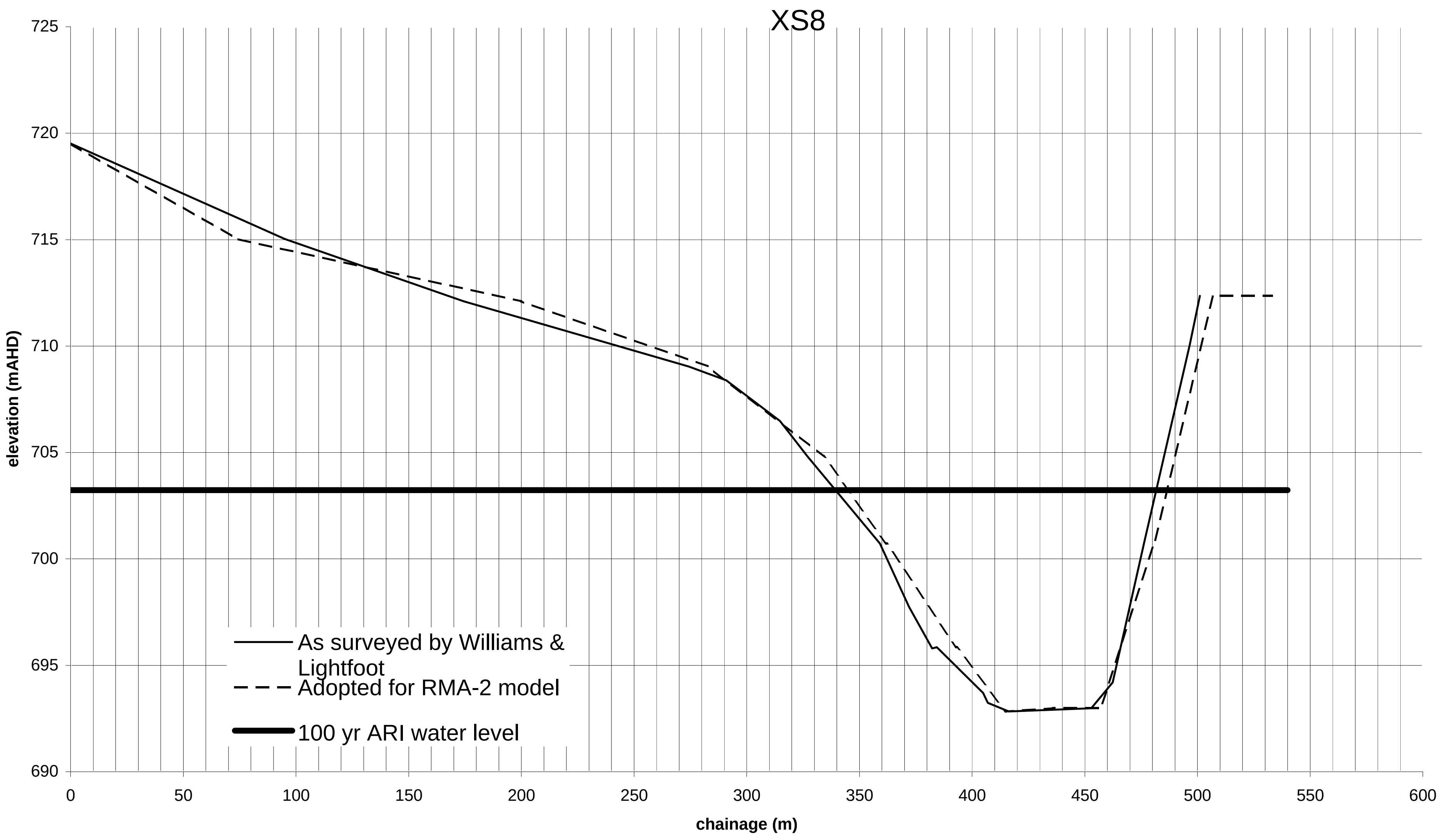


XS4
720
715
710
705
700
695
690
elevation (mAHD)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

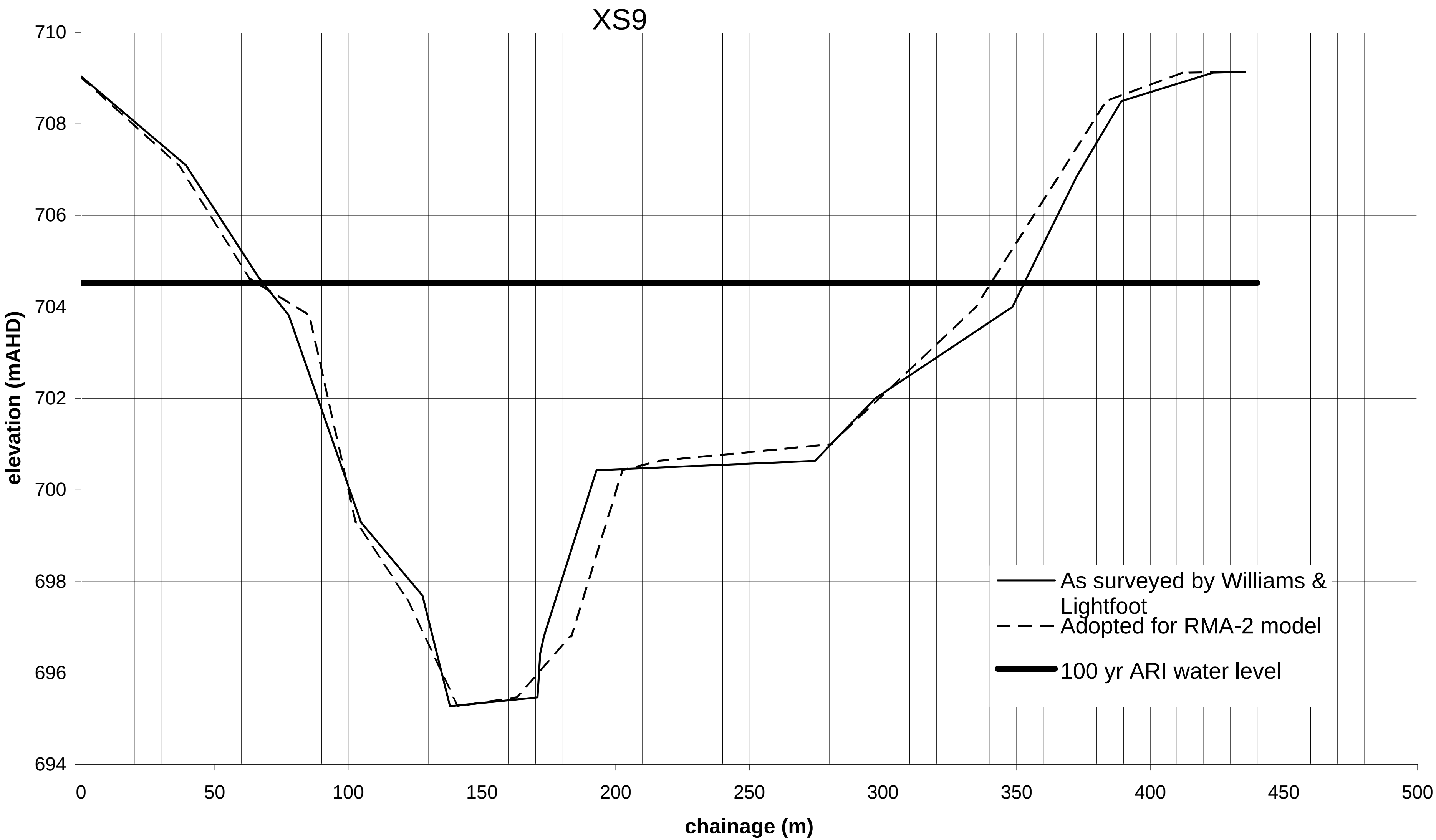

XS5
710
708
706
704
702
700
698
696
694
692
elevation (mAHD)
0
50
100
150
200
250
300
350
400
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


XS6
elevation (mAHD)
715
710
705
700
695
690
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

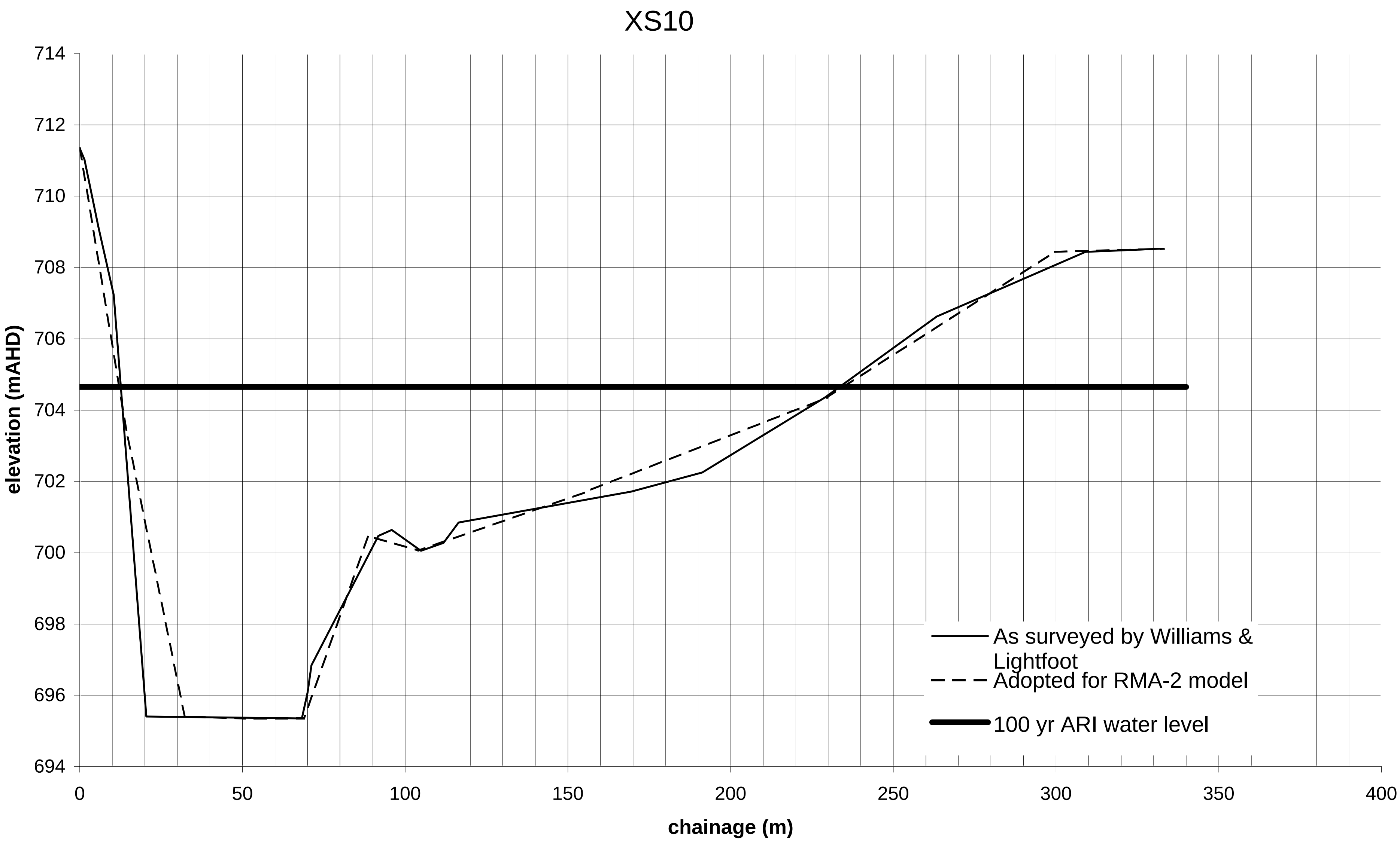

XS7
elevation (mAHD)
712
710
708
706
704
702
700
698
696
694
692
0
50
100
150
200
250
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

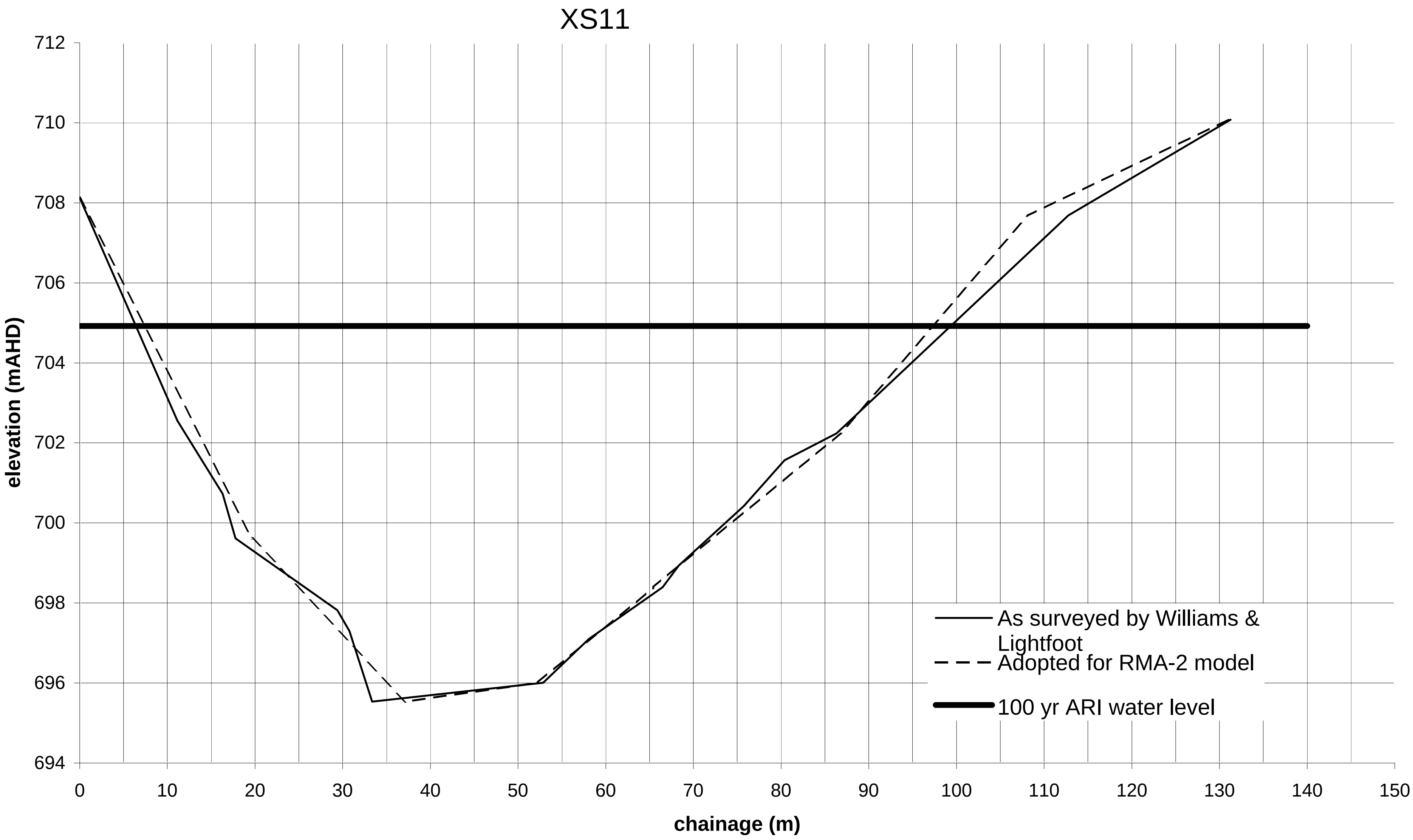

XS8
elevation (mAHD)
725
720
715
710
705
700
695
690
0
50
100
150
200
250
300
350
400
450
500
550
600
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

