Project Name: Nathalia Floodplain Management Plan

Project No. 34409.100

Report For: GBCMA, Moira Shire Council, DSE

PREPARATION AND REVIEW

Rev #	Date	Prepared by	Reviewed by	Issued for Distribution by
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10 November 2005

Our Ref: 34409.100
Your Ref: Q006/02

Guy Tierney
Goulburn Broken CMA
55 Welsford St
Shepparton Vic 3632

Dear Guy,

Re: Nathalia Floodplain Management Plan

Please find attached final report (5 copies) for the Nathalia Floodplain Management Plan. The report was prepared after your review and comments to the draft report, which we discussed on 03 November 2005 at our office.

Also find attached CD contains softcopy of the final report, Maps and Model files.

If you have any queries please do not hesitate to contact either myself or Dr.Uma Umakhanthan on ☎ (03) 9573 8100.

Yours faithfully

MAL SPEARS
Project Manager

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Executive Summary

The purpose of the study was to prepare a Floodplain Management Plan for Nathalia taking into account the surrounding environs. The Floodplain Management Plan includes the preparation of Flood Inundation Maps for the study area.

The preparation of a Floodplain Management Plan for Nathalia was an outcome of the Broken Creek strategy report, which recognised Nathalia as a Number 1 priority. Furthermore Nathalia was recognised as a high priority under the Draft Regional Floodplain Management Strategy for the Goulburn Broken Catchment Management District.

Hydrological Analysis

Historical flood information was gathered from published and recorded sources. There is little stream flow data available within the Broken Creek catchment. To model the rainfall runoff process from the Broken Creek catchment a RAFTS (Willing and Partners, 1994) model was developed. The RAFTS model for the Broken Creek catchment was from its headwaters to Walsh's Bridge which is the upstream limit of the hydraulic model. The RAFTS model was calibrated using the 1993 flood events and verified using the 1974 event. The calibration data available for the 1993 and 1974 flood event was limited. The RAFTS model included flows developed for breakouts from the Broken River system.

Design hydrographs for use in the hydraulic modelling were generated using the calibrated RAFTS model and design rainfall from Australian Rainfall and Runoff (1997).

The results from the RAFTS modelling are shown in the Table below.

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)
5	2.5	47	4,060
10	5	68	5,875
20	10	94	8,120
50	20	128	11,060
100	30	160	13,825
500	100	180	15,552

Hydraulic Modelling

The layout of the hydraulic model (RMA) was based upon topographical information, survey data and LIDAR data. Since 1993, many levees/farm channels have been altered within the study area. It is difficult to know what all these changes are as they have not been recorded. From discussion with the Moira Shire Council, the community and the work undertaken as part of the Broken Creek Management Strategy (1998) the main changes that have occurred around Nathalia Township since 1993 is the raising of the levees on both the left and right banks between the old railway bridge and the No. 13 Channel. The hydraulic model was adjusted to endeavour to reflect the catchment conditions which existed during the 1993 flood event.

Initially the flood event of 1993 was used to calibrate the model. The recorded hydrograph at Walsh's Bridge was entered into the model and the roughness factors adjusted until a reasonable match against the recorded flood levels was achieved.

Section 6, Figure 6.1 shows the inundation extent resulting from the model and Section 6, Table 6.2 shows the results. Generally the results are acceptable, particularly in Nathalia Township which was the focus of the modelling. Following calibration against the 1993 event the model was verified using the 1974 event.

Flood Mapping

The design flood flows shown in the above table were entered into the calibrated hydraulic model to produce flood inundation maps for each design event. The maps produced are as follows:

- A flood extent, shaded flood depth zones and flood contours for the 5, 10, 20, 50, 100 and 500-year ARI (Average Recurrence Interval) events within town
- A flood extent, shaded flood depth zones and flood contours for the 100-year ARI event of the entire study area.

A flood planning map indicating the extent of Land Subject to Inundation (LSIO) and Floodway Overlays (FO) was also prepared.

Risk Assessment

A detailed risk assessment was undertaken for the township of Nathalia and a Rapid Appraisal Method (RAM) was undertaken for the outer area. From the detailed risk assessment the Average Annual Damages (AAD) calculated for the township of Nathalia was $508,000 (in round terms). From the RAM the AAD calculated for the outer study area is $1,524,000.

Floodplain Management Measures

Several floodplain management measures were assessed. A summary of the options assessed and the final recommendations are show in the table below.

Management Option	Objective	Recommended for inclusion in the FMP
Flood Modification Measures		
Raise Levee for the 100-year ARI (Option1)	Protect town	Yes
Raise Levee for 100-year ARI (Option 2)	Protect town	No
Open up northern floodway by removing the levees on both the left and right banks between the old railway bridge and Drain 13 (Option 3)	Protect town	No (see option 5)
Open up northern floodway by placing a 50m siphon on the farm channel to the north of the show grounds, lower the east-west road by 0.3m over 50m between Allotments 4B and 4K and reconstruction of the irrigation layout in Allotment 4B. Open up the western floodway by including a 50m siphon for Channel 38/12 adjacent to Chinamans weir (Option 4)	Protect town	No (see option 5)
Option 3 and 4 combined (Option 5)	Protect town	No
Construct an overflow channel to the south east of town directing flow from the Broken Creek into the Broken River system (Option 6)	Protect town	No
Open up the southern floodway by placing a 100m siphon on channel 38/12 (Option 7)	Protect town	No
Option 3, 4 and 7 combined (Option 8)	Protect town	No

Management Option	Objective	Recommended for inclusion in the FMP
Remove the railway embankment between north of town located within the northern floodway (Option 9)	Protect town	No
Property Modification Measures		
New flood maps	Show level of flooding and therefore development controls applying to property	Yes
Land Use Zoning	Ensures consistent, equitable, and compatible land management within flood prone areas.	Yes
Voluntary Purchase	Removes development and people from high hazard areas	No
House Raising	Raises development above flood planning levels in flood affected areas	No
Flood Proofing	Minimises the potential impacts of flooding	No
Response Modification Measures		
Flood Warning	Enable and persuade the community to take the appropriate actions to increase safety and reduce the damages associated with flooding	Yes
Community Awareness & Preparedness	Ensure that the community is fully aware that floods are likely to interfere with normal activities in the floodplain	Yes
Emergency Plans	Provide a sound basis for planning, preparation, response and recovery activities by VICSES and other emergency service providers during flood event The flood inundation maps devised as part of this report should be incorporated The access during flood should be addressed with the Murray Valley Highway inundated during significant events and the town is isolated	Yes

Discussion of Preferred Structural Mitigation Scheme for Nathalia Township

During a 100-year ARI type flood, the township of Nathalia is vulnerable to flooding for long periods of time, likely to be more than ten days. The level of over the floor flooding is extensive with more 80% of the buildings affected including dwelling, retail, office, commercial and industrial buildings.

Ideally, opening up floodways is desirable as it lowers the flood height. Hydraulic analysis has however shown small reduction in flood height outside the town levees, leaving the town still vulnerable to flooding during a repeat of a 100-year ARI type flood.

All options, except the levee treatment to the 100-year ARI standard, would require floor levels to be set 300mm above flood level within town, which would mean finished floor heights would be some 900 to1,200mm above ground. Also, subdivision would be prohibited with floodway areas as defined under the Victoria Planning Provisions.

Initially levees with 600mm freeboard above the 100-year ARI flood height were considered. To raise the levees with this amount of freeboard would raise concerns from the community. The previous refusal by sections of the residents to accept the visual intrusion caused by the levees, even at the existing height, resulted in the absence of any levee in sections of Weir Street, indicates that increasing the existing levee height to provide 600mm freeboard over significant lengths is likely to be strongly opposed.

There are sections of the levee system which are not obstructing the creek view from any residences, including the majority of levee 3 and short sections of levees 1 and 2. These sections could be raised as an earthen bank, with the remaining levee provided by a different solution. The Goulburn Broken Catchment Management Authority has advised, given the nature of flood flows, the freeboard could be reduced to 300mm if the existing levee is structurally capped or similar.

The recreational structural treatment of providing a 1.2m wide shared foot/bike path along the majority of the levee would provide sufficient 300mm freeboard above the 100-year ARI flood height. This in turn would offer protection to the planning and building standard, but must be complimented with awareness, flood warning, and alerting programs. The existing levees would generally require raising by 200mm.

At an estimated cost of $1.5 million (including 40% contingencies) this option could be implement over a two year time frame with funding available on an equal basis from Australian, State and Local Governments. The elements of the preferred structure mitigation scheme include:

- temporary barrier system for 500m for Weir Street and Murray Valley Highway;
- provision of recreational 1.2m wide shared concrete foot/bike path along the existing levees for some 4,900m along levees 1 and 2;
- earthen strengthening along 2060m of levee 3 and portion of levee 2; and
- Lift and extend Levee 1 by 200m.

Discussion of Non-Structural Mitigation Options Recommended

The recommended non-structural options to be implemented into the Nathalia Floodplain Management Plan are as follows.

Planning Scheme Amendment

- It is recommended that the Moira Shire Council amend its planning scheme to include the revisions to the planning zones and overlays.
- It is recommended that the Moira Shire Council and the Goulburn Broken Catchment Management Authority adopt the 100-year ARI flood levels shown on the inundation maps.

Flood Warning Arrangements

It is recommended that the Bureau of Meteorology continue to provide flood warning for Nathalia with the following trigger levels at Walsh's Bridge are included:

- Minor: 1.5m
- Moderate: 2.58m
- Major: 3.34m

The recommendations for the warning process are:

- Undertake a calibration of the Casey Weir gauge during a large flow event.
- Replace existing flood level boards at Walsh's Bridge and Nathalia with a single flood level gauge. Also places the flood boards downstream of Walsh's Bridge.
- Add a telemetry (ERTS) stream gauge and link to the Bureau of Meteorology at the following sites:
    - Broken Creek at Nathalia (optional)
    - Broken Creek at Walsh's Bridge
    - Broken Creek and Katamatite (streamflow and rain gauges already operating)
    - Boosey Creek at Tungamah (streamflow and rain gauges already operating)
- Telephone alerting arrangements to communicate impending floods to the affected community (Expedite System as used for Benalla and Shepparton-Mooroopna).
- Develop and prepare flood education information and community flood response guidelines.

Dissemination of Flood Warning

In general the flood warning dissemination detailed in the Moira Shire Flood Sub-Plan is adequate. However, it is recommended that dissemination channels are made clearer, perhaps with a diagram detailing the steps undertaken and the ways that the message is to be delivered to the community.

Also there is considerable dependence on telephone landlines or mobile coverage for the successful passage of information and directions. Many components of the telephone system are subject to flooding or, in the case of overhead lines, breakage during floods. In addition, floods cut normal access routes to many sections, so sound communications links are vital to a successful flood operation. If telephone lines are inoperable and mobile coverage is not available other forms of communication such as radio linkages should be incorporated into the plans.

The Moira Shire may also explore the viability of automatic telephone dialling as an alternative to deliver flood warnings to individual properties. Telephone alerting arrangements to communicate impending floods to the affected community are now in place including the Expedite System as used in Benalla and Shepparton-Mooroopna.

The capital cost for all the above flood warning arrangements would require approximately $60,000 and approximately $5,000 per annum for maintenance costs. In the past funding for flood warning capital has been provided equally by the Australia and State governments with the on-going maintenance provided from the local beneficiaries, via local municipalities or CMAs. Note Nathalia gauge would require additional capital of $17,000 and $2,500 for annual maintenance.

Flood Response

The flood inundation maps for emergency response, should be incorporated into the Moira Shire Flood Sub-Plan (2002).

Also the Moira Shire Sub-Flood Plan (2002) details three local VICSES units within the Moira Shire, Yarrawonga, Cobram and Numurkah. The plan for Nathalia should state which unit is the first point of contact for Nathalia and where the office which co-ordinates activities for Nathalia is located. If a site is established for use in Nathalia it is important that an alternative location is established outside of town if the levees become overtopped and the town is inundated.

Access to and from Nathalia during a large flood should also be addressed in the Moira Flood Sub-Plan (2002). The main access road to Nathalia, the Murray Valley Highway, is inundated during a significant flood.

Access during floods is not only by roads. Consideration should be given in the emergency planning activity to where boats can be launched or berthed in quiet floodwaters. This approach should be considered as a last resort due to the risks involved in operating boats during floods. Development planning should also consider where helicopters could safely land in flood time.

Access also covers the continued operation of essential services, e.g. water supply, sewerage and power. The need to be able to shut down critical facilities, such as pump stations, by physical presence at the site, or by remote control is a flood access issue that must be included in flood plans.

Community Awareness and Preparedness

It is recommended that the Moira Shire in conjunction with the VICSES and the GBCMA develop a program to increase community awareness of existing flood risks, flood emergency response and flood warning arrangements. The program should at least outline contact phone numbers, context of local flooding issues, flood warning arrangements and tips for reducing damage and enhancing safety.

Flood Recovery

The location of evacuation centres and how well they are fitted out to cater for relatively large numbers of people of all ages is an essential item to be addressed in the Moira Shire Sub-Flood Plan (2002) for Nathalia. It is essential that these centres are above all risk of flooding which for Nathalia is out of town.

The importance of such centres, and the community's knowledge of their existence, cannot be overstressed. It is essential that the Moira Shire Sub-Flood Plan (2002) clearly establishes the location of evacuation centres, what facilities they have and what and where are alternative sites in the event of either overcrowding or threat of greater depths of flooding.

The sites should be chosen on the basis of:

- the available space for short term sleeping accommodation;
- the available space for storage of belongings;
- the capacity of the site to supply sufficient hygiene facilities; and
- the capacity of the site to service the food and beverage requirements of the evacuees.

1 Introduction

The purpose of the study was to prepare a Floodplain Management Plan for Nathalia taking into account its surrounding environs. The Floodplain Management Plan includes the preparation of Flood Inundation Maps for the study area for emergency purposes, flood overlays for planning purposes, recommendations for flood awareness and warning, and a preferred structural mitigation scheme.

The preparation of a Floodplain Management Plan for Nathalia was an outcome of the Broken Creek strategy report, which recognised Nathalia as a Number 1 priority. Furthermore Nathalia was recognised as a high priority under the Draft Regional Floodplain Management Strategy for the Goulburn Broken Catchment Management District.

This report details the scope and finding of the investigation undertaken for Nathalia. The investigation was broken into two components, technical investigation and formulation of a Floodplain Management Plan. Detailed below is a break down of each section of the report.

Section 2 presents details on the topographical details of the catchment under investigation.

Section 3 outlines the data gathered to undertake the investigation.

Section 4 details the survey that was undertaken during the course of the study.

Section 5 and 6 layout the hydrological and hydraulic analyses that was undertaken to assess and quantify the flood risks.

Section 7 details the process undertaken to produce the flood inundation maps.

Section 8 and 9 provides details of the risk assessment undertaken.

Section 10 outlines the treatment of risks and Section 11 is a detailed assessment of the mitigation options.

Section 12 outlines the flood effects from the gauge height.

Section 13 details the community consultation process undertaken.

Recommendations and conclusions of the study are presented in Section 14 and 15.

2 Description of Catchment

The town of Nathalia is located on the lower reaches of the Broken Creek, about 25km east of Barmah where the Broken Creek joins the Murray River. The catchment area of Broken Creek is about 3,450km^2. The catchment boundary to the north runs from Yarrawonga to Barmah, the Warby Ranges near the Ovens River define the catchment in the east and the catchment divide to the south runs just north of Lake Mokoan, Casey Weir, Orrvale and Shepparton. The Western boundary runs north of the Goulburn River from Shepparton to Barmah. The catchment area is difficult to define due partly to the flat nature of the topography for much of the catchment and partly due to overflows from the adjoining catchments. Overflows particularly occur to the south where during a large flood event on the Broken River water overflows into the Broken Creek catchment. In “natural” conditions transfer of floodwaters across catchment boundaries from the Murray River to the north and from the Goulburn River system to the west is also possible. Many of these overflow paths have been blocked by infrastructure (levees, irrigation channel, roads etc.). Figure 2.1 shows the catchment area.

As mentioned, the topography of the Broken Creek catchment is generally flat with the exception of Mount Major in the south west (near Dookie) and Mount Bruno and Mount Warby in the Warby Ranges in the east. In the flat areas, the elevation may only change by approximately 1m per 1,500m. The flat grade results in low flow velocities in the creek and its tributaries and widespread flooding of adjacent areas in major floods.

There are a number of temporary “lakes” in the Broken Creek catchment that fill at times of major floods and retard the flood flows. An example of this is near Walsh’s Bridge where the natural levees of an ancestral river that runs from the Goulburn River to the Broken Creek constrict the wide upstream floodplain into a narrow neck. A similar feature is also located west of Katamatite (SRWSC, 1978). During the 1993 flood event, flow records at Walsh’s Bridge indicate that flow was retarded at this location.

Flooding on the Broken Creek catchment is complex. The two largest flood events recorded at Nathalia in recent history, describe the nature of flooding in the catchment. In 1993 more of the flood flow at Nathalia was derived from the breakaway flows from the Broken River which arrived down Pine Lodge Creek, Congupna Creek and the Broken Creek. The locations of these breakouts are shown in Figure 2.1.

In 1974, more of the flow was reported to have derived from the upper Broken Creek catchment passing down Boosey Creek, an anabranch of the Broken Creek, through Tungamah. These two floods resulted in approximately the same flow being recorded at Nathalia of 115m^3/s (10,000 ML/d). During the 1974 flood it was reported that parts of the township of Nathalia were flooded. Following that event a flood study was undertaken to determine the nature of flooding in Nathalia and to identify appropriate flood mitigation options. As a result of the recommendations of that study a levee and floodway system was constructed. During the 1993 flood these works protected the township of Nathalia from extensive flooding. In the last 90 years there have been other flood events in the Broken Creek catchment namely 1916, 1939 and 1995. Flood photos of the 1916 event show that there was extensive flooding within the town.

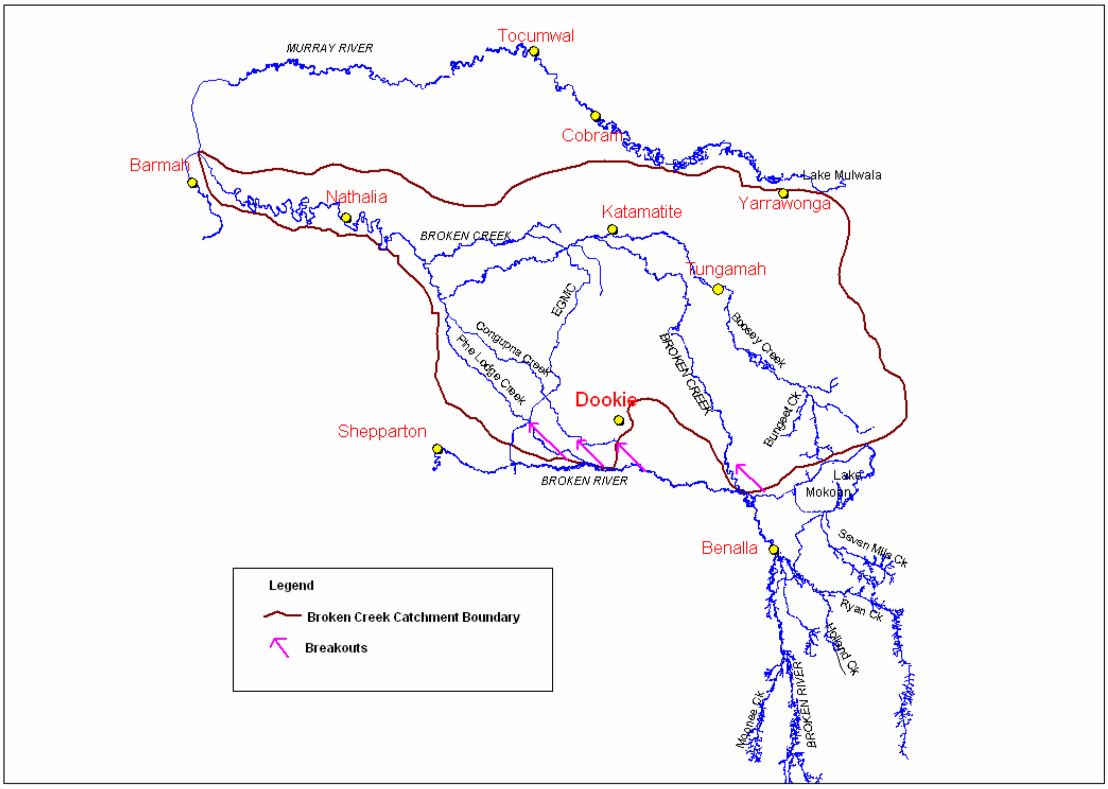

Figure 2.1: Broken Creek catchment and location of main breakouts from the Broken River catchment

Most of the land in the catchment is used for farming. There is a number of irrigation channels located through out the catchment. Water is supplied south of Broken Creek from Goulburn Weir via the East Goulburn Main Channel (EGMC) and north of Broken Creek from Yarrawonga Weir. Water from the EGMC discharges to the Broken Creek and Nine Mile Creek at Katandra Weir. There is limited transfer of water for water supply purposes from the weirs on the Broken River at Casey Weir near Benalla and at Gowangardie.

