Wimmera Catchment Management Authority

Waterways for Life.

Horsham Flood Study

Report No. J035/R3 Final, Ver. A

February 2003

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Specialist Water and Coastal Engineering Consultants

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Executive Summary

Background

Following the Horsham Floodplain Management Investigation undertaken by the State Rivers and Water Supply Commission (SRWSC) in 1982, a number of flood mitigation works were implemented to protect the township of Horsham from events up to and including the 100 year ARI event. These works included the construction of a levee system and river widening.

There have been concerns raised that river processes and extensive further development on the floodplain have altered the flood characteristics and therefore the areas subject to inundation during large flood events. For these reasons, a review of the Horsham flood levels and mapping has been identified as a high priority study in the Wimmera Catchment Management Authority's (Wimmera CMA's) Floodplain Management Strategy.

This "Horsham Flood Study" details the results of this review.

Review of Previous Investigations

There has been a significant amount of work documenting the impacts of flooding on Horsham. Much of this is summarised in the Flood Data Transfer Project (SKM, 2000). This current investigation has augmented the observed flood level information through additional flood levels sourced from Wimmera CMA records, and observed flood levels that have been surveyed directly.

Large portions of the previous SRWSC 1982 investigation are still relevant, and have served as the basis for much of the work undertaken in this current investigation. However, during the course of this current investigation, the method the SRWSC 1982 study used for derivation of design events has been substantially revised. This has resulted in increased design discharges for the Wimmera River.

The design discharges derived for Burnt Creek (DNRE, 1996) have also been revised using similar techniques.

Subsequent levee audits (Findlay Irrigation Services et al, 1996) have indicated that the levee constructed as a result of the SRWSC 1982 investigations does not correspond to the original design profile. The Menadue Street/Peppertree Lane area has a low point midway along the levee, and drops beneath the original design profile at either end.

Community Consultation

Information has been distributed to the community in two distinct phases. Firstly the study inception was publicly announced, along with a call for information relating to flooding. A series of public presences were held where interested parties could meet with the study team. Secondly, a series of public information sessions (preceded by a media briefing and radio and newspaper advertising) were conducted to provide feedback to the community about the study outcomes.

In general, the most common comments received were:

1. Many residents were concerned about the "choking" of the river by vegetation.
2. Concerns were expressed by several residents who had recently (within the last 10 years) built houses complying with minimum floor level requirements, but whose properties were shown to be inundated (by the ARI 100 year event) as a result of the study.
3. Concerns were expressed by a number of residents regarding the impact of stormwater flooding (as distinct from river flooding).

Data Gathering/Survey

Ortho-rectified digital photogrammetry was undertaken specifically for this project. Flown on the 16 march, 2002, the vertical and horizontal accuracies (68% confidence level or 1 sigma) of the data points is 0.1m.

Based on this photogrammetric survey, a Digital Terrain Model of the study area is now available.

Within the study area, 598 new floor levels of potentially flood affected commercial and residential buildings have been surveyed, with an additional 231 floor levels sourced from the 1984 flood level survey.

An additional 7 observed historic flood levels have also been gathered. These observed flood levels have been added to the Flood Data Transfer data set.

Three Wimmera River cross sections were taken with the aim of reproducing as accurately as possible the sections surveyed during the SRWSC 1982 investigation. The comparison of these two sets of sections indicate that there has been little change over the past 20 years in the areas surveyed.

Hydrologic Analysis

The hydrologic analyses previously undertaken have been reviewed in detail during the course of this investigation. A revised flood frequency analysis was undertaken, utilising an annual series approach (cf the partial series approach previously adopted) with additional data.

The design discharges thus derived are detailed in Table 1 below.

Table 1 - Wimmera River and Burnt Creek Design Discharges

Average recurrence interval (years)	Burnt Creek (Wimmera River Junction)		Wimmera River (Horsham (Walmer) Gauge)	
	Design peak flow (ML/d)	Design peak flow (m^3/s)	Design peak flow (ML/d)	Design peak flow (m^3/s)
5	1,200	14	12,900	149
10	1,800	21	18,100	209
20	2,500	29	23,700	274
50	3,400	39	31,200	361
100	4,200	49	37,000	428
200	5,100	59	43,000	498

For the ARI 100 year design Wimmera River discharge, this represents an increase of approximately 12% over that previously adopted. The corresponding ARI 100 year design flows for Burnt Creek have been reduced by approximately 11% compared to the previously adopted values.

It is considered appropriate (and conservative) to adopt coincident Wimmera River and Burnt Creek design events.

Hydraulic Analysis

A detailed hydrodynamic model of the Wimmera River and Burnt Creek systems has been established. This hydraulic model is based on the MIKE Flood combined 1D/2D package.

A detailed calibration exercise was undertaken to ensure accurate reproduction of the 1988 event. This was the largest event that has occurred since the flood mitigation works were undertaken in 1986/87.

Following calibration, the full suite of design events were simulated using the model. The results of these design event simulations were then used to characterise the flood risks faced by the Horsham community.

Inundation Mapping

On the basis of the hydraulic analysis, a series of detailed inundation maps have been prepared for the Horsham township. More specifically, these maps present the predicted inundation for events ranging from 5 year ARI to 200 year ARI.

These maps provide information relevant for both town planning and emergency response purposes.

Risk Assessment

Table 2 below summarises the hydraulic behaviour of the area, referenced to the design event frequency.

Table 2 Floodplain behaviour for varying levels of Design Flood Events

Event (ARI)	Behaviour
5 year (~'92)	Minor Inundation
10 year (~'96)	Overbank flooding upstream of Camerons Road
20 year ('81)	Wotonga Basin mini-weir overtopped
50 year	Breakout to town anabranch occurs at showgrounds Extensive inundation along Burnt Creek
100 year (<'09)	Breakout around upstream end of Menadue St/Peppertree Lane levee

This characterisation of risk indicates that the existing flood protection works (the combination of river widening, town levee and the mini-weir) have provided Horsham with relatively comprehensive protection for events up to the ARI 20 year level.

However, there is predicted to be a distinct increase in the damage suffered once the protection works are either overtopped (in the case of the mini-weir) or bypassed (upstream and downstream of the town levee). There is a danger that residents will be unprepared as a result of a perception that they are protected by the town levee. Actual flood damage may be increased correspondingly.

Flood Warning

Discussions undertaken during this investigation have indicated that there are no flood predictions undertaken specifically for Horsham. The Bureau of Meteorology provide predictions at Glenorchy and Quantong (downstream of Horsham). While Wimmera Mallee Water provide advice with regard to operation of the town weir to Horsham Rural City, they do not provide flood predictions for Horsham itself.

Recommendations

There have been a number of specific recommendations made as a result of the work undertaken as part of the Horsham Flood Study. These are briefly summarised below:

Floodplain Management and Flood Response Plan for Horsham

Work items include:

- Undertake public consultation to both educate the community and involve the community in the decision making process,
- Comprehensive update of the flood damage analysis,
- Quantification of the impact of pre-approved development in the floodplain,
- Consideration of appropriate planning controls over “at-risk” areas,
- Consideration of works to address weaknesses in the current town protection scheme,
- Formulation of potential mitigation schemes and the quantification of the associated benefits and costs from economic, social and environmental perspectives,
- Identify possible funding mechanisms
- Based on the results of the public consultation, prepare a Floodplain Management Plan,
- Review existing flood warning arrangements and recommend potential improvements,
- Prepare a flood response plan.

Stormwater Drainage Management Plan

Work items include:

- Quantification of the existing systems capacity,
- Hydrologic analysis for local catchment runoff,
- Consideration of potential local catchment/Wimmera River flood events,
- Flood mapping to compliment Wimmera CMA’s flood mapping
- Preparation of mitigation options and associated costings
- Consideration of the economic justification of proposed schemes.

Briefs for further investigations encompassing recommendations associated with the Floodplain Management Plan have been prepared.

Acknowledgements

Numerous organisations and individuals have contributed both time and valuable information to the Horsham Flood Study. The study team acknowledges the contributions made by these groups and individuals, in particular:

- The Technical Steering Committee for the study, consisting of:

  Elyse Riethmuller (Wimmera CMA & Project Manager)
  Jo Bourke (Wimmera CMA)
  John Young (Wimmera CMA)
  Gil Hopkins (Wimmera CMA)
  David Eltringham (Horsham Rural City Council)
  Robyn Neilson (Horsham Rural City Council)
  John Kemfert (Hindmarsh Shire)
  John Partington (Hindmarsh Shire)
  Allan Kingston (community representative)

- The staff of Horsham Rural City Council not mentioned above, in particular John Griffiths and Kevin Johnson,
- The staff of Wimmera Mallee Water, in particular John Martin,
- The staff of Grampians Rural Water Authority, in particular Ray Chiaramonte,
- The staff of Thiess Hydrographic Services, in particular Gavin Ryan.

The study team also wishes to thank all those stakeholders and members of the public that attended the information sessions, contributed flooding information, returned questionnaires and discussed their experiences with the study team.

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Document Status

Issue	Revision	Date	Issued to	Prepared by	Reviewed by	Approved by
Draft	E	14/12/02	Wimmera CMA (.pdf)	SQC	AMC	AMC
Final	A	7/02/03	Wimmera CMA (hardcopy & .pdf)	SQC	AMC	AMC

It is the responsibility of the reader to verify the currency of revision of this report.

1 Introduction

As part of the Wimmera Catchment Management Authority (CMA)'s Floodplain Management Strategy (Wimmera CMA, 2001), a review of flood levels and flood inundation mapping for Horsham was identified as a priority study.

In February 2002, a consortium lead by Water Technology Pty Ltd was commissioned to undertake this investigation on behalf of the Wimmera CMA and Horsham Rural City Council. Consortium members were:

Water Technology	Project Management Specialist water resources engineering
AAM	Aerial Photogrammetry
LICS	Field Survey GIS and Flood mapping & research
Neil M Craigie	Specialist Waterway Management
Sandra Brizga & Associates	Geomorphology

This report details the scope and findings of this investigation. This is the **Final (Version A)** issue of the report.

Section 2 presents the background to the study and the terms of reference. There have been numerous previous investigations of relevance to this current study. An overview of these previous investigations, along with key points of relevance to the current investigation is presented in Section 3.

Section 4 outlines the consultation and data gathering that was undertaken specifically as part of the current scope of work.

Section 5 provides an overview of the survey that was undertaken during the course of the investigation.

Section 6 provides an overview of the floodplain characteristics that give rise to flood risks in Horsham and the upstream floodplain. Please note that the flood risks considered in this investigation are those directly associated with elevated river levels. Consideration of elevated river levels and the associated impact on flooding through the stormwater drainage network has not been part of the scope of this investigation. Sections 7 and 8 detail the hydrologic and hydraulic analyses that have been undertaken to assess or quantify these flood risks.

The process whereby the results of the hydrologic and hydraulic analyses have been mapped for use as town planning and emergency response measures is described in Section 9.

Section 10 provides an overview of the implications of this study for authorities and stakeholders interests in Horsham. Conclusions of the study, and recommendations for the next stage in the risk management approach are presented in Sections 11 and 12 respectively.

The Inundation mapping and briefs for further investigations are contained in Appendices C and D respectively.

2 Study Context

2.1 Background

The study area is defined as the urban area of Horsham and the rural areas of the upstream floodplain to Dooen's Swamp. The extent of the study area is shown in Figure 2.1. The two main watercourses within the study area are the Wimmera River and Burnt Creek.

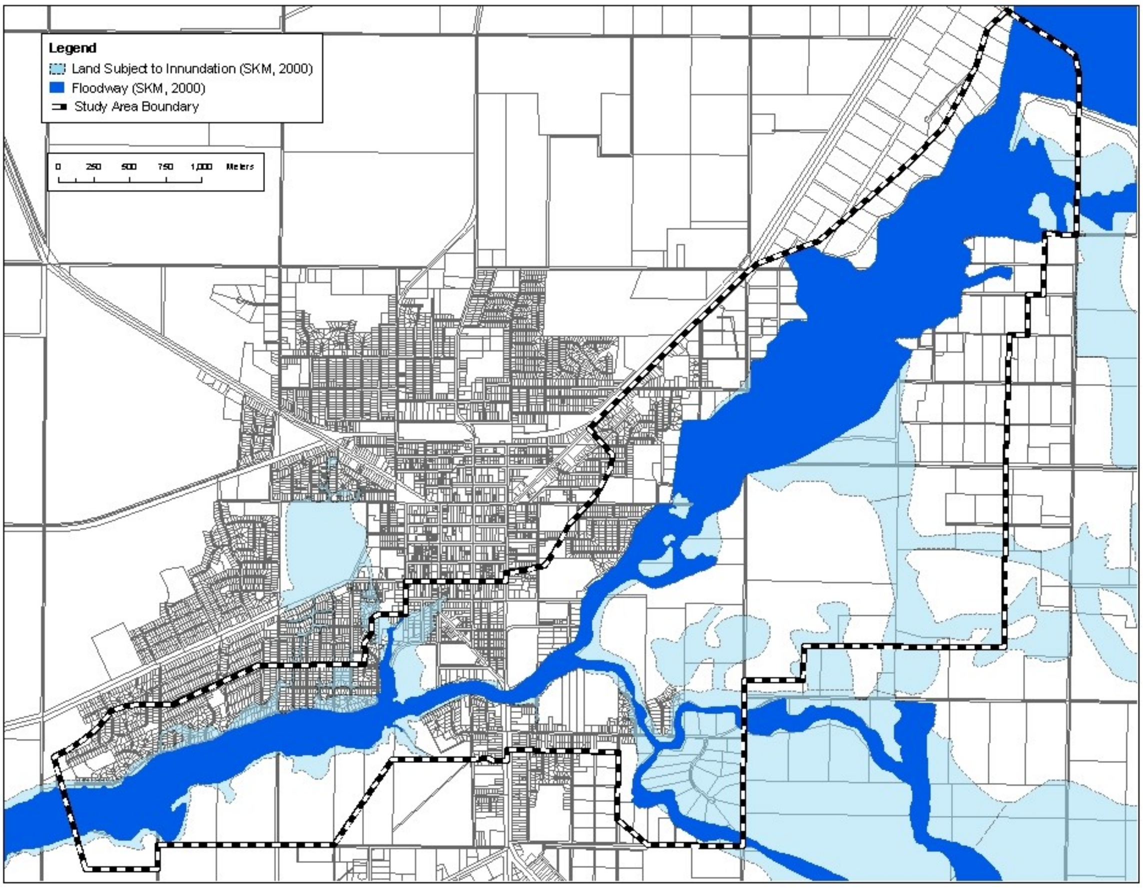

Figure 2.1 Study Area

A brief description of the background to the current study follows, mostly sourced from the project brief.

A comprehensive floodplain management study was undertaken by the State Rivers and Water Supply Commission in 1982 (SRWSC 1982). This study identified, assessed and recommended a number of mitigation flood works. The recommended works included:

- a levee upstream of the town (extending from Menadue St to Peppertree Lane),
- widening of the Wimmera River upstream of the Western Highway Crossing.

The construction of the recommended works was completed in 1987.

The 1982 study determined 1% flood levels along the Wimmera River for the post mitigation scenario. These 1% flood levels were designated and use for land use planning purposes (Plan No 147382A).

There is a concern that river processes and floodplain development (since the 1982 study) have resulted in a change to the flood behaviour within the study area.

The aims of this current study are then to provide a more accurate definition of flood levels, extent and flood risk. This improved knowledge of flood behaviour will facilitate more effective land use planning, emergency response practices and flood mitigation to minimise flood risk to the residents and infrastructure of Horsham.

2.2 Terms of Reference

Floodplain Management Investigations are carried out in accordance with current risk management procedures as set out in "AS/NZS 4360:1995 Risk Management". The key steps are:

- Establish the context
- Identify risks
- Analyse risks
- Assess and prioritise risks
- Treat risks

The work items undertaken in this Flood Study aim to address the first three steps of this approach, and provide enough information to enable authorities and stakeholders to undertake the fourth step, Assessing and Prioritising Risks, in an informed fashion.

As per the brief, work items undertaken as part of this investigation are:

1. Identify and review all previous flood and waterway management studies and historic flood data in the area.
2. Identify the nature, cause, frequency, extent, economic damages and social and environmental impacts of a range of flood events, the flood storage capacity for the Wimmera River, Burnt Creek and the floodplain and the effects of private and public works on flooding characteristics.
3. Review the adequacy of previous hydrological and hydraulic models.
4. Review the ARI of the historical floods and revise if necessary.
5. Review the designated 1% flood level and revise if necessary.
6. Review the effectiveness of existing flood mitigation works.
7. Determine the flood profiles for 20%, 5%, 2%, 1% and PMF flood event.
8. Map the floodways and areas of inundation during 20%, 5%, 2% 1% and PMF flood events.
9. Determine the effects of significant existing private and public works on flow distributions and flood profiles and identify a range of options for the management of these features.
10. Determine the potential impacts on flood levels if the Wimmera Mallee Stock and Domestic System is piped.
11. Make preliminary recommendation for risk treatment options and recommend the requirements for a detailed risk treatment study (floodplain management plan).
12. Prepare the funding applications and consultancy briefs for any additional studies identified.

3 Previous Investigations

There have been numerous investigations undertaken previously, or currently being undertaken that are of relevance to this current study. A brief discussion of the most relevant portions of these investigations follows.

3.1 Wimmera Floodplain Management Strategy

Wimmera CMA, 2001

The Wimmera Floodplain Management Strategy is the policy document that has established the framework under which this current investigation is being conducted. The introduction states:

> *"The Floodplain Management Strategy develops a number of programs aimed at addressing the structural and non-structural components of floodplain management in the Wimmera. A program for identifying and managing existing flood protection assets is detailed. Non-structural measures are identified to ensure that appropriate mechanisms are provided for flood plans, warning systems, flood monitoring, responsible land use planning and community eduction and awareness."*

This current investigation falls under Program 3 Flood Studies and Floodplain Management Plans as presented in the Wimmera Floodplain Management Strategy (2001).

3.2 River Basin Report – Wimmera River, Lower SubCatchment - Flood Data Transfer Project

Sinclair Knight Merz, report prepared for Department of Natural Resources and Environment, June 2000

In February 1998, NRE commissioned a series of consultancies for undertaking Flood Data Transfer (FDT) to the nine CMAs. In August 1999 Sinclair Knight Merz was appointed to undertake the FDT Project for the Wimmera-Mallee Catchment in northern Victoria. This was one part of the program of floodplain management reform, aimed at providing available flood data in a convenient form to the regional CMAs and other beneficiaries.