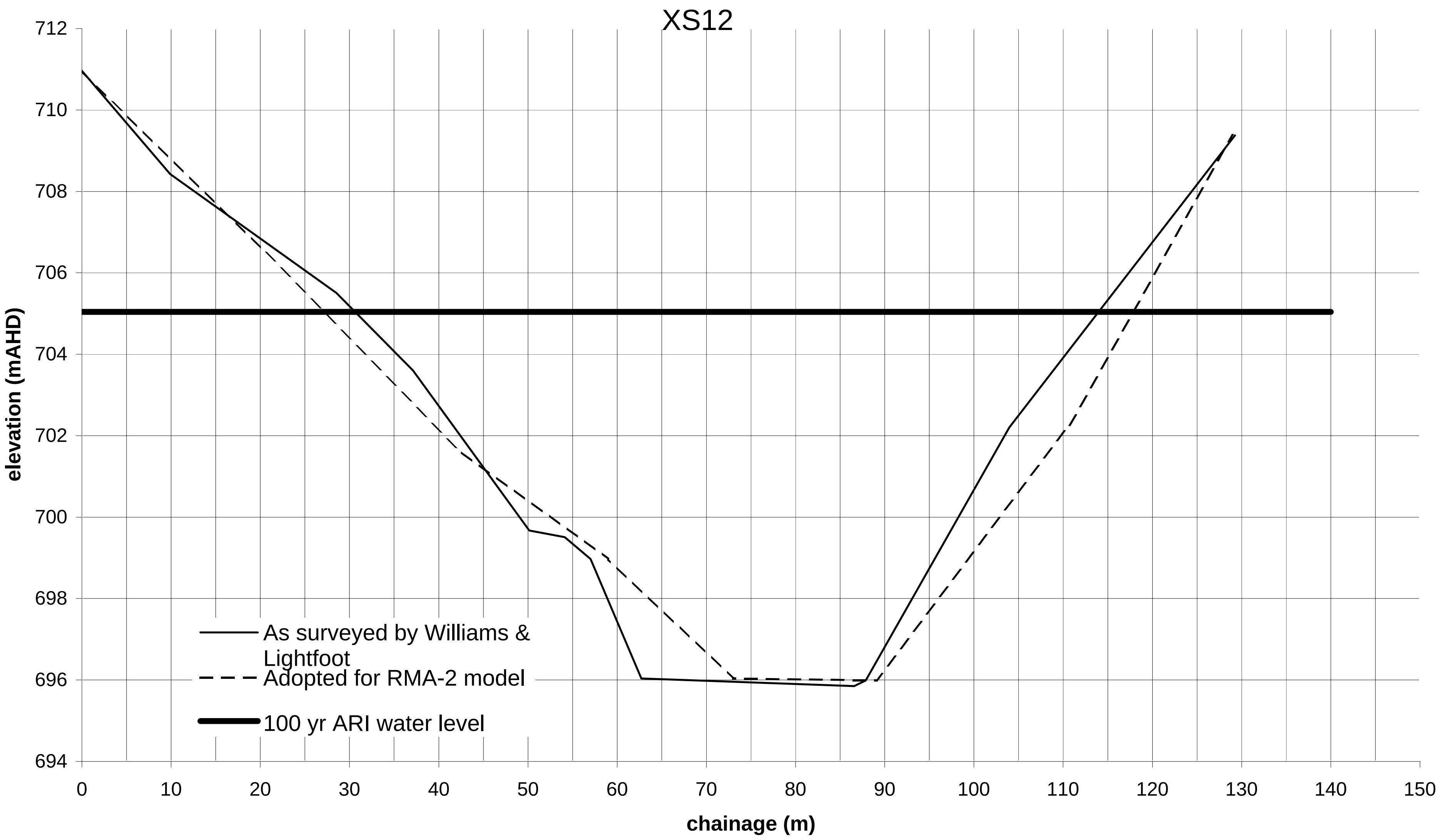
Appendix D

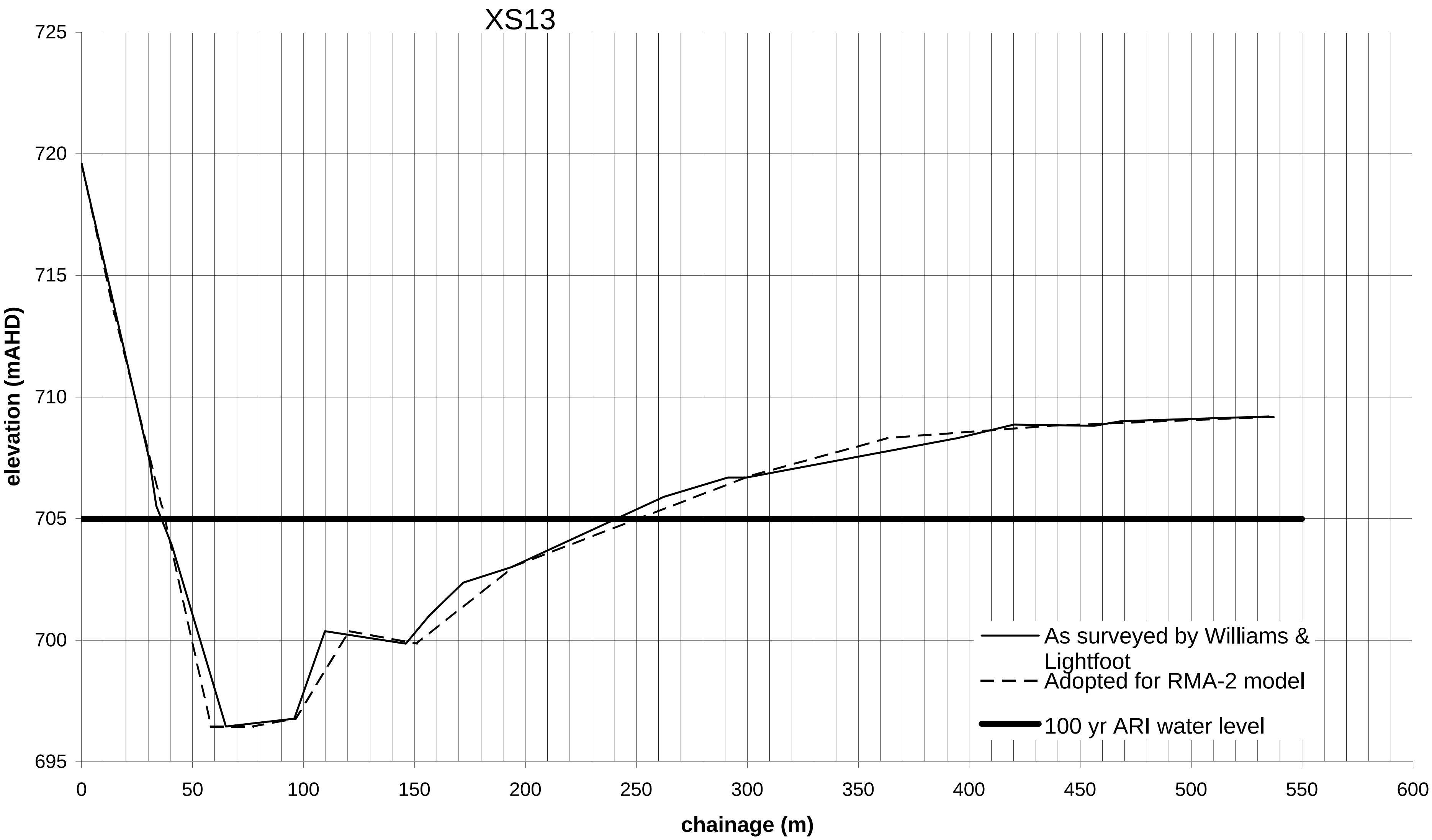

XS9
710
708
706
704
702
700
698
696
694
elevation (mAHD)
0
50
100
150
200
250
300
350
400
450
500
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level

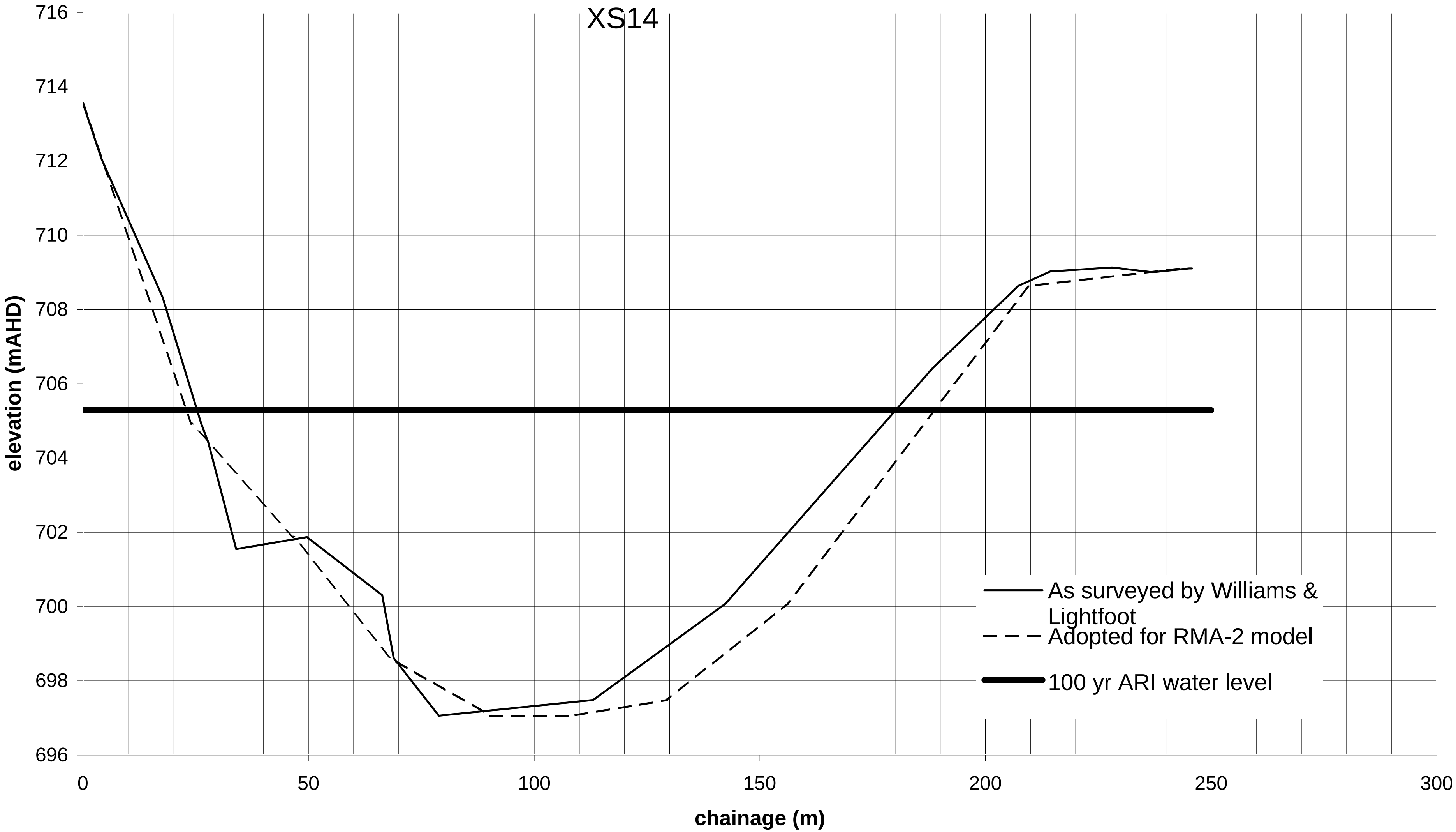
Appendix D

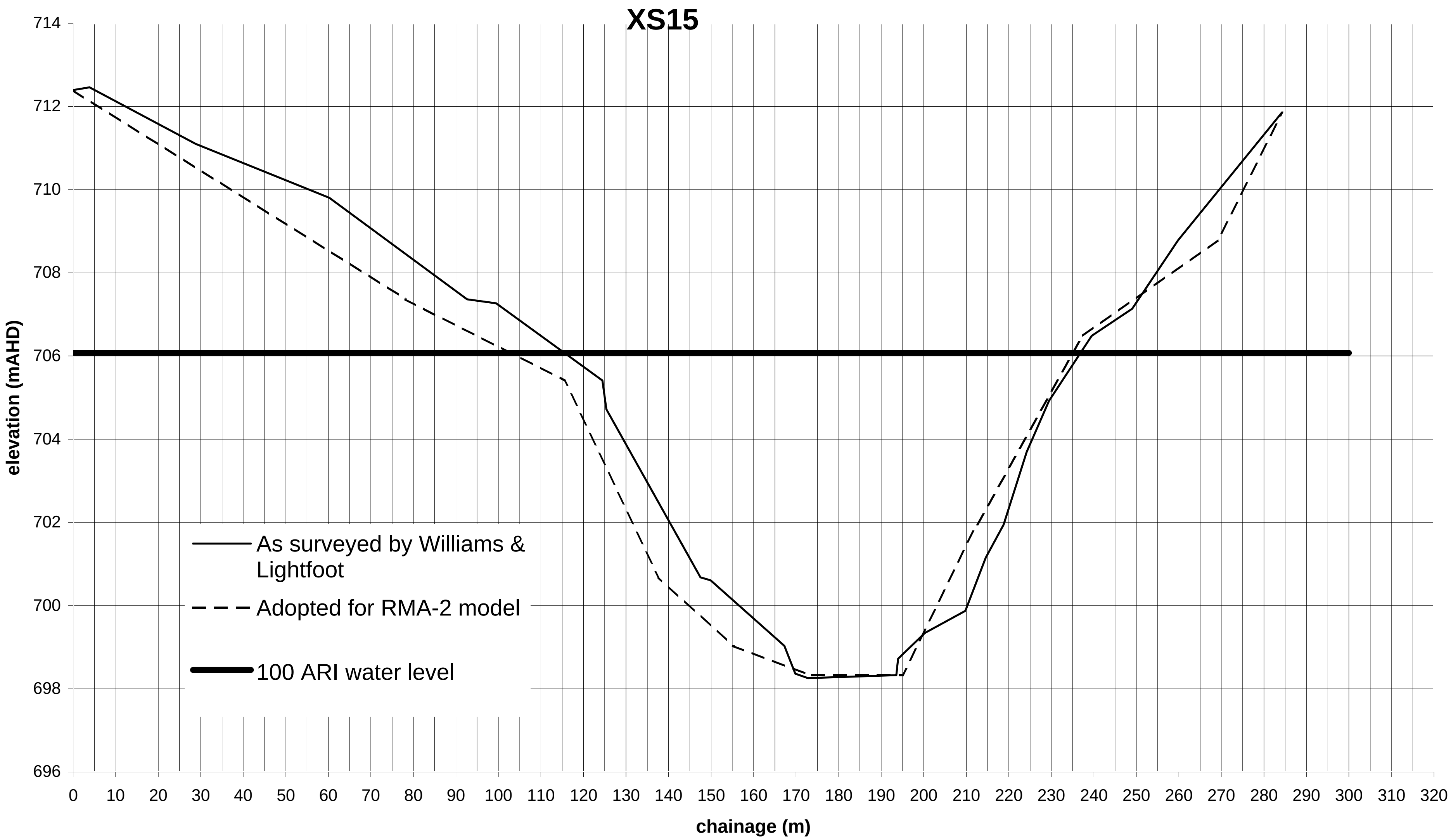

XS10
714
712
710
708
706
704
702
700
698
696
694
elevation (mAHD)
0
50
100
150
200
250
300
350
400
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