3 Information Available

3.1 General

Table 3.1 records the main sources of information that have been used throughout the study.

Table 3.1: Main sources of data used in investigation

No.	Name of Documents	Sources
1	Digital and Cadastral Information of Nathalia and Surrounds	Moira Shire Council
2	Nathalia Sewerage Contour Plans	GBCMA, GVW
3	Numerous Flood Photography covering the 1993 flood and others available	GBCMA
4	SR&WSC Broken Creek Flood Photography, August 1981	GBCMA
5	SR&WSC Nathalia – Barmah Forest, Broken Creek Flood Photography, August 1981	GBCMA
6	SR&WSC Broken Creek – Numurkah Area 70mm, May 1974	GBCMA
7	SR&WSC Broken Creek Flood Photography, May 1974	GBCMA
8	Flood Data Transfer Project (DNRE, 2000)	LICS
9	1993 Flood Level Reconnaissance (GBCMA, 2001)	LICS
10	Broken Creek Management Strategy – Volumes 1 and 2 (SKM, 1998)	SKM
11	Nathalia Audit Report (Findlay Consulting, 1997)	GBCMA
12	Documentation and Review of 1993 Victorian Floods: Volume 1: Flood Summary Report (HydroTechnology, 1995a).	GBCMA
13	Documentation and Review of 1993 Victorian Floods. Volume 4: Broken River Catchment Floods October1993 (HydroTechnology, 1995b).	GBCMA
14	Nathalia Flood Mitigation Report (SR&WSC, 1978).	GBCMA
15	Shepparton-Mooroopna Floodplain Management Study – Draft Hydrology Report (SKM, 2000)	SKM
16	Streamflow Data	Thiess Environmental
17	Topographic Maps	GBCMA
18	Rainfall Data	Bureau of Meteorology
19	LIDAR Data	GBCMA
20	Response from Community	Community
21	Survey of floor levels, levees, bridges and channel	LICS
22	Property evaluation	Hann McKenzie Valuers

Notes:
GBCMA = Goulburn Broken Catchment Management Authority

GVW = Goulburn Valley Water

SR&WSC = State Rivers and Water Supply Committee

SKM = Sinclair Knight Merz

3.2 HYDROLOGICAL DATA

The following section details the information used in the hydrological assessment.

Daily Rainfall Data

Daily rainfall data was used to derive spatial patterns during calibration events. The daily data is that recorded at 9:00am each day. All daily rainfall data was provided by the Bureau of Meteorology.

Figure 3.1 shows the locations of all available rainfall daily gauges in and around the Broken River catchment.

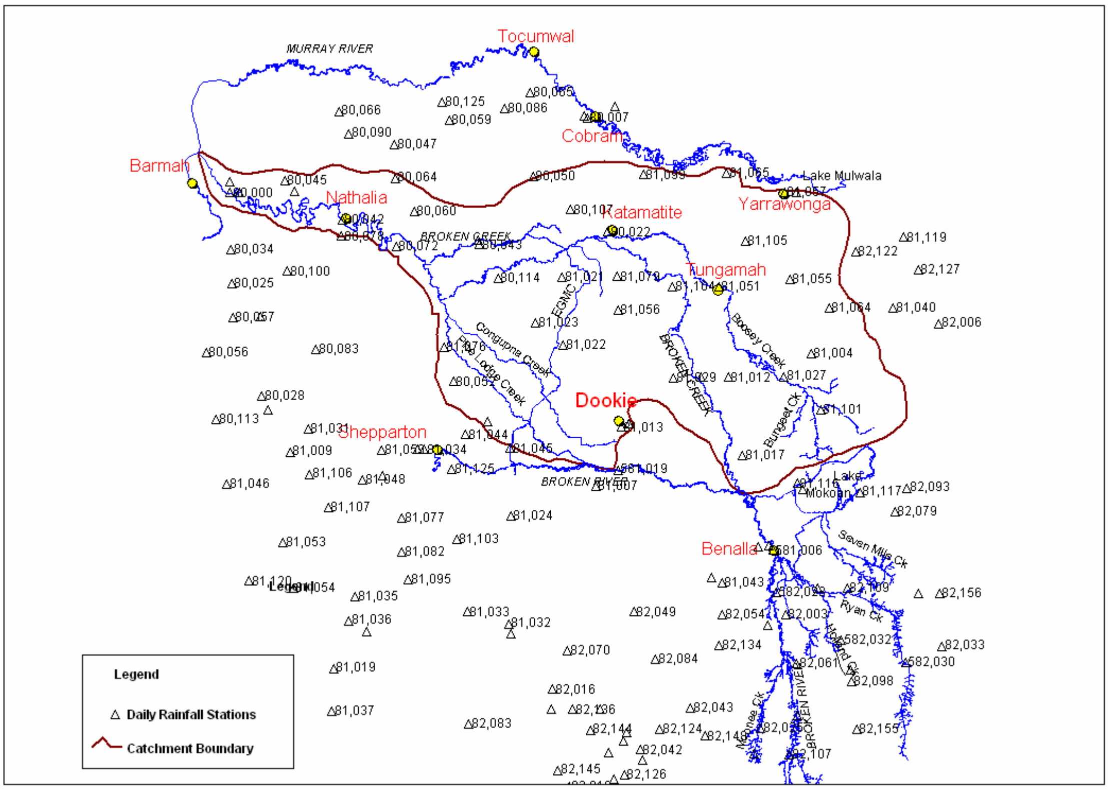

Figure 3.1: Location of daily rainfall stations in and around the Broken Creek catchment

Table 3.2: Details of daily rainfall stations with more than 50 years of data in and around the Broken Creek and Broken River catchments.

Number	Station name	Latitude	Longitude	Start date	End date	Record length (yrs)
80000	Barmah East	36.017	145.000	1887	1975	88
80007	Cobram Post Office	35.916	145.650	1888	1995	107
80022	Katamatite	36.083	145.683	1899	1982	83
80034	Madowla Park	36.100	145.000	1886	1954	68
80042	Nathalia (Post Office)	36.061	145.202	1887	2002	115
80043	Numurkah Post Office	36.100	145.450	1885	1984	99
80045	Picola	36.000	145.100	1903	1963	60
80059	Strathmerton (Woodlea)	35.917	145.400	1921	1976	55
80065	Yarroweyah	35.876	145.546	1890	2002	112
80066	Yielima Post Office	35.900	145.200	1885	1965	80
80072	Kaarimba	36.100	145.300	1867	1918	51
81004	Lake Rowan (Bungeet)	36.267	146.050	1887	1974	87
81007	Caniambo	36.458	145.656	1903	2002	99
81012	Devenish	36.300	145.900	1907	1969	62
81013	Dookie Agricultural College	36.371	145.704	1879	2002	123
81017	Goorambat	36.415	145.923	1889	2002	113
81021	Invergordon	36.150	145.600	1897	1990	93
81022	Katandra North	36.250	145.600	1867	1954	87
81023	Katandra West	36.217	145.550	1927	1996	69
81029	Boxwood	36.300	145.800	1884	1963	79
81044	Shepparton RWC	36.378	145.419	1877	1997	120
81051	Tungamah	36.168	145.884	1889	2002	113
81055	Wilby	36.157	146.013	1906	1999	93
81057	Yarrawonga Post Office	36.028	146.004	1879	1993	114
82002	Benalla (Shadforth Street)	36.549	145.969	1882	2002	120
82004	Benalla Sharon	36.667	145.967	1896	1952	56
82025	Lima East	36.817	145.950	1913	1973	60
82043	Strathbogie North	36.787	145.823	1879	2002	123
82054	Warrenbayne (Baddaginnie)	36.650	145.883	1897	1982	85
82061	Swanpool (Tiree)	36.723	146.017	1949	2002	53
82094	Baddaginnie	36.595	145.865	1908	1993	85

Pluviograph Data

Pluviograph data is scarce with only one pluviograph located within the Broken Creek Catchment, namely Dookie Agricultural College (81013). Several others are located around the perimeter of the Broken Creek catchment. These are listed in Table 3.3 and Figure 3.2 shows their locations.

Table 3.3: Details of pluviographs in and around the Broken Creek catchment

Station Number	Station name	Year Started	Year Ended	Record Length (yr)
80109	COBRAM (GOULBURN MURRAY)	1957	2001	44
81013	DOOKIE AGRICULTURAL COLLEGE	1950	2001	51
81049	TATURA INST SUSTAINABLE AG	1960	2001	41
81114	TATURA THEISS ENVIRON SERV	1975	1993	18
82121	OVENS RIVER (WANGARATTA)	1957	1993	36
82138	WANGARATTA AERO	1987	2001	14

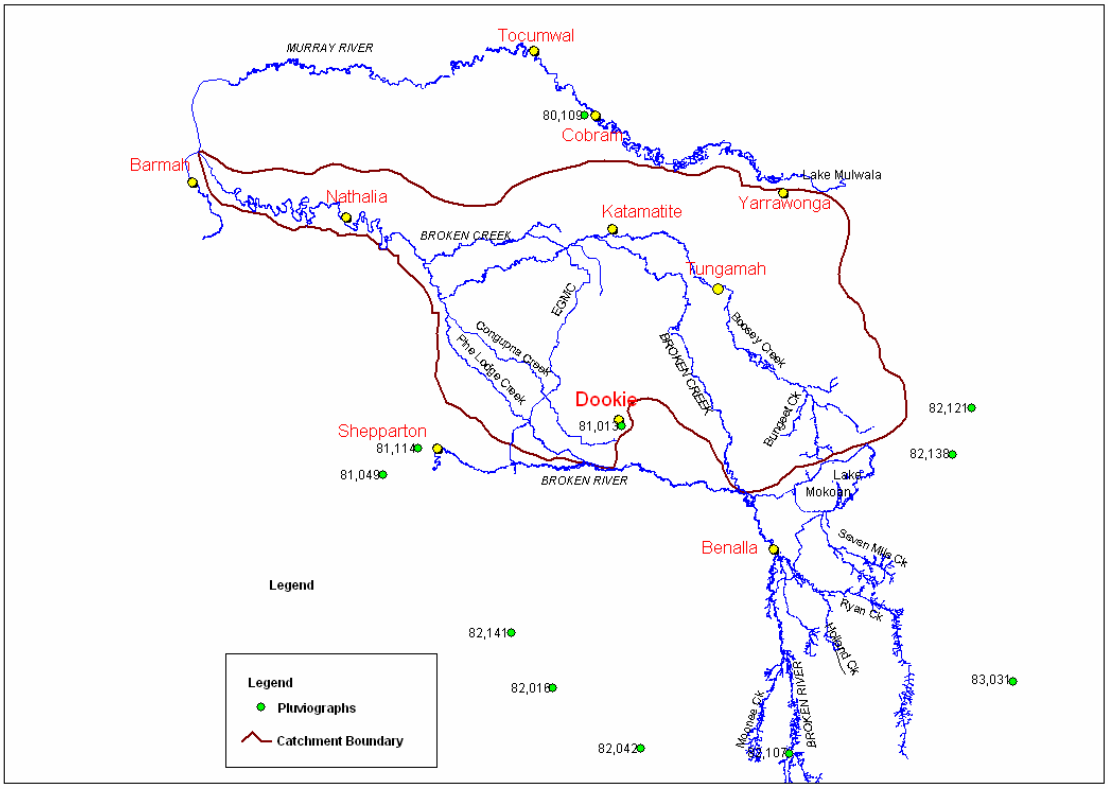

Figure 3.2: Location of Pluviographs in and around the Broken Creek catchment

3.3 STREAM FLOW DATA

Figure 3.3 shows the locations of the stream flow gauging stations. Table 3.4 lists the streamflow gauging stations available.

The streamflow gauging details include the period of continuous streamflow record for each gauge. The continuous period of record is the period of systematic recording of streamflow via a daily read staff gauge or a continuous recorder. For some streamflow gauges, such as Benalla, records are available during some flood events only.

The selection of suitable calibration events was dependant upon the availability of concurrent streamflow and pluviograph records. The two largest flow events available on the Broken Creek were selected for calibration. These were October 1993 and the May 1974 events. It should be noted from Table 3.4 and Figure 3.3 that there is no flow data recorded at or near the Nathalia Township, therefore the flood frequency curve for Nathalia can not be developed directly using an analysis of observed floods such as a flood frequency analysis method.

Table 3.4: General information of flow data for Broken Creek and Broken River catchments

Station No	Station name	Period of Record
404203	Broken River at Benalla	October 1977 to date
404204	Boosey Creek at Tungamah	November 1917 – August 1929 November 1966 to date
404210	Broken Creek at Rices Weir (near Barmah)	February 1965 to date
404214	Broken Creek at Katamatite	July 1966 to date
404215	Boosey Creek at Lake Rowan	July 1975 – January 1977
404216	Broken River at Goorambat (Casey Weir Head Gauge)	February 1888 to June 1916 July 1979 to date
404217	Broken Creek (channel) at Casey Weir (near Goorambat)	February 1888 to date
404200	Broken River at Goorambat (Casey Weir Tail Gauge)	July 1916 to June 1979
404222	Broken River at Orrvale	June 1977 to 1993
404224	Broken River at Gowangardie Weir	January 1991 to date

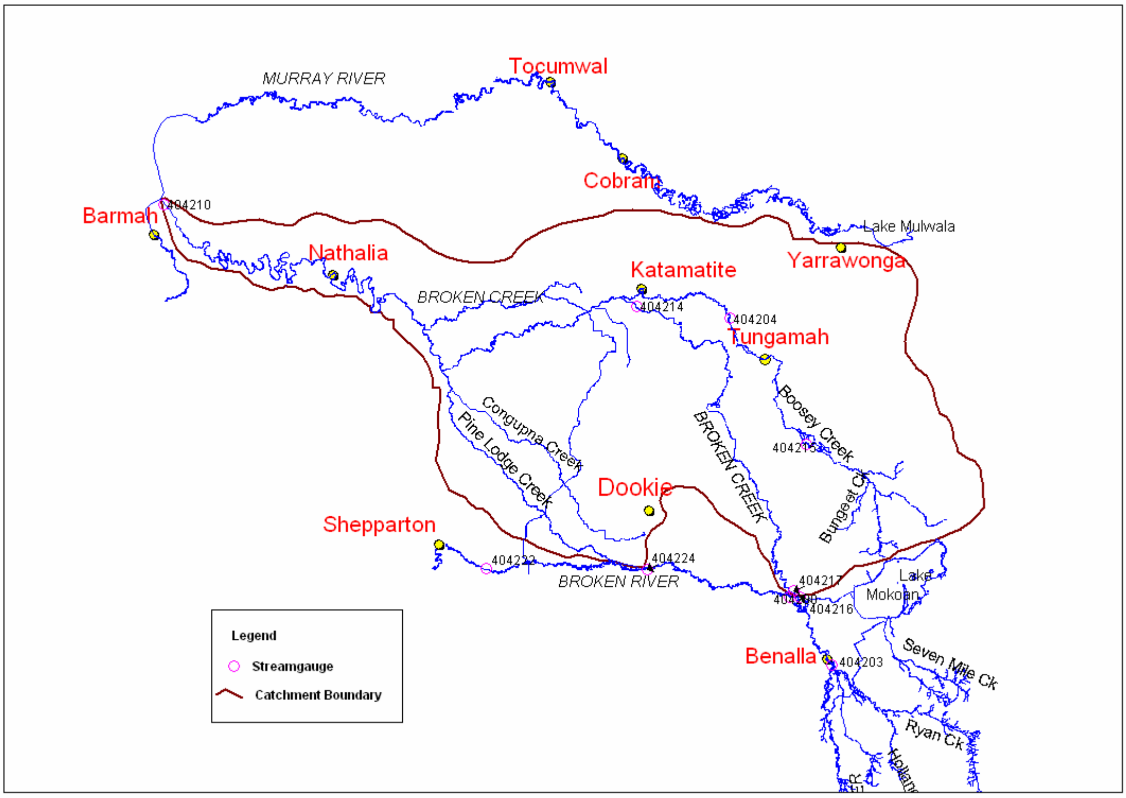

Figure 3.3: Location of Streamgauges in and around the Broken Creek catchment

Figure 3.4 and 3.5 show the hydrographs available for the October 1993 event. Figure 3.4 shows the hydrographs on the Broken River and Figure 3.5 shows the hydrographs on the Broken Creek. The hydrograph shown at Casey Weir (404216) on the Broken River is that supplied by Thiess. The rating table used for Casey Weir is extrapolated for flows higher than 336m^3/s (29,000 ML/d). Analysis by others has shown that the inaccuracies in high flows at Casey's Weir has an impact on the design peak flow estimates. SMEC as part of this study undertook an assessment of breakout flows at Casey Weir which is described later in Section 5. The hydrographs shown in Figure 3.5 at Walsh's Bridge, Pine Lodge Creek and Congupna Creek were measured during the 1993 event.