The objectives of the Flood Data Transfer (FDT) project were to:

- Produce and deliver high quality, consistent and comprehensive Geographic Information System (GIS) layer and hardcopy map products showing a range of flood data for urban and rural floodplains in Victoria;
- To deliver, in hardcopy and digital form, a series of flood information reports based on Municipal and river basin boundaries, and
- As part of the above, to reorganise the storage of existing flood and related information within the Flood Plain Management (FPM) unit of NRE.

Two forms of mapping were produced through the FDT project:

- *Flood Data Maps*, which incorporate relevant historical flood information captured from source maps, as well as relevant cadastre, infrastructure and hydrologic data; and
- *Flood Planning Maps*, which showed the analysed data incorporating 1% annual exceedance probability (AEP) flood level isolines (where possible) and floodways.

Table 3.1 presents an overview of the information collated as part of the FDT Project.

Table 3.1 Summary of information collected as part of the FDT project

Information	Area	Events
Interpretive Flood Extent Maps	Horsham Rural City Council (Wimmera River and Yarriambiack Creek)	Various historic flood events
	Yarriambiack Shire	Outer envelope of historic events specific mapping of 1983 event
Statistical and Historic Flood Levels	Horsham Rural City Council (Wimmera River, Burnt Creek and Yarriambiack Creek)	1909 – 1985 flood events. Some additional levels for 1992. 1981 flood profile for Wimmera River 1% flood profile for Wimmera River and Burnt Creek
	Yarriambiack Shire	1909 – 1981 flood events 1981 flood profile for Wimmera River 1% flood profile for Wimmera River and Burnt Creek
Flood Photography	Horsham Rural City Council	May 1956 Feb 1973 (vertical photography) Aug 1981 (vertical photography) Sep 1983 Sep 1988 (oblique photography) Dec 1992 Oct 1996 (oblique photography)
	Yarriambiack Shire	Historic flood photos 1894, 1909, 1923, 1930 and 1981 Feb 1973 (vertical photography) Aug 1981 (vertical photography) Sep 1988 (oblique photography) Oct 1996 (oblique photography)

Drawings 500703-27 and 500703-28, the flood data maps as prepared during the Flood Data Transfer Project are reproduced overleaf.

Based on this historic flood information, flood planning maps were prepared. These flood planning maps showed areas delineated as either “Floodway” or “1% AEP Flood Extent”.

1 in 100 year ARI (1% AEP) Flood Extent delineation was based on the flood extent from either the 1% AEP flood, or the largest flood for which data was available. Floodways are defined as areas where significant discharge or storage of water occurs during major floods (DNRE, 1998). Six main criteria have been used for floodway designation, these being:

1. Velocity – depth criteria as per DNRE, 1998.
2. Drain and Creek corridors which are strategically important in maintaining flow paths.
3. Flood storage areas, including lakes (generally greater than 0.5m depth).
4. High hazard areas where flash flooding may occur without warning.
5. Areas which flood more frequently than 10 years on average.
6. Areas where the duration of flooding is generally greater than 7 days.

A reach by reach description of the methodology used to develop the 1% AEP Flood Extent and Floodway maps are presented in SKM, 2000. In summary, these layers or maps were prepared principally on the basis of aerial photography (both vertical and oblique) of historic floods. In almost all areas, little associated topographic information was available.

Drawings 500704-27 and 500704-28, the flood planning maps as prepared during the Flood Data Transfer Project are reproduced overleaf.

3.3 Economic Evaluation of Flood Damages for the Wimmera CMA

Read Sturgess & Associates, report prepared for Department of Natural Resources and Environment, September, 2001.

This study was undertaken for the Floodplain Management Unit of Victoria’s Department of Natural Resources and Environment by Read Sturgess and Associates using the Rapid Appraisal Method (RAM) for consideration of flood damages in the Wimmera CMA’s region. While necessarily a broad brush investigation, this document provides a valuable overview of the regions exposure to loss, quantified in economic terms, due to flooding.

In order to undertake the economic evaluation, the Wimmera CMA region was divided into 33 sub-areas for specific consideration. Tables 3.2 and 3.2 below summarises the estimated damages (rounded to the neatest $1,000) associated with an ARI 100 year event for the study areas of relevance to this current investigation.

Table 3.2 Estimates of Damage associated with the 1 in 100 year ARI event in the study area
(extracted from Read Sturgess, 2001)

Damages for the ARI 100 Year Event	
Buildings	$3,502,000
Roads	$ 243,000
Agriculture	$ 12,000
Indirect	$1,503,000
Total	**$5,261,000**

Table 3.3 Estimates of physical damages and AAD
(extracted from Read Sturgess, 2001)

Physical Damages ion LSI Event	
Total Area Flooded	162 ha
No. large, non-residential buildings	8
No. urban buildings	166
No. urban properties	571
Average Annual Population Affected	**41**
Average Annual Damages	**$509,000**

3.4 Study of Flood Events within the Wyperfield National Park

Binnie and Partners report prepared for the Department of Conservation and Environment, 1991

As stated in the introduction, the primary aims of this investigation were:

- *To investigation the hydrology of the lower Wimmera River by flood frequency analysis and thereby determine the effects of River regulation and any long term climatic changes on the ability of the River to provide water to the terminal lakes system.*
- *To determine whether or not it would be feasible to employ and environmental allocation or any other practical means to promote flooding in the Park; and*
- *Identify any future studies that might be required (for example the effects of elevated River salinity levels on vegetation).*

The principal hydrological finding of the study is that diversion of the flow to the Wimmera-Mallee Stock and Domestic System (WMSDS) does decrease the frequency of flooding to Wyperfield and considered several options (including piping of the WMSDS for the provision of additional flows.

The hydrologic analysis was undertaken by considering the catchment in two parts. The upper catchment was defined as the river to the entrance to Lake Hindmarsh and was modelled using RORB. A spreadsheet model was developed for the lower catchment, enabling routing of events through Lake Hindmarsh and Albacutya downstream to the terminal lakes system. Diversions to the WMSDS were accounted for through use of the RWC headworks model of the system.

The investigation details a long term yield type analysis, characterising the volumetric response of the lake systems associated with the existing situation, and a number of potential operating scenarios. As such, the data presented is of limited use for this current investigation.

3.5 Horsham Floodplain Management Study

State Rivers and Water Supply Commission, 1982.

The aim of this study was develop a comprehensive floodplain management plan for Horsham to assist in urban planning and form a flood mitigation scheme for the (then) existing urban development on the floodplain.

Components of this investigation included:

- A comprehensive frequency analysis of Wimmera River flood flows at Horsham. This frequency analysis is the basis for much subsequent work. During the course of this current study, some concerns have been expressed to the study team regarding the magnitude of the design flows that have resulted from the partial series analysis utilised.
- A comprehensive floor level and flood mark survey for the Horsham vicinity.
- A comprehensive series of cross sections of the Wimmera River through Horsham.
- A HEC-2 analysis of design floods for the Wimmera River and Burnt Creek. On the basis of this analysis, 1% probability flood levels were declared.
- Various non-structural and structural mitigation options were investigated.
- A preferred strategy was identified. Non-structural works identified as part of this strategy included planning controls, amendments to flood warning procedures and preservation of upstream floodplains. Structural works included levee construction and works to increase the capacity of the Wimmera River channel.
- Public information sessions.

Detailed hydrology was undertaken which is of relevance to this current investigation. Consideration was given to changing land use patterns, (natural and artificial) catchment storage, initial loss estimation, and the major distributaries. The general conclusions may be summarised as follows:

1. Catchment land use change has had little impact on flood frequency distribution,
2. The natural storage of the floodplain has a significant impact on flood flows delivered to Horsham.
3. The incidence of major flows at Horsham is very much dependent upon catchment wetness.
4. The five off stream storages of Fyans, Taylors, Pine, Green and Dock lakes have little capacity to influence flood flows at Horsham.
5. Of the two on-river storages, only Lake Lonsdale has the capacity to alter flood flows at Horsham. This impact was considered to be of the order of 1 to 2 % reduction in peak flow (at Horsham) in large floods. Lake Bellfield was considered to have little impact on peak flows at Horsham. The corresponding reduction for small to medium flood events was estimated as up to 25%

Appendix G of the SRWSC report, "Frequency of Flood Flows at Horsham" presents the results of the flood frequency analysis performed on the Horsham gauge record. This analysis determined the design flow rates used for the subsequent Horsham hydraulic analysis. A Log-Pearson Type 3 distribution using a partial series approach as per AR&R (1977).

Note that this analysis yields an average return period for the 1909 event of 300 years. As noted previously, concerns have been expressed to the study team during the course of this investigation as to the magnitude of the ARI assigned to the 1909 event.

Table 3.4 presents the results of this analysis.

Table 3.4 Results of Historic Flood Frequency Analysis by SRWSC (reproduced from SRWSC 1982)

Annual Exceedence Probability (%)	Return Period (years)	Calculated Flow
10	10	215 m^3/s (18,600 ML/day)
5	20	256 m^3/s (22,100 ML/day)
2	50	318 m^3/s (27,500 ML/day)
1	100	370 m^3/s (32,000 ML/day)
0.5	200	429 m^3/s (37,100 ML/day)
0.1	1,000	594 m^3/s (51,300 ML/day)

3.6 Burnt Creek Flood Levels Analysis

Department of Conservation and Natural Resources report for City of Horsham, 1996

The then City of Horsham requested the Rural Water Corporation undertake a review of designated flood levels along Burnt Creek. This request was prompted by the observation of flood levels during the September/October 1992 event approaching the previous calculated 1 % AEP flood levels. The September/October 1992 flood was considered a minor flood event and observed flood levels should be well below the calculated 1% AEP levels.

The analysis firstly reviewed design peak flow estimates for Burnt Creek at the Wimmera River confluence. The catchment area of Burnt Creek at the Wimmera River confluence is approximately 186 km^2. Relevant streamflow data was obtained from the gauging station on Burnt Creek at Wonwondah East. The catchment area to the gauging station is 80.3 km^2. Three independent methods were employed to estimate design peak flows for Burnt Creek:

- Frequency analysis at Wonwondah East,
- Regional frequency analysis using streamflow data from nearby gauging stations,
- Catchment modelling using RORB.

The results of the frequency analysis at Wonwondah East were adjusted to provide design peak flows estimates for the Burnt Creek to the Wimmera River. The adjustment was based on the ratio of the catchment area and made allowance for the nature of the catchment.

Estimates of the 1 % AEP design peak flows obtained from the above three methods are shown in Table 3.5.

The estimates from the frequency analysis was adopted as the 1% AEP design peak flow.

Table 3.5 1% AEP design peak flows for the three methods.
(reproduced from DNRC, 1996)

Method	Burnt Creek at Wonwondah East	Burnt Creek at Wimmera river confluence
Frequency analysis	4700 ML/d 54 m^3/s	5200 ML/d 60 m^3/s
Regional frequency analysis	5440 ML/d 53 m^3/s	5800 ML/d 67 m^3/s
RORB	4300 ML/d 50 m^3/s	5800 ML/d 67m^3/s

A one dimensional hydraulic model (HECRAS) was developed for Burnt Creek downstream of the Western Highway. The model parameters were adjusted to obtain a reasonable agreement between observed and simulated flood levels for the September/October 1992 event. The 1% AEP flood levels along Burnt Creek were obtained by inputting to the hydraulic model the adopted 1% AEP design peak flow.

The calculated 1% AEP flood levels were found not to be significantly different from the levels determined in the 1982 study and the designated flood levels. The study concluded due to uncertainties in the modelling that any changes to designated 1% AEP flood levels was not warranted.

3.7 Derivation of Wimmera and Glenelg Daily Flows – Summary Report

Sinclair Knight Merz, draft report prepared for Department of Natural Resources and Environment, March, 2002.

The purpose of the Water Entitlements Project is to develop clearly specified water entitlements for the water authorities that take their water from the Wimmera-Mallee water supply system (Wimmera Mallee Water, Grampians Water, Coliban Water and Glenelg Water), as well as for the affected riverine environments (the Glenelg, Wimmera, Avoca and Avon/Richardson rivers).

The project is part of a statewide program to improve the way that water entitlements are defined and managed. To date, about 75% of Victoria's water resources have been converted into the new bulk entitlements. The project will develop new entitlements that provide:

- water authorities with more certainty about their rights to harvest and use water,
- greater flexibility for re-allocation of water
- a basis for protecting the environmental values of streams

Sinclair Knight Merz are undertaking aspects of the project on behalf of the Department of Natural Resources and Environment.

To complete the Bulk Entitlements Project additional flow data was required. This report presents the methodology and results of the derivation of daily flows at several locations in the Wimmera and Glenelg catchments for the period January 1990 to December 2000. Flows corresponding to both the existing level of development and daily natural flows were derived.

As for the previous investigation, significant detail is presented for the low to moderate flow regimes with little consideration of extreme events.

3.8 Stressed Rivers Project – Environmental Flows Study – Wimmera River System

Sinclair Knight Merz, report prepared for Wimmera CMA, January, 2002.

The aim of this project was to:

> *… provide a scientific basis for the implementation of the provisions for water dependant ecosystems, and in doing so, meet the objective of the State's Water for the Environment Program and objectives of the Wimmera Catchment Management Authority.*
>
> *Part A includes a catchment description, a synopsis of the key issues in the Wimmera River system, methods, environmental flow objectives, detailed environmental flow recommendations and key supporting recommendations. Part B consists of the Issues Paper completed during Stage 1 of the project. This contains a more detailed discussion of the environmental status of the catchment according to discipline categories of ecology, hydrology, geomorphology and water quality. The Appendices to Part B provide the detailed assessment of flow related issues for the system.*

The key issues associated with the determination of environmental flows considered in the investigation were:

- Modification to the natural flow regime,
- Deterioration of water quality, and
- Bed and bank instability.

The study area was divided into 5 reaches, the relevant reach for Horsham being Wimmera River Reach 3 – Mt William Creek to McKenzie River.

Detailed investigations into a range of hydrological, ecological and geomorphological features were undertaken at specific sites within each reach. At each site, between 6 and 9 cross sections were undertaken. To the study teams knowledge, these cross sections represent virtually the only available cross sectional information on the Wimmera River outside of the main townships. The site closest to Horsham is Site 5 – the Rifle Range.

Alteration from the natural flow regime is assessed on a mean monthly basis.

3.9 Draft Wimmera Waterway Management Strategy

Wimmera CMA, 2002.

As stated in the introduction:

> *This strategy provides a direction for waterway management within the Wimmera region. As well as providing a planning framework for the Strategy's programs, it incorporates the vision, objectives and targets necessary for implementation. The waterway strategy incorporate strategies for floodplain, rural drainage, water quality and urban stormwater already or currently being developed. The strategy also recognises the work previously undertaken through other strategies and plans such as the Wimmera River Integrated Catchment Management Strategy (Wimmera Catchment Coordination Group, 1992), Assessment and Review of Crown Frontages (SKM 1998b) and Wimmera River and Environs Action Plan (Thompson and Hay 1997).*
>
> *Within the Wimmera CMA, 11 waterway management reaches were defined by grouping areas of similar geomorphological characteristics, vegetation coverage and key infrastructure assets and controls. Horsham is located within Water Management Unit 8, Wimmera River – O'Bree's Crossing to Lake Albacutya.*

3.10 Draft Regional Waterway Management Strategy

Sinclair Knight Merz, report prepared for Wimmera CMA, 1999

The development of the Draft Regional Wimmera Waterway Management Strategy was undertaken by Sinclair Knight Merz. The draft provides the background information which was used to develop the final draft Wimmera Waterway Management Strategy (Wimmera CMA 2002). This investigation proceeded by dividing the study area into 17 segments covering tributaries, distributaries, mainstreams and terminal streams.

A summary of the segments of relevance to this current flood scoping study, along with the issues that were identified for each segment as presented in the Waterway Management Strategy is reproduced below. Note that the waterway management units have been referenced in accordance with the 11 current waterway management reaches, rather than the 17 reaches originally proposed.

Waterway Management Unit 7 - Wimmera River mainstream – Dooen swamp to O'Bree's Crossing

- The river is subject to natural outer bank erosion processes on bends and in many areas this is exacerbated by stock damage.
- Bank erosion on the south bank of the Horsham weir pool is probably related to continuous high ponded water levels lapping on resistant (dispersive) upper bank soils, aggravated by wind wave action and particularly by uncontrolled stock access.
- Elevated turbidity levels experienced from time to time in the river downstream of Horsham are related to bank erosion in the weir pool as well as to urban stormwater runoff.
- No other significant stability concerns appear to be evident in this reach.

3.11 Wimmera River Geomorphic Investigation, Sediment Sources, Transport and Fate

ID&A, report prepared for Wimmera CMA, 2002.

Following the development of the Draft Waterway Management Strategy, ID&A were commissioned to review and report on the proposed waterway management field trial sites identified in the strategy. The outcome of this review was that a geomorphological investigation study of sediment sources, transport and fate would be beneficial to establish a greater understanding of stream processes to direct waterway management activities.

As stated in the introduction,

> *Part of this investigation has analysed the changes that have and are likely to occur in flooding, particularly in the middle reaches of the river. Analysis of hydrology, hydraulic and effective discharge found that the likelihood of overbank flow events is less now than what it was in the early part of last century. This result indicates that works to extract sediment, vegetation and debris from the channel to reduce a perceived increase in flooding may not be warranted. Such work may also be detrimental to stream health.*

ID&A present the most current and detailed flood frequency analysis available to date. Appendix A Hydrologic Analysis presents the results of flood frequency analyses of three gauges within the Wimmera River catchment (including Glynwylln and Horsham on the Wimmera River itself) and one gauge on the Avoca for comparison purposes.

This analysis for the Wimmera River at Horsham and Avoca River was undertaken for two periods in an attempt to quantify the impacts of regulation. These periods were characterised as:

1900-1930 – pre-regulation, and
1970-2000 – post regulation.

Table 3.6 presents the results of this analysis.