XS11
elevation (mAHD)
712
710
708
706
704
702
700
698
696
694
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


XS12
elevation (mAHD)
712
710
708
706
704
702
700
698
696
694
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


XS13
725
720
715
710
705
700
695
elevation (mAHD)
0
50
100
150
200
250
300
350
400
450
500
550
600
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


XS14
elevation (mAHD)
716
714
712
710
708
706
704
702
700
698
696
0
50
100
150
200
250
300
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 yr ARI water level


XS15
714
712
710
708
706
704
702
700
698
696
elevation (mAHD)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320
chainage (m)
As surveyed by Williams & Lightfoot
Adopted for RMA-2 model
100 ARI water level

Appendix D

APPENDIX E

RAFTS MODEL OUTPUT FOR DESIGN FLOOD EVENTS

APPENDIX E – RAFTS HYDROLOGIC MODELLING RESULTS

BOMBALA FLOOD STUDY
Hydrologic Analysis of Existing Conditions

```
Max. no. of links allowed =   280
Max. no. of routng increments allowed =   600
Max. no. of rating curve points =   200
Max. no. of storm temporal points =  2000
Max. no. of channel subreaches =    55
Max link stack level =    20
Input Version number =         400
```

Modelling Results for 200 yr ARI Storm

```
ROUTING INCREMENT (MINS) =      10.00
STORM DURATION (MINS)    =       720.
RETURN PERIOD (YRS)      =       200.
BX                       =     1.0000
TOTAL OF FIRST SUB-AREAS  (km2) =   56311.00
TOTAL OF SECOND SUB-AREAS (km2) =       0.00
TOTAL OF ALL SUB-AREAS (km2)    =   56311.00
```

SUMMARY OF CATCHMENT AND RAINFALL DATA

Link Label	Catch. Area #1 (ha)	Catch. Area #2	Slope #1 (%)	Slope #2	% Impervious #1 (%)	% Impervious #2	Pern #1	Pern #2	B #1	B #2	Link No.
1.00	2272.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	2.057	0.000	1.000
5.00	1022.0	0.000	4.400	0.000	5.000	0.000	.120	0.00	1.295	0.000	2.000
1.01	1336.0	0.000	4.900	0.000	5.000	0.000	.120	0.00	1.411	0.000	1.001
1.02	655.00	0.000	3.900	0.000	5.000	0.000	.120	0.00	1.091	0.000	1.002
6.00	3328.0	0.000	3.200	0.000	5.000	0.000	.120	0.00	2.805	0.000	3.000
1.03	2673.0	0.000	3.300	0.000	5.000	0.000	.120	0.00	2.465	0.000	1.003
1.04	3255.0	0.000	2.300	0.000	5.000	0.000	.120	0.00	3.270	0.000	1.004
1.05	1271.0	0.000	3.700	0.000	5.000	0.000	.090	0.00	1.223	0.000	1.005
1.06	1631.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	1.942	0.000	1.006
3.00	5079.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	3.507	0.000	4.000
3.01	4282.0	0.000	2.100	0.000	5.000	0.000	.120	0.00	3.946	0.000	4.001
1.06#244	867.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.8679	0.000	1.007
7.00	720.00	0.000	1.800	0.000	5.000	0.000	.070	0.00	1.050	0.000	5.000
1.07	2060.0	0.000	2.700	0.000	5.000	0.000	.070	0.00	1.481	0.000	1.008
1.08	870.00	0.000	4.600	0.000	5.000	0.000	.100	0.00	.9892	0.000	1.009
8.00	1498.0	0.000	2.300	0.000	5.000	0.000	.070	0.00	1.360	0.000	6.000
1.09	1911.0	0.000	1.900	0.000	5.000	0.000	.070	0.00	1.697	0.000	1.010
1.10	202.00	0.000	4.000	0.000	5.000	0.000	.060	0.00	.3199	0.000	1.011
14.00	702.00	0.000	4.800	0.000	5.000	0.000	.070	0.00	.6352	0.000	7.000
13.00	759.00	0.000	3.800	0.000	5.000	0.000	.070	0.00	.7433	0.000	8.000
16.00	529.00	0.000	3.300	0.000	5.000	0.000	.120	0.00	1.061	0.000	9.000
13.01	349.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.5407	0.000	8.001
2.00	962.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.427	0.000	10.00
9.00	924.00	0.000	2.500	0.000	5.000	0.000	.120	0.00	1.629	0.000	11.00
2.01	593.00	0.000	3.800	0.000	5.000	0.000	.120	0.00	1.050	0.000	10.00

10.00	1649.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	2.461	0.000	12.00
2.02	1270.0	0.000	1.200	0.000	5.000	0.000	.090	0.00	2.145	0.000	10.00
4.00	1529.0	0.000	1.300	0.000	5.000	0.000	.120	0.00	2.934	0.000	13.00
4.01	1372.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	1.583	0.000	13.00
4.02	2754.0	0.000	1.400	0.000	5.000	0.000	.090	0.00	2.971	0.000	13.00
2.03	600.00	0.000	2.800	0.000	5.000	0.000	.120	0.00	1.230	0.000	10.00
11.00	764.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.266	0.000	14.00
2.04	1001.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	1.899	0.000	10.00
12.00	1852.0	0.000	2.600	0.000	5.000	0.000	.070	0.00	1.428	0.000	15.00
2.05	386.00	0.000	2.700	0.000	5.000	0.000	.070	0.00	.6202	0.000	10.01
2.06	707.00	0.000	4.300	0.000	5.000	0.000	.120	0.00	1.081	0.000	10.01
2.07	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	10.01
2.08	1162.0	0.000	2.900	0.000	5.000	0.000	.070	0.00	1.061	0.000	7.001
15.00	215.00	0.000	4.900	0.000	5.000	0.000	.060	0.00	.2986	0.000	16.00
2.09	248.00	0.000	4.200	0.000	5.000	0.000	.060	0.00	.3473	0.000	7.002
1.11	473.00	0.000	4.400	0.000	10.00	0.000	.050	0.00	.3365	0.000	1.012
1.12	579.00	0.000	3.000	0.000	10.00	0.000	.050	0.00	.4525	0.000	1.013
1.13	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	1.014

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2 (mm)	Cont. Loss #1 (mm/h)	Cont. Loss #2 (mm/h)	Excess Rain #1 (mm)	Excess Rain #2 (mm)	Peak Inflow (m^3/s)	Time to Peak	Link Lag mins
1.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	127.32	580.0	0.000
5.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	62.478	550.0	0.000
1.01	17.367	10.00	0.000	6.000	0.000	138.61	0.000	270.01	570.0	31.46
1.02	17.367	10.00	0.000	6.000	0.000	138.61	0.000	307.80	590.0	19.36
6.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	165.48	600.0	0.000
1.03	17.367	10.00	0.000	6.000	0.000	138.61	0.000	612.11	600.0	56.54
1.04	17.367	10.00	0.000	6.000	0.000	138.61	0.000	745.64	660.0	52.36
1.05	17.367	10.00	0.000	6.000	0.000	138.61	0.000	781.41	710.0	24.42
1.06	17.367	10.00	0.000	5.000	0.000	147.78	0.000	837.72	730.0	47.30
3.00	17.367	10.00	0.000	5.000	0.000	147.78	0.000	246.99	600.0	0.000
3.01	17.367	10.00	0.000	5.000	0.000	147.78	0.000	424.41	610.0	64.02
1.06#244	17.367	10.00	0.000	5.000	0.000	147.78	0.000	1217.9	730.0	13.31
7.00	17.367	10.00	0.000	5.000	0.000	147.78	0.000	46.879	550.0	0.000
1.07	17.367	10.00	0.000	5.000	0.000	147.78	0.000	1320.2	670.0	38.61
1.08	17.367	10.00	0.000	5.000	0.000	147.78	0.000	1344.7	710.0	23.76
8.00	17.367	10.00	0.000	5.000	0.000	147.78	0.000	97.319	550.0	0.000
1.09	17.367	10.00	0.000	5.000	0.000	147.78	0.000	1444.3	730.0	100.1
1.10	17.367	10.00	0.000	5.000	0.000	147.78	0.000	1444.7	830.0	9.900
14.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	63.237	430.0	0.000
13.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	61.861	430.0	0.000
16.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	32.553	550.0	0.000
13.01	17.367	10.00	0.000	6.000	0.000	138.61	0.000	121.25	430.0	20.00
2.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	56.462	570.0	0.000
9.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	51.248	580.0	0.000
2.01	17.367	10.00	0.000	6.000	0.000	138.61	0.000	143.74	570.0	20.60
10.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	77.701	600.0	0.000
2.02	17.367	10.00	0.000	6.000	0.000	138.61	0.000	283.49	600.0	45.60
4.00	17.367	10.00	0.000	5.000	0.000	147.78	0.000	63.214	610.0	0.000
4.01	17.367	10.00	0.000	5.000	0.000	147.78	0.000	145.15	600.0	27.80
4.02	17.367	10.00	0.000	6.000	0.000	138.61	0.000	269.39	610.0	61.70
2.03	17.367	10.00	0.000	6.000	0.000	138.61	0.000	576.55	660.0	36.10
11.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	46.158	560.0	0.000
2.04	17.367	10.00	0.000	6.000	0.000	138.61	0.000	644.97	690.0	25.70
12.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	115.32	550.0	0.000

2.05	17.367	10.00	0.000	6.000	0.000	138.61	0.000	707.34	710.0	14.40
2.06	17.367	10.00	0.000	6.000	0.000	138.61	0.000	727.81	710.0	3.500
2.07	17.367	10.00	0.000	6.000	0.000	138.61	0.000	727.81	710.0	23.10
2.08	17.367	10.00	0.000	6.000	0.000	138.61	0.000	881.33	610.0	26.60
15.00	17.367	10.00	0.000	6.000	0.000	138.61	0.000	24.898	430.0	0.000
2.09	17.367	10.00	0.000	6.000	0.000	138.61	0.000	895.59	640.0	15.00
1.11	17.367	10.00	0.000	5.000	0.000	147.78	0.000	2162.6	830.0	18.48
1.12	17.367	10.00	0.000	5.000	0.000	147.78	0.000	2163.8	850.0	27.61
1.13	17.367	10.00	0.000	5.000	0.000	147.78	0.000	2163.8	880.0	0.000

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ROUTING INCREMENT (MINS) =       4.00
STORM DURATION (MINS)    =       720.
RETURN PERIOD (YRS)      =       100.
BX                       =     1.0000
TOTAL OF FIRST SUB-AREAS  (km2) =   56311.00
TOTAL OF SECOND SUB-AREAS (km2) =       0.00
TOTAL OF ALL SUB-AREAS (km2)    =   56311.00
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SUMMARY OF CATCHMENT AND RAINFALL DATA

Link Label	Catch. Area #1 (ha)	Catch. Area #2	Slope #1 (%)	Slope #2	% Impervious #1 (%)	% Impervious #2	Pern #1	Pern #2	B #1	B #2	Link No.
1.00	2272.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	2.057	0.000	1.000
5.00	1022.0	0.000	4.400	0.000	5.000	0.000	.120	0.00	1.295	0.000	2.000
1.01	1336.0	0.000	4.900	0.000	5.000	0.000	.120	0.00	1.411	0.000	1.001
1.02	655.00	0.000	3.900	0.000	5.000	0.000	.120	0.00	1.091	0.000	1.002
6.00	3328.0	0.000	3.200	0.000	5.000	0.000	.120	0.00	2.805	0.000	3.000
1.03	2673.0	0.000	3.300	0.000	5.000	0.000	.120	0.00	2.465	0.000	1.003
1.04	3255.0	0.000	2.300	0.000	5.000	0.000	.120	0.00	3.270	0.000	1.004
1.05	1271.0	0.000	3.700	0.000	5.000	0.000	.090	0.00	1.223	0.000	1.005
1.06	1631.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	1.942	0.000	1.006
3.00	5079.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	3.507	0.000	4.000
3.01	4282.0	0.000	2.100	0.000	5.000	0.000	.120	0.00	3.946	0.000	4.001
1.06#244	867.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.8679	0.000	1.007
7.00	720.00	0.000	1.800	0.000	5.000	0.000	.070	0.00	1.050	0.000	5.000
1.07	2060.0	0.000	2.700	0.000	5.000	0.000	.070	0.00	1.481	0.000	1.008
1.08	870.00	0.000	4.600	0.000	5.000	0.000	.100	0.00	.9892	0.000	1.009
8.00	1498.0	0.000	2.300	0.000	5.000	0.000	.070	0.00	1.360	0.000	6.000
1.09	1911.0	0.000	1.900	0.000	5.000	0.000	.070	0.00	1.697	0.000	1.010
1.10	202.00	0.000	4.000	0.000	5.000	0.000	.060	0.00	.3199	0.000	1.011
14.00	702.00	0.000	4.800	0.000	5.000	0.000	.070	0.00	.6352	0.000	7.000
13.00	759.00	0.000	3.800	0.000	5.000	0.000	.070	0.00	.7433	0.000	8.000
16.00	529.00	0.000	3.300	0.000	5.000	0.000	.120	0.00	1.061	0.000	9.000
13.01	349.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.5407	0.000	8.001
2.00	962.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.427	0.000	10.00
9.00	924.00	0.000	2.500	0.000	5.000	0.000	.120	0.00	1.629	0.000	11.00
2.01	593.00	0.000	3.800	0.000	5.000	0.000	.120	0.00	1.050	0.000	10.00
10.00	1649.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	2.461	0.000	12.00
2.02	1270.0	0.000	1.200	0.000	5.000	0.000	.090	0.00	2.145	0.000	10.00
4.00	1529.0	0.000	1.300	0.000	5.000	0.000	.120	0.00	2.934	0.000	13.00
4.01	1372.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	1.583	0.000	13.00
4.02	2754.0	0.000	1.400	0.000	5.000	0.000	.090	0.00	2.971	0.000	13.00
2.03	600.00	0.000	2.800	0.000	5.000	0.000	.120	0.00	1.230	0.000	10.00
11.00	764.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.266	0.000	14.00
2.04	1001.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	1.899	0.000	10.00
12.00	1852.0	0.000	2.600	0.000	5.000	0.000	.070	0.00	1.428	0.000	15.00
2.05	386.00	0.000	2.700	0.000	5.000	0.000	.070	0.00	.6202	0.000	10.01
2.06	707.00	0.000	4.300	0.000	5.000	0.000	.120	0.00	1.081	0.000	10.01
2.07	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	10.01
2.08	1162.0	0.000	2.900	0.000	5.000	0.000	.070	0.00	1.061	0.000	7.001

15.00	215.00	0.000	4.900	0.000	5.000	0.000	.060	0.00	.2986	0.000	16.00
2.09	248.00	0.000	4.200	0.000	5.000	0.000	.060	0.00	.3473	0.000	7.002
1.11	473.00	0.000	4.400	0.000	10.00	0.000	.050	0.00	.3365	0.000	1.012
1.12	579.00	0.000	3.000	0.000	10.00	0.000	.050	0.00	.4525	0.000	1.013
1.13	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	1.014