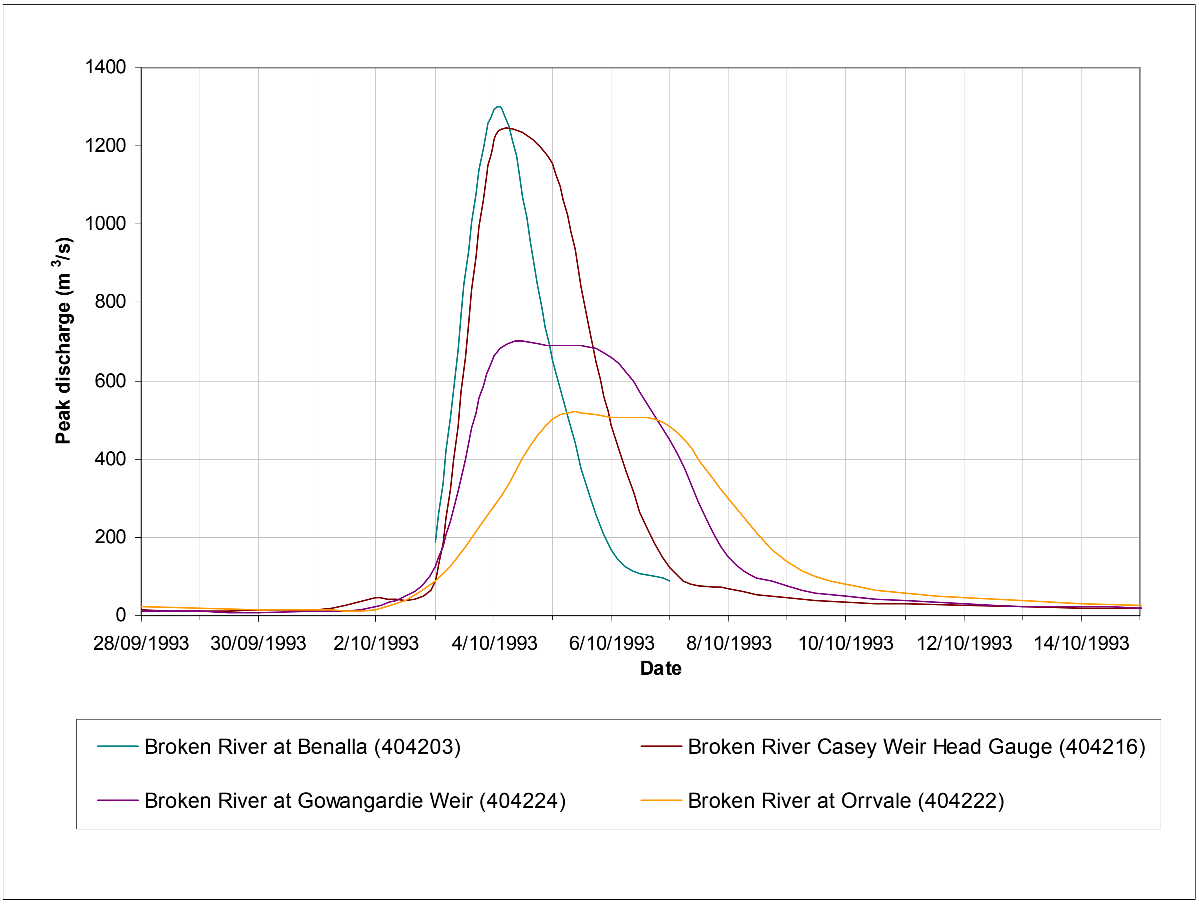

Figure 3.4: Hydrographs at various gauging stations along Broken River for the flood of October 1993

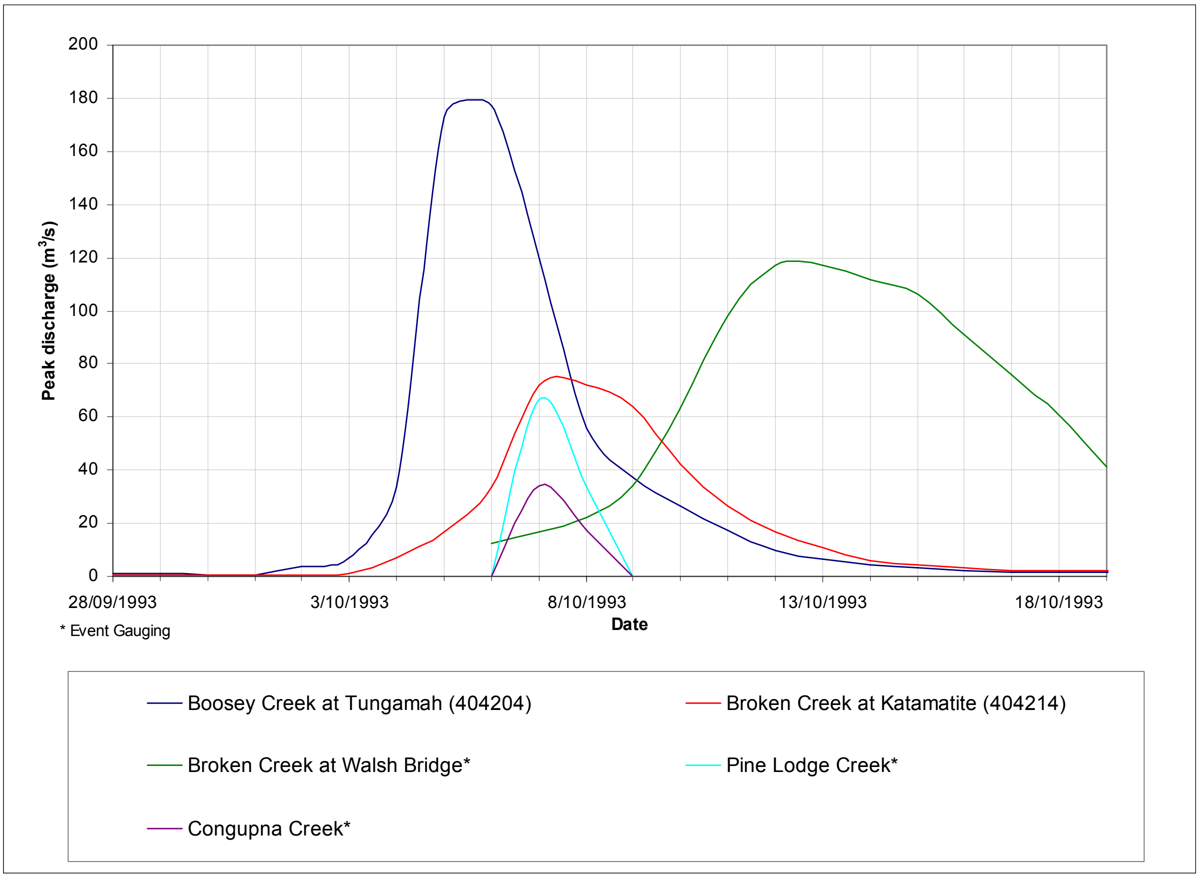

Figure 3.5: Hydrographs at various gauging stations along Broken Creek for the flood of October 1993

Benalla (404223) is a continuous recording station with data extracted on request i.e. during a flood event. The station is a height recorder and the highest stage with a rating of 1 (good continuous records) is 5.6m with the flow rating defined as good up to this point as well. The rating curve is extrapolated up to 5.9m.

In 1993 the peak level reached was 5.503m however, the last point recorded on the rising limb was 5.079m (05:00 4th October) and the gauge came back on line at 2.93m (19:00 6th October). For this period the data is quality coded 104 (records estimated) which refers to the stage data, which was lost and later levelled from debris.

Casey Weir (404216) is a continuous recording station with the highest point with a good quality code of 1 being 2.4m. The maximum gauge height the rating goes up to is 5.0m with a flow of 153,000 ML/d and a quality code of 150 (Rating extrapolated due to insufficient gauging).

In 1993 the peak level reached was 4.260m however; the last point recorded on the rising limb was approximately 3.3m (08:58 4th October) and the gauge came back on line at approximately 3.2m (17:29 5th October). For this period the stage was quality coded 104 (records estimated), while the rating table for these heights has a quality code of 150. Notes on the traces indicate that between these times the estimated trace was based on the hydrograph from Benalla Sewerage Farm upstream and the time of the peak was estimated from Broken Creek at Casey's Weir.

This information suggests that for both gauges some form of estimation was undertaken for the 1993 event. There does appear to be slightly more confidence in the rating curve for Benalla.

Figure 3.6 and Figure 3.7 shows the hydrographs for the May 1974 event. Figure 3.6 shows the hydrograph on the Broken River and Figure 3.7 shows the hydrograph on the Broken Creek. The amount of flow information available for the 1974 flood event is a lot less than during 1993. As a result the 1974 event was used to “verify” the calibration of the hydrological model using the 1993 event calibration parameters.

The hydrograph shown at Walsh’s Bridge in Figure 3.7 was derived using the hydraulic model, flood levels recorded during the event and the peak flow measured at Nathalia (discussed in section 6).

A hydrograph was not available at Tungamah (404204) or Katamatite (404214) but a peak flow of 220m^3/s (19,000 ML/d) and 85m^3/s (7,300 ML/d) was recorded at each of these stations respectively.

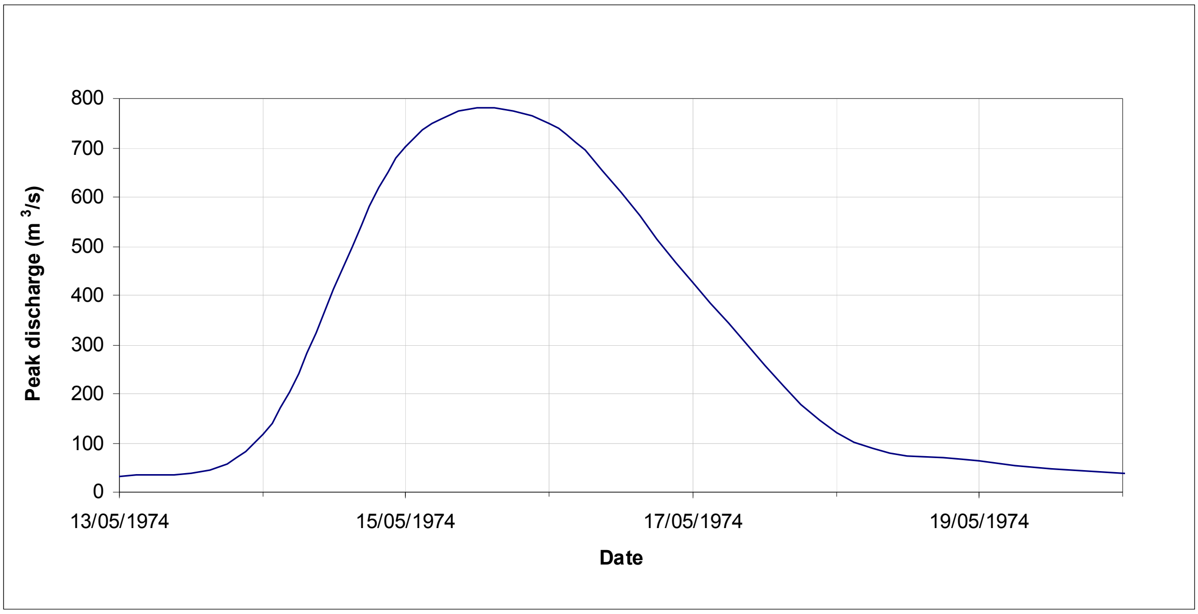

Figure 3.6: Hydrograph Supplied by Thiess at Casey Weir on the Broken River for the flood of May 1974

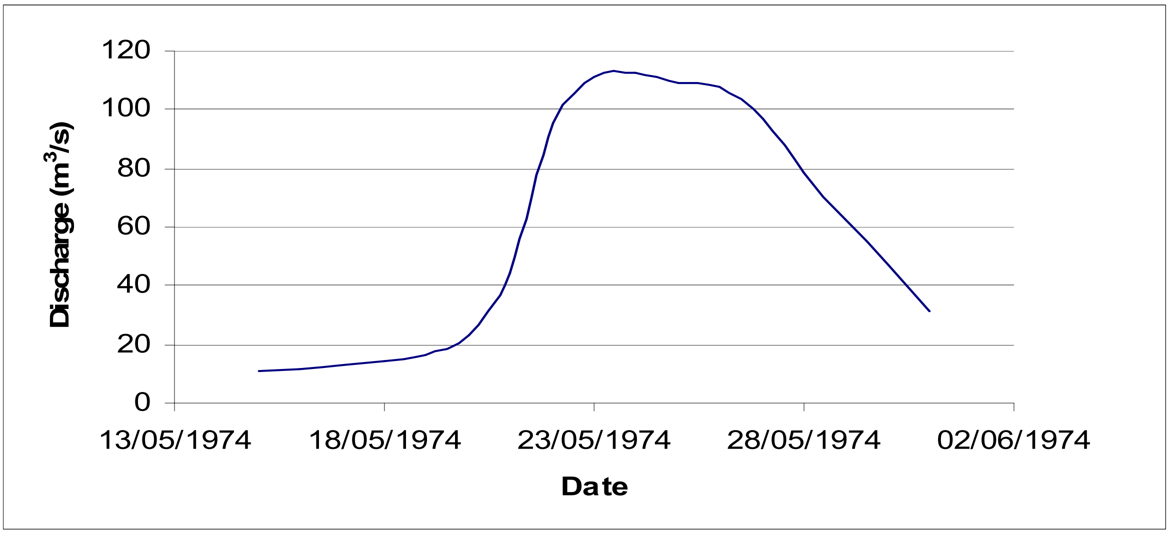

Figure 3.7: Hydrograph Derived at Walsh’s Bridge along Broken Creek for the flood of May 1974

3.4 Hydraulic Data

The data used in the hydraulic analysis included:

- Aerial photographs of the 1993 flood event taken as part of the DCNE 1995 report.
- Topographic maps of the study area.
- The 1993 flood level recognisance undertaken by LICS for GBCMA. For the study area there were also some 1974 flood levels surveyed. Figure 3.8 shows the location of the flood levels.
- LIDAR data. The vertical accuracy of this data was 0.15m and horizontally the accuracy was 1.0m.
- A survey of weirs and bridges. This was supplemented with data supplied by G-MW on the weirs.
- A survey was undertaken detailing key levees/channel/roads in the outer study area.
- The levee audit report undertaken for the Nathalia flood mitigation scheme. In this report the levees in and around Nathalia township were surveyed.

3.5 Flood Damage Assessment

The data used in the flood damage assessment included:

- Survey of floor levels in Nathalia
- Property evaluation
- Previous flood studies.

4 Survey

Throughout the project there has been three separate field surveys undertaken. These have been:

- Survey of weirs and bridges along the Broken Creek within the study area
- Cross sections around Casey Weir
- Survey of levees, channels and roads within the study area. At the same time a survey of floor levels within town was undertaken.

The location of the survey undertaken is shown in Appendix A

5 Hydrological Analysis

5.1 Overview

The approach and techniques used to assess the hydrology of the Broken Creek catchment and in particular its impacts at Nathalia is important as there is little gauged flow data from which to determine the flood frequency. It was important to agree on the technical approach that was to be adopted. The methodology undertaken for this hydrological study follows the reported methodology outlined in the discussion paper presented to and agreed by the Technical Steering Committee at the meeting on the 19th September 2002.

As detailed in Section 3.3, there is virtually no flow data available at or near Nathalia from which a flooding frequency at Nathalia can be reliably assessed. Therefore the design hydrograph at Nathalia must be estimated from design rainfall event simulation.

The preferred method for determining the flood frequency curve is to base the estimation of the design hydrographs from design rainfall. Design rainfall depths have been developed by the Bureau of Meteorology and form part of Australian Rainfall and Runoff (IEAust, 1997a). The design rainfall must then be converted to a flow rate at Nathalia taking into account the diverse runoff and streamflow characteristics across the catchment. This can be achieved through using a rainfall runoff routing program such as RAFTS (1994). The rainfall runoff model is then able to provide a design hydrograph for each ARI of interest at Nathalia. These hydrographs are then used as an input to a hydraulic model to provide the extent of flooding for each ARI of interest. The extent of flooding will be a key output for understanding the impacts of flooding at Nathalia.

For larger events flooding at Nathalia can be impacted on by breakout flows from the Broken River. In 1993 flows were reported to break out of the Broken River to the Broken Creek at Casey Weir and between Orrvale and Gowangardie. The magnitude of these breakouts was investigated by SMEC.

5.2 Breakout Flow Estimation

5.2.1 Correlation of Flows between the Broken Creek and Broken River Catchments

Obtaining design rainfall is generally straight forward as it is taken from Australian Rainfall and Runoff (IEAust, 1997a), with Cooperative Research Centre for Catchment Hydrology (CRCCH) areal reduction factors (Siriwadena et al, 1996). For Nathalia, the situation is more complex as flows from the adjoining Broken River catchment has, on occasions, broken across into the Broken Creek catchment. Consequently the magnitude and volume of these flows must also be estimated. The break out flows is dependent on the magnitude of the Broken River flows. A relationship between the Broken River and the Broken Creek catchment would normally be estimated using stream flow gauging information on the catchments. This data is not available so an alternative approach was established. Initially it was the assumed that these flows are dependent on the rainfall over the Broken River catchment. The key to estimating the break out flows is to understand what rainfall could be expected on the Broken River catchment when there is rainfall on the Broken Creek catchment. To estimate this SMEC assessed the correlation between rainfall stations in the headwaters of the Broken River and Broken Creek catchments (Appendix B).

The problem with establishing a correlation between rainfall stations is that storms by nature randomly traverse across an area such that if a rain gauge is sited in the storms path it may record a large amount of rainfall, but if it is not it may record very little rainfall even though the gauge may not be far away. The random nature of a storms path varies from storm to storm. This makes correlating between rainfall stations difficult and therefore it is not surprising that at best SMEC achieved a correlation between the Broken River and Broken Creek rain gauges of 0.54. The methodology adopted was agreed to by the Technical Steering Committee (TSC) on 19th September 2002 with the acknowledgement that further analysis would be costly and unlikely provide greater accuracy.

Following the rain gauge assessment SMEC and the TSC decided to adopt a sensitivity analysis approach to ascertain what impact the breakout flows have on flows at Nathalia. Initially the RAFTS model was run with the medium value for breakouts from the rainfall correlation relationship. For a 100-year ARI event in the Broken Creek this corresponded to a 30-year ARI event in the Broken River. The RAFTS model was then run for each ARI event with a breakout ARI of plus 15 years, which corresponds to a 95% confidence interval from the rainfall correlation relationship. The 1993 flood event contradicts the medium value for breakouts from the rainfall correlation i.e. a larger event occurred on the Broken River than on the Broken Creek resulting in the same flow at Nathalia. SMEC ran the RAFTS model with a 50-year ARI event on Broken Creek and a 100-year ARI event on the Broken River to ascertain what impact that had on flows at Nathalia.

The sensitivity analysis on the breakout flows are presented and discussed in section 5.5 below.

5.2.2 Modelling Breakout from the Broken River Catchment

For the modelling of breakout flows from the Broken River in the Broken Creek, design hydrographs at the break out locations were determined. This was achieved by relating the peaks and volumes from observed historic floods for various flood magnitudes using quantile estimation.

There are two main locations for breakouts from the Broken River into the Broken Creek catchment. The first is at Casey Weir, which is approximately 10km downstream from Benalla. The second is between Gowangardie and Orrvale. Flows which enter from Casey Weir enter the headwaters of Broken Creek and are reasonably well defined. In contrast, the second location between Gowangardie and Orrvale (refer to Figure 2.1 and 3.3) is less defined with water entering a number of small creeks prior to joining Nine Mile Creek which joins Broken Creek approximately 5km upstream of Walsh's Bridge.

5.2.3 Casey Weir Breakout Relationship

As mentioned in Section 3 there is a significant amount of data recorded at Casey Weir however, this data has a high degree of uncertainty associated with higher flows which introduces additional uncertainty into the estimates of the breakouts from the Broken River at this location.

In an attempt to reduce the uncertainty in the estimation of breakouts from the Broken River at Casey Weir, SMEC undertook a hydraulic analysis. To aid this analysis cross sectional information of the river and floodplain in the vicinity of Casey weir was obtained.

Under "normal" conditions, a relatively small flow can enter the Broken Creek system at Casey Weir through a diversion channel. In a large flood, on the Broken River, such as the 1993 event, flows can also enter the Broken Creek at a point approximately 2km downstream of Casey Weir. Breakouts from the Broken River occur when flood flows two kilometres downstream of Casey Weir are higher than the Midland Highway, which divides the Broken Creek and Broken River at that point.

As mentioned previously, there is a high degree of uncertainty associated with higher flows passing over Casey Weir. To estimate the breakout flows into the Broken Creek catchment and eliminate the problem of using the Casey Weir rating curve a relationship between the recorded levels at Casey Weir and the discharge into the Broken Creek system was established.

A relationship between levels at Casey Weir and discharge into the Broken Creek was assisted by the use of HECRAS. A HECRAS model was set up using the surveyed cross sections. Initially a HECRAS model of the Broken Creek channel only was set up. It was assumed that the level upstream of Casey Weir was the same across the entire weir. Using the HECRAS model an elevation discharge relationship between the Casey Weir Head Gauge and flow in the Broken Creek channel was calculated assuming no cross over flow from the Broken River catchment.

To determine the amount of flow that broke out across the Midland Highway from the Broken River into the Broken Creek a relationship was established. The level at which flow breaks out over the Midland Highway into the Broken Creek was determined from the survey to be approximately 158.3mAHD. As water in the Broken River rises to this level the road was assumed to act as a broad crested weir. From the survey an elevation discharge relationship over the road was calculated.

Next the two relationships needed to be tied together. This is complicated by the fact that the water slope along the Broken River will change over the course of a flood event. If it was assumed that the water slope between the Casey Weir head gauge and the point approximately 2km downstream on the Broken River where water breaks out, is the same throughout the entire event as it is at the peak of the flood, this could result in an over estimation of breakout flow. To accommodate for the changing water slope during the event the water slope recorded for the 1993, 1974 and 1981 from HydroTechnology (1995) was analysed. In both 1974 and 1981 flow did not reach a level that would have resulted in significant, if any, breakout flows. As a result the 1993 flood was focused on. From the information available it is not known exactly when the 1993 flood was no longer breaking out into the Broken Creek catchment. From the aerial photographs in the HydroTechnology report (1995) it indicates that flow ceased sometime before 2pm on the 5/10/1993. Using the level at Casey Weir at the peak (161.1mAHD) and the level at 2pm on the 5/10/1993 (160.3mAHD) and the corresponding level at the breakout point a linear relationship was calculated. This relationship was used to estimate the level on the Broken River at the breakout location given a level at the Casey Weir head gauge.

The final complication to establishing a relationship for the breakout flows at Casey Weir is, once water is flowing over the road into the Broken Creek this will decrease the driving head into the Broken Creek until the road is “drowned out”. Once the road is “drowned out” the capacity of the Broken Creek channel dictates the amount of flow that can be carried down the Broken Creek. The capacity of the Broken Creek channel was determined using the HECRAS model mentioned previously.