Table 3.6 Flood Frequency Summary Wimmera River Downstream of Horsham (reproduced from ID&A, 2002)

AEP	ARI	Pre-regulation discharge	Post Regulation Discharge	% Change
50 %	2 year	$97m^3/s$ (8,400 ML/day)	$53m^3/s$ (4,600 ML/day)	-45
20 %	5 year	$217m^3/s$ (18,700 ML/day)	$135m^3/s$ (11,700 ML/day)	-38
10 %	10 year	$311m^3/s$ (26,900 ML/day)	$200m^3/s$ (17,300 ML/day)	-36
5 %	20 year	$411m^3/s$ (35,500 ML/day)	$269m^3/s$ (23,200 ML/day)	-35

ID&A concluded that:

> *These results suggest a reduction in flood magnitude in the post regulation period when compared against the pre regulation periods. This is in contrast to the results for the Avoca River gauge. The analysis suggests that the reduction in stream flow and flood magnitude in the Wimmera River is likely to be the result of human intervention (flow regulation) alone and not associated with temporal variation in hydrology.*

Based on the results of this hydrologic analysis, and limited hydraulic analysis, ID&A utilised the concept of "effective discharge" to predict the direction and magnitude of the channel response to the modified flow regime post regulation. This was undertaken using the results at the Horsham gauging station, and a river cross section downstream of Horsham (upstream of McKenzie River). Note that these are small to medium sized events and not the ARI 100 year event.

In the Implications for Management section it is stated:

> *Based on this analysis there appears to have been a period of reduced flood frequency immediately following regulation. Because the process of channel adjustment is slow (dependent on sediment supply) and the introduction of regulation relatively rapid, there has been a period of reduced probability of overbank flooding. The bankfull flow of approximately 175m^3/s has an AEP of 10% on the post regulation flood frequency curve. In essence the large channel is operating within an environment of reduced flow.*
>
> *Channel adjustments will occur (albeit slowly) and as a result the occurrence of overbank flooding is likely to increase. However review of the flood frequency curve for the post regulation flow regime reveals that the AEP associated with a flow of 150 m^3/s, (the post regulation effective discharge) is approximately 20% (ie a 5 year ARI event). This is the same as the AEP of the pre-regulation effective discharge. In essence if the channel capacity of the Wimmera River adjusts to the new effective discharge, the occurrence of overbank flooding will not be significantly different to that which occurred prior to regulation.*

3.12 Summary of Previous Investigations

Table 3.7 below summarises the key points arising out of the previous investigations.

Table 3.7 Summary of information presented in previous investigations of relevance to this current study

Investigation	Key areas of relevance	Comments
Wimmera Floodplain Management Strategy *(Wimmera CMA, 2001)*	Establishes framework for the current investigation.	
Flood Data Transfer Project *(SKM, 2000)*	Consolidated available flood data from SRWC records. LSI and floodways mapped	Significant quantity of data available for flood events in the 80's. Some information available for the 1909 event. Due to lack of topographic data, the reliability of mapping in the study area has been defined as low.
Economic Evaluation of Flood Damages *(Read Sturgess, 2001)*	Presentation of "broad brush" economic damage figures.	Most current and comprehensive economic data available to date.
Study of Flood Events within the Wyperfield National Park *(Binnie and Partners, 1991)*	Hydrology of the Wimmera River system investigated.	Approach was primarily a long term yield type analysis. Of limited value for current investigation.
Horsham Floodplain Management Study *(SRWSC 1982)*	Detailed investigation of flooding with flood mitigation options developed along with consultation and planning instruments. Detailed consideration of catchment characteristics and flood frequency analysis of Horsham gauge leading to historically adopted design events.	Hydraulic analysis and flood mitigation proposals of limited relevance to the current (upstream) study area. Flood frequency analysis now quite dated and concern has been expressed regarding the (seemingly high) return period, which results for the 1909 event.
Burnt Creek flood level analysis. (*DNRC 1996)*	Estimated 1% AEP design peak flow and flood levels along Burnt Creek downstream of Western Highway	Simple one dimensional hydraulic model employed to simulate flood behaviour.
Derivation of Wimmera and Glenelg Daily Flows *(SKM, 2002)*	Daily flow records derived using a REALM model at several locations.	Emphasis on daily flows.

Table 3.7 Summary of information presented in previous investigations of relevance to this current study (continued)

Stressed Rivers Project – Environmental Flows Study *(SKM, 2002)*	Investigation of long term impacts of regulation on the hydrologic regime. Cross section survey and some hydraulic analysis undertaken.	Analysis used primarily mean monthly flows. Cross section survey at specific sites only. Little detail of hydraulic analysis presented.
Draft Waterway Management Strategy *(CMA, 2002)*	Establishes framework for current waterway management activities.	11 waterway management reaches defined and priorities presented.
Draft Waterway Management Strategy (SKM, 1999)	Detailed discussion of the physical and biological processes occurring in the Wimmera River and tributaries on a reach by reach basis. Detailed discussion of the processes leading to aggradation problems in the study area in general, and at key locations in particular.	The physical and biological processes described are key factors in determining flood flow distributions across the study area.
Wimmera River Geomorphic Investigation *(ID&A, 2002)*	Investigation of long term impacts of regulation on flooding. Presentation of an effective discharge analysis indicating a current period of reduced (overbank) flood flows due to differing timescales of regulation and the geomorphic response. Detailed discussion of the geomorphic processes occurring in the Wimmera River and tributaries on a reach by reach basis.	Most current hydrologic analysis of flood events, although large to extreme events not considered. Analysis based on cross section downstream of Horsham. Additional data (specifically cross sections & flow paths) required allowing accurate assessment in the current study area. Assessment of ongoing morphological processes. Note different reach delineation to waterway management reaches.

4 Consultation & Data Gathering

4.1 Public Consultation

Wimmera CMA and study team personnel conducted information sessions at the Horsham RSL on the 14 March 2002. Radio and newspaper advertising, and direct mail out of questionnaires preceded this information session. A copy of the questionnaire is included in Appendix A.

There were 16 surveys completed at the Horsham information session with an additional 4 received in the following weeks.

The most common concern expressed by residents was that the river was "choked" and that "cleaning out" of the river was necessary to alleviate flooding. Within the urban area of Horsham, a number of residents noted stormwater flooding as an issue as well as flooding directly from the river.

Based on discussions at the information sessions, it was evident that there are a number of concerned residents in the Weldon Power Court area on Burnt Creek. One residence's access was cut in both '92 and '96 with no warning that they were aware of.

A full range of responses was received in answer to the question regarding the general flood risk facing the township. The most common reasons given for a perception of a worsening flooding situation was "choking" of the river and filling of existing flood plain areas. There were several responses received indicating that the respondent thought the flooding situation was improving due to works undertaken on the flooding eg better roads and kerbing, and the works undertaken as a result of the previous floodplain management plan.

A summary of the survey responses received is presented in Appendix A.

Following completion of the technical aspects of the project, and the risk assessment workshop, a series of public information sessions were conducted. These were preceded by a media briefing (28/8/02) and radio and newspaper advertising.

Comments received during these information sessions include:

1. Many comments were made regarding "choking" of the river (as with the initial consultation),
2. Some concern was expressed by a number of residents who had recently (within the last 10 years) built houses complying with minimum floor level requirements, but whose properties were shown to be inundated (ARI 100 year event) as a result of this study.

Concern was expressed by a number of residents regarding the impact stormwater flooding.

4.2 Authority Consultation

Consultation with key authority personnel was undertaken at various stages of the investigation to both source relevant information and provide opportunity to comment on study findings.

Table 4.1 summarises comments by various authorities contacted during the course of the investigation.

Table 4.1 Summary of Authority Consultation

Authority	Comments
Horsham Rural City Council (HRRC)	Provided information on drainage lines, floor levels, flood levels, topographic information etc. Council are contacted by WMW when flood flows are anticipated. There is the perception that flood forecasts are not as early or as accurate as previously provided. Based on these forecasts, council personnel: • Remove boards from the Horsham Weir according to established operating procedures. • Notify 5 downstream landowners. • Establish a weir in Wotonga Basin to prevent backflow into the town. • Shut off sewerage outlets in the vicinity of Wotonga Basin. • Pump out from behind weir to prevent rising levels in the stormwater system. Several council staff members have commented that moving the Wotonga Basin mini-weir downstream, closer to the outlet to the Wimmera River would provide additional storage in the basin.
Wimmera Mallee Water (WMW)	System description contained in WMW Headworks Reference Manual (‘86/87). In ’83, areas downstream of Dock, Pine and Taylors Lake inundated for months. Dooen Swamp an important safety valve for Horsham. Current outlet arrangements have been modified. In the past, drains have been excavated and lower reaches have been laser graded. Maximum system capacity leading into Dock/Pine/Taylors Lake storages ~2,100 ML/day. Above this point, WM Water lose control of the system. WM Water attempt to keep bigger flows in the McKenzie River system (ie try to “cap” the Burnt Creek flow).
Grampians Rural Water Authority (GRWA)	Sewerage authority plans provide little detail for Horsham Are currently doing an asset inventory, which involves determination of horizontal positions to within 1m and vertical positions to within 2 to 3m.

Following completion of the technical aspects of the project, a risk assessment workshop was conducted with authority personnel (discussed in more detail in the following section). On the 3/9/02, a general briefing session was held for authority personnel providing an opportunity to discuss:

1. The floodplain management process in general,
2. Outcomes of the flood study,
3. The next stages in the development of a Floodplain Management Plan,
4. Implications for other authorities.

In attendance were staff from the following authorities:

- Wimmera Catchment Management Authority,
- Horsham Rural City Council,
- Yarriambiack Shire Council,
- Northern Grampians Shire Council,
- Wimmera Mallee Water,
- Grampians Rural Water Authority,
- Department of Natural Resources and Environment,
- Police,
- State Emergency Service,
- Victorian Country Fire Authority.

4.3 Risk Assessment Workshop

Once preliminary technical results were available and initial flood mapping was complete, a risk assessment workshop was conducted by the study team, with key authority personnel and the steering committee members. This workshop was conducted on 14/8/02 at the study team's offices with the aims of:

1. Providing an overview of the investigation's progress,
2. Summarising community and authority feedback received,
3. Providing an indication of the flooding risk to Horsham as characterised by the technical analysis to date,
4. Identifying in more detail what the likely consequences of various levels of flooding are, and
5. Identifying issues that need to be addressed in the development of a Floodplain Management Plan.

Key outcomes of the workshop are presented in Table 4.2 below:

Table 4.2 Summary of Risk Assessment Workshop Outcomes

Item	Comments
Flood Risk	General consensus that the community was not aware of the level of flood risk to Horsham Authorities concerned about the level of "weak points" in the existing flood mitigation scheme.
Existing areas	The issue of stormwater flooding in urban areas needs to be specifically addressed. The general awareness of potential flood risks needs to be heightened within the community. Improvements to the existing flood warning arrangements need to be made.
Current/future development	There is a significant amount of development either currently being undertaken or potentially being undertaken in the medium to short term. Developments currently being undertaken should be reviewed in the light of the updated information. The updated information needs to be incorporated in the development assessment process for future developments. Current development (at various stages of completeness) includes: • Federation Estate (construction well advanced), • Southbank Estate (currently under construction), • City Gardens Estate (currently under construction)
Emergency Services	Access for emergency services during flood events needs to be considered. Services would include: • CFA, • Ambulance • SES • School • Hospital
Water Quality Issues	There are a number of areas where water quality problems may result from flooding. These include: • Sewerage pumping stations • Historic tanning works, • Septic tanks

5 Survey and Digital Terrain Model Development

5.1 General

There have been 3 main sources of survey information gathered during the course of this investigation, these being:

1. Observed maximum flood levels, both those recorded historically and those gathered specifically as part of this investigation,
2. Floor level survey undertaken specifically for this project.
3. Topographic survey information, both historically available, and specifically gathered for this project.

Following collection of the topographic information, a Digital Terrain Model (DTM) was developed as a basis for the subsequent hydraulic modelling. These items are discussed in more detail below.

5.2 Flood Level Survey and General Flood Information

As a result of the questionnaire, numerous flood photo's have been obtained during the course of this investigation. These have been scanned and, as (as far as was possible) located within the GIS.

Additional historic flood marks were located in the State River and Water Supply Commission files held by the CMA and council files. In total, some 205 historic flood levels have been sourced for Horsham and immediate surrounds. These have been incorporated into the Flood Data Transfer data set.

Flood mark reconnaissance and the questionnaires resulted in an additional seven flood marks for the 1996 event and one additional mark for the 1909 event.

5.3 Floor Level Survey

Two data sources were used to characterise floor levels within the study area. A detailed floor level survey was carried out in 1981 as part of the Horsham Floodplain Management Plan (SRWSC 1982). In many areas, these floor levels are still accurate. In other areas, there has been significant development, and so a detailed floor level survey was conducted as part of this investigation. Table 5.1 below summarises the floor level information gathered during the course of this investigation.

Table 5.1 Floor Level Information Sources

Source	No. of Levels
1984 Flood Study	231
Recent Horsham Rural City Survey	6
Vacant Blocks	72
2002 survey (this project) – general	592
202 survey (this project) – shire buildings	6

5.4 Topographic Survey

5.4.1 Current Study's Aerial Photogrammetry

Aerial photogrammetry was flown by AAM Pty Ltd specifically for this current investigation. Figure 5.1 illustrates the extent of the photogrammetric survey. AAM's metadata report is presented in Appendix B.

The nominated accuracy for this survey was a standard error (68% confidence level or 1 sigma) of 0.1m in both the horizontal and vertical planes.

5.4.2 Current Study's Field Survey

Field survey was conducted by LICS to provide aerial photocontrol, waterway cross section and culvert/bridge structure details.

Cross section survey for the Wimmera River was undertaken at six locations. The six locations were chosen to correspond with the locations where cross sections were surveyed as part of the floodplain management study (SRWSC 1982).

Similarly for Burnt Creek, 8 cross sections were surveyed at locations previously surveyed as part of the floodplain management study (SRWSC 1982). Along Burnt Creek, a further 7 cross sections were surveyed at locations not previously surveyed.

Details of the bridge/culvert structures along Burnt Creek were surveyed at the three Williams Road crossings and Cameron Road (Burnt Creek South Arm). The details surveyed included invert and obvert levels and general arrangement of the structure.

The extent of the field survey is also illustrated in Figure 5.1.

5.4.3 Historic Level Information

There are two main sources of historic level information that have been used during the course of this investigation. These are the SRWSC 1982 investigation, and a levee audit undertaken in 1996. These sources of information are discussed in more detail below.

The State Rivers and Water Supply Commission undertook extensive topographic survey in the late 1970's prior to the floodplain management study (SRWSC 1982). The topographic survey undertaken included the following:

- 0.5 m contour plans based on photogrammetry survey over the entire study area.
- Cross section survey for the Wimmera River and Burnt Creek of the main channel and floodplain,

A levee audit undertaken by Findlay Irrigation Designs and BM Consulting Civil Engineers for DNRE in 1996 surveyed the levee constructed as part of the flood mitigation works recommended by the floodplain management study (SRWSC 1982). The levee crest levels were surveyed at approximately 30 metre intervals.

Details of the existing Horsham town weir were obtained from survey undertaken by the SRWSC as part of the floodplain management study.

5.5 DTM Development

The above topographic survey data was used to developed a digital terrain model (DTM) of the study area. The extent of the DTM is shown in Figure 4.1. The DTM provided the topographic base of the hydraulic analysis. For details of the hydraulic analysis refer to Section 7.

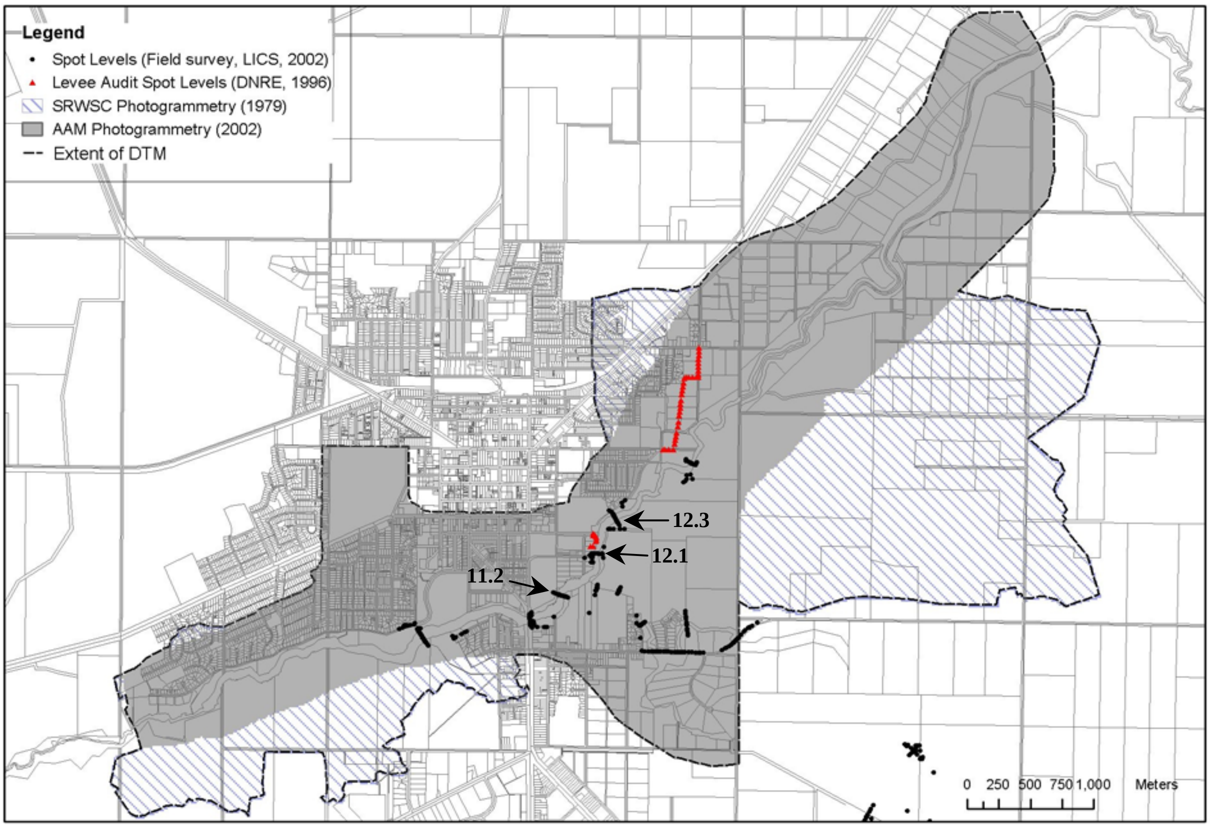

Figure 5.1 Field and Aerial Photogrammetric Survey Extents

During the hydraulic analysis (refer to Section 7) the flooding was found to extend beyond the extent of the current study's photogrammetric survey in several areas. To simulate the flooding behaviour in these areas it was necessary to supplement current study's photogrammetric survey with data from the SRWSC 0.5 m contour plans. Figure 5.1 shows the areas the SRWSC contour plans were employed.