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2	Cont. Loss #1 (mm/h)	Cont. Loss #2	Excess Rain #1 (mm)	Excess Rain #2	Peak Inflow (m^3/s)	Time to Peak	Link Lag mins
1.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	106.44	580.0	0.000
5.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	52.761	568.0	0.000
1.01	15.444	10.00	0.000	6.000	0.000	116.29	0.000	227.70	572.0	31.46
1.02	15.444	10.00	0.000	6.000	0.000	116.29	0.000	259.82	600.0	19.36
6.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	136.13	600.0	0.000
1.03	15.444	10.00	0.000	6.000	0.000	116.29	0.000	509.59	600.0	56.54
1.04	15.444	10.00	0.000	6.000	0.000	116.29	0.000	619.11	656.0	52.36
1.05	15.444	10.00	0.000	6.000	0.000	116.29	0.000	650.18	708.0	24.42
1.06	15.444	10.00	0.000	5.000	0.000	125.36	0.000	699.66	728.0	47.30
3.00	15.444	10.00	0.000	5.000	0.000	125.36	0.000	205.01	604.0	0.000
3.01	15.444	10.00	0.000	5.000	0.000	125.36	0.000	349.48	604.0	64.02
1.06#244	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1011.8	772.0	13.31
7.00	15.444	10.00	0.000	5.000	0.000	125.36	0.000	41.003	544.0	0.000
1.07	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1077.6	680.0	38.61
1.08	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1097.2	716.0	23.76
8.00	15.444	10.00	0.000	5.000	0.000	125.36	0.000	83.524	544.0	0.000
1.09	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1180.4	732.0	100.1
1.10	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1180.8	832.0	9.900
14.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	53.429	424.0	0.000
13.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	51.832	424.0	0.000
16.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	27.337	560.0	0.000
13.01	15.444	10.00	0.000	6.000	0.000	116.29	0.000	100.93	424.0	20.00
2.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	48.161	572.0	0.000
9.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	43.070	584.0	0.000
2.01	15.444	10.00	0.000	6.000	0.000	116.29	0.000	121.94	572.0	20.60
10.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	62.955	600.0	0.000
2.02	15.444	10.00	0.000	6.000	0.000	116.29	0.000	236.14	600.0	45.60
4.00	15.444	10.00	0.000	5.000	0.000	125.36	0.000	51.631	604.0	0.000
4.01	15.444	10.00	0.000	5.000	0.000	125.36	0.000	121.74	600.0	27.80
4.02	15.444	10.00	0.000	6.000	0.000	116.29	0.000	223.00	604.0	61.70
2.03	15.444	10.00	0.000	6.000	0.000	116.29	0.000	478.70	648.0	36.10
11.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	39.203	556.0	0.000
2.04	15.444	10.00	0.000	6.000	0.000	116.29	0.000	538.52	680.0	25.70
12.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	98.859	544.0	0.000
2.05	15.444	10.00	0.000	6.000	0.000	116.29	0.000	598.78	692.0	14.40
2.06	15.444	10.00	0.000	6.000	0.000	116.29	0.000	616.85	704.0	3.500
2.07	15.444	10.00	0.000	6.000	0.000	116.29	0.000	616.85	708.0	23.10
2.08	15.444	10.00	0.000	6.000	0.000	116.29	0.000	729.27	616.0	26.60
15.00	15.444	10.00	0.000	6.000	0.000	116.29	0.000	21.971	424.0	0.000
2.09	15.444	10.00	0.000	6.000	0.000	116.29	0.000	740.97	640.0	15.00
1.11	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1770.3	836.0	18.48
1.12	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1771.3	856.0	27.61
1.13	15.444	10.00	0.000	5.000	0.000	125.36	0.000	1771.3	884.0	0.000

Modelling Results for 20 yr ARI Storm

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ROUTING INCREMENT (MINS) =      10.00
STORM DURATION (MINS)    =      2160.
RETURN PERIOD (YRS)      =        20.
BX                       =     1.0000
TOTAL OF FIRST SUB-AREAS  (km2) =   56311.00
TOTAL OF SECOND SUB-AREAS (km2) =       0.00
TOTAL OF ALL SUB-AREAS (km2)    =   56311.00
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SUMMARY OF CATCHMENT AND RAINFALL DATA

Link Label	Catch. Area #1 (ha)	Catch. Area #2	Slope #1 (%)	Slope #2	% Impervious #1 (%)	% Impervious #2	Pern #1	Pern #2	B #1	B #2	Link No.
1.00	2272.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	2.057	0.000	1.000
5.00	1022.0	0.000	4.400	0.000	5.000	0.000	.120	0.00	1.295	0.000	2.000
1.01	1336.0	0.000	4.900	0.000	5.000	0.000	.120	0.00	1.411	0.000	1.001
1.02	655.00	0.000	3.900	0.000	5.000	0.000	.120	0.00	1.091	0.000	1.002
6.00	3328.0	0.000	3.200	0.000	5.000	0.000	.120	0.00	2.805	0.000	3.000
1.03	2673.0	0.000	3.300	0.000	5.000	0.000	.120	0.00	2.465	0.000	1.003
1.04	3255.0	0.000	2.300	0.000	5.000	0.000	.120	0.00	3.270	0.000	1.004
1.05	1271.0	0.000	3.700	0.000	5.000	0.000	.090	0.00	1.223	0.000	1.005
1.06	1631.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	1.942	0.000	1.006
3.00	5079.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	3.507	0.000	4.000
3.01	4282.0	0.000	2.100	0.000	5.000	0.000	.120	0.00	3.946	0.000	4.001
1.06#244	867.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.8679	0.000	1.007
7.00	720.00	0.000	1.800	0.000	5.000	0.000	.070	0.00	1.050	0.000	5.000
1.07	2060.0	0.000	2.700	0.000	5.000	0.000	.070	0.00	1.481	0.000	1.008
1.08	870.00	0.000	4.600	0.000	5.000	0.000	.100	0.00	.9892	0.000	1.009
8.00	1498.0	0.000	2.300	0.000	5.000	0.000	.070	0.00	1.360	0.000	6.000
1.09	1911.0	0.000	1.900	0.000	5.000	0.000	.070	0.00	1.697	0.000	1.010
1.10	202.00	0.000	4.000	0.000	5.000	0.000	.060	0.00	.3199	0.000	1.011
14.00	702.00	0.000	4.800	0.000	5.000	0.000	.070	0.00	.6352	0.000	7.000
13.00	759.00	0.000	3.800	0.000	5.000	0.000	.070	0.00	.7433	0.000	8.000
16.00	529.00	0.000	3.300	0.000	5.000	0.000	.120	0.00	1.061	0.000	9.000
13.01	349.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.5407	0.000	8.001
2.00	962.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.427	0.000	10.00
9.00	924.00	0.000	2.500	0.000	5.000	0.000	.120	0.00	1.629	0.000	11.00
2.01	593.00	0.000	3.800	0.000	5.000	0.000	.120	0.00	1.050	0.000	10.00
10.00	1649.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	2.461	0.000	12.00
2.02	1270.0	0.000	1.200	0.000	5.000	0.000	.090	0.00	2.145	0.000	10.00
4.00	1529.0	0.000	1.300	0.000	5.000	0.000	.120	0.00	2.934	0.000	13.00
4.01	1372.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	1.583	0.000	13.00
4.02	2754.0	0.000	1.400	0.000	5.000	0.000	.090	0.00	2.971	0.000	13.00
2.03	600.00	0.000	2.800	0.000	5.000	0.000	.120	0.00	1.230	0.000	10.00
11.00	764.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.266	0.000	14.00
2.04	1001.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	1.899	0.000	10.00
12.00	1852.0	0.000	2.600	0.000	5.000	0.000	.070	0.00	1.428	0.000	15.00
2.05	386.00	0.000	2.700	0.000	5.000	0.000	.070	0.00	.6202	0.000	10.01
2.06	707.00	0.000	4.300	0.000	5.000	0.000	.120	0.00	1.081	0.000	10.01
2.07	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	10.01
2.08	1162.0	0.000	2.900	0.000	5.000	0.000	.070	0.00	1.061	0.000	7.001
15.00	215.00	0.000	4.900	0.000	5.000	0.000	.060	0.00	.2986	0.000	16.00

2.09	248.00	0.000	4.200	0.000	5.000	0.000	.060	0.00	.3473	0.000	7.002
1.11	473.00	0.000	4.400	0.000	10.00	0.000	.050	0.00	.3365	0.000	1.012
1.12	579.00	0.000	3.000	0.000	10.00	0.000	.050	0.00	.4525	0.000	1.013
1.13	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	1.014

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2	Cont. Loss #1 (mm/h)	Cont. Loss #2	Excess Rain #1 (mm)	Excess Rain #2	Peak Inflow (m^3/s)	Time to Peak	Link Lag mins
1.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	61.685	1230.	0.000
5.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	32.461	1200.	0.000
1.01	5.747	10.00	0.000	6.000	0.000	80.490	0.000	135.91	1210.	31.46
1.02	5.747	10.00	0.000	6.000	0.000	80.490	0.000	155.66	1240.	19.36
6.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	78.743	1320.	0.000
1.03	5.747	10.00	0.000	6.000	0.000	80.490	0.000	298.56	1260.	56.54
1.04	5.747	10.00	0.000	6.000	0.000	80.490	0.000	366.30	1320.	52.36
1.05	5.747	10.00	0.000	6.000	0.000	80.490	0.000	389.53	1370.	24.42
1.06	5.747	10.00	0.000	5.000	0.000	92.628	0.000	426.13	1370.	47.30
3.00	5.747	10.00	0.000	5.000	0.000	92.628	0.000	128.89	1320.	0.000
3.01	5.747	10.00	0.000	5.000	0.000	92.628	0.000	223.01	1320.	64.02
1.06#244	5.747	10.00	0.000	5.000	0.000	92.628	0.000	656.80	1390.	13.31
7.00	5.747	10.00	0.000	5.000	0.000	92.628	0.000	26.196	1180.	0.000
1.07	5.747	10.00	0.000	5.000	0.000	92.628	0.000	703.74	1390.	38.61
1.08	5.747	10.00	0.000	5.000	0.000	92.628	0.000	714.19	1430.	23.76
8.00	5.747	10.00	0.000	5.000	0.000	92.628	0.000	53.602	1190.	0.000
1.09	5.747	10.00	0.000	5.000	0.000	92.628	0.000	761.00	1440.	100.1
1.10	5.747	10.00	0.000	5.000	0.000	92.628	0.000	761.27	1540.	9.900
14.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	29.213	1090.	0.000
13.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	29.415	1110.	0.000
16.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	16.893	1200.	0.000
13.01	5.747	10.00	0.000	6.000	0.000	80.490	0.000	57.924	1120.	20.00
2.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	28.550	1210.	0.000
9.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	24.724	1240.	0.000
2.01	5.747	10.00	0.000	6.000	0.000	80.490	0.000	72.170	1210.	20.60
10.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	37.262	1320.	0.000
2.02	5.747	10.00	0.000	6.000	0.000	80.490	0.000	135.31	1260.	45.60
4.00	5.747	10.00	0.000	5.000	0.000	92.628	0.000	33.573	1330.	0.000
4.01	5.747	10.00	0.000	5.000	0.000	92.628	0.000	74.343	1240.	27.80
4.02	5.747	10.00	0.000	6.000	0.000	80.490	0.000	133.19	1320.	61.70
2.03	5.747	10.00	0.000	6.000	0.000	80.490	0.000	281.37	1320.	36.10
11.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	23.481	1210.	0.000
2.04	5.747	10.00	0.000	6.000	0.000	80.490	0.000	321.34	1330.	25.70
12.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	60.619	1200.	0.000
2.05	5.747	10.00	0.000	6.000	0.000	80.490	0.000	365.76	1340.	14.40
2.06	5.747	10.00	0.000	6.000	0.000	80.490	0.000	380.54	1340.	3.500
2.07	5.747	10.00	0.000	6.000	0.000	80.490	0.000	380.54	1340.	23.10
2.08	5.747	10.00	0.000	6.000	0.000	80.490	0.000	447.32	1340.	26.60
15.00	5.747	10.00	0.000	6.000	0.000	80.490	0.000	10.303	1080.	0.000
2.09	5.747	10.00	0.000	6.000	0.000	80.490	0.000	452.60	1360.	15.00
1.11	5.747	10.00	0.000	5.000	0.000	92.628	0.000	1142.3	1490.	18.48
1.12	5.747	10.00	0.000	5.000	0.000	92.628	0.000	1143.5	1510.	27.61
1.13	5.747	10.00	0.000	5.000	0.000	92.628	0.000	1143.5	1540.	0.000

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2 (mm)	Cont. Loss #1 (mm/h)	Cont. Loss #2 (mm/h)	Excess Rain #1 (mm)	Excess Rain #2 (mm)	Peak Inflow (m^3/s)	Time to Peak	Link Lag (mins)
1.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	2.907	390.0	8.000
1.01	12.378	15.00	.0000	4.500	.0000	64.483	.000	5.123	390.0	4.000
3.00	12.378	15.00	.0000	2.500	.0000	77.681	.000	9.333	360.0	16.00
4.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	5.315	360.0	19.00
4.01	12.378	15.00	.0000	4.500	.0000	64.483	.000	19.891	390.0	4.000
1.02	12.378	10.00	15.00	.0000	4.500	101.41	64.483	26.694	390.0	25.00
2.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	4.528	420.0	23.00
2.01	12.378	15.00	.0000	4.500	.0000	64.483	.000	6.627	450.0	11.00
1.03	12.378	10.00	15.00	.0000	4.500	101.41	64.483	36.629	420.0	4.800
1.04	12.378	10.00	15.00	.0000	4.500	101.41	64.483	37.220	420.0	1.500
1.05	12.378	10.00	15.00	.0000	4.500	101.41	64.483	37.269	420.0	13.00
5.0	12.378	10.00	15.00	.0000	4.500	101.41	64.483	7.323	330.0	13.00
1.06	12.378	10.00	15.00	.0000	4.500	101.41	64.483	45.887	390.0	6.000
10.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	5.224	360.0	10.20
12.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	7.334	390.0	10.20
10.01	12.378	15.00	.0000	4.500	.0000	64.483	.000	14.504	360.0	6.800
11.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	3.758	360.0	6.800
10.02	12.378	15.00	.0000	4.500	.0000	64.483	.000	19.872	360.0	9.600
13.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	3.128	360.0	18.00
13.01	12.378	15.00	.0000	4.500	.0000	64.483	.000	8.222	360.0	9.600
10.03	12.378	15.00	.0000	4.500	.0000	64.483	.000	29.853	360.0	1.500
14.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	2.419	360.0	1.500
10.04	12.378	15.00	.0000	2.500	.0000	77.681	.000	32.327	360.0	12.00
15.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	4.472	360.0	10.00
15.01	12.378	15.00	.0000	4.500	.0000	64.483	.000	8.887	360.0	11.00
15.02	12.378	15.00	.0000	4.500	.0000	64.483	.000	11.564	360.0	6.000
16.00	12.378	15.00	.0000	4.500	.0000	64.483	.000	2.764	360.0	6.000
15.03	12.378	15.00	.0000	2.500	.0000	77.681	.000	15.233	360.0	12.00
17.00	12.378	15.00	.0000	2.500	.0000	77.681	.000	1.816	360.0	5.000
10.05	12.378	15.00	.0000	2.500	.0000	77.681	.000	52.595	360.0	8.000
10.06	12.378	15.00	.0000	2.500	.0000	77.681	.000	53.870	360.0	8.000
10.07	12.378	15.00	.0000	2.500	.0000	77.681	.000	55.619	360.0	8.000
10.08	12.378	15.00	.0000	2.500	.0000	77.681	.000	57.505	360.0	6.000
1.07	12.378	10.00	15.00	.0000	4.500	101.41	64.483	101.66	390.0	.0000