All these aspects where bought together to establish a relationship for breakout flows between the Broken River and the Broken Creek at Casey Weir. To summarise, the steps undertaken were as follows:

- Initially flow into the Broken Creek is through the diversion channel. This flow was calculated using HECRAS.
- Once water in the Broken River reaches a level of approximately 158.3mAHD water flows across the Midland Highway, this flow was calculated assuming the road acted as a broad crested weir.
- As more water flows across the Midland Highway the levels in the Broken Creek increase reducing the driving head across the Highway. Once the Midland Highway is drowned out the flow that flows into the Broken Creek channel is limited by the capacity of the channel and associated floodplain.

The relationship calculated between the elevation at Casey Weir versus the discharge into the Broken Creek is shown in Figure 5.1.

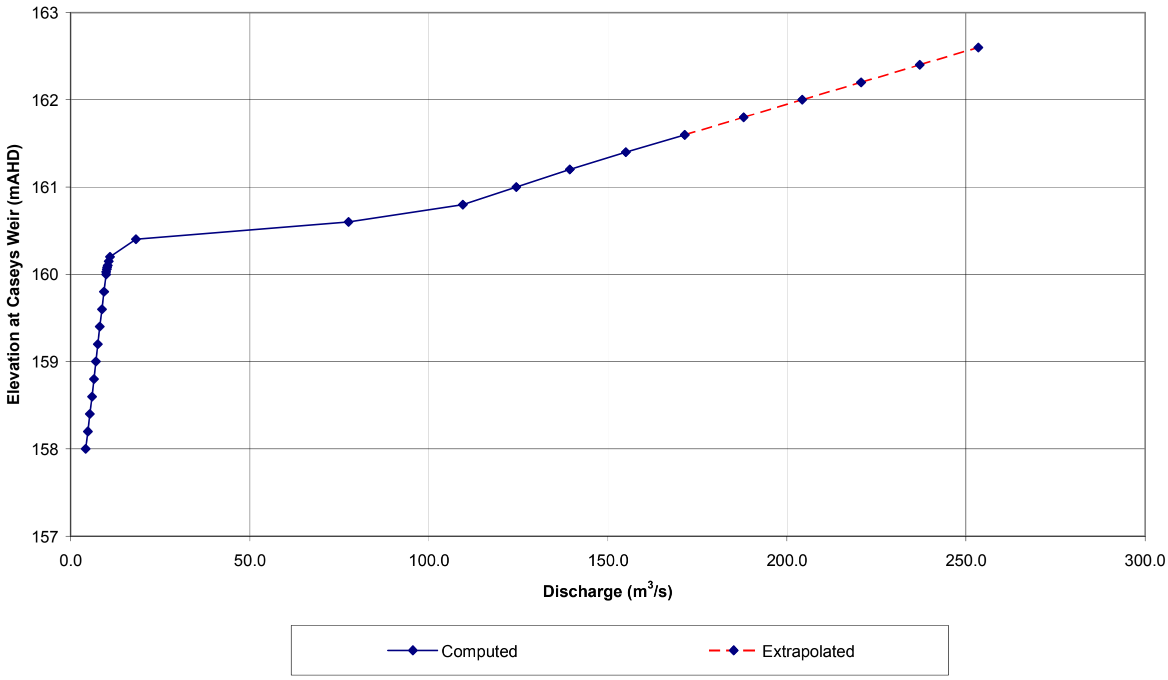

Figure 5.1: Relationship Established for Breakout Flows into the Broken River from the Broken Creek at Casey Weir

Flood Volume Estimation

To produce design hydrographs of breakout flow at Casey Weir the flood magnitudes, calculated using quantile estimation, in the Shepparton-Maroopna flood study (SKM, 2000) were used. The design 5-day volume quantiles calculated in the Shepparton-Mooroopna flood study are presented in Table 5.1

Table 5.1: Five Day Flood Volume Quantiles – Broken River at Casey Weir

ARI (years)	Broken River at Casey Weir 1889 – 1999 (ML)
5	63,600
10	83,200
20	102,000
50	127,000
100	145,000
200	164,000
500	188,000

* Source: SKM (2000)

Flood Flow Estimation

As mentioned previously the flow records at Casey Weir have a high degree of uncertainty associated with higher flows. SKM (2000) placed the 1993 event as a 500-year ARI event at Casey Weir where as the same event was calculated to be about a 100-year ARI event at Benalla. These differences appear to be inconsistent with the expected behaviour of the floodplain and the catchment between Benalla and Casey Weir. Given the inaccuracies in high flows at Casey's Weir, an alternative approach using the flows recorded at Benalla was adopted, as discussed below.

Alternative Approach

The October 1993 flood hydrograph at Benalla was selected as the representative hydrograph across the range of ARI events. To allow for routing between Benalla and Casey Weir a RORB model was set up between Benalla and Orrvale. This model was also used to estimate breakout flows between Gowangardie and Orrvale as discussed in Section 5.3.4.

The RORB model was calibrated by adjusting the parameters to achieve a match to the recorded 1993 hydrograph at Gowangardie (404224). The calibration result is shown in Figure 5.2. A match was achieved using the parameters shown in Table 5.2. The losses used were taken from an analysis undertaken by SRWSC (1984).

Records at Lake Mokoan indicate that there were no flows released from the Lake into the Broken River during the 1993 event, so it was ignored in the RORB model.

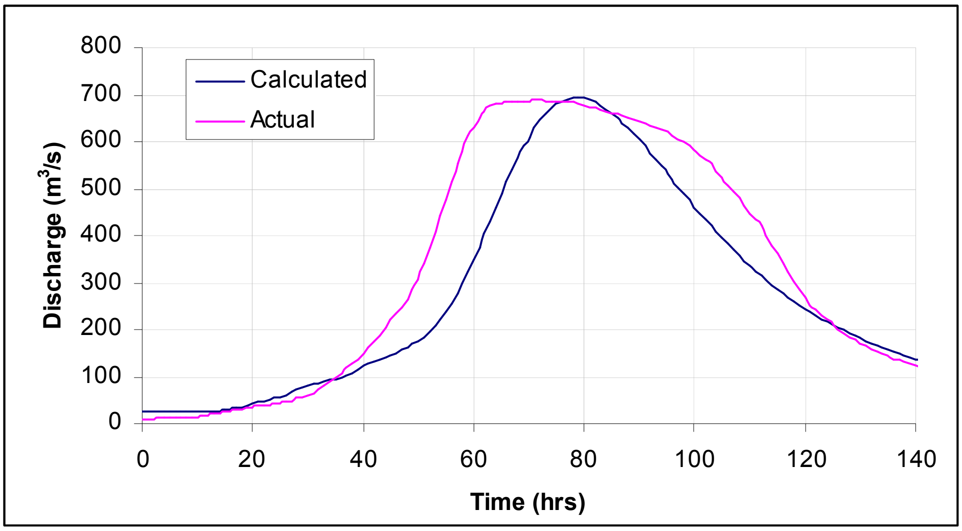

Figure 5.2: Calibration of 1993 event for Gowangardie (404224)

Table 5.2: RORB parameters used in calibration

Initial Loss (mm)	Continuing Loss (mm/hr)	m	k_c
20	1.5	0.85	82

Using the rating curve shown in Figure 5.1 and the flood levels recorded at Casey Weir during the 1993 event an estimation of the breakout flow at Casey Weir for the 1993 event was calculated. This was allowed for in the RORB model. Figure 5.3 shows the breakout hydrograph used.

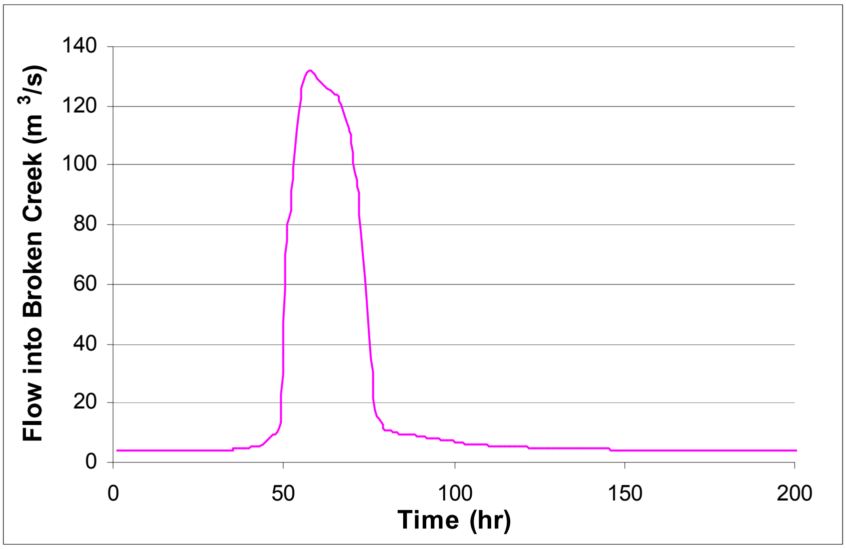

Figure 5.3: Breakout flows into Broken Creek at Casey Weir during 1993 Flood Event

To check the routing parameters i.e. m and k_c the 1996 flood event on the Broken River at Benalla was entered into the RORB model. This event was considerably smaller than the 1993 event but was chosen as it was the only other event available were there was a recorded hydrograph at both Benalla (404203) and Gowangardie (404224). The result is shown in Figure 5.4 which indicates that the routing parameters used, reasonably represent the catchment response.

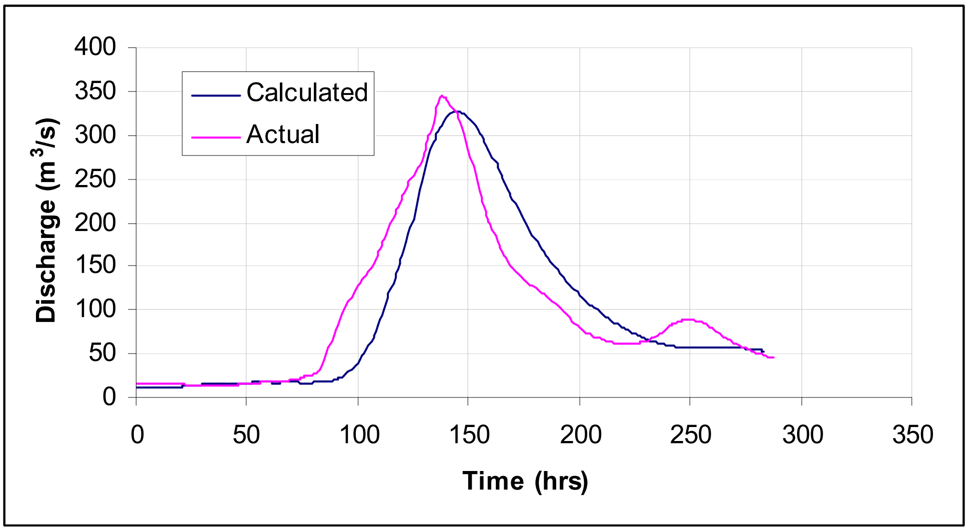

Figure 5.4: Verification of 1993 event at Gowangardie (404224) using 1996 event

Gowangardie was used as the calibration point because, apart from the breakout flow at Casey Weir, higher ground to the north and south does not permit spills from the Broken River to adjacent catchments (HydroTechnology 1995).

Design Breakout Flow Hydrographs at Casey Weir

To calculate design breakout flows into the Broken Creek system at Casey Weir from the Broken River, design "elevation" hydrographs were calculated. These "elevation" hydrographs were then related to the relationship shown in Figure 5.1 to calculate breakout flows into the Broken Creek system from the Broken River at Casey Weir. This was achieved by scaling the ordinates of the routed 1993 hydrograph from RORB at Casey Weir by the ratio of the design 5 day flood volume, shown in Table 5.1, to the routed 1993 flood volume.

Then the levels recorded at Casey Weir for the 1993 event were matched against the calculated 1993 hydrograph. A series of design "elevation" hydrographs were calculated, using the relationship shown in Figure 5.1 to produce design hydrographs for the breakout flows at Casey Weir. Figure 5.5 displays the design flood hydrographs for the required range of ARIs.

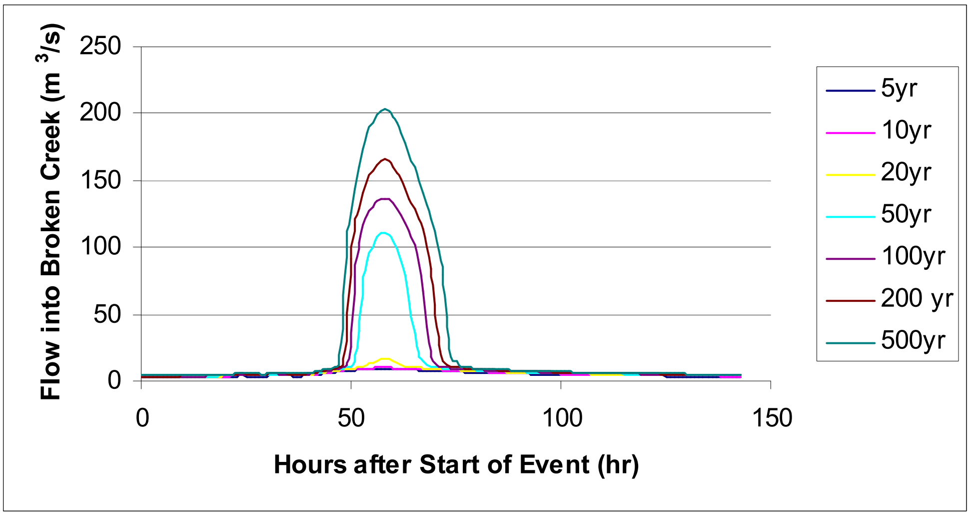

Figure 5.5: Breakout flows into Broken Creek at Casey Weir for Design Flood Events

5.2.4 Gowangardie to Orrvale Channel Breakout Relationship

The establishment of a relationship for breakout flows between Gowangardie and Orrvale is difficult as there is little information.

During the 1993 flood event, downstream of Gowangardie experienced extensive flooding to the north from water spilling over the right bank of the Broken River. These spills were collected by parallel watercourses which then drained north to the Broken Creek system (HydroTechnology 1995).

The first step was to establish design hydrographs at Gowangardie. There is insufficient streamflow data available at Gowangardie to establish a relationship using the flood quantile method. SMEC made the assumption that the ratios established at Casey Weir for the design flood volume could be used at Gowangardie. This was considered a reasonable assumption due to the lack of available gauging data at Gowangardie and as the Gowangardie gauge is only located approximately 20km downstream of Casey Weir.

The 1993 hydrograph recorded at Gowangardie was selected as the hydrograph representing the 100-year ARI. Design hydrographs for Gowangardie were obtained by scaling the ordinates of the October 1993 hydrograph at Gowangardie by the ratio of the design flood volumes at Casey Weir. Figure 5.6 displays the design flood hydrographs for the required range of ARIs.

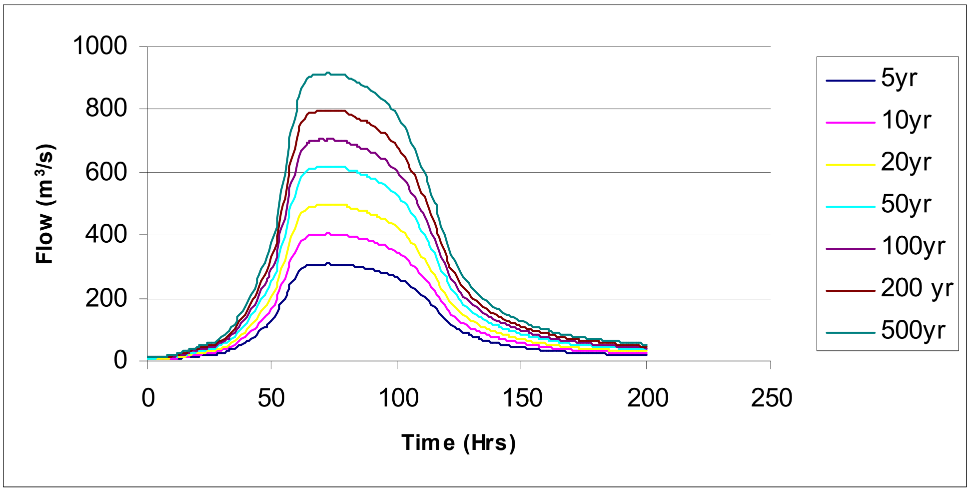

Figure 5.6: Design Flood Events at Gowangardie

To establish a relationship for the design breakout flows between Gowangardie and Orrvale the RORB routing parameters ascertained from the calibration of the 1993 event described in Section 4.3.3 from Casey Weir to Gowangardie were used. The design hydrographs at Gowangardie (404224) were routed to Orrvale (404222) assuming no outflows. These were compared to the statistically expected hydrographs for Orrvale developed from quantile analysis of the flow peaks and volumes by SKM (2000). The difference between the routed and statistical hydrographs would be the expected breakout flows. The design breakout flows between Gowangardie and Orrvale are shown in Figure 5.7.

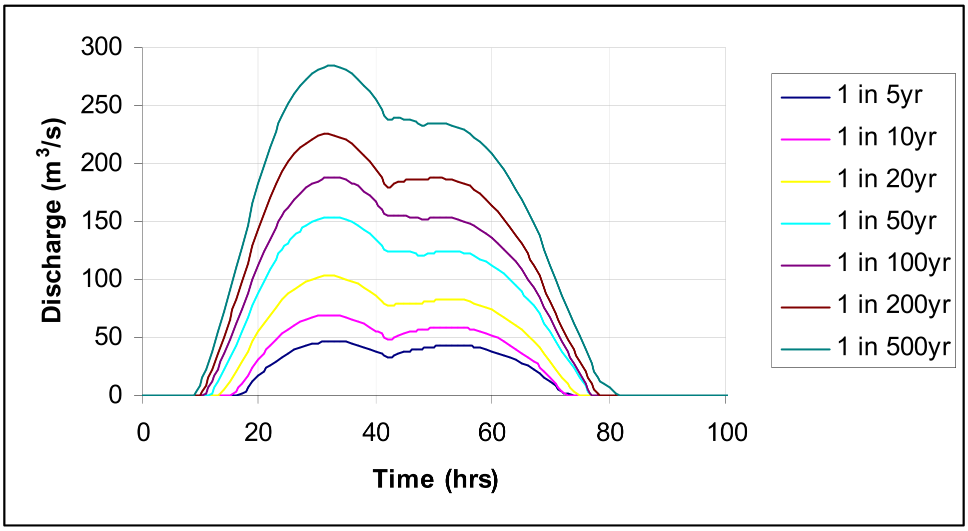

Figure 5.7: Design Breakout Flow between Gowangardie and Orrvale

Conservatively all breakout flow between Gowangardie and Orrvale was assumed to travel to the north.

The literature suggests that breakouts between Gowangardie and Orrvale only occur when floods on Broken River exceed the 20-year ARI event. A sensitivity analysis of breakout flows between Gowangardie and Orrvale was undertaken and the results are discussed in Section 5.12 below.

5.2.5 Summary

As for any estimated relationship, there will be some uncertainty in the predictions. This is in part due to the fact that no two floods behave exactly the same and the quality and quantity of data that is available. The above relationships utilise the known data and hydraulic information that can be inferred from known records. Hence the relationships developed will provide the best estimates of the breakout flows.

5.3 Casey Weir Rating Curve

As discussed previously, there is a high degree of uncertainty associated with higher flows at Casey Weir which introduces additional uncertainty into the estimates of the breakouts from the Broken River. Further to the work described in Section 5.2, additional work was undertaken to define flows at Casey Weir under high flow conditions. Two events were chosen, the 1993 and 1974 event. A HECRAS model was set up, which included the Broken River and Broken Creek system. Flood levels were reported along the Broken River, for the 1993 and 1974 flood events, in the HydroTechnology (1995) report. The downstream recorded flood level in the Broken River from the HydroTechnology report, for these two events, was set as the level at boundary of the HECRAS model. Flows were then entered into the model at Casey Weir until, the flow entered resulted in a match to the recorded level at Casey Weir.