6 Waterway and Floodplain Features

Two waterways flow through the study area, the Wimmera River and Burnt Creek. The features of both waterways and their interaction influence the nature of flooding throughout study area. The following sections provide a brief discussion of key features of the waterway and their floodplain. Figure 6.1 shows the location of key waterway and floodplain features.

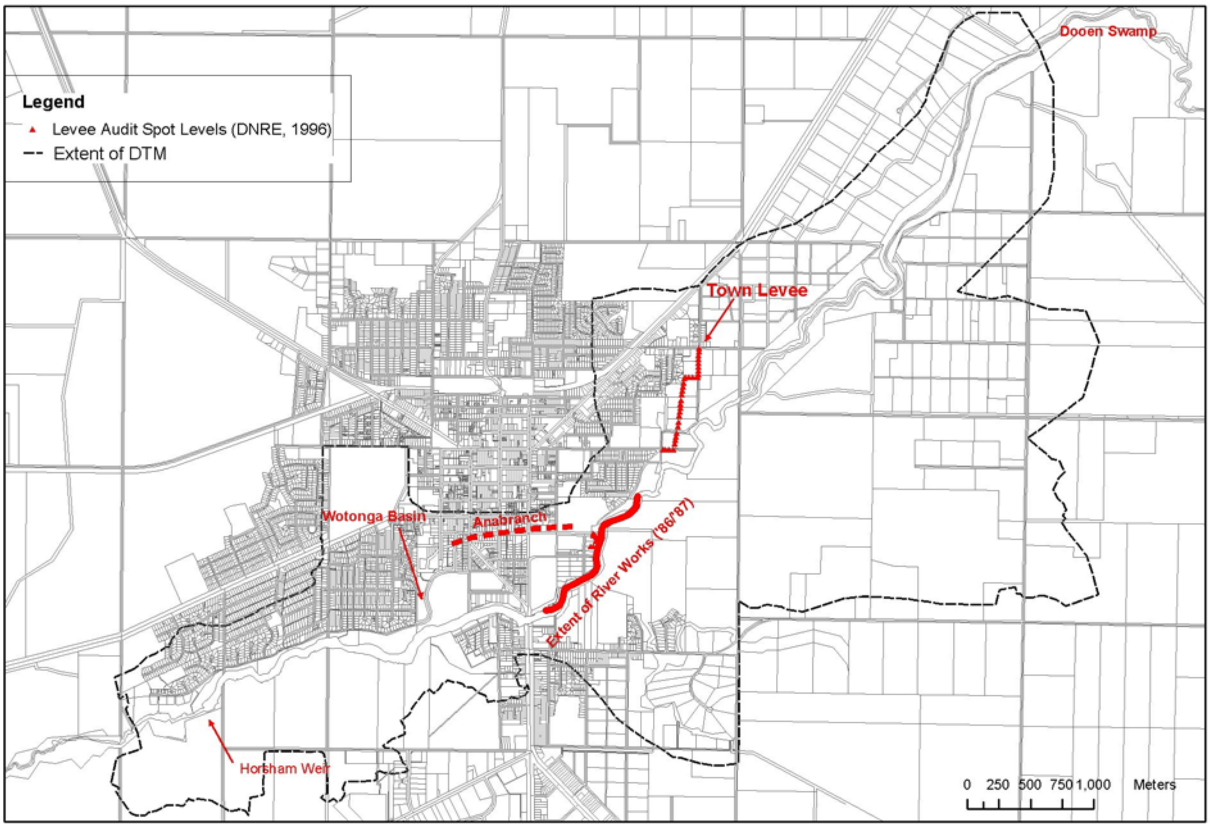

Figure 6.1 Key Waterway and Floodplain Features

6.2 Horsham Town Weir

The town weir is located on the Wimmera River just downstream of Drummond Street. The weir is a concrete structure with a number of removable stop boards. Figure 6.2 is a photograph of the weir looking upstream for a low flow in the Wimmera River.

Figure 6.2 Horsham Town weir – looking upstream at low flow

During low flow periods the water levels in the Wimmera River through the town are controlled by the Horsham Town Weir. The influence of the weir during low flows also extends to the lower reach of Burnt Creek downstream of Williams Road.

Current operating rules for Horsham Weir are designed to minimise the impact of the weir at high flows. Removal of the weir stop boards commences when the Wimmera River flow reaches 613 ML/d (7 m^3/s). All stop boards are removed when the Wimmera River flows reaches 5,145 ML/d (60 m^3/s). A flow of 5,145 ML/d corresponds approximately to a 50 % AEP or 2 year ARI flow.

The weir has no significant impact on water levels at high flows due to the removal of the stop boards and drowning out of the weir. Figure 6.3 is an aerial view (looking south) over the Wimmera River adjacent to the weir during the September 1988. The figure shows the complete drowning of the weir.

Figure 6.3 Aerial View of Horsham Town Weir looking south during Sep. 1988 flood

6.3 Wimmera River – Reach from Town Weir to Gillespie Street

The reach of the Wimmera River from the Town Weir to just downstream of Gillespie Street has undergone significant modification to the natural waterway since settlement, especially over the last thirty-five years. The aim of the modification was to increase the bankfull capacity. The modification over the last thirty-five years included:

- "River Improvements Works" – consisted of relocating the town weir downstream some 3 km to the present day location (1969) and deepening and reshaping the river channel downstream of the Western Highway crossing (1973)
- Flood mitigation works (1987) – consisted of the construction of the levee along Menadue Street in association with widening and deepening the river channel for a 1.2km reach upstream of Western Highway crossing (to Gillespie St).

The above modifications have resulted in a bankfull capacity of this reach varying from 160 m^3/s at Gillespie Street to greater than 240 m^3/s at the Western Highway crossing.

Figures 6.3, 6.4 and 6.5 present cross sections (in the Western Highway – Gillespie St reach) as originally surveyed by the State Rivers and Water Supply Commission in 1979, as proposed as part of the Horsham Flood Mitigation Scheme in 1982, and as resurveyed during this current investigation. The location of these cross sections is shown on Figure 5.1.

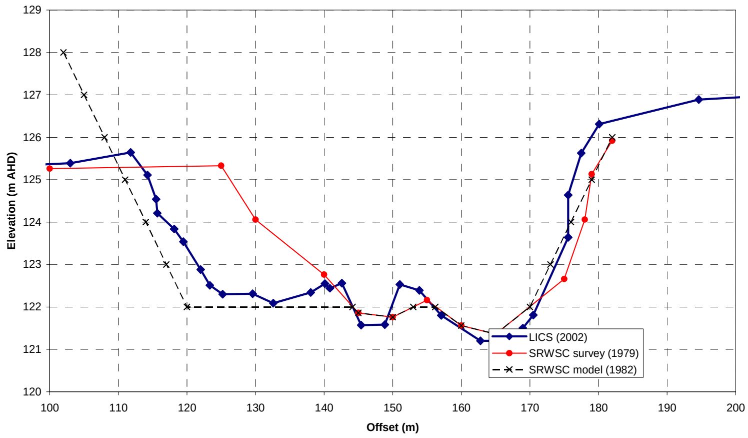

Figure 6.4 SRWSC Section 11.2 – Historical Surveys

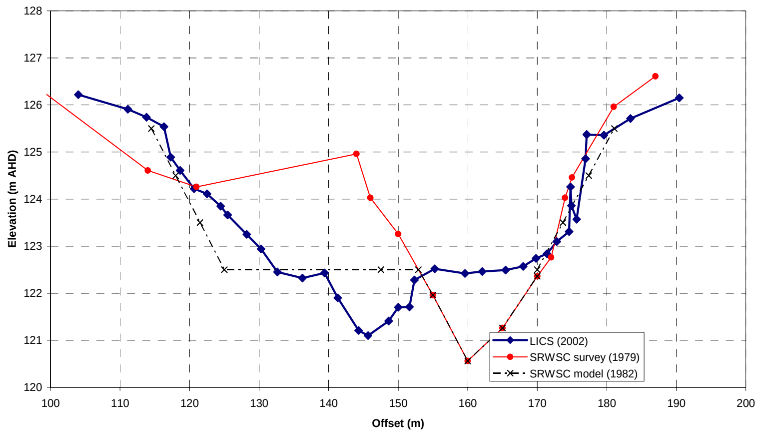

Figure 6.5 SRWSC Section 12.1 – Historical Surveys

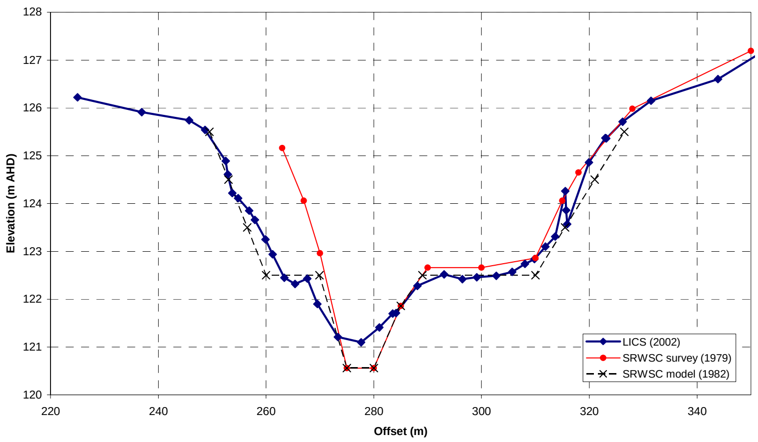

Figure 6.6 SRWSC Section 12.3 – Historical Surveys

This survey illustrates the significant enlargement of the main channel associated with the mitigation works.

6.4 Wimmera River – Reach from Gillespie Street to Dooen's Swamp

Compared with the immediately downstream reach, the Wimmera River from Gillespie Street to Dooen's Swamp, has undergone relatively minor channel works, some removal of riparian vegetation being the only major modification. The floodplain has seen widespread clearing of vegetation and farming development.

The bankfull capacity of this reach is lower than the downstream reach due to the absence of any significant modifications. Upstream of Gillespie St, the capacity is about $130m^3/s$.

6.5 Wimmera River Anabranch

The anabranch consists of a depression which breaks away from the main channel at the eastern end of Hamilton Street to re-enter through the Botanical Gardens and Wotonga Basin. During the early 1900's a number of floods occurred which resulted in flow along the anabranch. SRWSC (1982) estimated flow along the anabranch would occur with an ARI of 3 years under natural conditions. General developments at the upstream end of the anabranch reduced the frequency of flow along the anabranch. This reduction in flooding frequency lead to development along the anabranch further downstream. The construction of the levee along Menadue Street in 1987 was undertaken to reduce flood risk for the existing development along the anabranch.

6.6 Wotonga Basin and Racecourse

Wotonga Basin is located downstream of the Botanical Gardens. The area, as outlined previously, is where the anabranch re-joins the main channel. In addition, backwater flooding occurs in this area. Under natural conditions during large floods this backwater flooding would extend to the present day racecourse. However due to filling associated with urban development, the "river improvement works" and a low level weir, overland flooding of the racecourse has been prevented.

Following notification by Wimmera Mallee Water of impending flooding, Council personnel install drop boards to prevent backwater into the anabranch area. This provides a weir level of approximately 125.9m AHD. During flood events, the area behind the weir is pumped out to maintain capacity in the stormwater system. Figure 6.7 illustrates this operation in 1983.

Figure 6.7 Wotonga Basin Pump Out Operations

The racecourse and adjacent residential areas are located on (relatively) low lying land adjacent to the Wimmera River Anabranch. Note that flooding in these areas may be caused by:

1. Wimmera River flooding resulting elevated tailwater levels at the stormwater outlets and "backing up" the stormwater system,
2. Local rainfall events exceeding the capacity of the stormwater system in this area,
3. A combination of 1 and 2 above.

Figure 6.8 presents a schematic of the stormwater drainage network through this area.

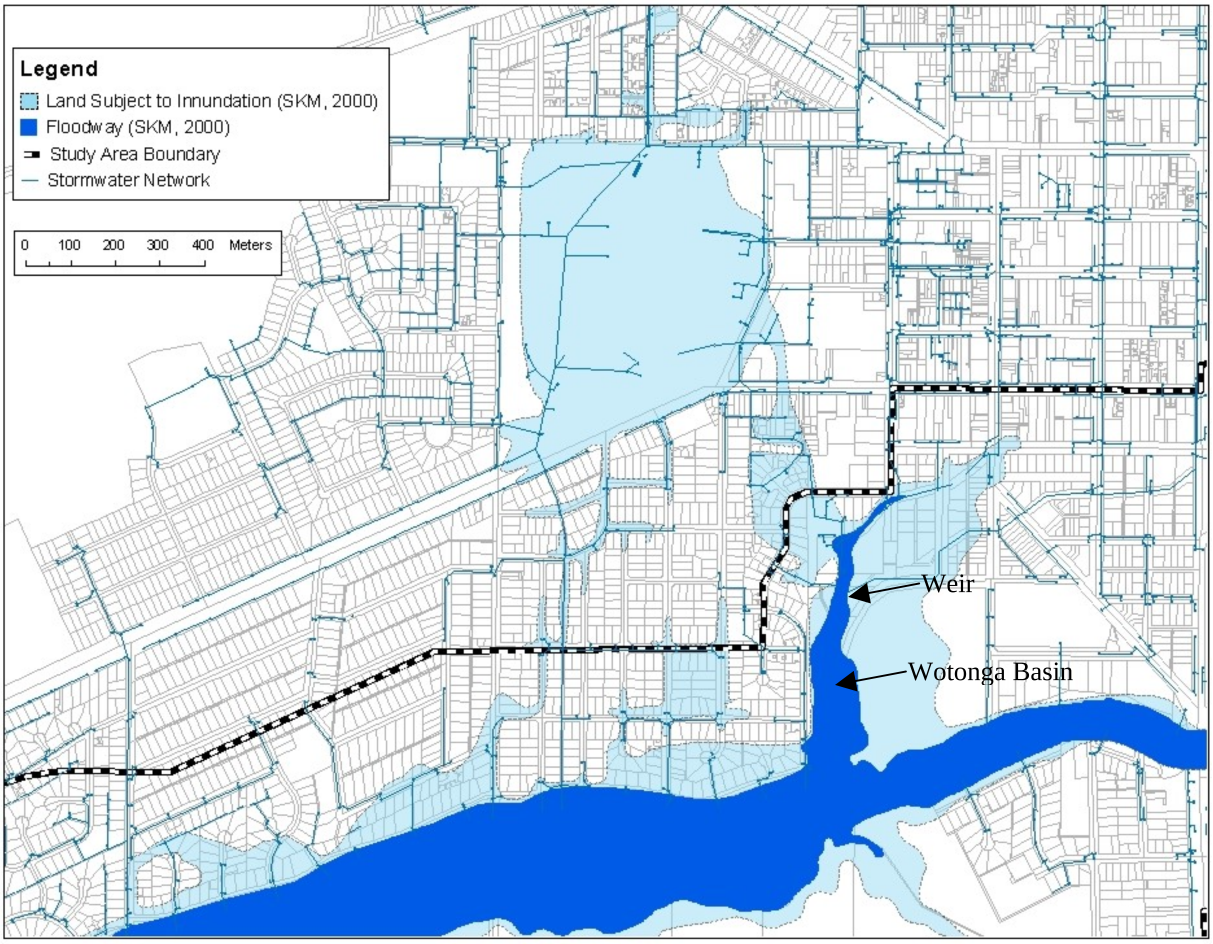

Figure 6.8 Stormwater Drainage Schematic in the vicinity of the Wotonga Basin

7 Hydrologic Analysis

7.1 General

There is a significant length of streamflow gauging data available for the Wimmera River at Horsham. As part of the Horsham Floodplain Management Study, SRWSC (1982), this was analysed in detail and a series of design events derived.

The available streamflow record and analysis detailed in SRWSC (1982) have been reviewed as part of this current investigation. Further analysis has been undertaken, and a revised set of design events for the Wimmera River at Horsham determined. This review and additional analysis are discussed in the following section.

7.2 Flood Data Transfer Project Outcomes

Table 7.1 presents the availability of streamflow gauging for the Wimmera River and tributaries in the area of interest as summarised through the FDT Project (SKM, 2000).

Table 7.1 Gauging Stations (extracts of Table 3.1 SKM, 2000).

Gauge Station (No.)	River/Creek, Location	Period of Observation	Gauge Station Area (km^2)	Comments
415201	Wimmera River, Glenorchy	1910 – 1918 1946 to date	1,953	Good for frequency analyses
415240	Wimmera River, Faux Bridge	1978-1987	2,270	Short record
415239	Wimmera River, Drung Drung	1978-1992	Not defined	Short record
415200	Wimmera River, Horsham	1881-date[1]	4,066	Good for frequency analyses
415241	Yarriambiack Creek, Murtoa	1978-1986	Not defined	Short record
415242	Two Mile Creek, Murtoa Road	1978-1989	Not defined	No stage discharge established
415223	Burnt Creek, Wonwondah East	1965-date	80	

[1] Discontinuous record

> *Historic floods for the Wimmera River downstream of Glenorchy are listed in Table 3.2 along with estimated annual exceedance probabilities (AEP's) for the two main gauging stations suitable for flood frequency analyses. …*
>
> *Anecdotal evidence points to the August 1909 flood as being the largest major flood for which detailed records exist. About 82mm of rain fell over the Wimmera catchment during the 19 hours ending 6 pm August 1909, causing widespread flooding (Commonwealth Bureau of Meteorology, 1909). At Elmhurst, in the upper reaches of the catchment, the flood was estimated to be at least 0.6m higher than the 1870 flood. At Glenorchy, all but 6 houses were flooded. …*
>
> *Along the Yarriambiack Creek, details of the 1909 flood were scarce. However, 1909 flood levels were available for Warracknabeal in the Shire of Yarriambiack.*

Table 7.2 presents a summary of the flood data sourced for the current study area as part of the FDT project.