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ROUTING INCREMENT (MINS) =      10.00
STORM DURATION (MINS)    =      2160.
RETURN PERIOD (YRS)      =         5.
BX                       =     1.0000
TOTAL OF FIRST SUB-AREAS  (km2) =   56311.00
TOTAL OF SECOND SUB-AREAS (km2) =       0.00
TOTAL OF ALL SUB-AREAS (km2)    =   56311.00
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SUMMARY OF CATCHMENT AND RAINFALL DATA

Link Label	Catch. Area #1 (ha)	Catch. Area #2	Slope (%) #1	Slope (%) #2	% Impervious (%) #1	% Impervious (%) #2	Pern #1	Pern #2	B #1	B #2	Link No.
1.00	2272.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	2.057	0.000	1.000
5.00	1022.0	0.000	4.400	0.000	5.000	0.000	.120	0.00	1.295	0.000	2.000
1.01	1336.0	0.000	4.900	0.000	5.000	0.000	.120	0.00	1.411	0.000	1.001
1.02	655.00	0.000	3.900	0.000	5.000	0.000	.120	0.00	1.091	0.000	1.002
6.00	3328.0	0.000	3.200	0.000	5.000	0.000	.120	0.00	2.805	0.000	3.000
1.03	2673.0	0.000	3.300	0.000	5.000	0.000	.120	0.00	2.465	0.000	1.003
1.04	3255.0	0.000	2.300	0.000	5.000	0.000	.120	0.00	3.270	0.000	1.004
1.05	1271.0	0.000	3.700	0.000	5.000	0.000	.090	0.00	1.223	0.000	1.005
1.06	1631.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	1.942	0.000	1.006
3.00	5079.0	0.000	1.900	0.000	5.000	0.000	.090	0.00	3.507	0.000	4.000
3.01	4282.0	0.000	2.100	0.000	5.000	0.000	.120	0.00	3.946	0.000	4.001
1.06#244	867.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.8679	0.000	1.007
7.00	720.00	0.000	1.800	0.000	5.000	0.000	.070	0.00	1.050	0.000	5.000
1.07	2060.0	0.000	2.700	0.000	5.000	0.000	.070	0.00	1.481	0.000	1.008
1.08	870.00	0.000	4.600	0.000	5.000	0.000	.100	0.00	.9892	0.000	1.009
8.00	1498.0	0.000	2.300	0.000	5.000	0.000	.070	0.00	1.360	0.000	6.000
1.09	1911.0	0.000	1.900	0.000	5.000	0.000	.070	0.00	1.697	0.000	1.010
1.10	202.00	0.000	4.000	0.000	5.000	0.000	.060	0.00	.3199	0.000	1.011
14.00	702.00	0.000	4.800	0.000	5.000	0.000	.070	0.00	.6352	0.000	7.000
13.00	759.00	0.000	3.800	0.000	5.000	0.000	.070	0.00	.7433	0.000	8.000
16.00	529.00	0.000	3.300	0.000	5.000	0.000	.120	0.00	1.061	0.000	9.000
13.01	349.00	0.000	3.200	0.000	5.000	0.000	.070	0.00	.5407	0.000	8.001
2.00	962.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.427	0.000	10.00
9.00	924.00	0.000	2.500	0.000	5.000	0.000	.120	0.00	1.629	0.000	11.00
2.01	593.00	0.000	3.800	0.000	5.000	0.000	.120	0.00	1.050	0.000	10.00
10.00	1649.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	2.461	0.000	12.00
2.02	1270.0	0.000	1.200	0.000	5.000	0.000	.090	0.00	2.145	0.000	10.00
4.00	1529.0	0.000	1.300	0.000	5.000	0.000	.120	0.00	2.934	0.000	13.00
4.01	1372.0	0.000	4.000	0.000	5.000	0.000	.120	0.00	1.583	0.000	13.00
4.02	2754.0	0.000	1.400	0.000	5.000	0.000	.090	0.00	2.971	0.000	13.00
2.03	600.00	0.000	2.800	0.000	5.000	0.000	.120	0.00	1.230	0.000	10.00
11.00	764.00	0.000	3.400	0.000	5.000	0.000	.120	0.00	1.266	0.000	14.00
2.04	1001.0	0.000	2.000	0.000	5.000	0.000	.120	0.00	1.899	0.000	10.00
12.00	1852.0	0.000	2.600	0.000	5.000	0.000	.070	0.00	1.428	0.000	15.00
2.05	386.00	0.000	2.700	0.000	5.000	0.000	.070	0.00	.6202	0.000	10.01
2.06	707.00	0.000	4.300	0.000	5.000	0.000	.120	0.00	1.081	0.000	10.01
2.07	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	10.01
2.08	1162.0	0.000	2.900	0.000	5.000	0.000	.070	0.00	1.061	0.000	7.001
15.00	215.00	0.000	4.900	0.000	5.000	0.000	.060	0.00	.2986	0.000	16.00

2.09	248.00	0.000	4.200	0.000	5.000	0.000	.060	0.00	.3473	0.000	7.002
1.11	473.00	0.000	4.400	0.000	10.00	0.000	.050	0.00	.3365	0.000	1.012
1.12	579.00	0.000	3.000	0.000	10.00	0.000	.050	0.00	.4525	0.000	1.013
1.13	.00001	0.000	.0010	0.000	1.000	0.000	.025	0.00	.0020	0.000	1.014

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2	Cont. Loss #1 (mm/h)	Cont. Loss #2	Excess Rain #1 (mm)	Excess Rain #2	Peak Inflow (m^3/s)	Time to Peak	Link Lag mins
1.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	34.472	1280.	0.000
5.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	19.142	1210.	0.000
1.01	4.438	10.00	0.000	6.000	0.000	48.010	0.000	76.902	1230.	31.46
1.02	4.438	10.00	0.000	6.000	0.000	48.010	0.000	88.836	1250.	19.36
6.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	42.934	1320.	0.000
1.03	4.438	10.00	0.000	6.000	0.000	48.010	0.000	166.46	1300.	56.54
1.04	4.438	10.00	0.000	6.000	0.000	48.010	0.000	200.88	1350.	52.36
1.05	4.438	10.00	0.000	6.000	0.000	48.010	0.000	214.52	1380.	24.42
1.06	4.438	10.00	0.000	5.000	0.000	58.010	0.000	238.62	1390.	47.30
3.00	4.438	10.00	0.000	5.000	0.000	58.010	0.000	73.975	1330.	0.000
3.01	4.438	10.00	0.000	5.000	0.000	58.010	0.000	125.29	1330.	64.02
1.06#244	4.438	10.00	0.000	5.000	0.000	58.010	0.000	365.66	1430.	13.31
7.00	4.438	10.00	0.000	5.000	0.000	58.010	0.000	17.061	1200.	0.000
1.07	4.438	10.00	0.000	5.000	0.000	58.010	0.000	397.09	1400.	38.61
1.08	4.438	10.00	0.000	5.000	0.000	58.010	0.000	404.13	1440.	23.76
8.00	4.438	10.00	0.000	5.000	0.000	58.010	0.000	34.587	1200.	0.000
1.09	4.438	10.00	0.000	5.000	0.000	58.010	0.000	436.95	1450.	100.1
1.10	4.438	10.00	0.000	5.000	0.000	58.010	0.000	437.17	1550.	9.900
14.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	18.316	1110.	0.000
13.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	18.315	1130.	0.000
16.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	9.888	1210.	0.000
13.01	4.438	10.00	0.000	6.000	0.000	48.010	0.000	35.354	1150.	20.00
2.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	16.177	1240.	0.000
9.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	13.765	1290.	0.000
2.01	4.438	10.00	0.000	6.000	0.000	48.010	0.000	40.752	1230.	20.60
10.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	19.810	1320.	0.000
2.02	4.438	10.00	0.000	6.000	0.000	48.010	0.000	75.234	1310.	45.60
4.00	4.438	10.00	0.000	5.000	0.000	58.010	0.000	18.589	1330.	0.000
4.01	4.438	10.00	0.000	5.000	0.000	58.010	0.000	44.421	1290.	27.80
4.02	4.438	10.00	0.000	6.000	0.000	48.010	0.000	75.457	1330.	61.70
2.03	4.438	10.00	0.000	6.000	0.000	48.010	0.000	158.01	1370.	36.10
11.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	13.507	1220.	0.000
2.04	4.438	10.00	0.000	6.000	0.000	48.010	0.000	179.33	1370.	25.70
12.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	36.465	1210.	0.000
2.05	4.438	10.00	0.000	6.000	0.000	48.010	0.000	205.66	1360.	14.40
2.06	4.438	10.00	0.000	6.000	0.000	48.010	0.000	214.64	1360.	3.500
2.07	4.438	10.00	0.000	6.000	0.000	48.010	0.000	214.64	1360.	23.10
2.08	4.438	10.00	0.000	6.000	0.000	48.010	0.000	254.03	1350.	26.60
15.00	4.438	10.00	0.000	6.000	0.000	48.010	0.000	6.916	1080.	0.000
2.09	4.438	10.00	0.000	6.000	0.000	48.010	0.000	256.68	1380.	15.00
1.11	4.438	10.00	0.000	5.000	0.000	58.010	0.000	657.42	1490.	18.48
1.12	4.438	10.00	0.000	5.000	0.000	58.010	0.000	658.42	1510.	27.61
1.13	4.438	10.00	0.000	5.000	0.000	58.010	0.000	658.42	1540.	0.000

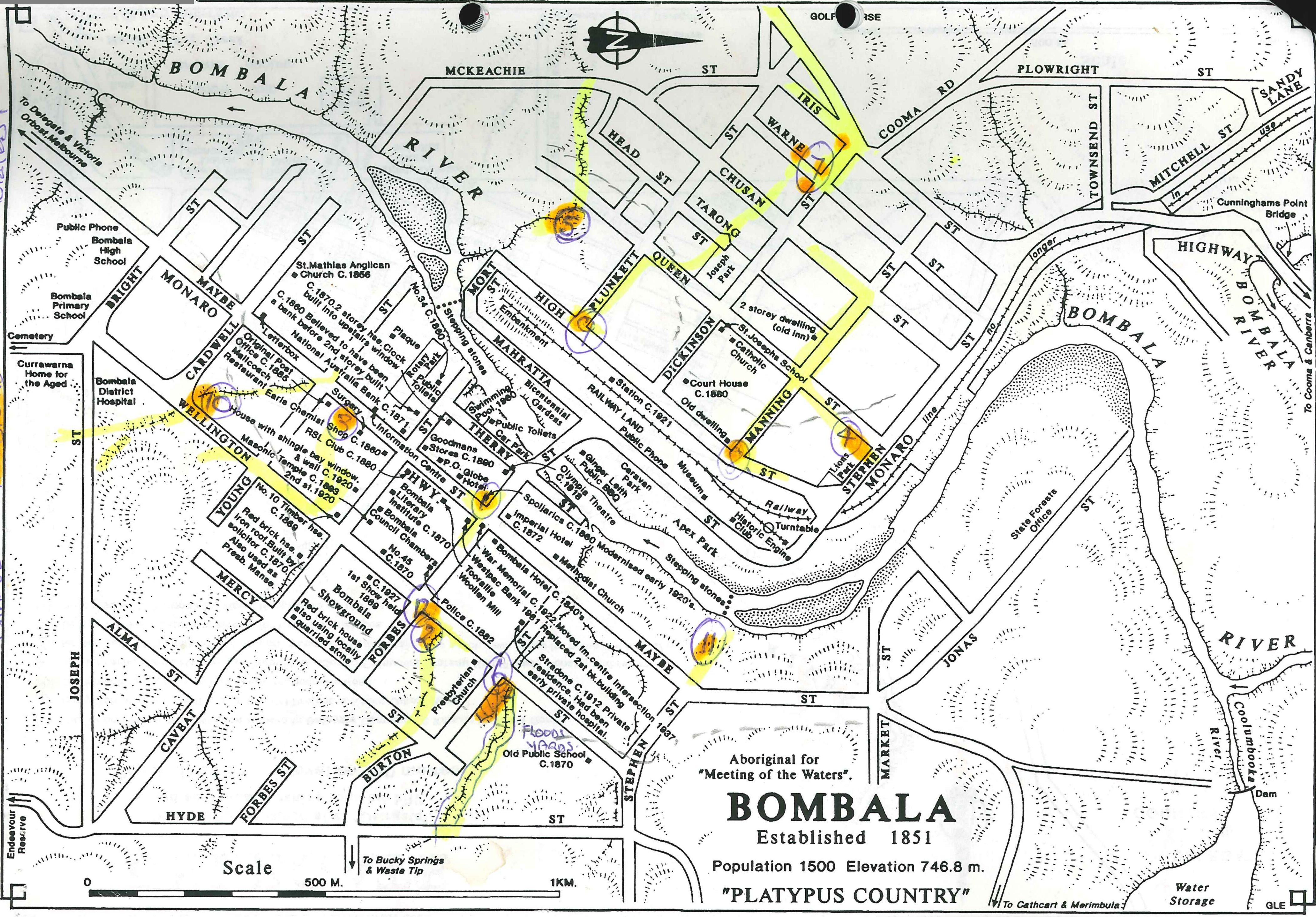
Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2 (mm)	Cont. Loss #1 (mm/h)	Cont. Loss #2 (mm/h)	Excess Rain #1 (mm)	Excess Rain #2 (mm)	Peak Inflow (m^3/s)	Time to Peak	Link Lag (mins)
1.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	39.959	100.0	8.000
1.01	221.00	15.00	.0000	4.500	.0000	418.75	.000	69.016	110.0	4.000
3.00	221.00	15.00	.0000	2.500	.0000	422.42	.000	106.60	80.00	16.00
4.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	68.394	90.00	19.00
4.01	221.00	15.00	.0000	4.500	.0000	418.75	.000	245.35	100.0	4.000
1.02	221.00	10.00	15.00	.0000	4.500	432.00	418.75	336.07	100.0	25.00
2.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	63.544	130.0	23.00
2.01	221.00	15.00	.0000	4.500	.0000	418.75	.000	92.190	150.0	11.00
1.03	221.00	10.00	15.00	.0000	4.500	432.00	418.75	458.94	130.0	4.800
1.04	221.00	10.00	15.00	.0000	4.500	432.00	418.75	464.24	130.0	1.500
1.05	221.00	10.00	15.00	.0000	4.500	432.00	418.75	464.76	130.0	13.00
5.0	221.00	10.00	15.00	.0000	4.500	432.00	418.75	93.022	90.00	13.00
1.06	221.00	10.00	15.00	.0000	4.500	432.00	418.75	535.03	130.0	6.000
10.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	66.300	80.00	10.20
12.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	100.05	100.0	10.20
10.01	221.00	15.00	.0000	4.500	.0000	418.75	.000	187.64	100.0	6.800
11.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	49.135	90.00	6.800
10.02	221.00	15.00	.0000	4.500	.0000	418.75	.000	248.91	110.0	9.600
13.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	38.851	70.00	18.00
13.01	221.00	15.00	.0000	4.500	.0000	418.75	.000	107.56	90.00	9.600
10.03	221.00	15.00	.0000	4.500	.0000	418.75	.000	365.35	110.0	1.500
14.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	30.399	80.00	1.500
10.04	221.00	15.00	.0000	2.500	.0000	422.42	.000	389.14	110.0	12.00
15.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	56.826	80.00	10.00
15.01	221.00	15.00	.0000	4.500	.0000	418.75	.000	114.77	90.00	11.00
15.02	221.00	15.00	.0000	4.500	.0000	418.75	.000	147.77	100.0	6.000
16.00	221.00	15.00	.0000	4.500	.0000	418.75	.000	34.611	80.00	6.000
15.03	221.00	15.00	.0000	2.500	.0000	422.42	.000	188.04	100.0	12.00
17.00	221.00	15.00	.0000	2.500	.0000	422.42	.000	21.524	100.0	5.000
10.05	221.00	15.00	.0000	2.500	.0000	422.42	.000	637.07	120.0	8.000
10.06	221.00	15.00	.0000	2.500	.0000	422.42	.000	651.28	130.0	8.000
10.07	221.00	15.00	.0000	2.500	.0000	422.42	.000	667.75	140.0	8.000
10.08	221.00	15.00	.0000	2.500	.0000	422.42	.000	680.14	150.0	6.000
1.07	221.00	10.00	15.00	.0000	4.500	432.00	418.75	1211.9	150.0	.0000