An estimate was made of storage within the Broken River floodplain, based on the topography and the information contained in the HydroTechnology (1995) report. Once again there will be some uncertainty in the predictions of flow. This is in part due to the fact that no two floods behave exactly the same and the quality and quantity of data that is available. To establish a rating curve at Casey Weir with any certainty SMEC recommend that detailed flow and level readings upstream and downstream of Casey Weir be undertaken during the next flood event.

Figure 5.8 shows the current rating curve at Casey Weir as supplied by Thiess versus the rating curve established from the HECRAS modelling. For flow below 336m^3/s (29,000 ML/d) the current curve was maintained and adjusted between the modelled 1974 and 1993 event.

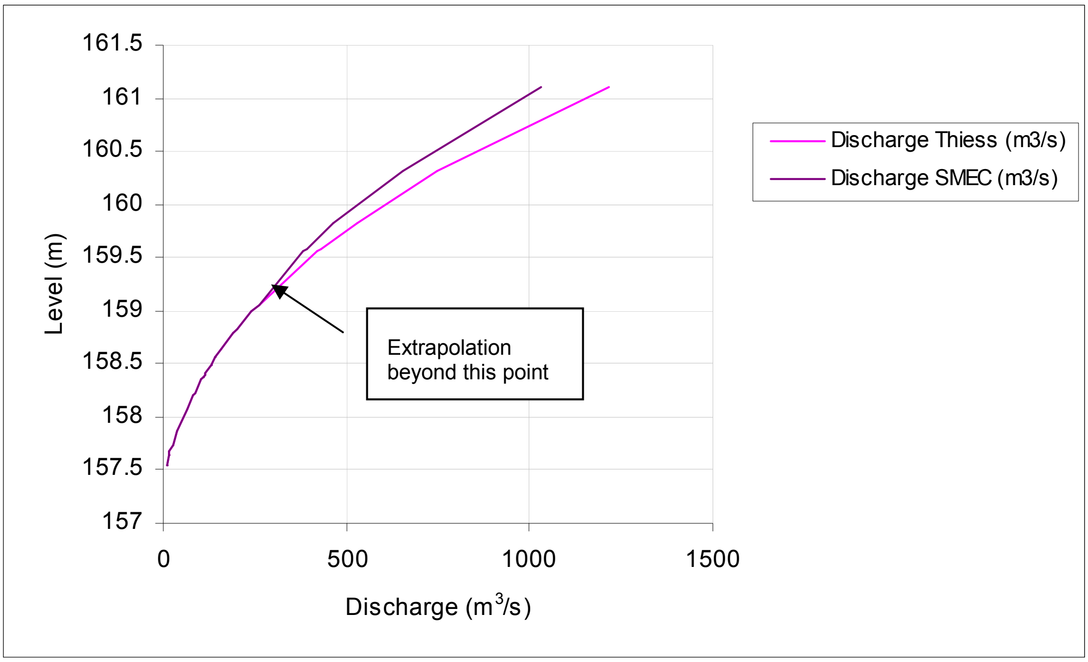

Figure 5.8: Rating Curve at Casey Weir

5.4 RAFTS Model

As part of the Broken Creek Management Strategy (SKM 1998) several hydrological models were built to represent sub-catchments of the Broken Creek. These included models of the Muckatah Depression, Upper Broken Creek and Lower Broken Creek systems. The runoff routing model, RAFTS (Willing and Partners, 1994) was used.

As part of this current investigation these models were refined and developed to better represent the catchment. Breakout flows were added and storage areas refined (particularly around Walsh's Bridge).

The models were then calibrated against the available stream gauge information for the 1993 and 1974 flood events. The calibrated model was then used to estimate the rainfall excess from the design events of interest and route this to Walsh's Bridge for use in the hydraulic modelling of the floodplain at Nathalia.

5.4.1 Calibration of 1993 Event

The 1993 event was the focus for calibration as it was the largest recorded event. The 1974 event was used to verify the calibration result of the 1993 event.

There is good pluviograph coverage of the southern part of the catchment, with Dookie (81013) situation within the catchment and covering the entire calibration event. To the South West of the catchment there are the pluviographs 81049 (Tatura Institute Sustainability Agriculture) and 81114 (Tatura Thiess Environmental Services) which cover the entire event and to the South East there is 82121 (Ovens River, Wangaratta). To the north 80109 (Cobram) has missing data during the peak of the rainfall event. The pluviographs which covered the entire calibration period were used to define the temporal distribution of rainfall.

There is good coverage over the entire catchment of daily rainfall stations. The rainfall depth over the duration of the event was estimated for the RAFTS sub-catchments to account for the spatial variation of rainfall across the catchment. Isohyets were constructed for the 1993 event from the daily rainfall stations and the rainfall depth on each sub-area then estimated. The isohyetal map for the 1993 event is shown in Figure 5.9.

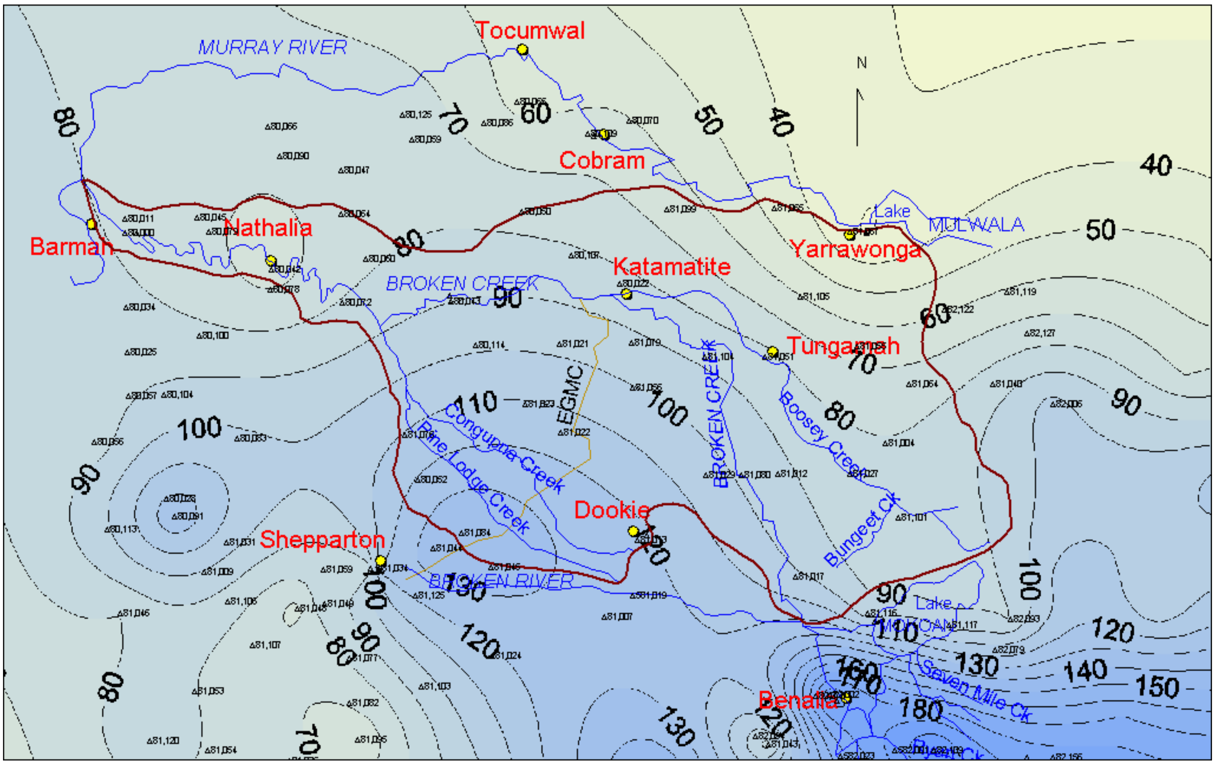

Figure 5.9: Isohyetal Map for 1993 Event

Breakout Flows for 1993 Flood Event

As described in Section 5.2.3 an elevation discharge relationship was derived for breakout flows at Casey Weir from the Broken River system into the Broken Creek system. The recorded levels for the 1993 event were related to this curve to obtain the breakout flows at Casey Weir as seen in Figure 5.3.

As described in Section 5.2.4 for breakout flows from the Broken River into the Broken Creek system between Gowangardie and Orrvale a RORB model was set up between Benalla and Orrvale. The recorded hydrograph at Benalla was entered and the RORB model was calibrated to achieve a match at Gowangardie. These parameters were then utilised and the hydrograph recorded at Gownagardie entered into the RORB model and the flow was routed to Orrvale. The difference between the recorded hydrograph and the routed hydrograph from RORB was taken to be the breakout flow. This is illustrated in Figure 5.10.

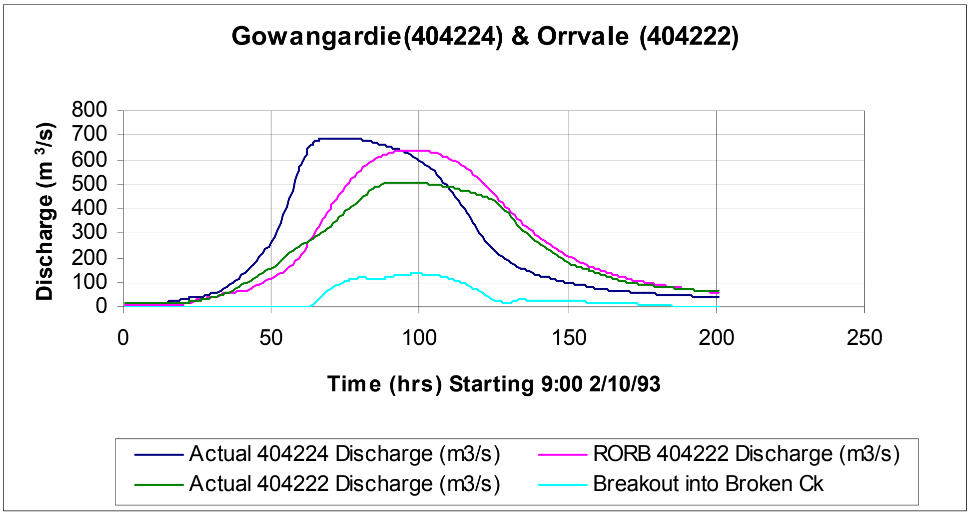

Figure 5.10: Breakout Flow into Broken Creek between Gowangardie and Orrvale

Calibration Results

There are five (5) sections within the catchment which had information available to calibrate the RAFTS model. These were Tungamah (404204) and Katamatite (404214) in the Upper Broken system. A flow reading was taken on the Shepparton Katamatite Road at Pine Lodge Creek and Congupna Creek. A flow reading was also taken at Walsh's Bridge with a peak discharge of 116m^3/s (10,100 ML/d). It is worth noting that at the peak, a discharge of approximately 35m^3/s (3,000 ML/d) was recorded as floodplain storage at Walsh's Bridge.

The results from the RAFTS model versus the recorded data are shown in Figures 5.11 to 5.15