Table 7.2 Flood Data at Gauging Stations Along Wimmera River (reproduction of Table 3.2 SKM, 2000).

Flood	Gauging Station and Location		
	415201 Glenorchy	415200 Horsham	Comments
Oct. 1894	No records	3.87m gauge 44,300 ML/day 1.2%AEP	Major flood along the Wimmera River. Townships of Horsham, Glenorchy, Dimboola & Jeparit affected
Aug. 1909	No records	3.87m gauge (est) 43,900 ML/day 1.3%AEP	Widespread flooding along the Wimmera River and Dunmunkle and Yarriambiack Creeks. Townships of Horsham, Glenorchy, Warraknabeal, Dimboola, Jeparit and Rupanyup affected.
Feb 1911	No records	3.65m gauge 26,300 ML/day 8.3%AEP	
Sep 1915	No records	3.84m gauge 40,900 ML/day 1.8%AEP	Major flood along Wimmera River and Yarriambiack Creek. Townships of Horsham, Glenorchy Warracknabeal, Dimboola & Jeparit affected.
Sep 1916	No records	3.73m gauge 31,700 ML/day 4.8%AEP	Major flood along Wimmera River. Townships of Horsham and Glenorchy affected.
Aug 1923	No records	3.63m gauge[1] 25,000 ML/day 9.2%AEP[1]	
Oct 1973	4.97m gauge 25,200 ML/day 4.3% AEP	3.35m gauge[1] 14,100 ML/day 30%AEP[1]	
Oct 1975	4.91m gauge 20,100 ML/day 9.1% AEP	3.39m gauge[1] 15,200 ML/day 23%AEP[1]	
Aug 1980	4.72m gauge 13,500 ML/day 20% AEP	2.93m gauge[1] 7,870 ML/day 40%AEP[1]	
Aug 1981	4.85m gauge 17,200 ML/day 12.5% AEP	3.55m gauge[1] 21,000 ML/day 12%AEP[1]	Significant flooding along Wimmera River & Yarriambiack Creek. Horsham, Warracknabeal, Dimboola & Jeparit may have been affected to some degree.
Sep 1983	4.86m gauge 17,700 ML/day 12% AEP	3.64m gauge[1] 25,300 ML/day 9.1%AEP[1]	
Sep 1988	4.97m gauge 25,200 ML/day 4.2% AEP	3.50m gauge[1] 19,100 ML/day 16%AEP[1]	
Oct 1996	4.77m gauge 14,500 ML/day 21% AEP	3.49m gauge[1] 18,500 ML/day 17%AEP[1]	Flood along Wimmera River. Township of Dimboola affected.
Sep 1992	4.77m gauge 14,600 ML/day 20% AEP	2.94m gauge[1] 7,900 ML/day 40%AEP[1]	
Oct 1992	4.69m gauge 13,000 ML/day 25% AEP	3.30m gauge[1] 12,800 ML/day 27%AEP[1]	

Source: RWC, 1987 and Thiess, 1999 and Thiess Environmental Services. Gauge heights have been adjusted in places to suite current site.
[1] Gauge heights and flood frequency estimated from Thiess, 1999.

7.3 Review of Horsham Floodplain Management Study SRWSC (1982) - Hydrologic Analyses

A number of large floods occurred prior to 1924 including events in 1889, 1894, 1909 and 1915. This is in contrast to the subsequent period (1924 to 2001) where only a few large floods have occurred. The general community attribute the absence of large floods since 1923 to development within the catchment such as land use change and the construction of water storages.

The 1982 study undertook a comprehensive investigation into the factors influencing the nature of flooding in the Wimmera River catchment and at Horsham. Conclusions of this investigation are summarised as follows:

- The major change in land use since 1880's has been from natural pasture to sown pasture. The absence of large floods since 1923 cannot be attributed to land use change, although total runoff (yield) from the catchment may have reduced.
- Commanding approximately 25% of the catchment, Lake Lonsdale has generally reduced large flood peak flows at Horsham by 1% to 2% since its construction in 1902. However, peak flows for moderate flood events may have been reduced by 25 %.
- Lake Bellfield commands less than 3% of the catchment area to Horsham. Given this small catchment and the modest impact of Lake Lonsdale, the impact of Bellfield on flood peak flows at Horsham was considered negligible.
- Changes to the offtake to Yarriambiack Creek have increased peak flows for large flood events at Horsham by of the order of 5% from the natural conditions. In particular the reconstruction of the Wimmera Highway crossing in 1959 has contributed to this increase.
- Large floods in Horsham are due to a rainfall scenario where intense rainfall has occurred after a prolonged period of general rainfall. The period of general rainfall "wets up" the catchment and also partially fills the natural floodplain storage. These two effects combine to increase the runoff generated during the intense rainfall event and results in a large flood at Horsham. Apart from August 1981 and September 1983 this rainfall scenario has not occurred since the 1920's.
- The absence of large floods since 1923 was not due to subsequent catchment development (i.e. land use change and construction of storages), but rather was due to the rainfall scenario outlined above not having occurred.

To evaluate the probability of large floods, the 1982 study undertook a frequency analysis of the re-estimated peak flows over the period 1889 to 1981 (93 years). Current practice is to use a series of annual peak flows in flood frequency analysis for determining the probability of large floods with ARIs greater than 10 years. An annual series consists of the maximum peak flow in each calendar year. For catchments with a high variability in streamflow, like the Wimmera River, the annual series may contain peak flows which are very low and/or zero for given years. At the time of the 1982 study, then available approaches had difficulty in dealing with annual series containing very low and/or zero peak flows.

To overcome these difficulties the 1982 study adopted the use of partial series of peak flows in the flood frequency analysis. A partial series of peak flows consists of all independent peak flows above a given value and may contain more than one peak flow from a single calendar year. The selection of peak flows above a given value prevents the inclusion of very low and/or zero flows in the frequency analysis.

A partial series of peak flow above 6,800 ML/d was compiled from the revised streamflow record. The value of 6,800 ML/d was selected to result in the number of peak flows in the series being equal to the number of years in the streamflow record (93 years). A log Pearson 3 distribution was fitted to the partial series. Table 7.3 displays the results of the frequency analysis from the 1982 study. The 1909 flood was estimated to have an average recurrence interval of 300 years.

Table 7.3 Results of frequency analysis (partial series) for the period 1889 to 1982 (SRWSC 1982)

Average recurrence interval (years)	Design peak flow (ML/d)	Design peak flow (m^3/s)
10	19,100	221
20	22,800	264
50	28,300	328
100	33,000	382
200	38,300	443

The 1982 study did not consider the probable maximum flood (PMF).

As discussed, the 1982 study concluded that land use change and construction of water storages has had a minimal impact on the magnitude of large floods at Horsham. These conclusions were made following a comprehensive investigation. Following a review of the 1982 study it is considered the conclusions regarding the impact of the land change use and water storages are valid. As a result, this study did not undertake any further investigation into the impacts of land use change and storage construction on large floods.

7.4 Design Peak Flow Estimates – Wimmera River

7.4.1 Streamflow Records

Systematic records of streamflows (flood levels) have been kept at Horsham since 1889 to date. These records have been collected at a number of different sites along the Wimmera River and the anabranch as follows:

- Old Town Weir head gauge: June 1889- October 1962 (Wimmera River)
- Old Town Weir tail gauge: June 1889- October 1962 (Wimmera River)
- Hamilton St. gauge: August 1909 - 1940’s (?) (Anabranch)
- Town drain gauge: 1940’s(?) – 1960 (Anabranch)
- Tree gauge: 1940’s(?) – 1960 (Anabranch)
- Carines corner gauge: August 1955 – 1960 (Anabranch)
- Beaurepaires gauge: 1960 – October 1962 (Anabranch)
- Walmer gauge : 1970 to data (Wimmera River)

Figures 7.1 and 7.2 display the location of the streamflow gauges.

Apart from the Walmer gauge, all of the above gauges were located at Horsham. For large floods at Horsham, prior to the current mitigation works construction, flow occurs in both the river and the anabranch. Hence to estimate the total flow at Horsham requires flood levels for the river and the anabranch. The Walmer gauge is located about 5.7 km downstream of the old town weir. The flood flow at Walmer is reasonably well confined to the river channel and adjacent floodplain. Rating curves have been employed to estimate flow from the recorded flood levels at various gauges.

Two sources of streamflow data are available for this study:

- Thiess – Hydrographic Services
- Horsham Floodplain Management Study SRWSC (1982)

Figure 7.1 Streamflow gauge locations – Wimmera River and Burnt Creek

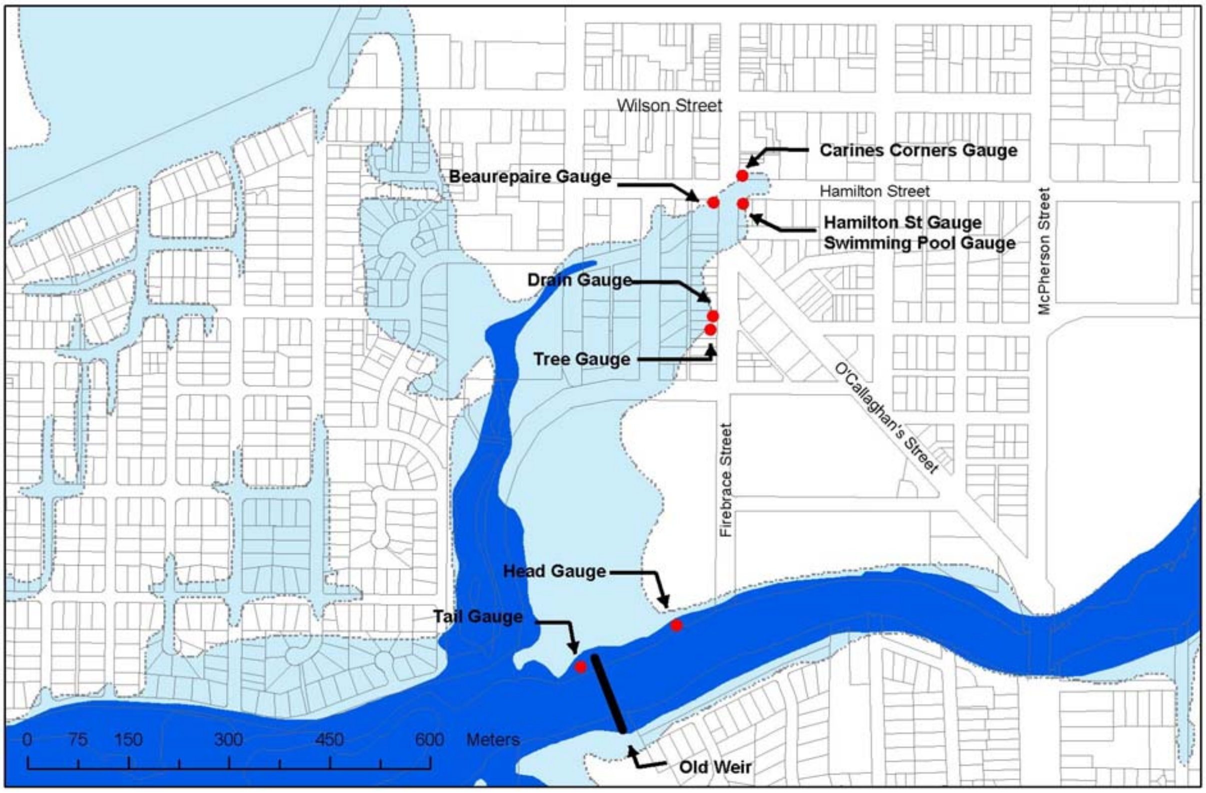

Figure 7.2 Streamflow Gauges Locations – Horsham Town Gauges

Thiess Streamflow data

For this study, streamflow data was obtained from Thiess - Hydrographic Services for the period January 1889 to December 2001 at Horsham (gauge number 415200) as outlined earlier. The details of the available data are shown in Table 7.1.

Table 7.4 Details of streamflow record at Horsham obtained from Thiess

Period of record	Type of streamflow record obtained
1/1/1889 to 31/12/2001	Mean daily flow
7/5/1975 to 31/12/2001	Daily peak flow

For the frequency analysis outlined in the following sections, it was necessary to estimate the daily peak flows for the entire period 1/1/1889 to 31/12/2001. A relationship was developed between the mean daily flow and the daily peak flow for each month over the period of concurrent data (7/5/1975 to 31/12/2001). Figure 7.3 displays this relationship between the mean daily flow and daily maximum instantaneous peak flow.

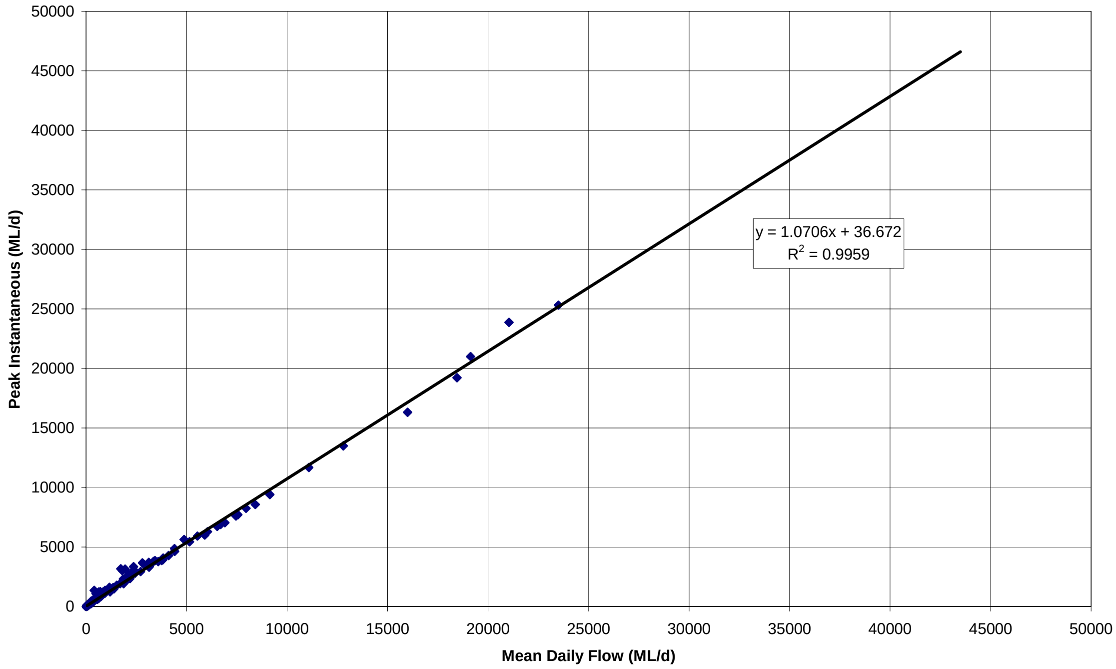

Figure 7.3 Relationship between mean daily flow and daily peak flow for the Wimmera River at Horsham

Daily peak flows were estimated using the mean daily flow and the above relationship for the period 1/1/1889 to 6/5/1975. When the estimated daily peak flows (1/1/1889 to 6/5/1975) were combined with the recorded daily peak flows (7/5/1975) to form a complete series of daily maximum instantaneous flows over the entire period for analysis.

SRWSC (1982) Streamflow Data

The 1982 study reviewed the reliability of the streamflow records from the different sites. The flood level records from the different sites were reconciled to a common survey datum to ensure consistency. Peak flows were then re-estimated using the revised flood levels and a rating curve developed in 1964 by SRWSC. This 1964 rating curve accounted for flow in both the main river channel and the anabranch and this had the following impacts on the largest ten flood events:

- For eight events the peak flows increased by up to 23%,
- For two events the peak flows decreased by up to 40%.

Comparison of streamflow data

As outlined earlier the SRWSC 1982 study revised the available streamflow records at Horsham for the period 1889 to 1981. Figure 7.4 shows a comparison of daily peak flows from Thiess and the SRWSC 1982 study. The comparison is made for the annual maximum instantaneous flows above 10 000 ML/d.

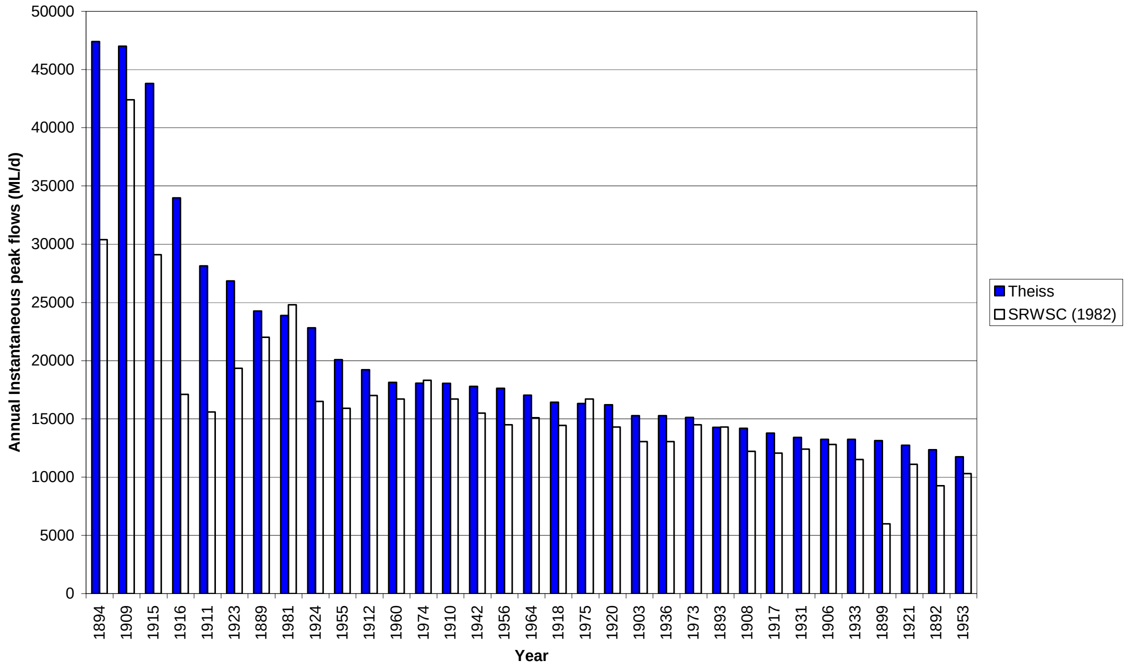

Figure 7.4 Comparison of annual maximum peak flow from Thiess and SRWSC (1982)

From Figure 7.4**,** the annual maximum peak flows from Thiess are larger than the SRWSC 1982 study from the years 1974, 1975 and 1981. Significant differences occur for the years 1894, 1909, 1911, 1915, 1916 and 1923. These differences are of particular note given they directly impact on the largest floods are involved. This current study did not investigate the exact causes of these differences. However, based on SRWSC 1982, the differences are most likely due to the uncertainties in survey datums and rating curves.