APPENDIX F
RMA -2 HYDRAULIC MODELLING RESULTS

TABLE F1 - HYDRAULIC RESULTS FROM RMA-2 SIMULATIONS OF BOMBALA RIVER

LOCATION	RMA-2 MODEL CROSS-SECTION	CHAINAGE RELATI	CHAINAGE (metres)	WATER SURFACE ELEVATION (mAHD)							CHANNEL VELOCITY (m/s)						
				PMF	0.2% AEP	0.5% AEP	1% AEP	2% AEP	5% AEP	20% AEP	PMF	0.2% AEP	0.5% AEP	1% AEP	2% AEP	5% AEP	20% AEP
Cunnighams Point Bridge	XS 15	-20	0	713.2	707.9	706.9	706.1	705.3	704.5	702.9	2.9	1.8	1.6	1.5	1.4	1.3	1.0
	CS 14	0	20	713.0	707.7	706.7	705.9	705.1	704.3	702.7	3.6	2.6	2.4	2.3	2.2	2.1	1.8
	XS 14	440	460	712.3	707.0	706.1	705.3	704.5	703.7	702.0	2.6	2.0	1.8	1.7	1.5	1.4	1.2
	CS 13	850	870	712.4	706.9	706.0	705.1	704.3	703.5	701.7	0.4	0.9	0.9	0.9	0.8	0.8	0.7
	XS 13	1020	1040	712.4	706.8	705.8	705.0	704.2	703.4	701.6	0.8	1.6	1.6	1.5	1.4	1.4	1.2
Confluence of Bombala and Coolumbooka Rivers	CS 12	1361	1381	712.2	706.6	705.6	704.8	704.0	703.2	701.4	2.0	2.0	1.9	1.8	1.8	1.7	1.4
	XS 10	1420	1440	712.1	706.5	705.5	704.7	703.9	703.1	701.3	2.5	2.4	2.4	2.2	2.1	2.0	1.6
	XS 9	1640	1660	711.9	706.3	705.4	704.5	703.8	702.9	701.2	2.4	2.2	2.1	2.0	1.9	1.8	1.6
	CS 11	1865	1885	711.8	706.3	705.3	704.5	703.7	702.8	701.1	1.3	1.4	1.4	1.4	1.4	1.4	1.2
Queen Street	CS 10	2610	2630	711.2	705.7	704.7	703.9	703.1	702.3	700.6	2.7	2.7	2.5	2.4	2.2	2.0	1.7
High Street	CS 9	2855	2875	711.2	705.6	704.7	703.9	703.1	702.3	700.5	1.7	1.8	1.7	1.6	1.4	1.3	1.0
	CS 8	3145	3165	711.2	705.6	704.6	703.8	703.0	702.2	700.5	1.5	1.6	1.5	1.5	1.4	1.3	1.1
Forbes Street Bridge	CS 6	3700	3720	710.9	705.3	704.3	703.5	702.7	701.9	700.1	2.0	1.8	1.8	1.7	1.7	1.6	1.5
Caveat Street	CS 5	3935	3955	710.9	705.3	704.3	703.4	702.6	701.8	700.0	1.9	1.6	1.6	1.5	1.5	1.5	1.4
Young Street	CS 4	4240	4260	710.8	705.2	704.2	703.4	702.6	701.8	700.0	1.3	0.8	0.7	0.6	0.6	0.5	0.5
Cardwell Street	XS 8	4505	4525	710.4	705.0	704.1	703.2	702.5	701.7	699.9	2.9	1.9	1.7	1.6	1.5	1.3	1.0
	CS 3	4600	4620	709.9	704.7	703.8	703.0	702.3	701.5	699.8	4.2	3.0	2.7	2.5	2.3	2.1	1.7
Bright Street	XS 7	4720	4740	709.6	704.6	703.7	702.9	702.2	701.4	699.7	4.3	2.8	2.6	2.4	2.2	2.0	1.6
	CS 2	5580	5600	708.8	703.9	703.0	702.3	701.6	700.9	699.4	4.7	3.1	2.8	2.5	2.3	2.0	1.4
Sewerage Treatment Plant	CS 1	6774	6794	708.3	703.1	702.2	701.5	700.9	700.2	698.7	4.7	3.8	3.5	3.2	2.9	2.6	2.0
	XS 6	7647	7667	707.6	702.6	701.7	700.9	700.3	699.7	698.2	4.8	3.3	3.1	3.0	2.8	2.6	2.1
	XS 5	7999	8019	707.5	702.0	701.0	700.2	699.5	698.8	697.4	1.7	1.4	1.2	1.1	1.0	0.9	0.7
	XS 4	8404	8424	703.9	699.5	698.7	697.9	697.3	696.6	695.2	5.9	4.3	3.9	3.7	3.4	3.1	2.5
	XS 3	8694	8714	701.3	697.3	696.6	696.0	695.4	694.8	693.7	6.2	4.4	4.1	3.8	3.5	3.2	2.6
	XS 2	9074	9094	697.5	693.5	692.8	692.2	691.7	691.3	690.7	5.2	3.5	3.2	2.9	2.5	2.3	1.8
"The Falls"	XS 1	9554	9574	693.7	688.7	688.1	687.6	687.2	686.5	685.3	5.1	3.7	3.4	3.1	2.8	2.6	2.3

APPENDIX G
BOMBALA SHIRE COUNCIL – VILLAGE OVERLAND FLOW INVESTIGATION INFORMATION



YELLOW CATCHMENT ← NUMBERED

ORANGE HOT SPOTS

1. NICKI SPOLJARIC'S CORNER FURNITURE JOB.
WATER BUILDS UP AND ENTERS SHOP IN MAJOR DOWN POURS.

2. STEFAN SANAKO'S HOUSE WELLINGTON ST
WATER COMES FROM MERCY ST CATCHMENT AND THROUGH HIS BACK YARD IN AN OPEN DRAIN AND FLOODS HIS GARDEN IN MAJOR DOWN POURS. HEAVY RAIN.

3. MICK COTTERILL'S MOTORS
WATER FLOODS THROUGH FROM FROM WELLINGTON ST CATCH MENT AND BE HIND HOSPITAL BUILDS UP AND FLOODS HIS WORKSHOP & SHOW FLOOR etc.

4. EROLL WILSON IN QUEEN ST
WATER COMES DOWN FROM MANNING ST AND CHOSAN ST CATCHMENT AND FLOOD ACROSS RD IN QUEEN ST AROUND TERRY LOMAS HOUSE AND WASHES ACROSS NATURE STRIP AND INTO EROLLS YARD AND EX KORRELLA'S YARD ON CORNER.

5. JOHN PODGER HOUSE IN QUEEN ST
WATER RUSHES DOWN MAIN CULVERT AND IS SCOURING OUT HIS LAND. ("MAJOR EROSION")

(6) OZZIE BENSONS RESIDENCE AND NEIGHBOUR'S
MERCY ST CATCHMENT AND HYDE ST WATER FLOODS THEIR BACK YARD IN HEAVY RAIN.

(7). CATCHMENT GUNNINGRAH RD AND IRIS ST
HEAVY RAIN EFFECT'S HOUSES BELOW IN DICKENSON ST (ie) CORNER OF WARNE ST AND DICKENSON ST. WATER WASHES INTO YARDS.

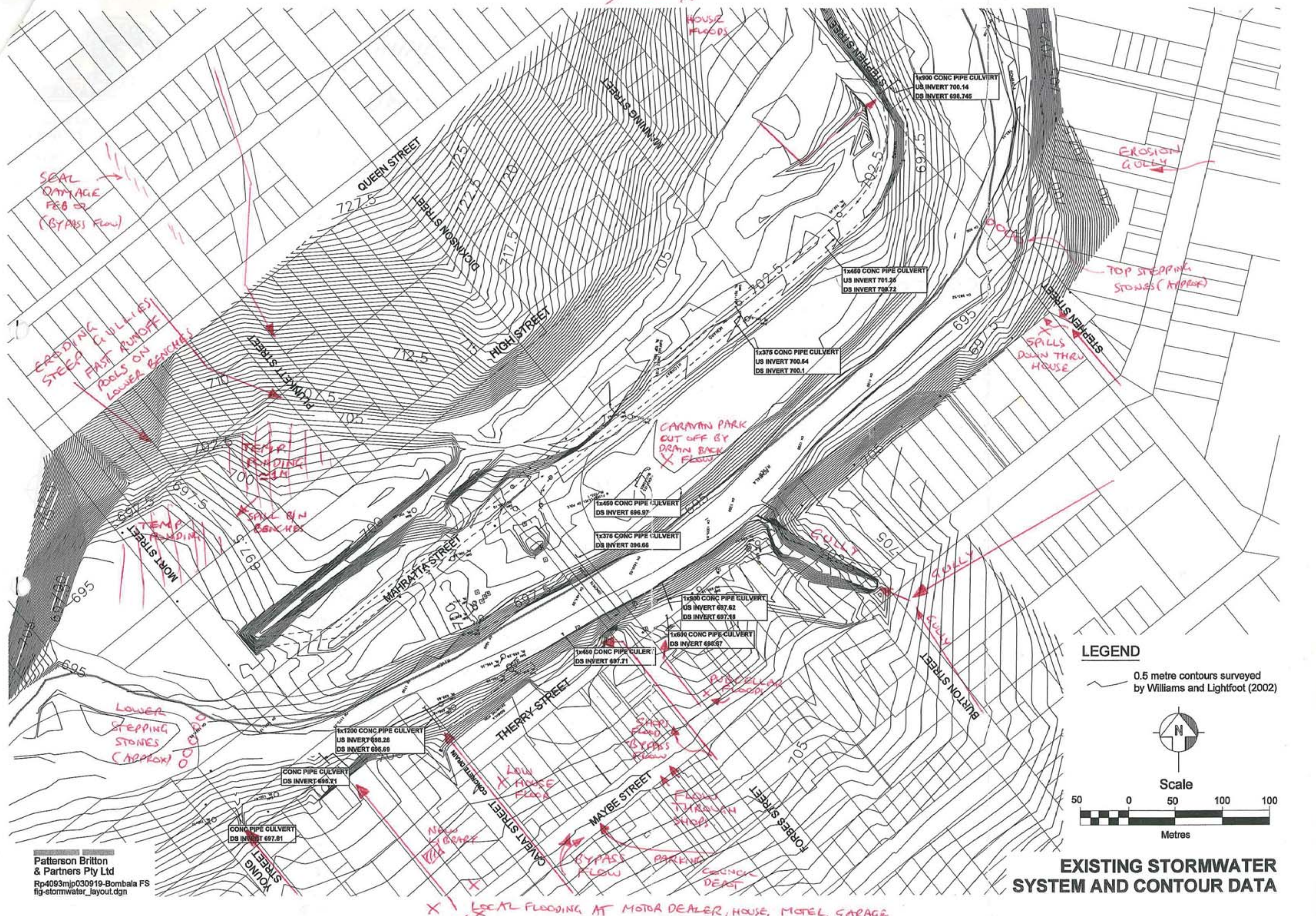
(8). MANNING CHUSAN ST QUEEN ST CATCHMENT.
WATER AT THE BOTTOM OF MANNING FLOODS OVER RD, HAS TROUBLE DISCHARGING THROUGH PIPE SYSTEM. (SAFETY ISSUE.) INTERSECTION HIGH ST.

(9). BOTTOM OF PLUNKETT ST. CATCHMENT WATER DISCHARGES ACROSS THE RD AT HIGH ST INTERSECTION. (STARTS IN TARONG PLACE CATCHMENTS & ~~DRAIN~~.) THIS IS LINKED TO IRIS ST CATCHMENT. NO 7.

(10) WATER FROM BEHIND HOSPITAL CATCHMENT FLOODS OVER AND BUILDS UP AT WELLINGTON ST. CROSSING BELOW HOSPITAL ON NATURE STRIP.

(11). WATER SPILLS FROM DRAIN IN VERY ST INTO FAYE CAMPBELL'S HOUSE AND YARD.

(12). WELLINGTON ST OPEN DRAIN ON PRESBYTERIAN CHURCH SIDE VERY FLAT FALL WATER LAYS IN FRONT OF HOUSES BACK UP TO CORNER OF FORBES ST.