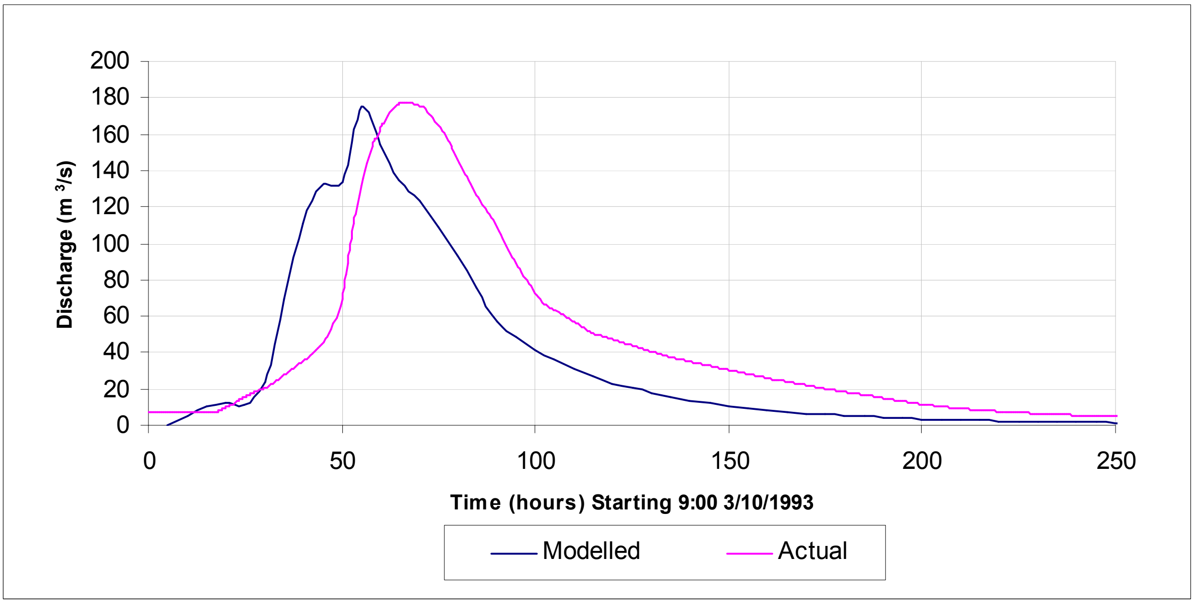

Figure 5.11: Calibration of 1993 Event at Tungamah 404204

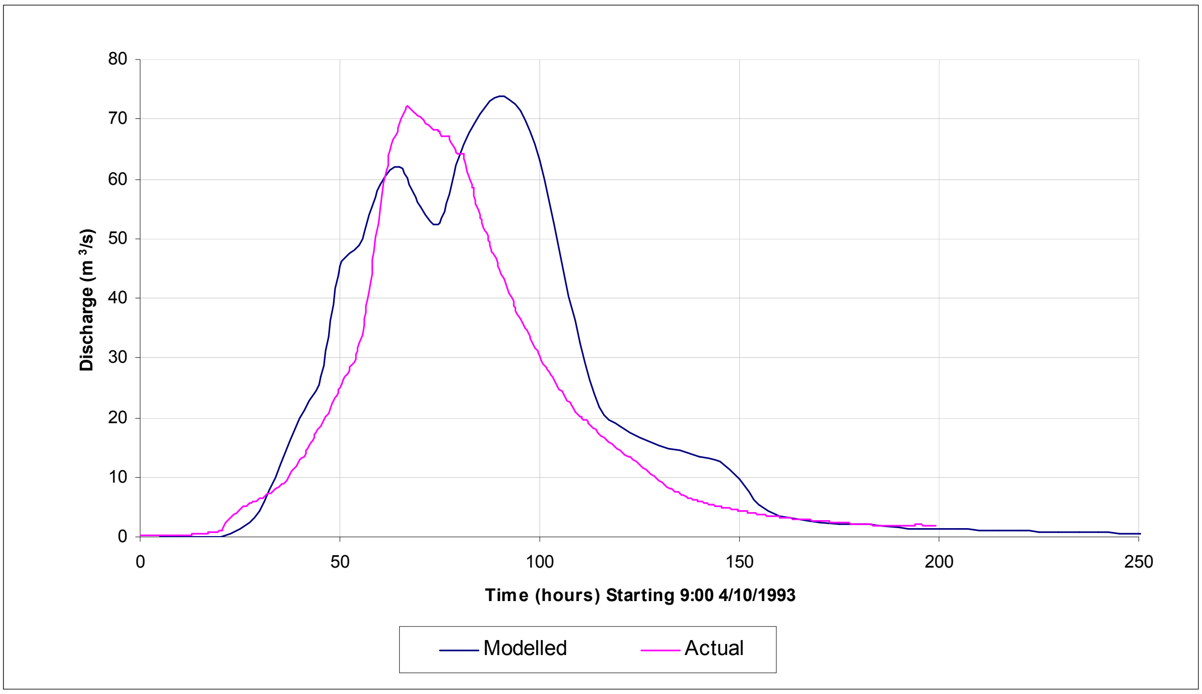

Figure 5.12: Calibration of 1993 Event at Katamatite 404214

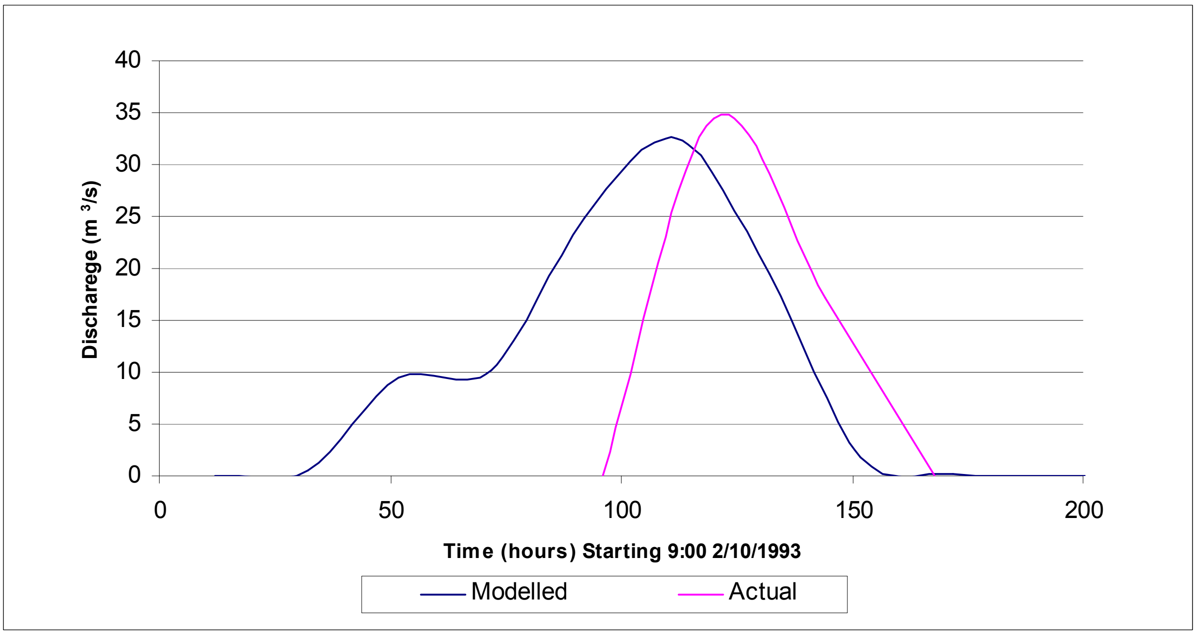

Figure 5.13: Calibration of 1993 Event at Congupuna Creek

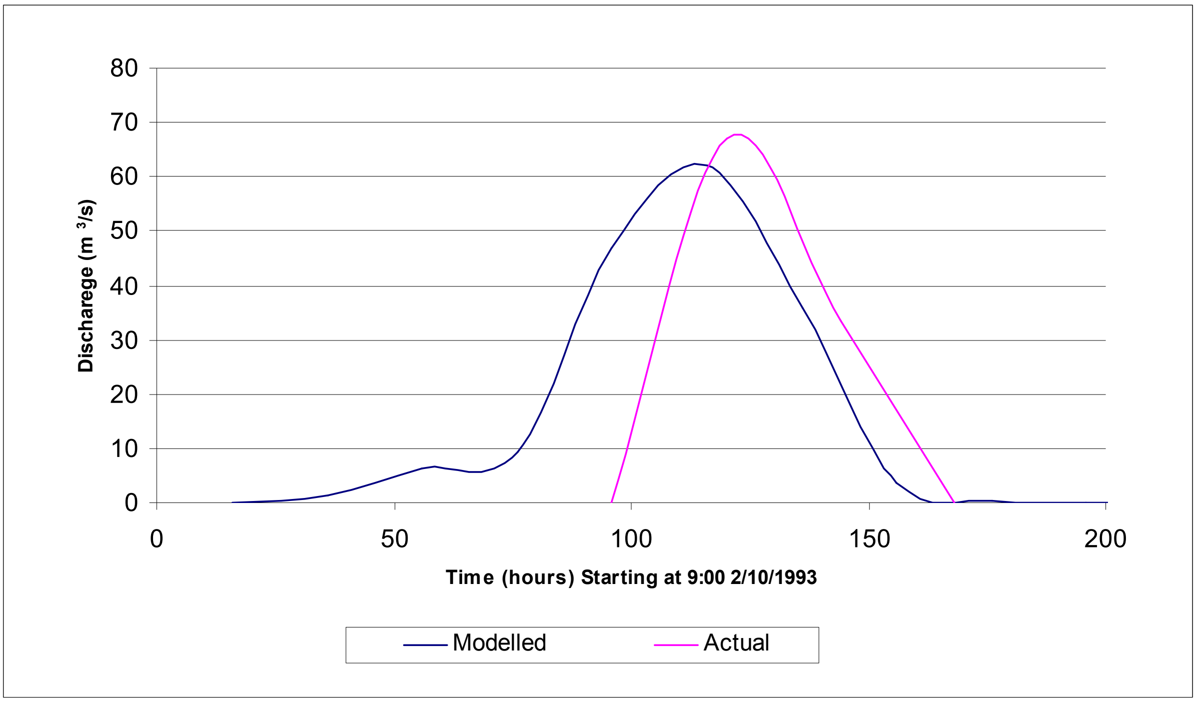

Figure 5.14: Calibration of 1993 Event at Pine Lodge Creek

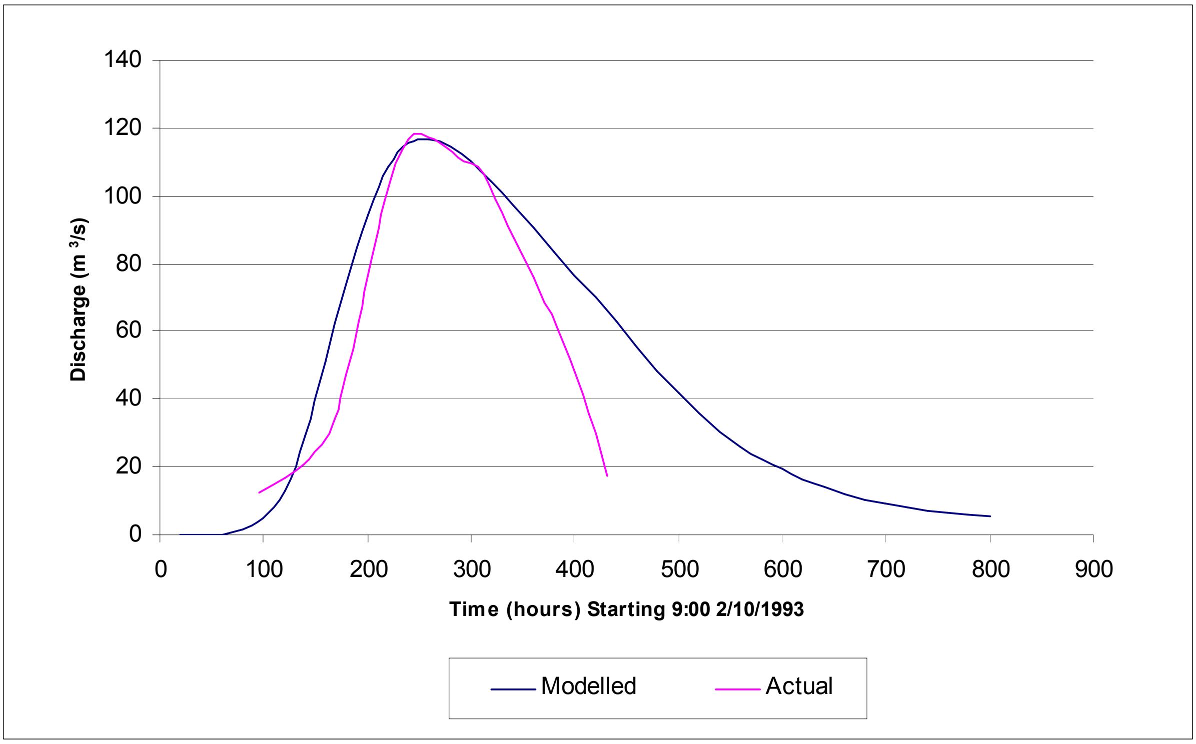

Figure 5.15: Calibration of 1993 Event at Walsh's Bridge

5.4.2 Verification Using 1974 Event

The 1974 event was used to verify the calibration achieved on the 1993 event. The stream gauge information available is considerably less than the 1993 event. Compared with the 1993 flood event, in 1974 more of the flow was reported to have derived from the upper Broken Creek catchment passing down Broken Creek through Tungamah. These two floods resulted in approximately the same flow at Nathalia of 116m^3/s (10,000 ML/d).

There are three (3) pluviographs within and next to the catchment which cover the entire event, Dookie (81013), Ovens River (Wangaratta) (82121) and Cobram (80109). These pluviographs were used to define the temporal distribution of the rainfall.

There is good coverage over the entire catchment of daily rainfall stations. The rainfall depth over the duration of the event was estimated for the RAFTS sub-catchments to account for the spatial variation of rainfall across the catchment. Isohyets were constructed for the 1974 event from the daily rainfall stations and the rainfall depth on each sub-area then estimated. The isohyetal map for the 1974 event is shown in Figure 5.16.

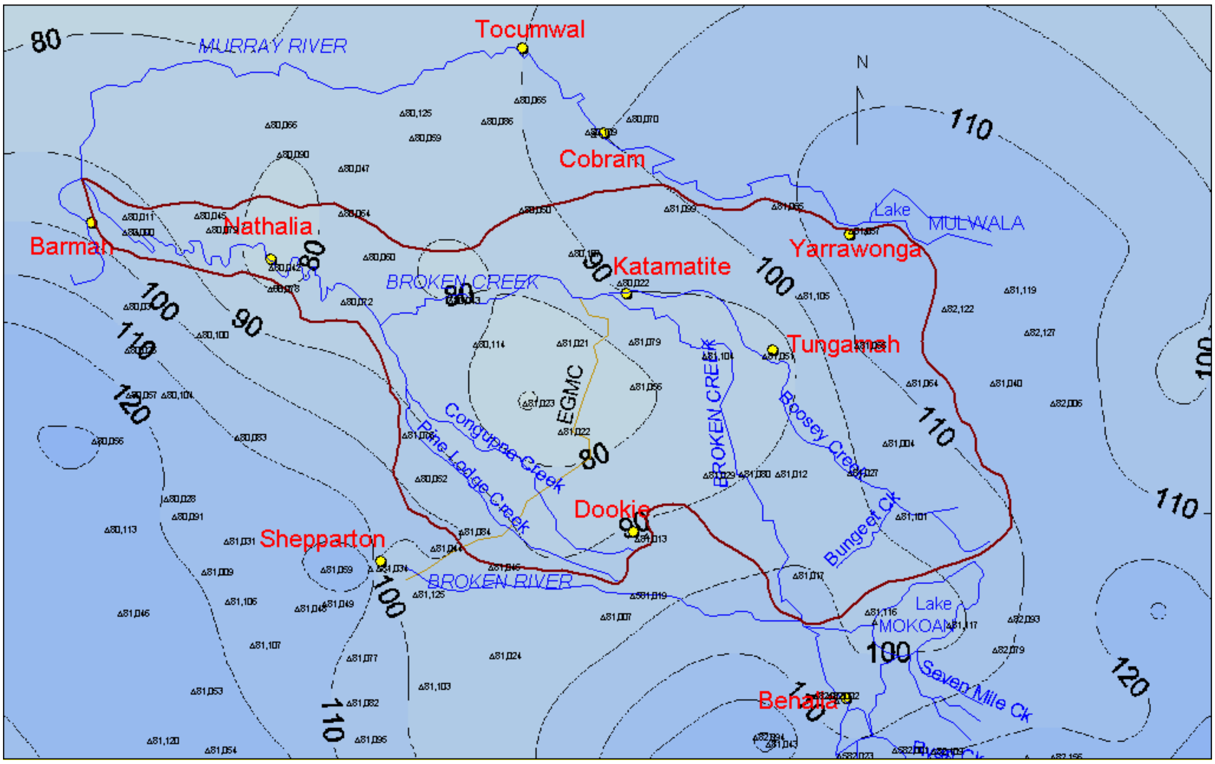

Figure 5.16: Isohyetal Map for 1974 Event

5.4.3 Breakout Flows for 1974 Flood Event

As described in Section 5.2.3 an elevation discharge relationship was derived for breakout flows at Casey Weir from the Broken River system into the Broken Creek system. The recorded levels for the 1974 event were related to this curve to obtain the breakout flows at Casey Weir. The recorded levels show that there was no breakout flow at Casey Weir only flow which would have entered the Broken Creek via the channel at Casey Weir.

From an analysis of the material available for the 1974 flood it is unclear as to the extent (if at all), that flows broke out from the Broken River into the Broken Creek between Gowangardie and Orrvale. It is however, less than the 1993 event. As there is not a recorded hydrograph at Gowangardie Weir or Orrvale for the 1974 event it was not possible to assess the potential for breakout flows in this area using the methodology adopted for the 1993 flood event, of routing the hydrograph at Gowangardie through the RORB model.

For the 1974 event, a design breakout flow, as derived in Section 5.2.3 was used. From the flood frequency curve at Benalla, derived as part of the Shepparton – Mooroopna Floodplain Management Study (SKM 2000), the 1974 event was about a 20-year ARI event. Assuming the same ARI between Gowangardie and Orrvale as Benalla, a 20-year ARI design hydrograph for breakout flow between Gowangardie and Orrvale was used as shown in Figure 5.7.

5.4.4 Validation Results

As mentioned previously the amount of streamflow information available within the Broken Creek catchment for the 1974 event is minimal. The peak flows at Tungamah (404204) and Katamatite (404214) were 220m^3/s (19,000 ML/d) and 85m^3/s (7,300 ML/d) respectively as documented in the Hydrotechnology (1995) report. Several flood level readings were recorded at Walsh's Bridge and in Nathalia, which were used to derive a flood hydrograph for the 1974 event. The flow recorded at Nathalia in 1974 was approximately 116m^3/s (10,000 ML/d).

The RAFTS model predicted a flow of 215m^3/s (18,600 ML/d) at Tungamah and 85m^3/s (7,300 ML/d) at Katamatite.

The result from the RAFTS model versus the derived hydrograph at Walsh's Bridge is shown in Figure 5.17.

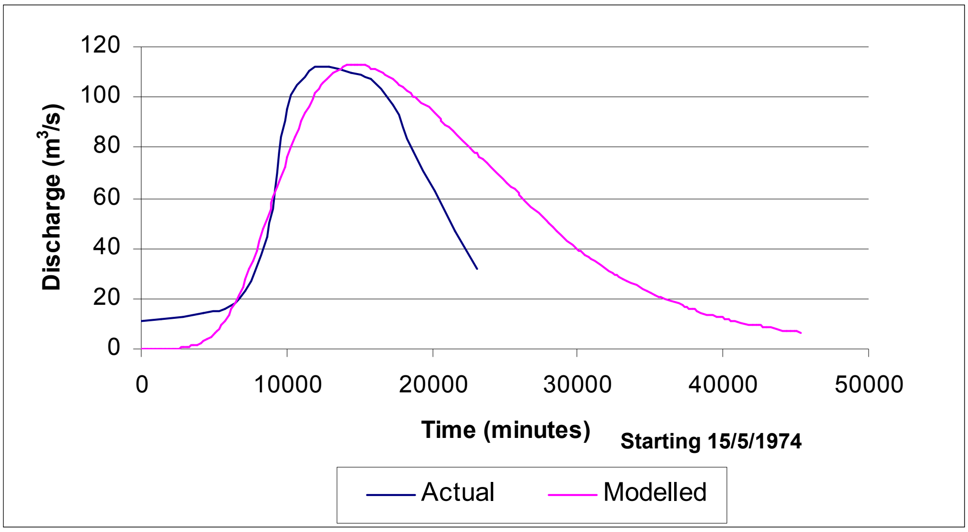

Figure 5.17: Validation of 1974 Event at Walsh's Bridge

Flood Hydrograph at Walsh's Bridge for 1974 Flood Event

The flood hydrograph at Walsh's Bridge for the 1974 event was derived using the RMA hydraulic model (described in Section 6). Flood levels for the 1974 event were recorded at Walsh's Bridge and in Nathalia. These recorded levels were related to the elevation discharge information extracted from the hydraulic model setup for the 1974 event. The extracted hydrograph was limited to a peak of about 116m^3/s (10,000 ML/d) as recorded in HydroTechnology (1995) and Nathalia Mitigation Report (1978).

5.5 Design flood estimation

The flood frequency curves derived to asses the flood magnitude in Nathalia was determined using the method outlined in Australian Rainfall and Runoff (ARR).

This section summarises the methods used and the results obtained. The RAFTS model used for the calibration and validation event was used to define the design flow events.

5.6 Design Rainfall

Design rainfall depths for AEPs from 20% to 1% were estimated from an IFD analysis using the procedure described in ARR. The intensities from the IFD analysis are point rainfalls and were reduced to account for catchment area using areal reduction factors as reported in Siriwadena et al, 1996.

From the RAFTS modelling undertaken the 72hr storm is the critical duration storm for all AEP events. Consequently, to accurately estimate rainfall depths for events between the AEP of 1% and Probable Maximum Precipitation (PMP) the Bureau of Meteorology would need to undertaken an investigation to estimate the PMP rainfall depth. From discussions with the Technical Steering Committee it was decided that an estimate using procedures described in ARR would be sufficient for this analysis.

5.7 Design Temporal Patterns

Temporal patterns used to distribute rainfall depths over time for AEPs from 20% to 1% were taken from ARR (1987).

For the 2% and 1% AEP events for storm durations above 24 hours the GSAM temporal pattern was also assessed. This is consistent with the recommendations in Book VI of ARR (1999).

As discussed in the, Broken Creek management strategy (1998), the Broken Creek catchment falls into Zone 2 of the temporal pattern zones in ARR (1987). “Previous studies in this area (e.g. Deakin Main Drain, (MBCG, 1993)) have indicated that the Zone 2 temporal pattern may not best represent the typical temporal patterns of rainfall in the area. A better pattern is provided by Zone 1 from ARR (1987).” For consistency the Zone 1 temporal pattern was used for AEPs from 20% to 1%.

5.8 Design Spatial Patterns

As recommended in ARR for AEPs from 20% to 1% the rainfall was uniformly distributed.

5.9 Design Losses

There is little initial loss and continuing loss data available. Design losses were chosen to reflect the observed losses from the calibration events and other investigations in the area.

Other investigations include an analysis by Willing and Partners as reported in the HydroTechnology (1995) report. The Willing and Partners investigation undertook RAFTS modelling on the Broken River system and used an initial loss of 17.5mm and a continuing loss of 3.3mm/hr to 4.0mm/hr. An investigation undertaken by SRWSC (1984) also reported in HydroTechnology (1995) used an initial loss of 20mm and a continuing loss of 1.5mm/hr.

In the Broken Creek Management Study (1998) the initial losses assumed were 18mm and 30mm for irrigation land and dryland respectively. The continuing loss of 1mm/hr was adopted for both irrigation and dryland.

The losses used by SMEC for the calibration were 20mm for initial loss and varied between 1.5 and 2.5 for continuing loss.

The regional losses based on those developed by the CRC for Catchment Hydrology (Hill et al. 1996) were calculated but deemed to be too high based on the work undertaken in the Broken Creek Management Study (1998) and the current work undertaken.

To be consistent with values used previously SMEC used 18mm and 30mm for irrigation land and dryland respectively and 1mm/hr for the continuing loss. These values were consistent with those used in the calibration of the RAFTS model.

5.10 Rainfall Runoff Modelling Results

Peak flows were estimated at Walsh's Bridge using the RAFTS model of the entire Broken Creek catchment. This model includes the breakout flows derived at Casey Weir and between Gowangardie and Orrvale.

Peak flows for the selected ARI are shown in Table 5.3 including the peak flow contributing due to breakouts. The flood frequency curve is shown in Figure 5.18.

The recorded peak at Walsh's bridge for the 1993 flood was approximately 117m^3/s (10,100 ML/d) which from the flood frequency curve was between a 20 and a 50-year ARI. Based on the historical flood events this century at Nathalia this estimate appears reasonable. The flood events in 1919 and 1974 flooded the town and the flood event in 1993 would have except for the mitigation works undertaken.

Table 5.3: Results of RAFTS modelling – Peak Design Flows at Walsh's Bridge

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)	Breakout Flow (m^3/s) Casey Weir	Breakout Flow (m^3/s) D/S Orrvale
5	2.5	47	4,060	3	-
10	5	68	5,875	9	50
20	10	94	8,120	10	70
50	20	128	11,060	16	100
100	30	160	13,825	45	115
500	100	180	15,552	140	190
PMF	100	1095	94,608	140	190

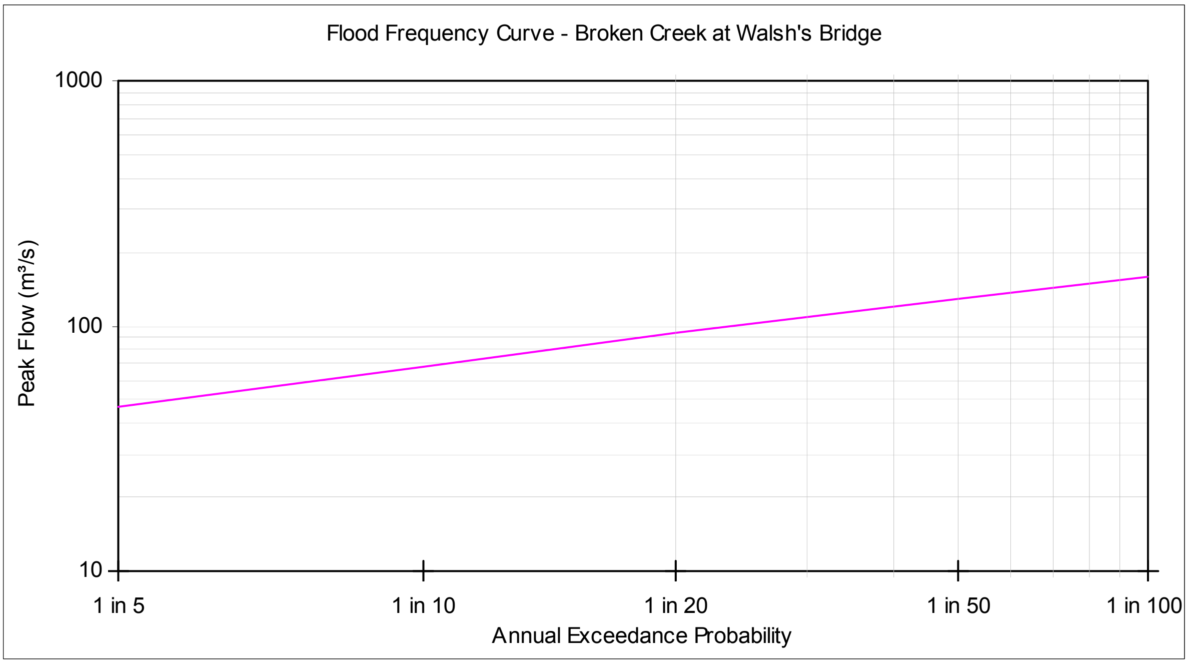

Figure 5.18: Flood Frequency Curve for Broken Creek at Walsh's Bridge.

The hydrographs derived from the RAFTS models will be entered into the hydraulic model and routed to Nathalia. The hydraulic modelling is discussed in detail in Section 6.

5.11 Rainfall Runoff Modelling Results - GSAM

As discussed in Section 5.2, for the 50 and 100-year ARI events the RAFTS model was run with the GSAM temporal pattern. The results are shown in Table 5.4 and the Flood Frequency Curve shown in Figure 5.19.