The peak flows from the SRWSC 1982 study were derived from a thorough investigation of survey datum and rating curves. It is therefore considered reasonable, for the purposes of this current study, to adopt the peak flows derived by the SRWSC 1982 study for the period 1889 to 1981. To complete the streamflow record through to 2001 the Thiess peak flows were adopted for the period 1982 to 2001.

It is doubtful that further improvements in the accuracy of the composite record can be made without extensive investigations. While the peak flow estimates for early events have larger levels of uncertainty associated with them than more recent events, the composite record is considered to be of an appropriate order of accuracy for estimating design floods.

To avoid future uncertainty, it is recommended that Thiess be advised of the revised peak flow estimates from the SRWSC 1982 investigation.

7.4.2 Flood Frequency Analysis

As discussed previously the 1982 study employed a partial series in the flood frequency analysis. The partial series approach overcame inadequacies in then available techniques to deal with very low and/or zero peak flows. Since the 1982, study techniques have been developed to deal with the presence of very low and/or zero peak flows in annual series and are outlined in Australian Rainfall and Runoff (IEAust 1987).

Current practice is to use an annual series of peak flows to estimate the probability of large flood with ARIs greater than 10 years (IEAust 1987). In line with this current practice, this study adopts an annual peak series for use in a flood frequency analysis.

A flood frequency analysis was undertaken for the period 1889 to 2001. As discussed the best available annual peak flows series consisted for the following:

- SRWSC 1982 revised peak flows for the period 1889 to 1981,
- Thiess peak flows for the period 1982 to 2001.

A log Pearson 3 distribution was fitted to the annual peak flows series using the techniques outlined in IEAust (1987). Peak flows less than 1,000 ML/d were excluded from the analysis in accordance with IEAust (1987).

Results from the frequency analysis are presented in Table 7.4 and Figure 7.5**.** The fit of distribution to the observed peak flows is considered reasonable particular for the larger flood events.

Table 7.4 Results of frequency analysis (annual series) for Thiess and SRWSC (1982) peak flows (1889 to 2001)

Average recurrence interval (years)	Design peak flow (ML/d)	Design peak flow (m^3/s)
5	12,900	149
10	18,100	209
20	23,700	274
50	31,200	361
100	37,000	428
200	43,000	498

The design peak flows in Table 7.4 have increased from the estimates in the SRWSC 1982 (refer to Table 7.1).

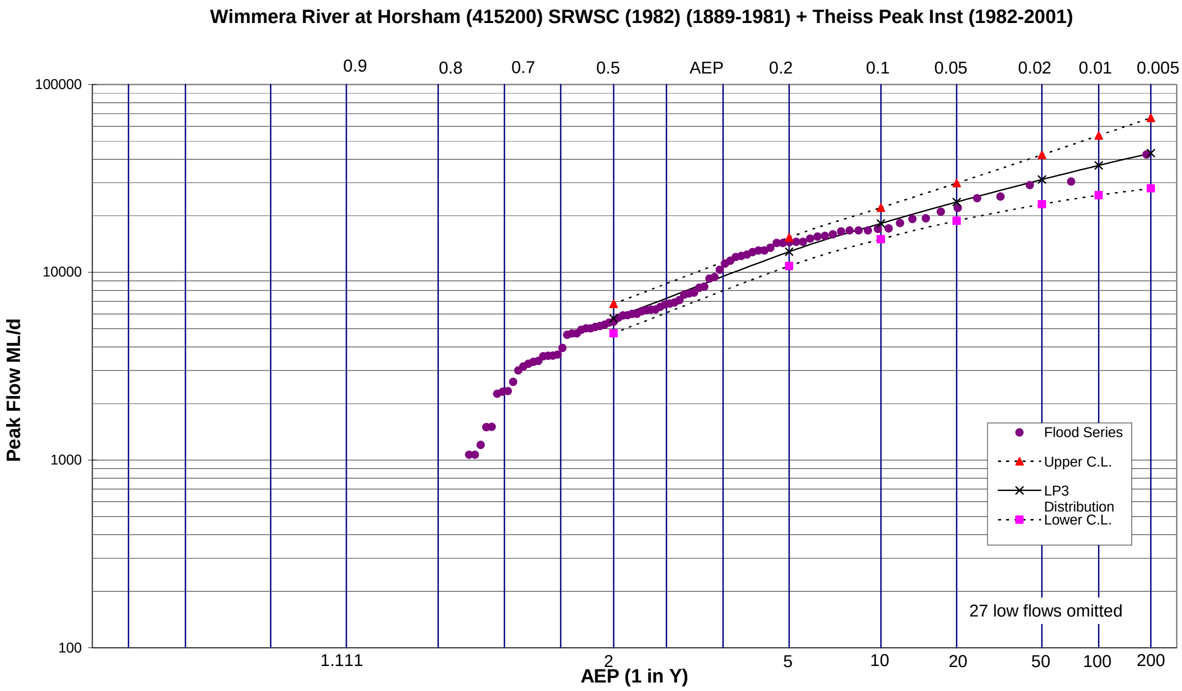

Figure 7.5 Flood frequency curve for Wimmera River at Horsham

Table 7.5 presents compares the frequency analysis results as derived during the course of this investigation, with the results of the SRWSC 1982 study.

Table 7.5 Comparison of the revised flood frequency distribution with the SRWSC 1982 distribution

Average Recurrence Interval (years)	Design Peak Flow (SRWSC 1982) (ML/day)	Revised Design Peak Flow (ML/day)	Percentage change
10	19,100	18,100	-5%
20	22,800	23,700	+4%
50	28,300	31,200	+10%
100	33,000	37,000	+12%
200	38,300	43,000	+12%

Also note that as discussed in the section 7.4, the previous estimate (SRWSC 1909) of the average recurrence interval for the 1909 event was 300 years. The revised flood frequency analysis results in an average recurrence interval for the 1909 event as 200 years.

7.5 Design Peak Flow Estimates – Burnt Creek

7.5.1 Streamflow Records

In 1996, The Department of Conservation and Natural Resources undertook a review of the of the designated flood levels along Burnt Creek. This review was requested by the then City of Horsham following the 1992 event (a relatively minor event) when levels in the Weldon Power Court area approached the calculated 1% probability flood levels.

A frequency analysis was carried out for the gauging station at Wonwondah East with available records (1966 to 1992). As the catchment area of Burnt Creek to the Wonwondah East gauge is approximately half the catchment area to Horsham, the results of this frequency analysis were scaled up on the basis of catchment area to provide a series of design events for Burnt Creek at Horsham. These results are presented in Table 7.6.

A regional analysis and a RORB analysis were also carried out. While both of these methods produced somewhat higher estimates of flows at Horsham, the results of the frequency analysis were adopted for the purposes of 1996 investigation.

Table 7.6 Results of Frequency Analysis of the Burnt Creek gauging station at Wonwondah East (extracts from DCNR, 96)

Annual Exceedance Probability	Average Recurrence Interval (years)	Wonwondah East Flow (ML/day)	Wonwondah East Flow (m^3/s)
50%	2	665	8
20%	5	1,400	16
10%	10	1,900	22
2%	50	3,200	37
1%	100	4,700	54

7.5.2 Flood Frequency Analysis

The results of the flood frequency analysis as detailed in DCNR (1996) have been presented in the previous section. The present flood frequency analysis utilised a 36 year period of record (1966 to 2001) available for the Wonwondah East gauge.

This flood frequency analysis has been revised for this current investigation and utilises the rainfall data for the available record i.e. 1966 to 2001 (36 years). As the Wonwondah East gauge represents runoff from sightly less than half of the Burnt Creek catchment to the junction with the Wimmera River, it is necessary to transpose the results of the flood frequency analysis. This has been done using a relationship of the form:

$$Q_{Wimmera} = pQ_{Wonwondah}\left(A_{Wimmera}/A_{Wonwondah}\right)^{0.7}$$

p = *1.0 for 5, 10, 20 year*
0.8 for 50 year, and
0.7 for 100 and 200 year

The results of this process are presented in Table 7.6 and Figure 7.6.

Table 7.6 Results of frequency analysis (annual series) at Wonwondah East (415223)

Average Recurrence Interval (years)	Design peak flow Wonwondah East (ML/day)	Design peak flow Wimmera Junction (ML/day)	Design peak flow Wimmera Junction (m^3/s)
5	1,200	2,190	25
10	1,800	3,260	38
20	2,500	3,990	46
50	3,400	4,920	57
100	4,200	5,300	61
200	5,100	6,360	74

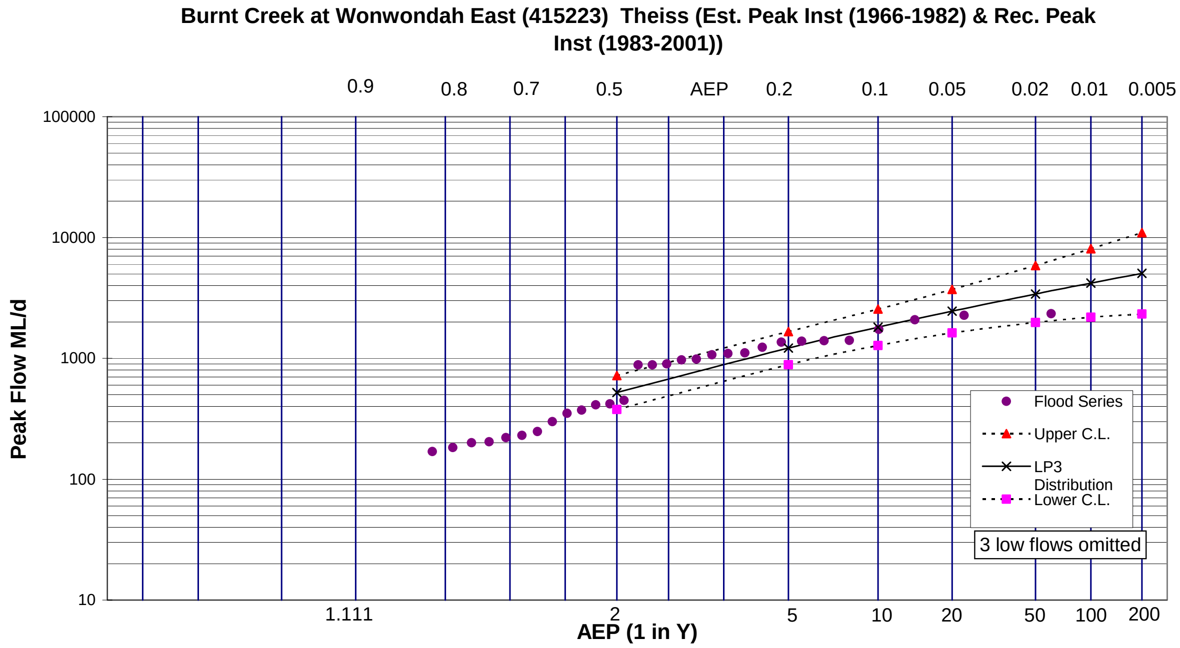

Figure 7.6 Flood frequency curve for Burnt Creek at Horsham

Table 7.7 presents compares the frequency analysis results as derived during the course of this investigation, with the results of the DCNR, 1996 study for the Wonwondah East gauge.

Table 7.7 Comparison of the revised flood frequency distribution (Wonwondah East gauge) with the SRWSC 1982 distribution

Average Recurrence Interval (years)	Design Peak Flow (DCNR, 1996) (ML/day)	Revised Design Peak Flow (ML/day)	Percentage change
10	1,900	1,800	-5%
50	3,200	3,400	+6%
100	4,700	4,200	-11%

8 Hydraulic Analysis

8.1 General

The construction of a terrain model and subsequently the construction of a hydraulic model enables the simulation of Wimmera River flow within the study area to be simulated in great detail. Varying flow conditions ranging from the reproduction of historical events, to the simulation of hypothetical "design" events can be modelled. These flow conditions can be applied to both the existing topography, and also to topographies that have been altered to represent changes eg flood mitigation measures or catastrophic failures.

Hydraulic modelling of the study area has been undertaken utilising the MIKE 21 modelling system. MIKE 21 solves the full non-linear equations describing conservation of mass and momentum in two horizontal dimensions. It is commonly referred to as a full two dimensional or 2D hydraulic model.

MIKE 21 has been developed by the Danish Hydraulic Institute for modelling two-dimensional flows in estuaries, bays and coastal seas. Recent developments have broadened its application to complex two-dimensional flows in river and floodplain systems. The use of a fully two-dimensional model enables the following:

- The 2-D model computes water levels and velocities at each grid point as a function of the local ground level, bed resistance, hydraulic grade and any shear stresses from flow in adjacent grid points. As such, the model can readily describe major and minor flow paths down to the same scale as the model grid. No prior assumptions need be made as to the path the flow will take or its direction.
- The 2-D model can accurately represent flow around individual structures (such as buildings, bridges, etc.) and the formation of any eddies or flow separation zones along with their associated head losses. These are included explicitly in the model formulation, and do not need to be incorporated in the bed-friction term.

The 2-D model can provide details of water levels and velocities throughout the model domain. This detailed information can be provided on the same scale as the model grid.

8.2 Model Establishment

The basis of the two dimensional model is the topographic grid. This is illustrated in Figure 8.1 and is based on the photogrammetry as supplied by AAM. A 10m grid has been used for the purposes of the Horsham Flood Study. As discussed in Section 4, field survey of key features (eg levees and river cross sections) was also conducted. These features have been specifically incorporated into the model grid to ensure accurate representation.

The other essential input to the hydraulic model directly related to the topography is the hydraulic roughness. This was based principally on the aerial photograph (AAM, 2002) and is illustrated in Figure 8.2.

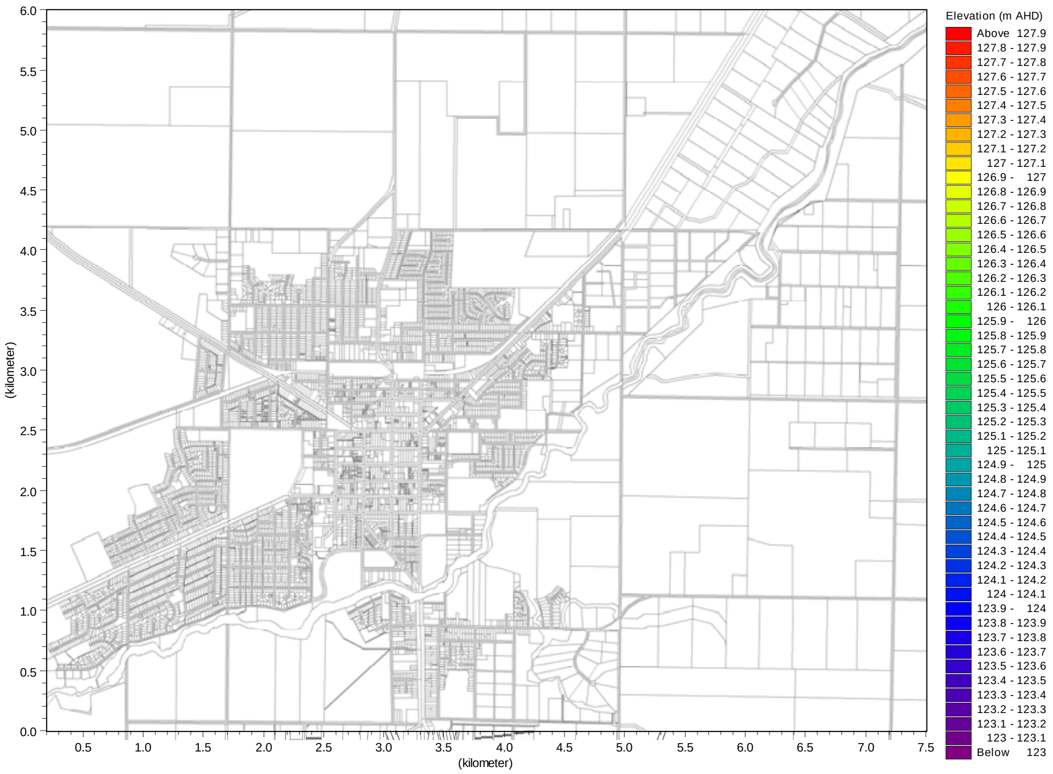

Figure 8.1 Hydraulic Model Topography

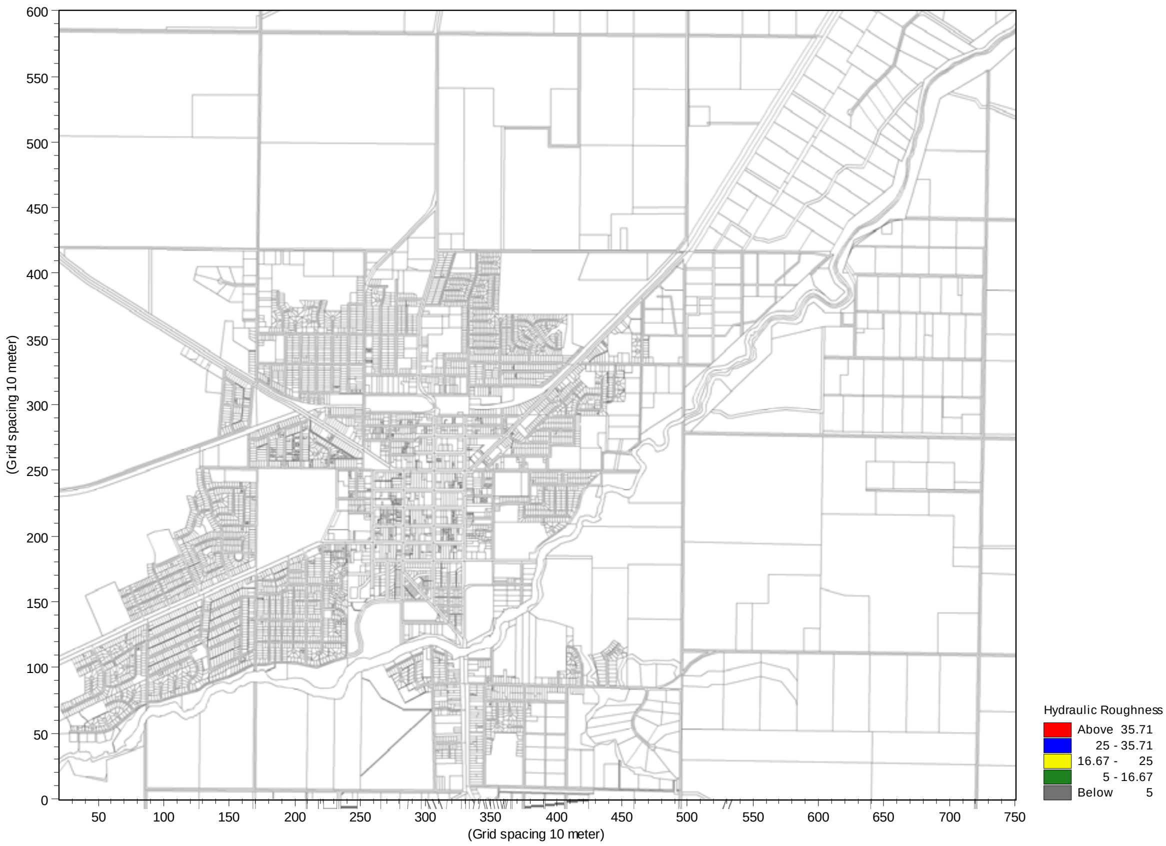

Figure 8.2 Hydraulic Model Roughness

Table 8.1 summarises the hydraulic roughness elements as schematised in the hydraulic roughness map (Figure 8.2).