EXISTING STORMWATER SYSTEM AND CONTOUR DATA

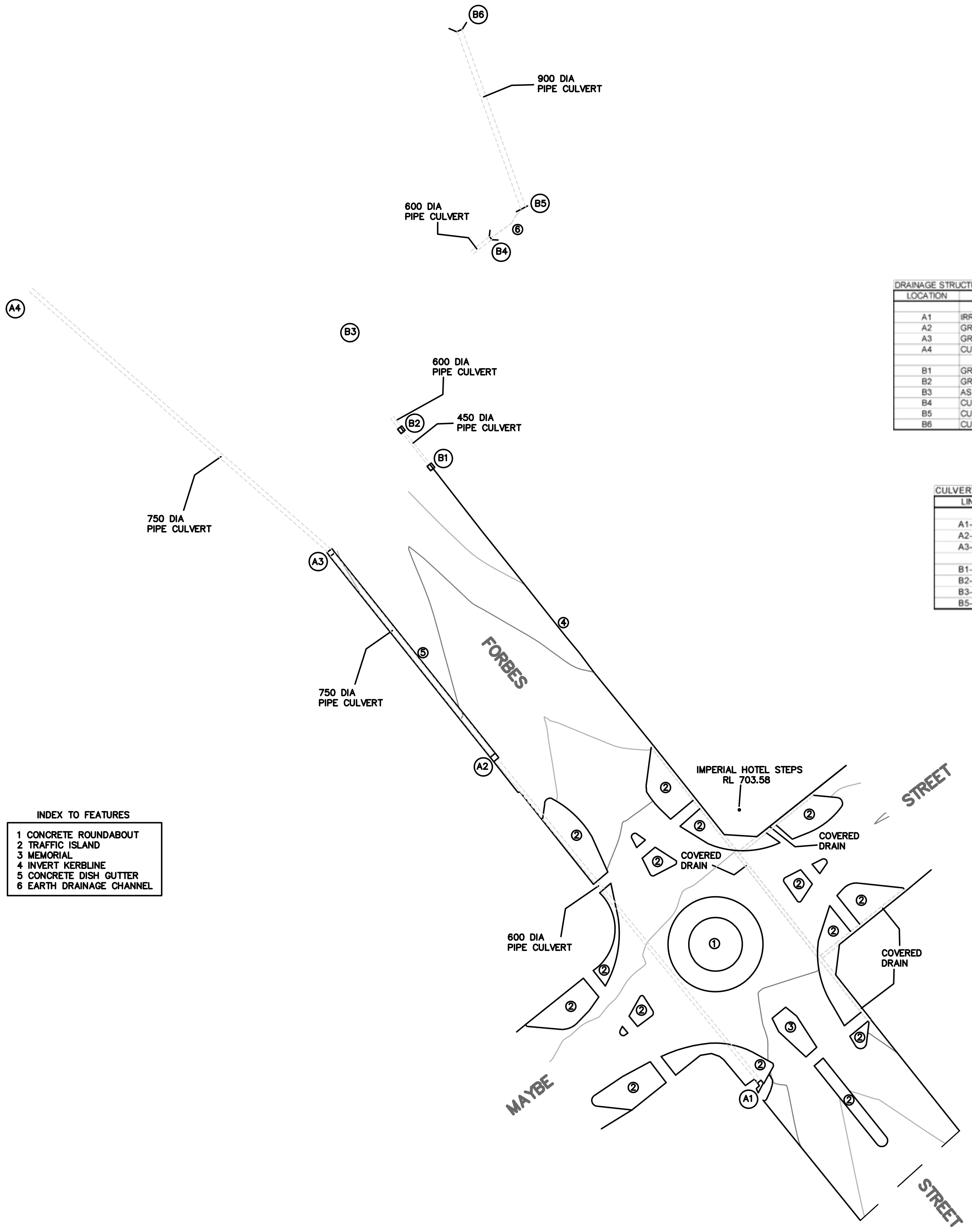
APPENDIX H
VOFI RAFTS MODEL INPUT PARAMETERS

TABLE H1 - ADOPTED HYDROLOGIC MODEL PARAMETERS FOR VILLAGE OVERLAND FLOW INVESTIGATION

SUB-CATCHMENT	HYDROLOGIC MODEL NODE	SUB CATCHMENT AREA (ha)	CATCHMENT SLOPE (%)	IMPERVIOUS AREAS				PERVIOUS AREAS				% IMPERVIOUS
				Impervious Area (ha)	Mannings 'n'	Initial Loss (mm)	Continuing Loss (mm/hr)	Pervious Area (ha)	Mannings 'n'	Initial Loss (mm)	Continuing Loss (mm/hr)	
A_u	1.00	43.7	8.1	4.4	0.015	1.5	0.5	39.3	0.035	5.0	2.5	10
A_l	1.01	40.6	4.5	24.4	0.015	1.5	0.5	16.2	0.035	5.0	2.5	60
B_u	2.00	58.7	11.0	8.8	0.015	1.5	0.5	49.9	0.035	5.0	2.5	15
B_l	2.01	25.3	4.2	17.7	0.015	1.5	0.5	7.6	0.035	5.0	2.5	70
C_u	3.00	8.9	5.0	2.7	0.015	1.5	0.5	6.2	0.035	5.0	2.5	30
C_l	3.01	15.2	3.6	11.4	0.015	1.5	0.5	3.8	0.035	5.0	2.5	75
D_u	4.00	37.5	9.0	7.5	0.015	1.5	0.5	30.0	0.035	5.0	2.5	20
D_l	4.01	3.1	4.3	2.0	0.015	1.5	0.5	1.1	0.035	5.0	2.5	65
E	4.02	159.8	5.0	32.0	0.015	1.5	0.5	127.8	0.035	5.0	2.5	20
F	5.00	48.5	5.2	29.1	0.015	1.5	0.5	19.4	0.035	5.0	2.5	60
G_u	6.00	1.7	6.9	1.3	0.015	1.5	0.5	0.4	0.035	5.0	2.5	75
G_l	6.01	37.6	6.7	18.8	0.015	1.5	0.5	18.8	0.035	5.0	2.5	50
Totals		480.60		160.0				320.6				33.28

APPENDIX I

VILLAGE OVERLAND FLOW SURVEY DATA



INDEX TO FEATURES

1 CONCRETE ROUNDABOUT
2 TRAFFIC ISLAND
3 MEMORIAL
4 INVERT KERBLINE
5 CONCRETE DISH GUTTER
6 EARTH DRAINAGE CHANNEL

DRAINAGE STRUCTURES

LOCATION	TYPE	BREADTH	WIDTH	HEIGHT	SILL LEVEL	BASE LEVEL
A1	IRREGULAR GRATED SURFACE INLET			1.71	703.38	701.67
A2	GRATED SURFACE INLET	0.95	1.09	1.44	701.6	700.16
A3	GRATED SURFACE INLET	0.85	1.06	1.29	700.86	699.57
A4	CULVERT OUTLET NO HEADWALL					698.44
B1	GRATED KERB INLET	0.94	0.9	0.98	700.61	699.63
B2	GRATED KERB INLET	0.94	0.9	1.03	700.59	699.56
B3	ASSUMED JUNCTION LOCATION NOT FOUND					
B4	CULVERT OUTLET WITH CONCRETE HEADWALL			0.91	699.56	698.65
B5	CULVERT INLET WITH BRICK HEADWALL			1.48	699.06	697.58
B6	CULVERT OUTLET WITH CONCRETE HEADWALL			1.21	698.36	697.15

CULVERTS

LINE		LENGTH	US INVERT	DS INVERT
A1-A2	600 DIAMETER PIPE CULVERT	70	701.67	700.16
A2-A3	750 DIAMETER PIPE CULVERT	43.3	700.16	699.58
A3-A4	750 DIAMETER PIPE CULVERT	66.6	699.57	698.44
B1-B2	450 DIAMETER PIPE CULVERT	7.1	699.61	699.56
B2-B3	600 DIAMETER PIPE CULVERT	UNKNOWN	699.56	UNKNOWN
B3-B4	600 DIAMETER PIPE CULVERT	UNKNOWN	UNKNOWN	698.65
B5-B6	900 DIAMETER PIPE CULVERT	31.8	697.58	697.15

UNDERGROUND SERVICES EXIST WITHIN THE WORKS AREA
THE DESIGNER / CONTRACTOR / BUILDER SHALL, BEFORE THE COMMENCEMENT OF ANY WORKS CONTACT ANY RELEVANT AUTHORITY AS WELL AS DIAL 1100 "DIAL BEFORE YOU DIG" TO ASCERTAIN THE EXACT LOCATION OF THESE OR ANY OTHER UNDERGROUND SERVICES

0 10 20 30 40 50
SCALE 1:500 AT A1

AMDT	DATE	AMENDMENT DETAILS

CAUTION
THE INFORMATION SHOWN ON THIS PLAN MAY BE INSUFFICIENT FOR SOME TYPES OF DETAIL DESIGN. WILLIAMS AND LIGHTFOOT SHOULD BE CONSULTED AS TO THE SUITABILITY OF THE INFORMATION SHOWN HEREIN PRIOR TO THE COMMENCEMENT OF ANY DESIGN WORKS BASED ON THIS PLAN

WILLIAMS
CONSULTING SURVEYORS
ENVIRONMENTAL ENGINEERS
8 DAWSON STREET
COOMA NSW 2630
TEL (02) 6452 1947
FAX (02) 6452 5828
PO BOX 619
COOMA NSW 2630

DATUM : AHD
CONTOUR INTERVAL 0.5m
SCALE 1:500 AT A1
GRID : MGA

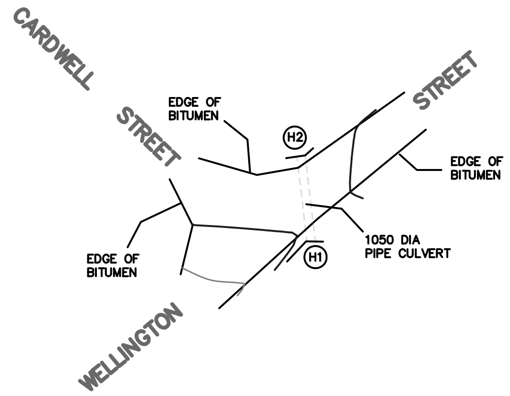
DATE	SURVEYED	DRAWN
07/09/09	PW	GM

LEVEL AND DETAIL SURVEY OF
DRAINAGE INFRASTRUCTURE
INTERSECTION OF FORBES AND MAYBE STREETS
BOMBALA

FOR : WORLEY PARSONS

REFERENCE NUMBER
09054A

SHEET 1 OF 1



DRAINAGE STRUCTURES

LOCATION	TYPE	BREADTH	WIDTH	HEIGHT	SILL LEVEL	BASE LEVEL
H1	CULVERT INLET WITH CONCRETE HEADWALL			1.55	724.82	723.27
H2	CULVERT OUTLET WITH CONCRETE HEADWALL			1.46	724.57	723.11

CULVERTS

LINE		LENGTH	US INVERT	DS INVERT
H1-H2	1050 DIA PIPE CULVERT	11	723.27	723.11

UNDERGROUND SERVICES EXIST WITHIN THE WORKS AREA
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0 10 20 30 40 50
SCALE 1:500 AT A1

AMDT	DATE	AMENDMENT DETAILS

WILLIAMS

CONSULTING SURVEYORS
ENVIRONMENTAL ENGINEERS

8 DAWSON STREET
COOMA NSW 2630
TEL (02) 6452 1947
FAX (02) 6452 5828
PO BOX 619
COOMA NSW 2630

DATUM : AHD
CONTOUR INTERVAL 0.5m
SCALE 1:500 AT A1
GRID : MGA

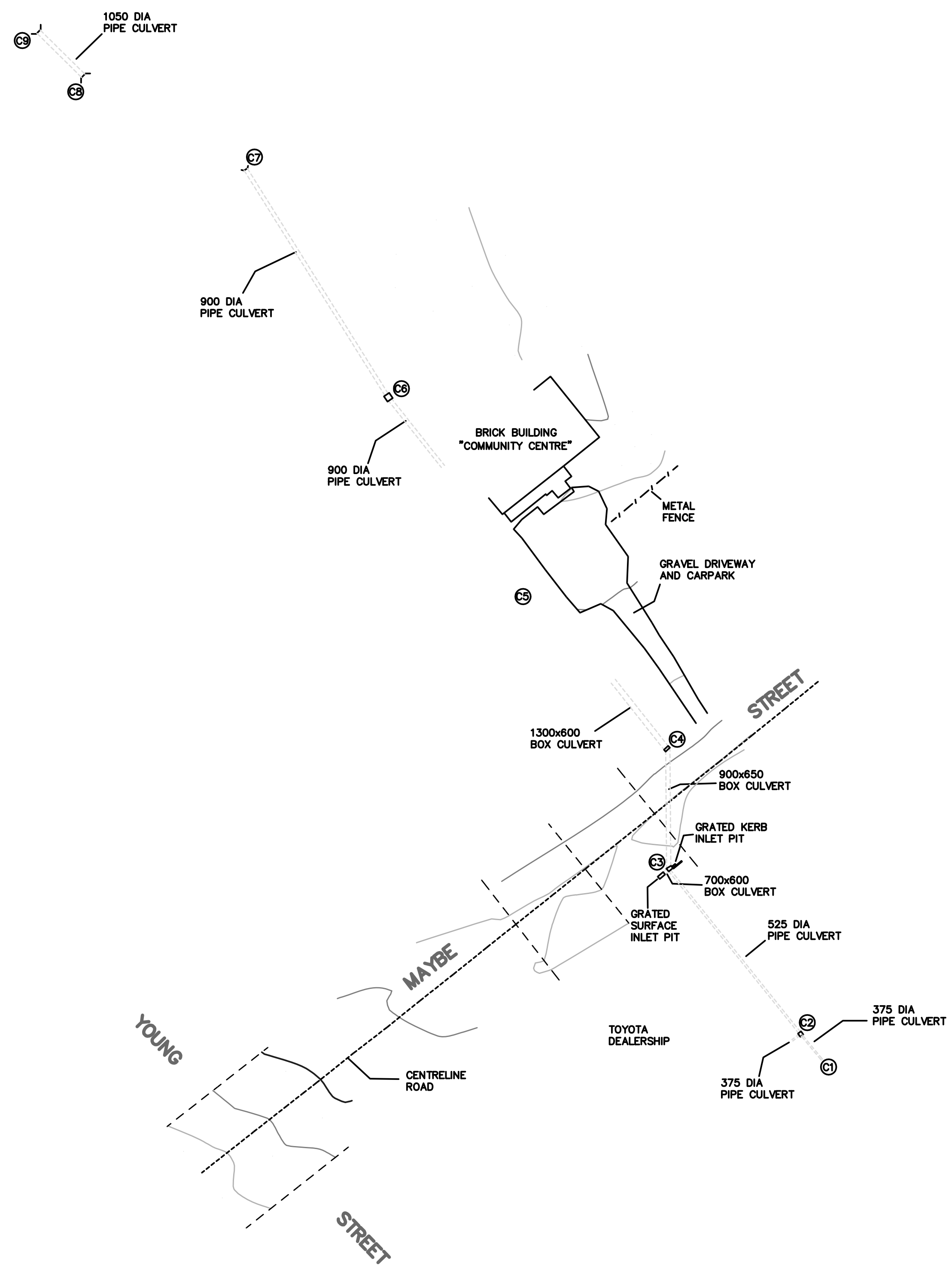
DATE	SURVEYED	DRAWN
07/09/09	PW	GM

LEVEL AND DETAIL SURVEY OF
DRAINAGE INFRASTRUCTURE
WELLINGTON AND CARDWELL STREETS
BOMBALA

FOR : WORLEY PARSONS

REFERENCE NUMBER
09054E

SHEET 1 OF 1



DRAINAGE STRUCTURES

LOCATION	TYPE	BREADTH	WIDTH	HEIGHT	SILL LEVEL	BASE LEVEL
C1	CULVERT INLET NO HEADWALL					703.76
C2	GRATED SURFACE INLET	0.95	0.90	0.65	704.25	703.60
C3	COVERED SIDE INLET	1.29	0.70	1.14	703.89	702.75
C4	COVERED SIDE INLET	1.36	0.60	0.65	702.86	702.21
C5	BOX / PIPE CULVERT JUNCTION LOCATION UNKNOWN					
C6	COVERED JUNCTION	1.50	1.50	2.50	701.86	699.36
C7	CULVERT OUTLET WITH CONCRETE HEADWALL			1.14	699.89	698.75
C8	CULVERT INLET WITH CONCRETE HEADWALL			1.45	697.31	695.86
C9	CULVERT OUTLET WITH CONCRETE HEADWALL			1.38	696.74	695.36

CULVERTS

LINE		LENGTH	US INVERT	DS INVERT
C1-C2	375 DIAMETER PIPE CULVERT	7.40	703.76	703.60
C2-C3	525 DIAMETER PIPE CULVERT	48.80	703.65	702.75
C3-C4	900x650 BOX CULVERT	27.50	702.75	702.21
C4-C5	1300x600 BOX CULVERT	UNKNOWN	702.21	UNKNOWN
C5-C6	900 DIAMETER PIPE CULVERT	UNKNOWN	UNKNOWN	700.73
C6-C7	900 DIAMETER PIPE CULVERT	62.50	699.36	698.75
C8-C9	1050 DIAMETER PIPE CULVERT	14.80	695.86	695.36