Table 5.4: Results of RAFTS modelling with GSAM Temporal Pattern – Peak Design Flows at Walsh's Bridge

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)	Breakout Flow (m^3/s) Casey Weir	Breakout Flow (m^3/s) D/S Orrvale
5*	2.5	47	4,060	3	-
10*	5	68	5,875	9	50
20*	10	94	8,120	10	70
50	20	111	9,590	16	100
100	30	142	12,270	45	115

* Same as Table 5.3

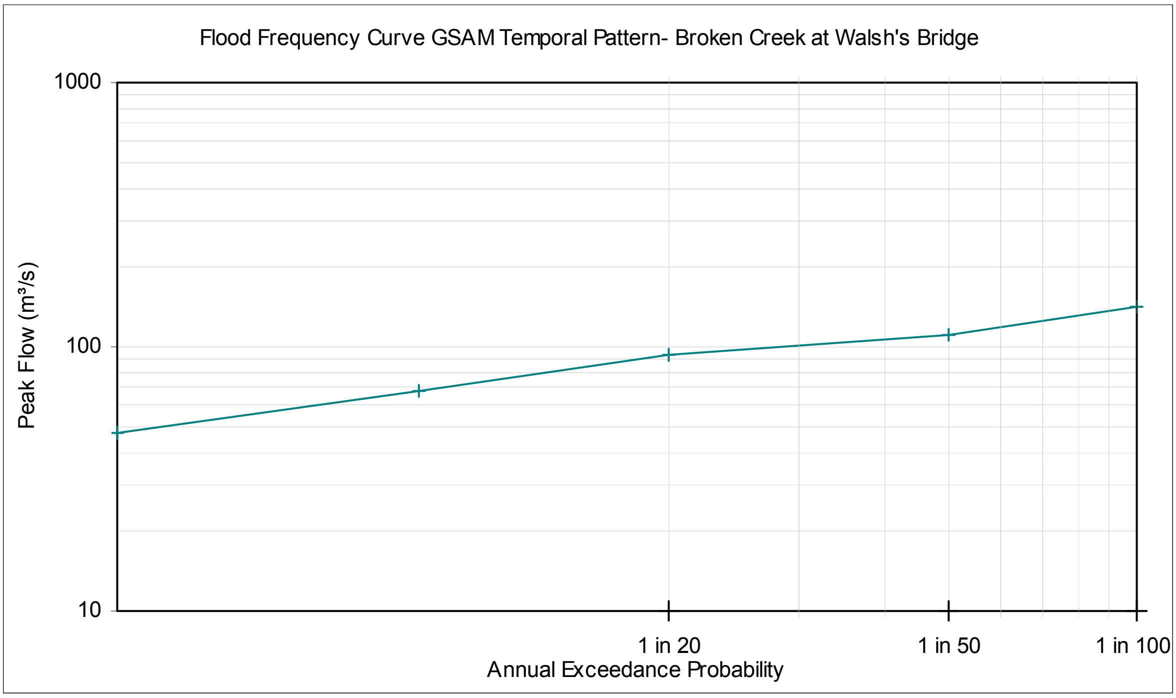

Figure 5.19: Flood Frequency Curve for Broken Creek at Walsh's Bridge using GSAM Temporal Pattern.

From the results in Table 5.4 the GSAM temporal pattern decreases the 50-year ARI flow by $17m^3/s$ (1,469 ML/d) and the 100-year ARI flow by $18m^3/s$ (1,555 ML/d). As a conservative approach SMEC recommends using the results generated using the ARR temporal patterns which is shown in Table 5.3 above.

5.12 Sensitivity Analysis

As discussed in Section 5.2 the estimate of the ARI of breakout flows has a certain level of uncertainty. SMEC undertook a sensitivity analysis on different ARI events on the Broken River and the impact that has on flows at Walsh's Bridge. The results are shown in Table 5.5 and the flood frequency curves shown in Figure 5.20.

Table 5.5: Results of Sensitivity Analysis RAFTS – Peak Design Flows at Walsh's Bridge

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)	Breakout Flow (m^3/s) Casey Weir	Breakout Flow (m^3/s) D/S Orrvale
5	17.5	61	5,270	14	90
10	20	76	6,570	16	100
20	25	101	8,725	30	110
50	35	134	11,580	65	130
100	50	166	14,340	110	155

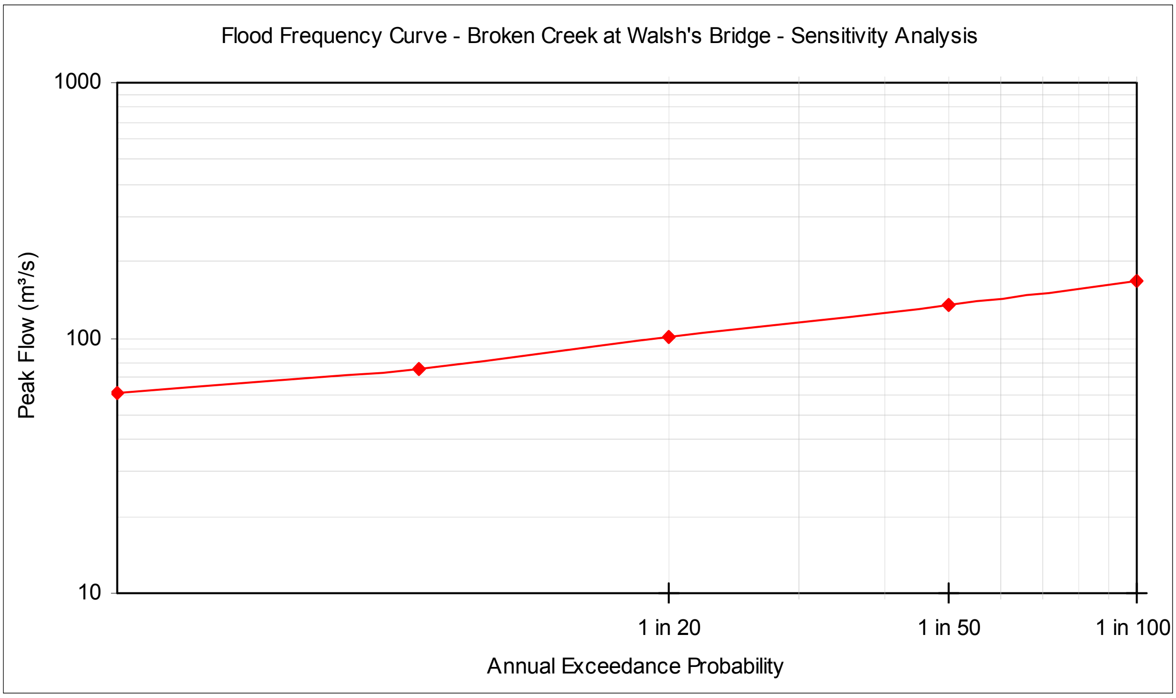

Figure 5.20: Flood Frequency Curve for Broken Creek at Walsh's Bridge from Sensitivity Analysis

From the results in Table 5.5 the model is fairly insensitive for higher flows. For the more frequent events the model is more sensitive as there is a greater contribution from breakout flows.

An assessment of the impact on peak flows at Casey Weir was undertaken assuming that breakout flows between Gowangardie and Orrvale only occurred at a 20-year ARI event and greater. This was done as there is some question as to when breakouts occur between Gowangardie and Orrvale. Breakouts at Casey's Weir remained unchanged. The results are shown in Table 5.6 and the flood frequency curve is shown in Figure 5.21.

Table 5.6: Results of RAFTS modelling with No Breakouts between Gowangardie and Orrvale for event less than 1 in 20 year on the Broken River

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)	Breakout Flow (m^3/s) Casey Weir	Breakout Flow (m^3/s) D/S Orrvale
5	No breakout	47	4,060	-	-
10	No breakout	63	5,440	-	-
20	No breakout	88	7,600	-	-
50	20	128	11,060	16	100
100	30	160	13,825	45	115

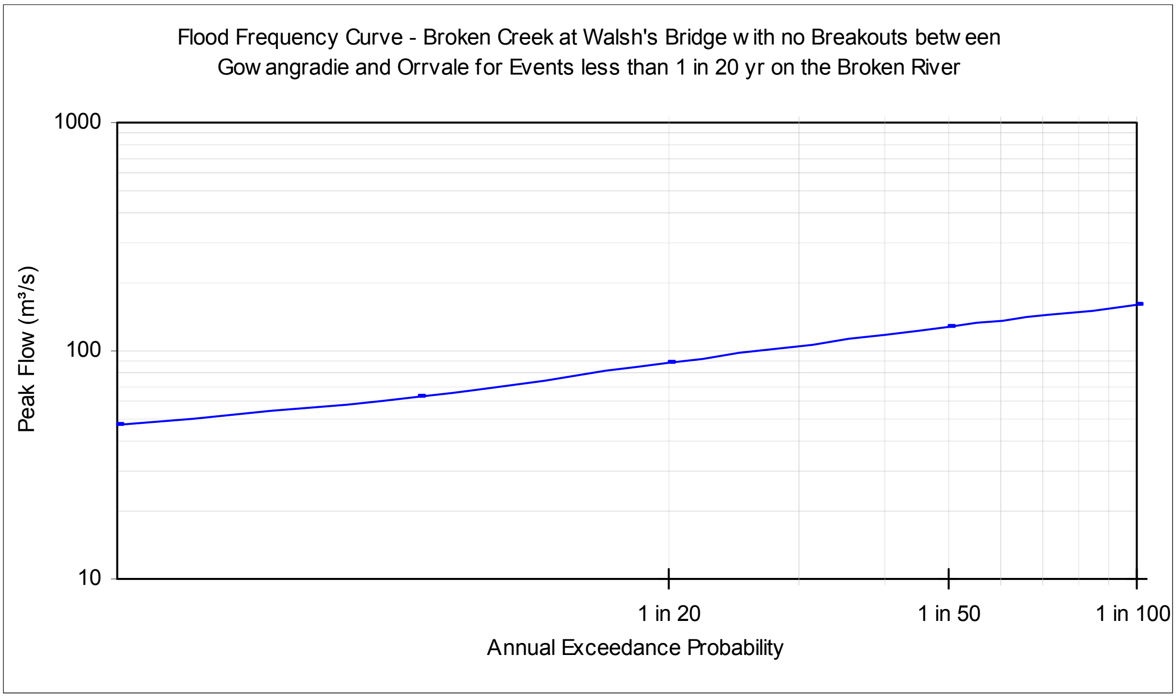

Figure 5.21: Flood Frequency Curve for Broken Creek at Walsh's Bridge with no breakouts between Gowangardie and Orrvale for Events less than 1 in 20 year on the Broken River.

From the results in Table 5.6 the breakouts only affects the results for the 10 and 20-year ARI event on the Broken Creek with a reduction of flow at Walsh's Bridge of $5m^3/s$ (432 ML/d) and $6m^3/s$ (518 ML/d) respectively. Consequently the model is insensitive to breakout flow less than a 20-year ARI on the Broken River between Gowangardie and Orrvale.

For each of the events considered so far the rainfall event which contributes to floods within Broken Creek has been centred over the Broken Creek catchment. A sensitivity analysis was undertaken assuming the main flow contribution was from the Broken River, as it was for the 1993 flood event. For comparison two different events were simulated, a 50-year ARI event on the Broken Creek with a 100-year ARI event on the Broken River and a 100-year ARI event on the Broken Creek with a 50-year ARI event on the Broken River. The results are shown in Table 5.7 below.

Table 5.7: Results of Different Events on the Broken Creek and Broken River – Peak Flows at Walsh's Bridge

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)	Breakout Flow (m^3/s) Casey Weir	Breakout Flow (m^3/s) D/S Orrvale
50	100	150	12,960	140	190
100	50	166	14,340	110	155

The results in Table 5.7 show a $16m^3/s$ (1,382 ML/d), or about a 10% difference in flows at Walsh's Bridge. The two major historical flood events on the Broken Creek system i.e. 1974 and 1993 reflect this result, with a similar flow recorded at Nathalia from two different flood regimes. To determine the impact of the different flooding regimes on Nathalia both of these events were placed into the RMA model and the impact of the different events determined.

5.13 Summary

A summary of the results used in the hydraulic modelling process and the inundation mapping is shown in Table 5.8 below.

Table 5.8: Peak Design Flows at Walsh's Bridge Used in the Hydraulic Model and Inundation Mapping

Average Recurrence Interval (years) Broken Creek	Average Recurrence Interval (years) Broken River	Flow (m^3/s)	Flow (ML/d)
Design Flows Used For Mapping and Damage Assessment			
5	2.5	47	4,060
10	5	68	5,875
20	10	94	8,120
50	20	128	11,060
100	30	160	13,825
500	100	180	15,552

6 Hydraulic Modelling

6.1 Introduction

This section of the report details the approach employed and the calibration results of the hydraulic modelling.

Figure 6.1 shows the extent of the hydraulic model. The models eastern boundary is Walsh's Bridge South Road. To the south the model boundary follows Goulburn-Murray Water's No. 12 Main Channel. To the north the model boundary follows No. 6 channel until the Murray Valley Highway where it heads north until the Katunga Picola Road which joins the Echuca Nathalia Road.

The focus of the study was the Nathalia Township. However, at the outset of the study it was considered prudent to gain a sound understanding of the flooding patterns upstream and downstream of the town as it directly affects Nathalia. Therefore, the extent of the hydraulic model as shown in Figure 6.1 was necessary to route the flow through Nathalia correctly taking into account of the complex array of infrastructure of the floodplain, i.e, irrigation channels, levees, road and railway embankments, etc.

The hydraulic model was calibrated against the observed behaviour of the October 1993 flood event using the flood levels recorded, aerial flood photographs and the information provided by the community.

The calibrated model was adjusted to try and account for the changes within the catchment since 1993. Using the updated calibrated model the design hydrographs were entered into the hydraulic model and inundation maps produced.

6.2 RMA2 Model

The RMA2 model was used to determine flood levels and flood extent for the study area shown in Figure 6.1. The RMA2 model is a two-dimensional hydraulic model. It computes water surface elevations and horizontal velocity components for subcritical, free surface flow in two dimensional flow fields. The original RMA2 was developed by King et al (1973) of University of California for the US Army Corp of Engineers. Further developments and subsequent enhancements have been undertaken by King and Norton of Resource Management Associates (RMA), and by the Waterways Experimental Station Hydraulics Laboratory, culminating in the current version of the model.

The layout of the hydraulic model was based upon topographical information and the LIDAR data supplied by Goulburn Broken Catchment Management Authority. Initially outside of town the LIDAR data only was used to define levees, road and channel embankments. However, a survey of key embankments, roads, channels and levees outside of town was undertaken in June 2004. This information was then fed into the hydraulic model. Within town detailed survey of the levees undertaken for the levee audit (1996) was used to supplement the LIDAR data. Bridge and weir dimensions were taken from a detailed survey undertaken as part of this investigation.

6.3 Model Calibration for the 1993 Flood Event

The flood event of 1993 was used to calibrate the model. The recorded hydrograph at Walsh's Bridge was entered into the model and the roughness values were adjusted until a reasonable match was achieved against the recorded flood levels. The roughness values were represented by Mannings n. Table 6.1 shows the Mannings n values adopted for Nathalia. The main focus of the modelling was in the Nathalia Township.

Table 6.1: Mannings n used in Hydraulic Model

Location	Mannings n
River	0.05
River Bank	0.15
Floodplain	0.14

The downstream boundary condition was originally based on a HECRAS model. Cross sections were entered into the model and an elevation discharge relationship formed. The sensitivity of the model to the boundary conditions was tested by adjusting the elevation discharge relationship. The model was found to be insensitive to the boundary conditions. Consequently, the boundary conditions were adjusted until a reasonable match was achieved at the downstream section of the model.

During the 1993 flood event, the Nathalia Township essentially remained flood free. Sand bags and pumping was required along Weir Street and the Murray Valley Highway north of town was blocked.

Since 1993, many levees/farm channels have been altered within the study area. It is difficult to know what all these changes are as they have not been recorded. From discussion with Council, members of the Community Reference group and the work undertaken as part of the Broken Creek Management Strategy (1998) the main changes that have occurred around the Nathalia township since 1993 is the raising of the levees on both the left and right banks between the old railway bridge and the No. 13 Channel outlet. The Broken Creek Management Strategy (1998) reported that these changes could result in raising the water levels in town by approximately 200mm if a similar event to the 1993 flood were to occur.

The LIDAR data contains the current information on features throughout the study area and was used to define levels for the majority of the study area. Where changes were know to have occurred to levees/channels the levels were adjusted to reflect conditions in 1993. As mentioned the focus of these changes was in town.

Figure 6.1 illustrates the location of available flood data. There is a reasonable amount of data available in which to calibrate against for the 1993 event, particularly close to the creek. The results of the calibration are shown in Table 6.2 and the inundation map produced is shown in Figure 6.1 attached.

Table 6.2: Calibration Results for 1993 Flood Event

Number on Figure 6.1	Depth Surveyed	Depth Modelled	Difference	Location
1	104.2	104.14	-0.06	Floodplain – Hicks Rd 1.25km south of Walsh's Bridge Rd
2	103.91	104.13	0.22	Floodplain – Walsh's Bridge Rd 500m east of intersection with Hicks Rd
3	104.15	104.13	-0.02	Floodplain – "Pinewood"
4	103.07	104.10	1.03	River Bank – 500 west of "Tooranie Park"
5	104.30	104.07	-0.23	River Bank – "Greenacres"
6	104.07	104.00	-0.07	River Bank – Intersection of Prentices and Walsh's Bridge Rd
7	103.84	103.95	0.11	River Bank – Intersection of Channel No. 36/12 and Channel No.12
8	103.52	103.34	-0.18	Floodplain – 500m east of Carland Bridge
9	103.38	103.34	-0.04	River Bank – 500m north of Carland Bridge
10	103.04	102.73	-0.31	River Bank – 1.3km north of intersection of Katamatite and Thompson Rd
11	102.18	102.54	0.36	River Bank – Nathalia Waaia Rd (Old Railway)
12	102.01	102.54	0.53	River Bank – Nathalia Waaia Rd (Old Railway)
13	102.27	102.46	0.19	River Bank – 500m south of Nathalia Waaia Rd
14	102.63	102.45	-0.18	River Bank – Paynes Rd
15	102.49	102.43	-0.06	River Bank – Paynes Rd
16	102.44	102.57	0.13	Floodplain – 500m east of intersection of Paynes and Katamatite Rd
17	102.44	102.43	-0.01	River Bank – Intersection of Paynes and Katamatite Rd
18	102.45	102.42	-0.03	River Bank – 2km upstream of Nathalia Township weir
19	102.44	102.42	-0.02	River Bank – 2km upstream of Nathalia Township weir
20	102.41	102.39	-0.02	River Bank – 1km upstream of Nathalia Township weir
21	102.31	102.39	0.08	River Bank – 500m upstream of Nathalia Township weir
22	102.38	102.39	0.01	River Bank – 200m upstream of Nathalia Township weir
23	102.22	102.38	0.16	River Bank – Nathalia Township weir
24	102.30	102.37	0.07	River Bank – In town – Mainfold St
25	102.19	102.37	0.18	River Bank – In town – Pearce St
26	101.99	102.28	0.29	River Bank – In town – Park St
27	102.10	102.22	0.12	River Bank – In town – Sports Oval
28	102.15	102.21	0.06	River Bank – In town – Railway St
29	102.14	102.19	0.05	Floodplain – North Martin St

Table 6.2 (continued): Calibration Results for 1993 Flood Event

Number on Figure 6.1	Depth Surveyed	Depth Modelled	Difference	Location
30	102.05	102.19	0.14	River Bank – In town – Park St
31	102.13	102.15	0.02	River Bank – In town – Pelly St
33	102.12	102.15	0.03	River Bank – In town – Muntz Ave
34	101.98	102.10	0.12	River Bank – In town – Gifford St
35	102.09	102.09	0.00	River Bank – In town – Nathalia Town Bridge
36	102.09	102.07	-0.02	River Bank – In town – McDonnell St
37	102.06	102.07	-0.02	River Bank – In town – Weir St
38	102	101.88	-0.12	River Bank – Old Railway Bridge Nth of Town
39	101.9	101.87	-0.03	River Bank – Weir St Nth of Town
40	101.97	101.96	-0.01	Floodplain – Northern Floodway
41	101.95	101.94	-0.01	Floodplain – Northern Floodway
42	101.87	101.93	0.06	Floodplain – Northern Floodway
43	101.85	101.92	0.07	Floodplain – Northern Floodway
44	101.74	101.80	0.06	River Bank – 1km downstream of town
45	101.98	101.68	-0.30	River Bank – 2km downstream of town
46	101.83	101.66	-0.17	River Bank – Outlet Channel 13
47	100.97	101.23	0.26	Floodplain – In depression west of town at Old Railway Bridge
48	100.8	101.15	0.35	Floodplain – In depression west of town on Bourke Rd
49	101.11	101.11	0.00	Floodplain – In depression west of town on Balls Rd
50	100.81	101.07	0.26	Floodplain – In depression
51	100.87	101.06	0.19	Floodplain – In depression
52	101.47	101.55	0.08	River Bank – Balls Rd
53	101.46	101.47	0.01	River Bank – Echuca Rd 1km west of Peter Clay Rd
54	101.28	101.29	0.01	River Bank – Echuca Rd
55	101.2	101.12	-0.08	River – Magnussons Weir
56	101.18	101.11	-0.07	River Bank – Old Railway Bridge
57	101.04	101.03	-0.01	River Bank – Hares Rd
58	100.96	101.00	0.04	River Bank – 2km south Hares Rd
59	100.81	100.80	-0.01	River Bank – 2.1km south Hares Rd
60	100.77	100.77	0.00	River Bank – 2km south Hares Rd
61	100.76	100.77	0.01	River Bank – 2.2km south Hares Rd
62	100.27	100.61	0.34	River Bank – “Jamba Springs”
63	100.66	100.57	-0.09	Floodplain – Hardings Rd
64	99.99	99.86	-0.13	River – Luckies Weir
65	99.79	99.87	0.08	Floodplain – Depression Hares Rd
66	101.05	99.86	-1.19	Floodplain – Depression Hares Rd

Table 6.2 (continued): Calibration Results for 1993 Flood Event

Number on Figure 6.1	Depth Surveyed	Depth Modelled	Difference	Location
67	100.96	99.90	-1.06	River Bank – Bourkes Bridge
68	101.1	99.99	-1.11	River Bank – Ormond Rd
69	99.87	99.88	0.01	River Bank – Hardings Rd
70	99.78	99.86	0.08	River Bank – Hardings Rd near Akoiran
71	99.63	99.78	0.15	River – Firmans Bridge
72	98.98	99.12	0.14	River – Hardings Weir
73	98.9	98.79	-0.11	River Bank – near tennis court
74	98.27	98.12	-0.15	Floodplain – North of River near Picola South Rd
75	98.76	98.85	0.09	Floodplain – Corner of Hares and Murray Rd
76	99.72	99.86	0.14	Floodplain – Corner of Ormond and Murray Rd
77	99.58	99.86	0.28	Floodplain – Murray Rd near old railway line

As mentioned previously the focus of the modelling was in town. Looking at nodes between 20 and 43 the results in town are within acceptable limits. The modelled levels upstream between nodes 1 and 20 and downstream between nodes 43 to 77 are also generally within acceptable limits. However there are some areas where a good calibration has not been achieved. These areas are generally due to the survey levels being outside the realistic profile of the flood. This is demonstrated in Figure 6.2 which is a plot of levels along the river compared with the model results. This clearly shows that some of the recorded levels appear to be in error. Number 4, 11, 12 and 13 appear to be low and number 45, 46, 66, 67 and 68 appear to be high.