Table 8.1 Adopted Hydraulic Roughness Parameters

Floodplain Element	Manning's M	Manning's n (n = 1/M)
General floodplain roughness (open space, lightly vegetated)	25	0.04
Main channel roughness	33	0.03
Open vegetated areas	16.7	0.06
Thickly vegetated areas	10	0.10
Urban Area (houses, back yards etc)	5	0.20
Clear, paved areas (streets)	66.7	0.015

Note the roughness adopted for urban areas and streets. Through previous experience, it has been found that the most appropriate way to model the significantly reduced flow capacity of residential areas (houses, fences etc), while accurately accounting for the floodplain storage in these areas, is to adopt an extremely high hydraulic roughness for these areas.

The hydraulic model exhibits inundation in these urban areas but with higher velocities (due to the higher conveyance) in the adjacent streets. Values adopted through previous projects were utilised for this investigation and are considered a realistic representation of the complex process.

8.3 Calibration

"Calibration" refers to the process whereby the hydraulic model's representation of flooding through the study area is systematically compared to observed flooding behaviour. This process may incorporate gauged stream flows, observed maximum flood levels, areas of inundation as shown in aerial photographs and residents or observers' recollections of flooding patterns. Where the model does not adequately represent what was observed, the reason for the discrepancy is identified, the model adjusted and the additional simulations undertaken until adequate representation of the historical event is reached.

As outlined previously, significant alternations to the Wimmera River have occurred over the last thirty-five years. The hydraulic model developed by this study is based on current topographic data and simulates flood behaviour as influenced by the current topography. As such the ability of the hydraulic model to simulate observed historical flood behaviour should be viewed with any changes to the topography in mind.

The September 1988 event was chosen as the principal calibration event. This event occurred after the mitigation works described in Section 5. The topographic data used by this study is representative of the nature of the topography at the time of September 1988 flood.

Extensive aerial photography was taken during the September 1988 flood. The aerial photography provides an indication of the flooding extent experienced in the September 1988 event. During the model calibration, the observed and modelled flood extents were compared. A good agreement between observed and modelled flood extents was achieved throughout the study area. Figures 8.3 and 8.4 present the modelled flood extents for the September 1988 flood.

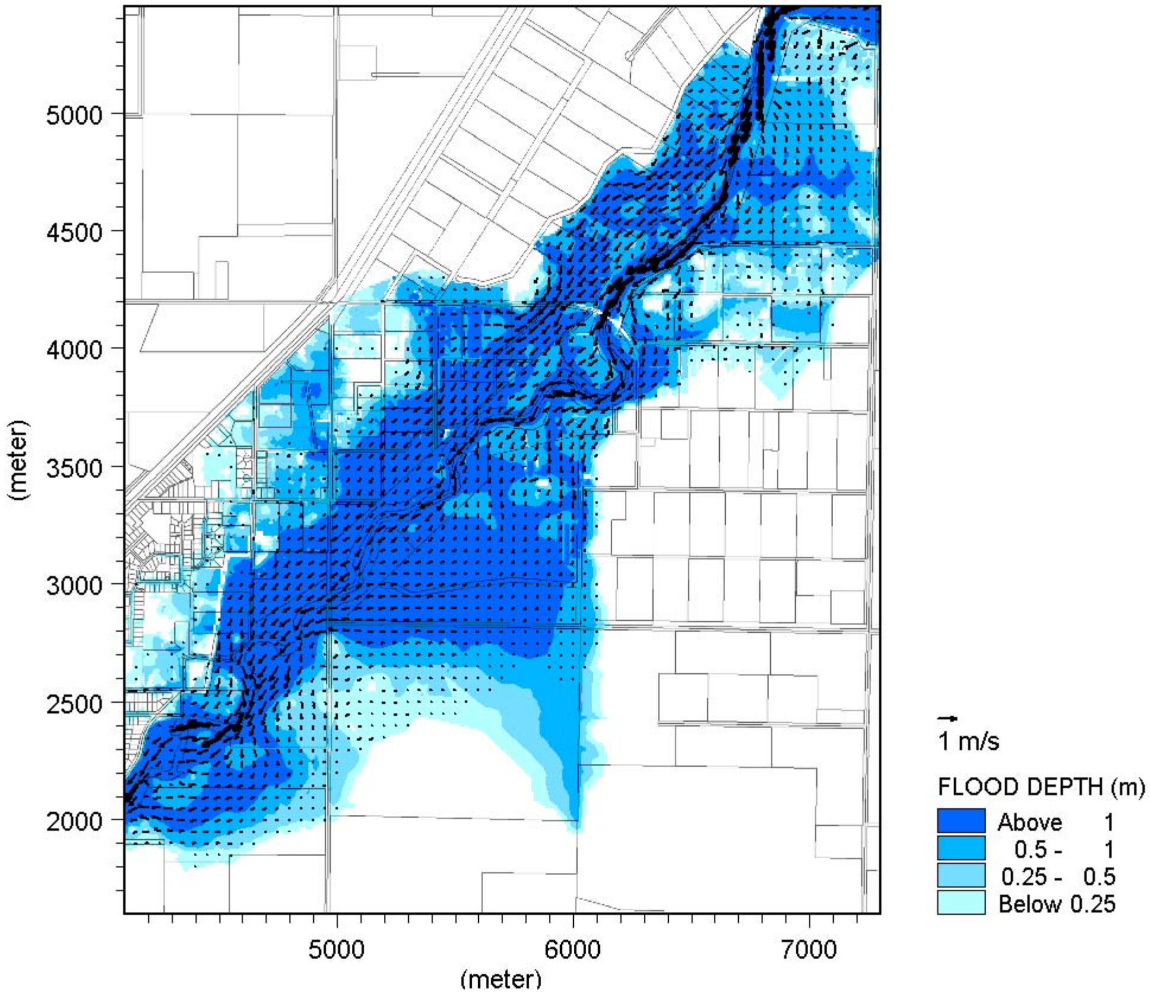

Figure 8.3 Modelled Flood Extent – September 1988 event (upstream)

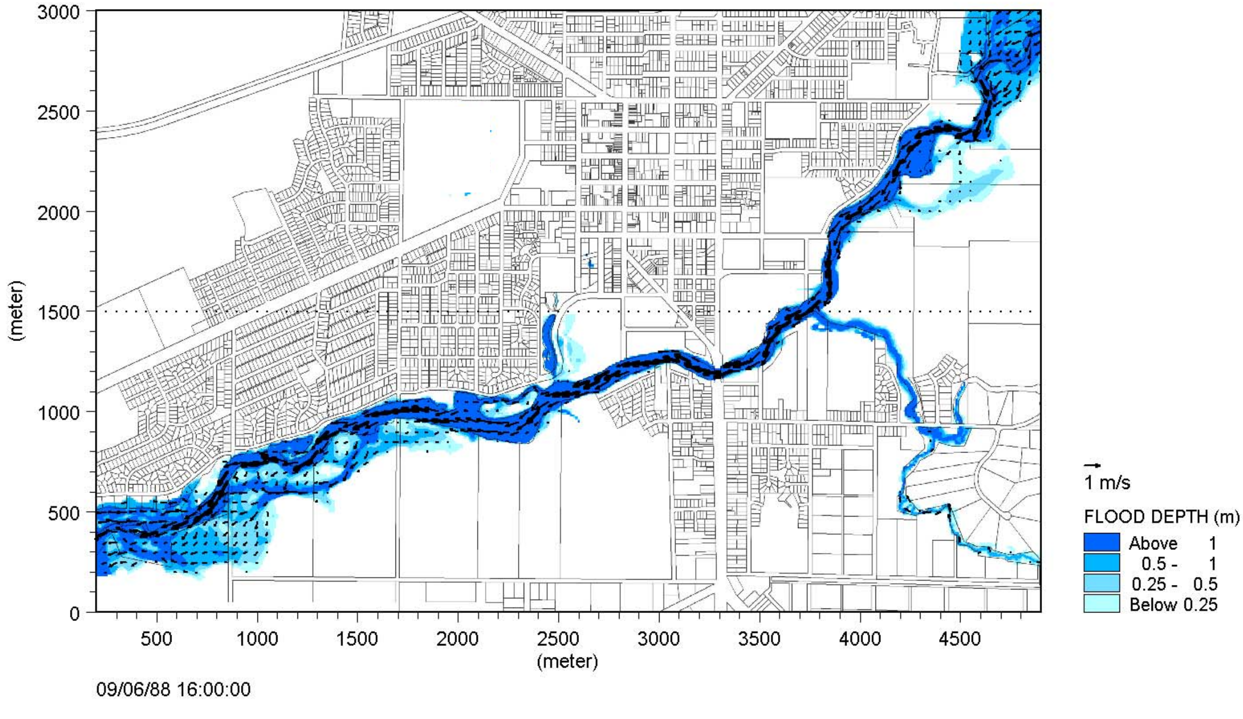

Figure 8.4 Modelled Flood Extent – September 1988 event (downstream)

Observed water surface levels are available at the Western Highway Crossing for the September 1988 event. The hydraulic model predicts a peak water surface water level at the Western Highway for the September 1988 event of 125.74 m AHD. This modelled peak water level favourably compares with the observed peak water level of 125.72 m AHD.

8.4 Design Events

Following calibration of the hydraulic model, the full set of design event flows were simulated. Figure 8.5 presents the predicted design event profiles for the Wimmera River.

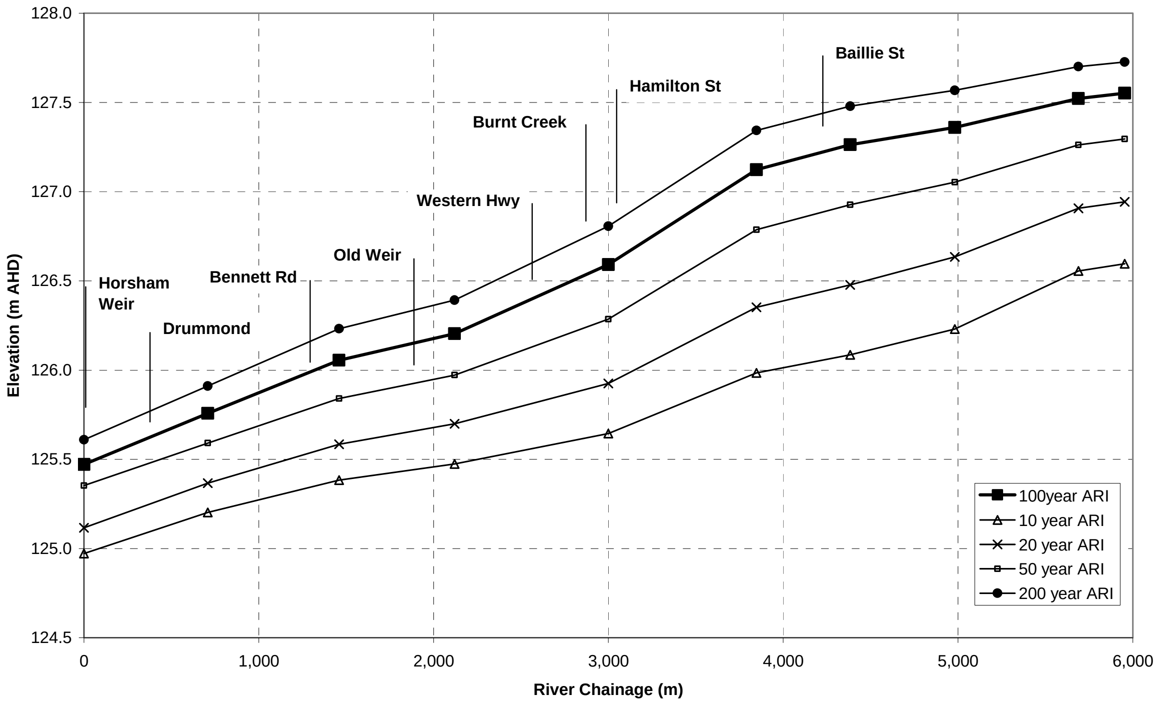

Figure 8.5 Predicted Design Event Profiles for the Wimmera River

Figures 8.6 and 8.7 present the predicted peak inundation corresponding to the ARI 100 year event.

These results are discussed in more detail in the following sections.

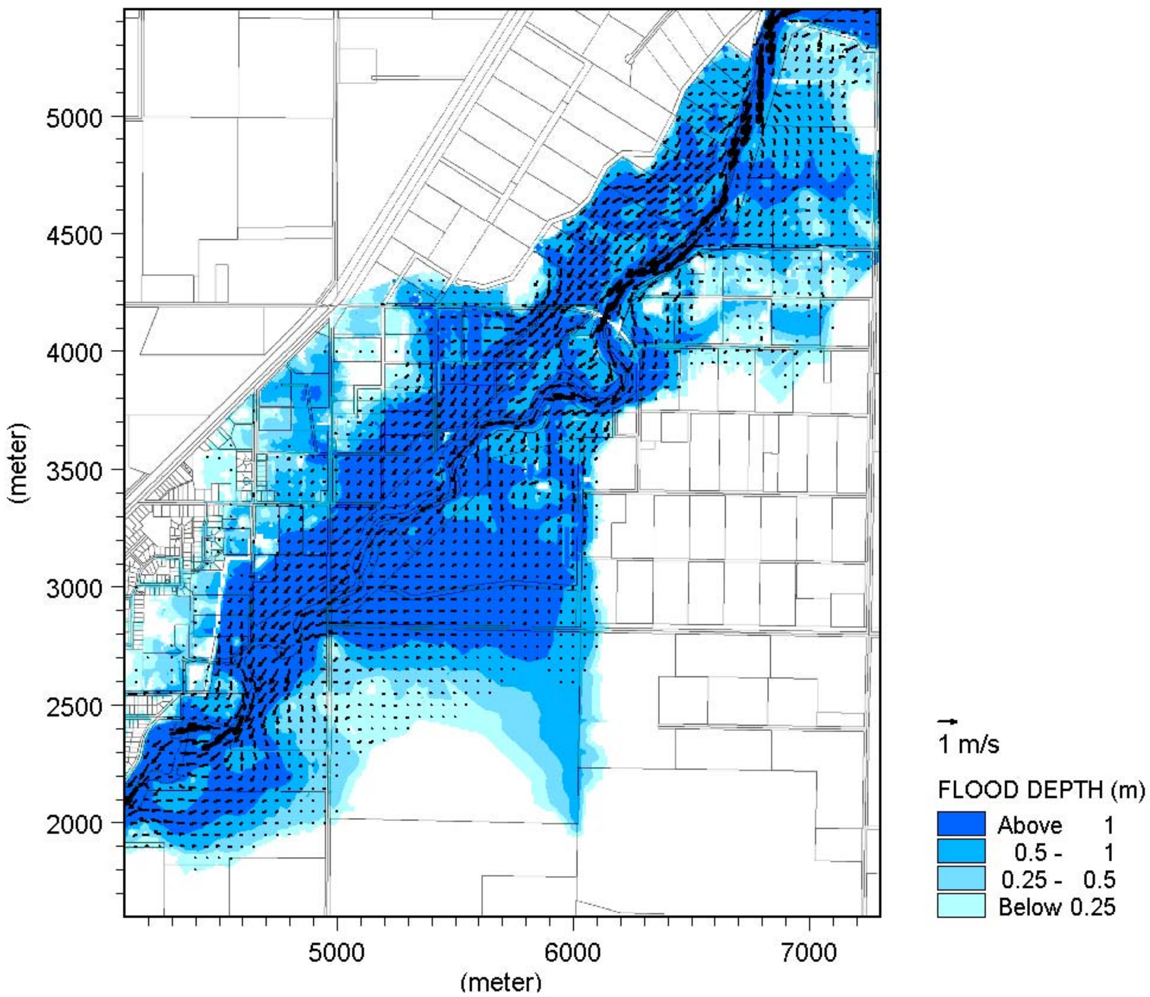

Figure 8.6 Predicted Peak Flood Inundation (Depths) ARI 100 Year Event (upstream)

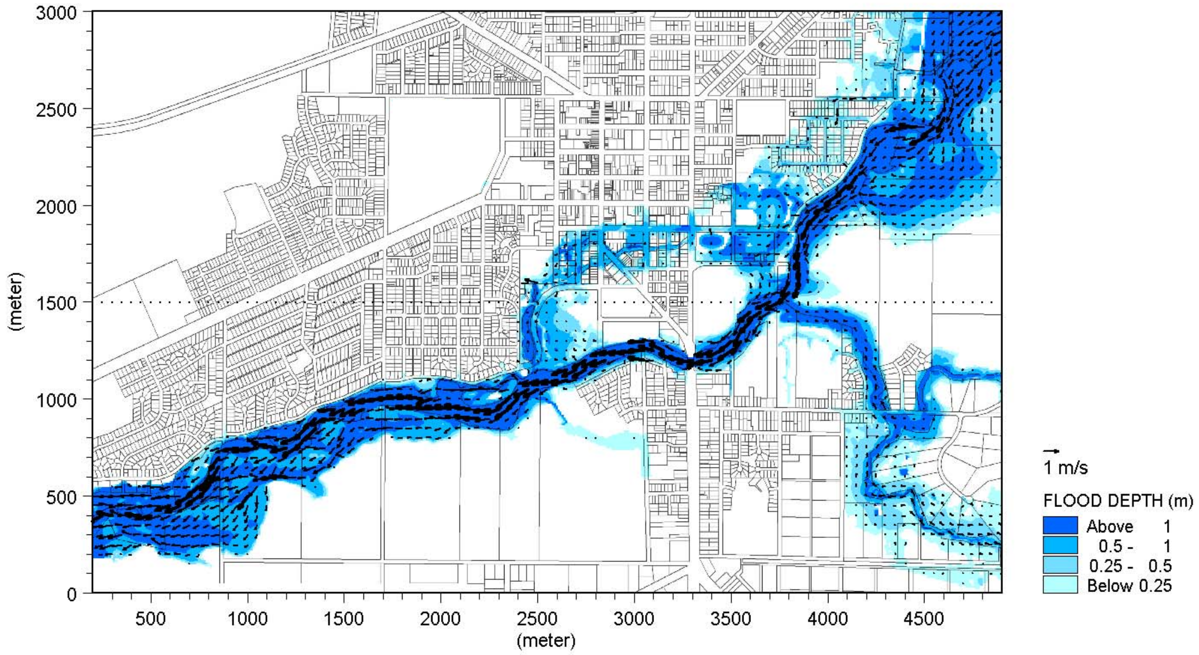

Figure 8.7 Predicted Peak Flood Inundation (Depths) ARI 100 Year Event (downstream)

9 Design Event Mapping

The flood inundation maps prepared as a result of this investigation are presented in Appendix C (A3 size). These are outlined in Table 8.1 below.