UNDERGROUND SERVICES EXIST WITHIN THE WORKS AREA
THE DESIGNER / CONTRACTOR / BUILDER SHALL, BEFORE THE COMMENCEMENT OF ANY WORKS CONTACT ANY RELEVANT AUTHORITY AS WELL AS DIAL 1100 "DIAL BEFORE YOU DIG" TO ASCERTAIN THE EXACT LOCATION OF THESE OR ANY OTHER UNDERGROUND SERVICES

0 10 20 30 40 50
SCALE 1:800 AT A1

AMDT	DATE	AMENDMENT DETAILS

WILLIAMS
CONSULTING SURVEYORS ENVIRONMENTAL ENGINEERS
8 DAWSON STREET COOMA NSW 2630
TEL (02) 6452 1947 FAX (02) 6452 5828
PO BOX 619 COOMA NSW 2630

DATUM : AHD CONTOUR INTERVAL 0.5m
SCALE 1:800 AT A1 GRID : MGA

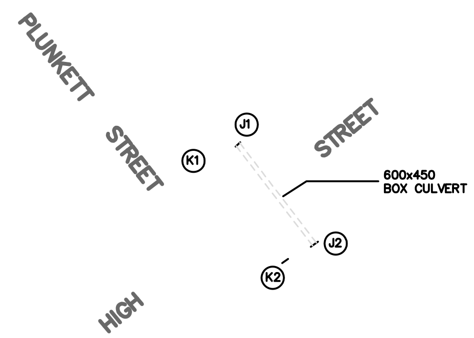
DATE	SURVEYED	DRAWN
07/09/09	PW	GM

LEVEL AND DETAIL SURVEY OF
DRAINAGE INFRASTRUCTURE
IN MAYBE STREET BETWEEN YOUNG AND CAVEAT STREETS
BOMBALA

FOR : WORLEY PARSONS

REFERENCE NUMBER
09054B

SHEET 1 OF 1



DRAINAGE STRUCTURES

LOCATION	TYPE	BREADTH	WIDTH	HEIGHT	SILL LEVEL	BASE LEVEL
J1	CULVERT INLET WITH CONCRETE HEADWALL			0.68	700.23	699.55
J2	CULVERT OUTLET WITH CONCRETE HEADWALL			0.61	699.94	699.33
K1	INLET BURIED LOCATION NOT KNOWN					
K2	CULVERT OUTLET WITH CONCRETE HEADWALL			0.52	699.89	699.37

CULVERTS

LINE		LENGTH	US INVERT	DS INVERT
J1-J2	600x450 BOX CULVERT	15.9	699.55	699.33
K1-K2	600x450 BOX CULVERT			699.37

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0 10 20 30 40 50

SCALE 1:500 AT A1

AMDT	DATE	AMENDMENT DETAILS

CAUTION
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WILLIAMS
CONSULTING SURVEYORS
ENVIRONMENTAL ENGINEERS
8 DAWSON STREET
COOMA NSW 2630
TEL (02) 6452 1947
FAX (02) 6452 5828
PO BOX 619
COOMA NSW 2630

DATUM : AHD CONTOUR INTERVAL 0.5m

SCALE 1:500 AT A1 GRID : MGA

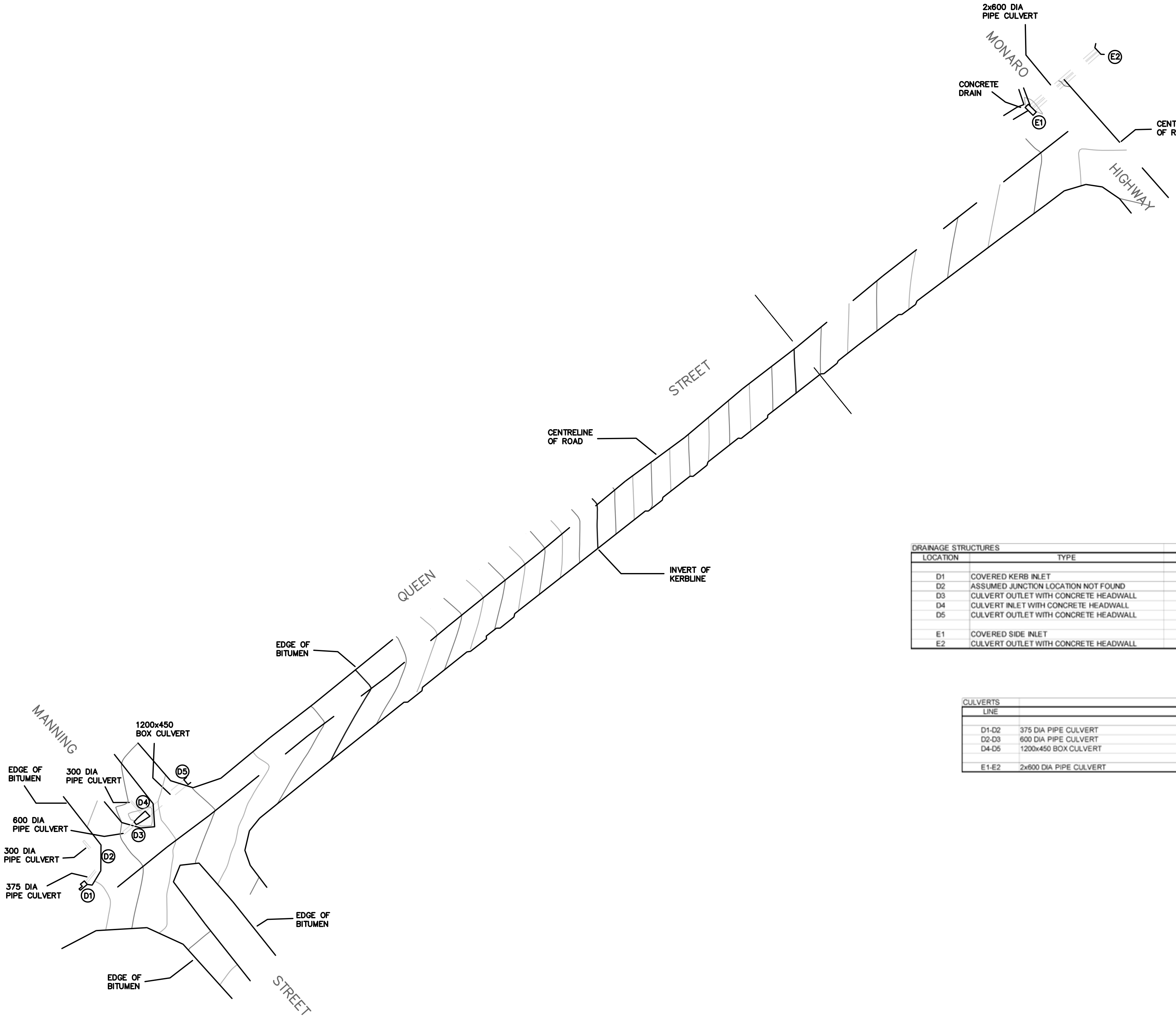
DATE	SURVEYED	DRAWN
07/09/09	PW	GM

LEVEL AND DETAIL SURVEY OF
DRAINAGE INFRASTRUCTURE
PLUNKETT AND HIGH STREETS
BOMBALA

FOR : WORLEY PARSONS

REFERENCE NUMBER
09054G

SHEET 1 OF 1



DRAINAGE STRUCTURES

LOCATION	TYPE	BREADTH	WIDTH	HEIGHT	SILL LEVEL	BASE LEVEL
D1	COVERED KERB INLET	1.00	0.55	0.64	722.96	722.32
D2	ASSUMED JUNCTION LOCATION NOT FOUND					
D3	CULVERT OUTLET WITH CONCRETE HEADWALL			0.90	722.12	721.22
D4	CULVERT INLET WITH CONCRETE HEADWALL			0.87	721.89	721.02
D5	CULVERT OUTLET WITH CONCRETE HEADWALL			0.84	721.72	720.88
E1	COVERED SIDE INLET	2.20	0.90	0.75	706.04	705.29
E2	CULVERT OUTLET WITH CONCRETE HEADWALL			0.93	705.78	704.85

CULVERTS

LINE		LENGTH	US INVERT	DS INVERT
D1-D2	375 DIA PIPE CULVERT	UNKNOWN	722.32	UNKNOWN
D2-D3	600 DIA PIPE CULVERT	UNKNOWN	UNKNOWN	721.22
D4-D5	1200x450 BOX CULVERT	9.7	721.02	720.88
E1-E2	2x600 DIA PIPE CULVERT	17.1	705.29	704.85

UNDERGROUND SERVICES EXIST WITHIN THE WORKS AREA
THE DESIGNER / CONTRACTOR / BUILDER SHALL, BEFORE THE COMMENCEMENT OF ANY WORKS CONTACT ANY RELEVANT AUTHORITY AS WELL AS DIAL 1100 "DIAL BEFORE YOU DIG" TO ASCERTAIN THE EXACT LOCATION OF THESE OR ANY OTHER UNDERGROUND SERVICES

0 10 20 30 40 50
SCALE 1:500 AT A1

AMDT	DATE	AMENDMENT DETAILS

WILLIAMS
CONSULTING SURVEYORS
ENVIRONMENTAL ENGINEERS
8 DAWSON STREET
COOMA NSW 2630
TEL (02) 6452 1947
FAX (02) 6452 5828
PO BOX 619
COOMA NSW 2630

DATUM : AHD CONTOUR INTERVAL 0.5m
SCALE 1:500 ATA1 GRID : MGA

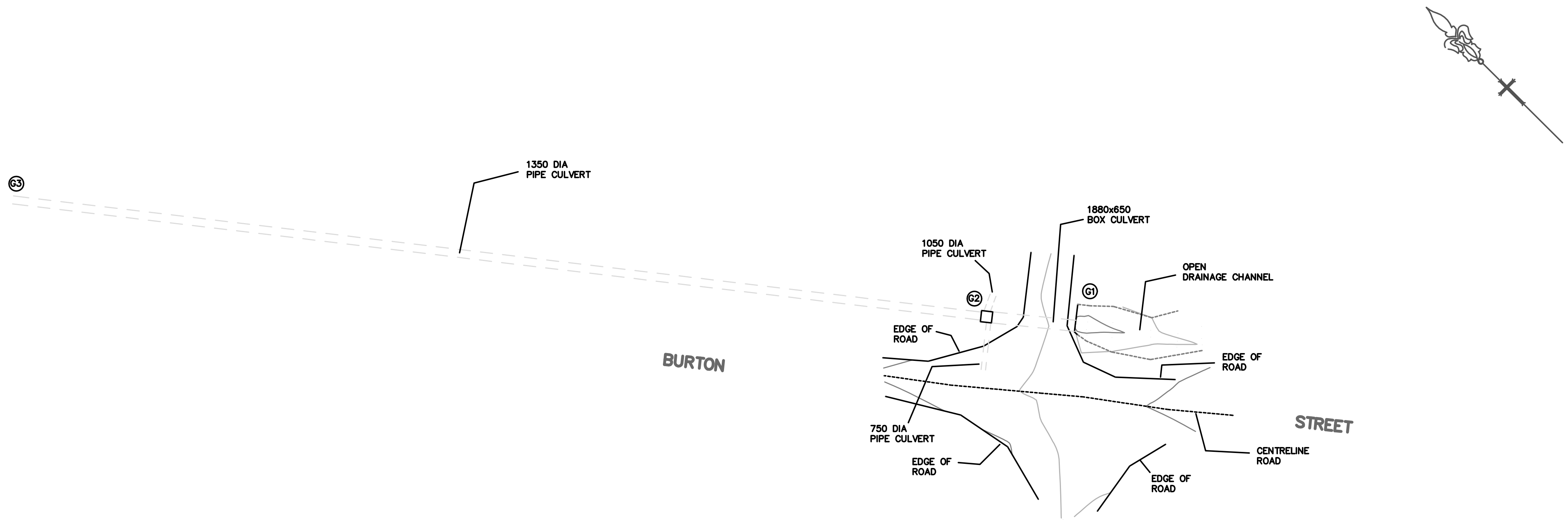
DATE	SURVEYED	DRAWN
07/09/09	PW	GM

LEVEL AND DETAIL SURVEY OF
DRAINAGE INFRASTRUCTURE
QUEEN AND MANNING STREETS
BOMBALA

FOR : WORLEY PARSONS

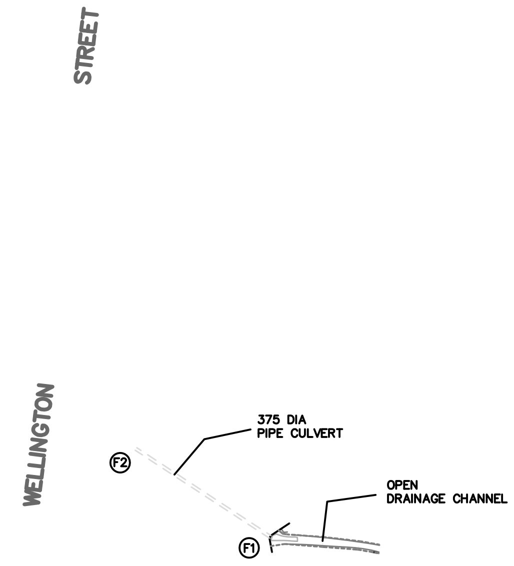
REFERENCE NUMBER
09054C

SHEET 1 OF 1



DRAINAGE STRUCTURES						
LOCATION	TYPE	BREADTH	WIDTH	HEIGHT	SILL LEVEL	BASE LEVEL
F1	CULVERT INLET WITH CONCRETE HEADWALL			0.71	709.63	708.92
F2	CULVERT OUTLET NO HEADWALL					708.84
G1	CULVERT INLET WITH CONCRETE HEADWALL			1.09	709.15	708.06
G2	COVERED JUNCTION PIT	1.88	1.88	4.35	708.61	704.26
G3	CULVERT OUTLET NO HEADWALL					702.22

CULVERTS				
LINE	TYPE	LENGTH	US INVERT	DS INVERT
F1-F2	375 DIA PIPE CULVERT	20.3	708.92	708.84
G1-G2	1880x650 BOX CULVERT	14.1	708.06	707.92
G2-G3	1350 DIA PIPE CULVERT	164.4	704.26	702.22



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0 10 20 30 40 50
SCALE 1:500 AT A1

AMDT	DATE	AMENDMENT DETAILS

CAUTION
THE INFORMATION SHOWN ON THIS PLAN MAY BE INSUFFICIENT FOR SOME TYPES OF DETAIL DESIGN. WILLIAMS AND LIGHTFOOT SHOULD BE CONSULTED AS TO THE SUITABILITY OF THE INFORMATION SHOWN HEREIN PRIOR TO THE COMMENCEMENT OF ANY DESIGN WORKS BASED ON THIS PLAN

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DATUM : AHD   CONTOUR INTERVAL 0.5m
SCALE 1:500 AT A1   GRID : MGA

DATE	SURVEYED	DRAWN
07/09/09	PW	GM

LEVEL AND DETAIL SURVEY OF
DRAINAGE INFRASTRUCTURE
WELLINGTON AND BURTON STREETS
BOMBALA

FOR : WORLEY PARSONS

REFERENCE NUMBER
09054D

SHEET 1 OF 1