Table 8.1 Wimmera River and Burnt Creek Flooding Inundation Maps for Horsham

No.	Drawing
590,001	5 year Average Recurrence Interval Flood Event - Flood Depths and Flood Contours (3 sheets)
590,002	20 year Average Recurrence Interval Flood Event - Flood Depths and Flood Contours (3 sheets)
590,003	50 year Average Recurrence Interval Flood Event - Flood Depths and Flood Contours (3 sheets)
590,004	100 year Average Recurrence Interval Flood Event - Flood Depths and Flood Contours (3 sheets)
590,005	200 year Average Recurrence Interval Flood Event - Flood Depths and Flood Contours (3 sheets)
590,006	5 year Average Recurrence Interval Flood Event - Flood Depths (3 sheets)
590,007	20 year Average Recurrence Interval Flood Event - Flood Depths (3 sheets)
590,008	50 year Average Recurrence Interval Flood Event - Flood Depths (3 sheets)
590,009	100 year Average Recurrence Interval Flood Event - Flood Depths (3 sheets)
590,010	200 year Average Recurrence Interval Flood Event - Flood Depths (3 sheets)

On each map, the surveyed floor levels have been compared to the predicted flood height. If floor levels are predicted to be inundated, a visual indication (a red dot) is provided.

Also note that each map has been “tied in” to the Horsham (Walmer) gauge. An indication of the predicted maximum gauge height for each design event is provided, along with a comparison of historic events. This has been provided with a view to the potential use of these maps for flood warning purposes.

At the time of writing of this report the Bureau of Meteorology (BOM) provides flood predictions for the Glenorchy and Quantong Gauging stations. BOM do not provide flood predictions for the Horsham gauge. However, it is envisaged that at some stage in the future, predictions may be made for the Horsham gauge, or correlations between the Horsham gauge and other gauging stations may be developed.

10 Discussion

The hydraulic analysis has raised several concerns regarding the differences between of the perceived and simulated flooding behaviour within the study area.

The mitigation works constructed in 1986 were designed to prevent flow along the anabranch for floods up to the 1% AEP (100 year), hence reducing the flooding risk for development along the anabranch.

The hydraulic analysis has shown a breakout from the Wimmera River through the Showgrounds and into the anabranch. This breakout begins at a 2 % AEP (50 year) flood event and was not shown to occur in the previous study (SRWSC 1982). Comparison of the ground levels from this study's photogrammetric survey and the SRWSC 0.5 m contour plan indicates significant differences adjacent to the showgrounds. Ground levels from this study's photogrammetric survey are approximately 0.5 m lower than corresponding levels in the SRWSC 1.0 m contour plans. The lower ground levels and higher design peak flow estimates employed by this study has highlighted this breakout.

The Menadue Street levee (to Peppertree Lane) was designed to prevent flow into the upstream end of the anabranch. The levee crest level was set to 0.5 m above the estimated 1% AEP flood level. The Levee Audit Report (Findlay Irrigation Services et al, 1996) indicates that while most of the levee has the design freeboard, the freeboard reduces near the road sections. Figure 10.1 presents an extract of the surveyed long section, superimposed on the original levee design (SRWSC 1982).

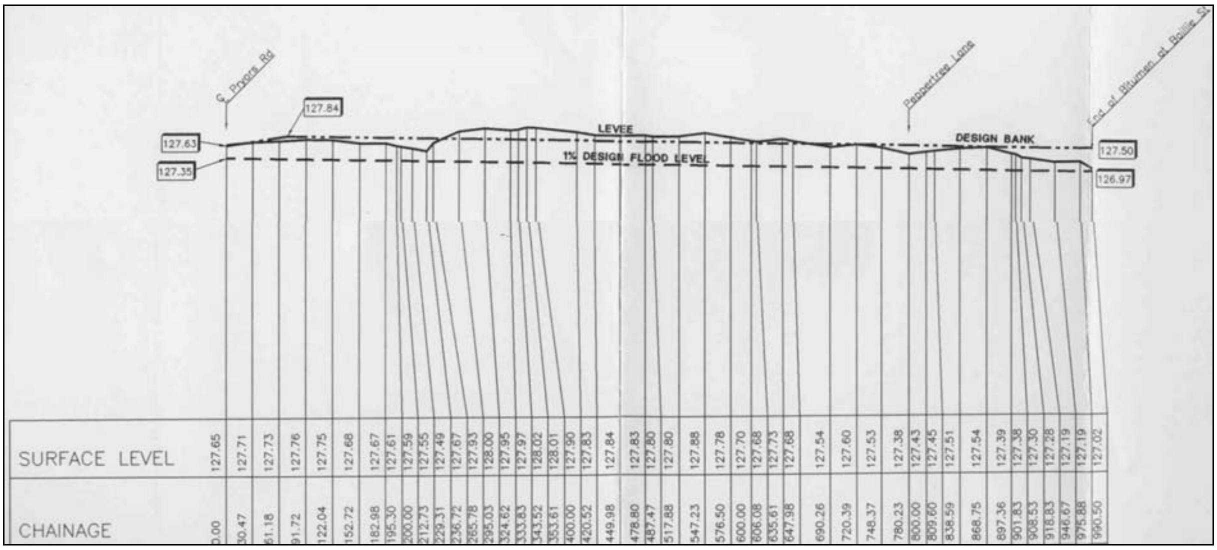

Figure 10.1 Comparison of the Menadue St/Peppertree Lane levee crest (extract from Findlay Irrigation Services et al, 1996).

The possibility is identified that flood waters may circumvent the levee system due to the lower levels at either end. The results of this study's hydraulic analysis support this statement with flow (in the 1% AEP event) predicted to occur around the northern end of the existing levee. Further during a 1% AEP flood, Menadue Street near Baillie Street is overtopped by the flow. As a result flow occurs through the anabranch for the 1% AEP flood.

The study team understands that the following the 1982 investigations and associated works, the community expectation is that the mitigation works constructed in 1986 were to prevent flooding along the anabranch for the 1% AEP flood. Results from this study indicate this expectation is not realised due to a combination of factors including:

- Increased design flows following a review of previously adopted hydrology.
- More accurate and comprehensive topographical survey (the photogrammetry) enabling more accurate definition of flow paths.
- Reduced freeboard at either end of the existing levee system.

Careful consideration is needed in the communication of the existing flood risk to the community given this mismatch between expectation and reality.

11 Conclusions

Based on the work completed as part of the Horsham Flood Study, the following conclusions have been made:

11.1 Previous Investigations

1. There has been a significant amount of work documenting the impacts of flooding on Horsham. Much of this is summarised in the FDT Project (SKM, 2000). This current investigation has augmented the observed flood level information through additional flood levels sourced from Wimmera CMA records, and observed flood levels that have been surveyed directly.
2. Much of the previous SRWSC 1982 investigation is still relevant, and has served as the basis for much of the work undertaken in this current investigation. However, during the course of this current investigation, the partial series approach adopted in the SRWSC 1982 study has been revised using both the longer record now available, and an annual series approach. This has resulted in increased design discharges for the Wimmera River.
3. The design discharges derived for Burnt Creek (DNRE, 1996) have also been revised using similar techniques.
4. Following the SRWSC 1982 investigation, structural works were undertaken as part of a Floodplain Management Plan. These works consisted of a combination of creek widening and levee protection works. As detailed in Findlay Irrigation Services et al, 1996 the levee constructed in the Menadue St/Peppertree Lane area has a low point midway along the levee, and drops beneath the original design profile at either end.

11.2 Data Gathering/Survey

5. Ortho-rectified digital photogrammetry is now available for the Horsham township.
6. Based on this photogrammetric survey, a Digital Terrain Model of the study area is now available.
7. 598 new floor levels have been gathered, with an additional 231 sourced from the 1984 floor level survey.
8. An additional 7 observed flood levels have been gathered.
9. 3 Wimmera River cross sections were taken with the aim of reproducing as accurately as possible the sections surveyed during the SRWSC 1982 investigation. The comparison of these two sets of sections indicate that there has been little change over the past 20 years in the areas surveyed.

11.3 Hydrologic Analysis

10. The design discharges as derived during the course of this investigation are:

Table 11.1Wimmera River and Burnt Creek Design Discharges at Horsham

Average recurrence interval (years)	Burnt Creek (Wimmera River Junction)		Wimmera River (Horsham (Walmer) Gauge)	
	Design peak flow (ML/d)	Design peak flow (m^3/s)	Design peak flow (ML/d)	Design peak flow (m^3/s)
5	1,200	14	12,900	149
10	1,800	21	18,100	209
20	2,500	29	23,700	274
50	3,400	39	31,200	361
100	4,200	49	37,000	428
200	5,100	59	43,000	498

For the ARI 100 year design Wimmera River discharge, this represents an increase of approximately 12% over that previously adopted. The corresponding ARI 100 year design flows for Burnt Creek have reduced by approximately 11% compared to the previously adopted values.

11. It is considered appropriate (and conservative) to adopt coincident Wimmera River and Burnt Creek design events.

11.4 Hydraulic Analysis

12. A detailed hydrodynamic model of the Wimmera River and Burnt Creek systems has been established. This hydraulic model is based on the MIKE Flood combined 1D/2D package.

13. A detailed calibration exercise was undertaken to ensure accurate reproduction of the 1988 event. This was the largest event that has occurred since the flood mitigation works were undertaken in 1986/87.

14. Following calibration, the full suite of design events were simulated using the model.

11.5 Risk Assessment

15. Table 11.2 below summarises the hydraulic behaviour of the area, referenced to the design event frequency.

Table 11.2 Floodplain behaviour for varying levels of Design Flood Events

Event (ARI)	Behaviour
5 year (~'92)	Minor Inundation
10 year (~'96)	Overbank flooding upstream of Camerons Road
20 year ('81)	Wotonga Basin mini-weir overtopped
50 year	Breakout to town anabranch occurs at showgrounds Extensive inundation along Burnt Creek
100 year (<'09)	Breakout around upstream end of Menadue St/Peppertree Lane levee

16. This characterisation of risk indicates that the existing flood protection works (the combination of river widening, town levee and the mini-weir) have provided Horsham with relatively comprehensive protection for events up to the ARI 20 year level.

17. However, there is predicted to be a distinct increase in the damage suffered once the protection works are either overtopped (in the case of the mini-weir) or bypassed (upstream and downstream of the town levee). There is a danger that residents will be unprepared as a result of a perception that they are protected by the town levee. Actual flood damage may be increased correspondingly.

11.6 Community Consultation

18. Information has been distributed to the community in two distinct phases. Firstly the study inception was publicly announced, along with a call for information relating to flooding. A series of public presences were held where interested parties could meet with the study team. Secondly, a series of public information sessions were conducted to provide feedback to the community about the study outcomes.

11.7 Flood Warning

19. Discussions undertaken during this investigation have indicated that there are no flood predictions undertaken specifically for Horsham. The Bureau of Meteorology provide predictions at Glenorchy and Quantong (downstream of Horsham). While Wimmera Mallee Water provide advice with regard to operation of the town weir to Horsham Rural City, they do not provide flood predictions for Horsham itself.

12 Recommendations for future investigations

The study team recommends that the following additional investigations be conducted:

- Floodplain management study and plan for Horsham
- Flood response plan for Horsham
- Stormwater drainage management plan for the urban area of Horsham

Within a risk management framework, the current study has identified and analysed the existing risk from flooding due to overland flow from the Wimmera River.

The floodplain management study and plan will assess the consequences to the community from the existing flooding risk and develop mitigation measures aimed at reducing these consequences. A flood response plan will provide a framework for effective and efficient flood response and recovery. Both the management and response plans will promote a greater community awareness of flooding risks, consequences and community actions that can reduce both the risks and the consequences.

This current study identified areas of Horsham which are subjected to stormwater flooding. The stormwater flooding can occur due to:

- local high rainfall events,
- backwater flooding through stormwater drainage system during floods in the Wimmera River,
- combination of the above two situations.

A stormwater drainage management plan will first identify and assess stormwater flooding risks. In cases where the existing risks of stormwater flooding are unacceptable, mitigation measures will be assessed.

Sections 12.1 and 12.2 outline the key objectives for the recommended future investigations. Detailed briefs for the recommended future investigations are provided in Appendix D.

12.1 Floodplain management and flood response plans

The aim of this investigation would be to assess and prioritise the flood risks facing the Horsham community. The study should consider:

- What are the current risks facing the community (as defined by this current investigation)?
- Are these risks acceptable? The feedback gained through the course of this investigation is that in many areas, stakeholders feel that the current risks are not acceptable.
- If these risks aren't acceptable, what mechanisms are available to minimise flood risks?
- What are the environmental, economic and social benefits and costs associated with such mechanisms?

Specific works items that will need to be addressed as part of such a study include:

1. A comprehensive update of the flood damage calculations presented in Read Sturgess (2001), based on the results of this current flood study.

2. Quantification of the impact of current (pre-approved) development activity including:
   - Southbank estate,
   - Federation estate,
   - City Gardens estate,
   - Barnes Boulevard,
   - Filling adjacent to showgrounds.
   - Rural residential areas to the north-east of the Wimmera River.
3. Consideration of the impact of overland flow on the rural residential areas to the east of the Wimmera River.
4. Consideration of the most appropriate planning controls over development in the "at risk" areas of the floodplain ie:
   - Burnt Creek,
   - Southbank,
   - Upstream rural residential areas,
   - Residential/commercial areas behind the existing town levee system,
   - Residential/commercial areas in the town anabranch flow path.
5. Consideration of works to address the weaknesses in the current town protection scheme that have been identified in the course of this study. Stormwater flooding will be addressed as part of the stormwater drainage management plan. Consideration of such works should include, but not be limited to:
   - Modification to the Wotonga Basin mini-weir and surrounds to provide a higher level of protection,
   - Extension of the existing bunding works to eliminate the existing low point adjacent to the show grounds,
   - Augmentation of the existing levee to at least remove low points, if not raise the crest along it's length,
   - Consideration of end treatments or possible lengthening of the levee to eliminate the low points at the northern end,
   - Consideration of Burnt Creek channel and anabranch systems to identify possible (beneficial) modification to the system.

   Possible flood mitigation schemes, comprising components or combinations of the above works (or any other beneficial works identified) should be developed.
6. Quantification of the benefits and costs from economic, environmental and social viewpoints associated with each of these flood mitigation schemes.
7. Identification of funding mechanisms for proposed schemes.
8. Consultation to gauge public opinion as to the relative merits or otherwise of the proposed schemes.
9. Consideration of the exposure of essential services (e.g. SES, Council, WMW, GWA, police, ambulance, hospital etc) to flooding.

10. Formalisation of the existing flood warning system as part of the flood response plan. At present, there are established procedures (principally between Horsham Rural City Council and Wimmera Mallee Water) that are initiated in the event of a flood. These are primarily aimed at operation of the town weir. Based on discussions undertaken during the course of the study, neither the Bureau of Meteorology nor Wimmera Mallee Water provide flood warnings for Horsham.
11. Investigation of the existing mechanisms of providing flood warning information for the general community, and, where deficiencies are identified, proposing additional mechanisms.
12. Development of a preferred scheme in consultation with other authorities, key stakeholder groups and the public.
13. Development of an operational framework for flood response and recovery including defining of roles and responsibilities of relevant authorities,

12.2 Stormwater drainage management plan

A key finding to come out of this flood study is that there are large portions of Horsham that are exposed to flood damage not directly related to flood flows from the Wimmera River or Burnt Creek. As a minimum it is recommended that HRCC investigate the installation of flood flaps (or alternatives) on the outlets to the existing stormwater infrastructure to prevent "back up" flooding.

The topographic data and analysis of river flooding behaviour undertaken as part of the current study will provide an excellent basis for a comprehensive review of the adequacy of the existing stormwater drainage network. Such an investigation would include, the following specific work items:

1. Quantification of the existing system capacity. Where there is uncertainty as to what stormwater drainage infrastructure actually exists, survey should be undertaken to accurately establish the capacity of the drainage network.
2. Hydrologic analysis to quantify local catchment flows.
3. Consideration of the potential combinations of Wimmera River flood events, and local catchment runoff.
4. Flood mapping to complement the flood mapping undertaken as part of this current flood study.
5. Consideration of mitigation options.
6. Preparation of cost estimates associated with mitigation options.
7. Consideration of benefit/costs of proposed schemes.

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