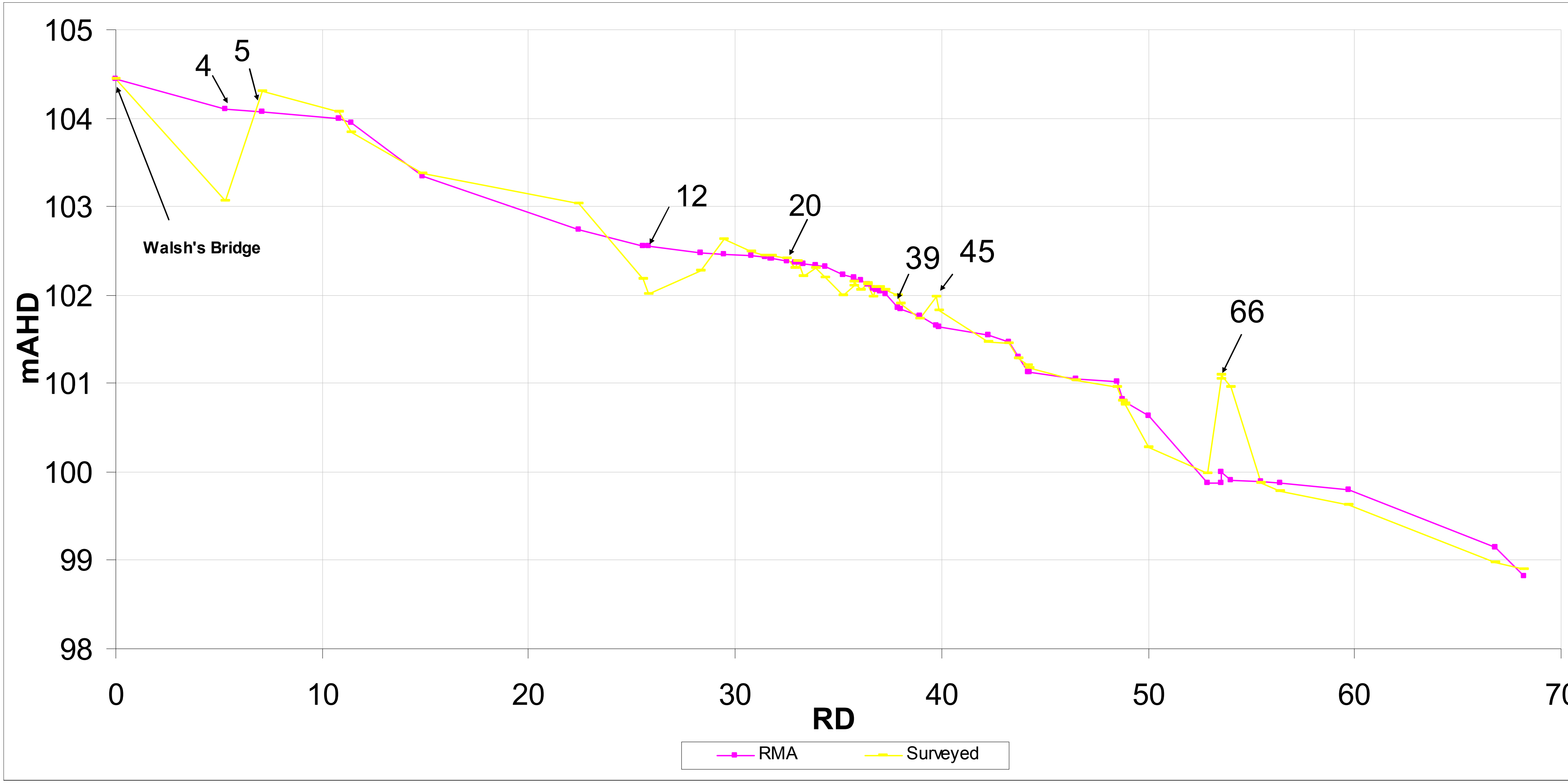

Figure 6.2: Modelling Results along the Broken Creek for 1993 Flood Event

6.4 Model Validation for the 1974 Flood Event

There is little information on the changes that have occurred within the study area between 1974 and 1993. The major change in town between these two flood events was the addition of levees. For the 1974 event the levees where removed from the hydraulic model used for the 1993 event and the hydrograph calculated in Section 5.4.4 for the 1974 event entered into the model.

Compared to the 1993 flood event there are fewer surveyed flood level data points available for the 1974 event. Figure 6.1 illustrates the location of available flood data. The results of the validation run are shown in Table 6.3.

Table 6.3: Calibration Results for 1974 Flood Event

Number on Figure 6.1	Depth Surveyed	Depth Modelled	Difference
A	102.57	102.48	-0.09
B	102.5	102.47	-0.03
C	102.44	102.44	0.00
D	102.19	102.08	-0.11
E	101.9	101.90	0.00
F	101.54	101.49	-0.05
G	101.56	101.28	-0.28
H	100.89	100.86	-0.03
I	100.4	100.49	0.09

From Table 6.3 the validation using the 1974 event has produced results within the acceptable tolerance range.

6.5 Design Events

The calibrated model was adjusted to account for the current conditions within the study area. The main changes were around the Nathalia township with the levees on both the left and right banks between the old railway bridge and the No. 13 Channel outlet raised.

Using the adjusted model the following design hydrographs were input into the model with the breakout flows on the Broken River as shown in Table 5.3:

- 5-year ARI on Broken Creek
- 10-year ARI on Broken Creek
- 20-year ARI on Broken Creek
- 50-year ARI on Broken Creek
- 100-year ARI on Broken Creek
- 500-year ARI on Broken Creek

In addition to the hydrographs listed above three additional hydrographs were entered into the model, these were as follows:

- 50-year ARI on the Broken Creek and 100-year ARI on the Broken River
- 100-year ARI on the Broken Creek and 50-year ARI on the Broken River
- 100-year ARI on the Broken Creek and 100-year ARI on the Broken River

7 Flood Mapping

7.1 Flood Inundation Mapping for Emergency Response

7.1.1 Overview

Flood inundation maps have been produced for the design flood combinations outlined in Section 5.13. The maps produced are as follows:

- A flood extent, shaded flood depth zones and flood contours for the 5, 10, 20, 50, 100 and 500-year ARI events for within town
- A flood extent, shaded flood depth zones and flood contours for the 100-year ARI event of the entire study area.

For each maps the location of existing buildings is also shown and this information is colour coded to identify whether flooding occurs above or below the floor level. If a floor is inundated then this is identified as a red dot. Also highlighted are key features and buildings, such as the police station, hospital and fire station.

The floodplain at Nathalia is very flat and as expected the velocities are low, generally being less than 0.1m/s. For the 100-year ARI event velocities at various locations have been indicated with the use of arrows.

Maps of the town areas have been produced on a single B1 sheet at 1:5,000 in both hardcopy and PDF format. The map of the entire study areas has been produced on a single B1 sheet at 1:30,000 in both hardcopy and PDF format.

The maps will provide an invaluable tool in emergency planning and response. The flood inundation maps are provided in separate volumes with examples of the maps presented in A3 size in Appendix C.

7.1.2 Flood Inundation Data

The flood inundation maps were developed to show both flood elevation (in the form of flood surface contours) and flood depths (in the form of shaded depth zones).

The flood elevation was determined from the hydraulic model by contouring flood surface data. The contour interval of 0.2m was adopted. Shaded depth zones were also derived from the hydraulic model. The flood depth zones shown on the maps are:

- Less than 0.25m
- 0.25m to 0.5m
- 0.5m to 1.0m
- Greater than 1.0m

7.1.3 Map Base

The main features of the map base is a cadastre obtained from the Moira Shire Council. Street names and locations of significance for emergency planning and response have been highlighted. These buildings are the:

- Fire Station
- Ambulance
- Hospital
- Police
- Shire Offices

7.1.4 Gauge Correlations

Each flood inundation map represents a specific level at Nathalia and upstream at Walsh's Bridge. Whilst these have been described in terms of ARI events this is only used for ease of definition and an ARI serves no practical use in assisting with emergency response. Therefore, each event has been linked to a gauge height at Walsh's Bridge and consequently at Nathalia. Table 7.1 shows the link to gauge heights at Walsh's Bridge and consequently Nathalia. These gauge heights are shown on each flood inundation map.

Table 7.1: Correlations of Upstream Gauge (Walsh's Bridge) with Nathalia Gauge

Gauge Height at Walsh's Bridge (m AHD)	Gauge Height at Walsh's Bridge (m)	ARI at Walsh's Bridge (years)	Flow at Walsh's Bridge (m^3/s)	Gauge Height at Nathalia (m AHD)	Gauge Height at Nathalia (m)
103.94	2.96	5	47	101.87	1.86
104.16	3.18	10	68	102.13	2.12
104.32	3.34	20	94	102.22	2.21
104.49	3.51	50	128	102.32	2.31
104.61	3.63	100	160	102.39	2.38
104.77	3.79	500	180	102.49	2.48

7.2 Planning Map

A flood planning map for Nathalia, indicating the extent of Land Subject to Inundation Overlay (LSIO) and Floodway Overlays (FO) has been prepared in A1 format, with an A3 copy presented in Appendix C.

LSIO is derived from the 100-year ARI flood extent as modelled by RMA

FO has been delineated according to depth of flow modelled for the 100-year ARI event, the inundation extent for the 10-year ARI event and identified hydraulic links.

Flood levels in 200mm increments have been based on the 100-year ARI event peak flood levels as modelled in RMA.

Given the general slow nature of flows i.e. velocities up to 0.2m/s on the floodplain and 0.3m/s in the river, velocity has not been considered when delineating the floodway.

8 Risk Assessment – Inner Study Area

8.1 INTRODUCTION

The risk assessment was broken into two parts. A detailed assessment of flood risk was undertaken for the inner study area (town) and a Rapid Appraisal Method (RAM) was undertaken for the outer area. The following section details the outcomes of the inner study area assessment. Figure 8.1 shows the delineation of the outer and inner study area.

Over the past two decades, procedures have been developed to arrive at objective estimates of the financial impact of flooding on properties, disruption, lost income, clean-up and such like.

A flood has a variety of effects on the lives and livelihoods of people whose possessions and places of residence or of employment are inundated. Because of this, the types and costs of flood damage can be categorised in a number of ways.

At the broadest level, flood damages are either financial or social in nature and are often respectively referred to as the tangible and intangible costs of flooding. The total financial "damage" caused by a flood can be separated into two major components, the cost of the direct damage to inundated property and the cost of the indirect damage associated with the disruption of social, community and business relationships during the aftermath of a flood.

8.2 FINANCIAL DAMAGES

The direct costs of flooding can be subdivided into the cost of damage to the actual structure of an inundated building, the cost of damage to its contents, and the cost of the immediate post flood clean up operations. These costs are referred to as "structural", "contents" and "clean up" costs.

The type of structural damage sustained by a building depends upon both the materials and manner of its construction and the depth of inundation and velocity of the floodwaters. Inundation by deep, fast-flowing floodwaters may actually wash a building away, whereas shallow, slow moving water may cause relatively minor structural damage.

A large proportion of the buildings exposed to potential flooding in Nathalia are used for residential purposes. The materials and manner of their construction are variable, most are brick or weatherboard. There are also a number of commercial and industrial properties, particularly around Blake Street, subject to inundation and damage.

The damage to the contents of residential dwellings and out buildings includes the cost of cleaning, repairing or replacing flood damaged furnishings (carpets, furniture, etc), appliances, services (electricity, telephone, water supply and sewerage) and clothing. Flood damage to cars and other equipment stored on the property is also included in the contents category. Contents damage to commercial property includes damage to raw materials, plant and equipment, stock, and "incidentals". The last category includes damage to office furnishings, employees' possessions, and services.

After a flood has subsided, there is a concentrated clean-up period. It is common for community minded people and organisations to rally as volunteers to help in the clean-up of flooded houses. Walls require washing down, both inside and out, in an attempt to reduce silt staining, silt is removed from the houses and irreparably damaged items are taken away for disposal. Similarly, volunteers and employees help in the clean-up operations at commercial establishments affected by the flooding.

The cost of immediate post flood clean-up operations is essentially the value of the time of those engaged in the clean-up process plus the cost of removing and dumping flood damaged materials, together with loss of business for commercial establishments.

8.3 INDIRECT DAMAGE

A flood can severely disrupt the goods and services provided by commercial establishments in the community (this includes industrial and rural ventures). It may take many weeks for a community to regain their pre-flood levels of productivity. The indirect flood damages to the community include the loss of production, revenue and wages, which occurs during the flood and the post-flood recuperative phase. Indirect damages also arise in a number of other ways. For example, the disruption and diversion of traffic, both during and immediately after a flood, represents another indirect loss.

Indirect residential damages may include clean up costs, loss of wage or salary, cost of removal, accommodation, inconvenience, and loss of amenity. Inconvenience and loss of amenity includes such factors as possible loss of schooling, the loss of personal mementoes, cancellation of social events and the like, many of which are intangible losses which are very difficult to quantify.

Indirect commercial damage may include costs of removal and storage, loss of business confidence and loss of trading profit. Smith's study of Lismore (1980) found that indirect costs were 18.5% of direct damage suffered by the commercial sector and 35% in the industrial sector. It is normal to include clean up costs as a direct damage. If it is incorporated into the equation as a percentage of indirect costs, then the indirect costs can be up to 25% of the total direct costs (Smith 1980).

8.4 ACTUAL AND POTENTIAL DAMAGES

Damage estimates based on the costs arising from an actual flood event are referred to as actual flood damages. Actual damages are often less than potential damages due to actions taken to reduce flooding after flood warnings are issued. The data available for an actual damages study are in general more reliable than those used in a potential damages study. In the actual damage situation the areas, depths and duration of flooding and the number of properties inundated can usually be estimated reliably. Financial costs are more accurate when based on damage sustained during an actual event.

8.4.1 Commercial/Industrial

For the purposes of calculating the commercial/industrial damages for the current study, damages were estimated using an extensive database gathered by SMEC in previous floodplain management studies. These include the Gunnedah Floodplain Management Study (SMEC 1999), Upper Nepean River Floodplain Management Study & Plan (SMEC 2001), the Wollondilly River and Mulwaree Chain of Ponds Floodplain Management Study and Plan (SMEC 2002) and the Cowra and Gooloogong Floodplain Management Studies (SMEC 2004).

8.4.2 Infrastructure / Public sector

A major component of infrastructure damage is concerned with transport – damages to roads, bridges and culverts and locally to rail and air connections where applicable. Other losses are to services such as water, sewage treatment plants, gas, electricity and telephones. The variability in terms of location, the period of inundation, problems of sedimentation and erosion are such that no standard technique is possible. Australian and international literature suggests that infrastructure damage is normally within the range of 7% to 20% of that to the private sector (DI Smith et al 1986).

In this study, specific data on previous flood damage to roads at Nathalia was not available so the Rapid Appraisal Method for Floodplain Management (2000) was adopted for damage to roads. The Rapid Appraisal Method (RAM) uses a total cost per kilometre for a major, minor and unsealed road. This single estimate of cost per kilometre of road inundated includes:

- Initial repair to roads
- Subsequent additional maintenance to roads
- Initial repairs to bridges; and
- Subsequent additional maintenance to bridges.

The costs listed in the RAM report are based on the 1993 flood in North Eastern Victoria and the 1998 floods in East Gippsland.

8.4.3 Residential

For the residential properties, it was necessary to derive estimates of potential flood damage for a range of flood magnitudes. In addition, it was necessary to take account of community "flood awareness" and their experiences in coping with floods, that is, the higher the awareness and experience, the lower the ratio of potential damages to actual damages will be. Preparedness of a community is a function of both the turnover of the population and the time since the last flood. The higher the awareness and experience, the lower the ratio of potential damages to actual damages will be. A reduction factor is applied to reflect community flood awareness and flood warning procedures.

In Nathalia there is generally a reasonable level of flood awareness in the community with the last major event occurring in 1993. However, the Rapid Appraisal Method (2000) defines an inexperienced community as one that has not experienced a flood for five (5) years. Also historically the community has had approximately 2 days warning before the flood peak arrives in town. In reflection of this, the flood warning ratio was assumed to be 0.7 based on a greater than 12 hour warning time with an inexperience community.

8.5 FLOOD DAMAGE ESTIMATES DERIVED IN THE PRESENT STUDY

This study estimates the flood damage likely to occur in Nathalia for the following two major damage categories:

- the **direct financial costs** of damage to property; and
- the **indirect financial costs** associated with the disruption of social, community, industrial and commercial relationships during the post-flood period. Indirect commercial damage may include costs of removal and storage, loss of business confidence and loss of trading profit.

For residential properties, direct damage estimates represent the sum of the structural, contents and clean-up cost components. The indirect damage estimates derived in this study are calculated as a percentage of the direct damages. The estimates also include consideration of the flood warning system and the reduction in potential flood damages that may be achieved with the warning system installed and adequate emergency procedures in place. The equations used to calculate the potential damages that incorporate these factors are discussed further in Appendix D.

The current residential indirect damages were estimated at 30% of the direct damages; however this could be reduced when a flood warning system is in place. This factor was based on a review of previous studies i.e. Upper Nepean (SMEC 2001), Gunnedah (SMEC 1999), Wollondilly River (SMEC 2002), Cowra and Gooloogong (SMEC 2004) and Tamworth (PPK 1993) and an assessment of the conditions within Nathalia.

For commercial and infrastructure calculations, an allowance for clean up costs has been included in the indirect component. The direct damages were estimated based on curves relating flood height to level of damage sustained, then factored up by 25% for indirect damages. It is possible that the factors used in the estimation of indirect damages underestimate the true value of these damages. The current estimates are based on previous studies and experience, as the true value could only be determined by a detailed survey of business owners to determine the actual costs incurred to there business during the 1993 flood.

8.6 ESTIMATION OF FLOOD DAMAGE

A variety of factors affect the flood damage caused to a particular piece of property. In this study, the following three factors have been used to predict direct potential flood damages:

- the use to which the land is put (hereinafter referred to as land use);
- the "size" of the buildings and other improvements associated with the land use; and
- the depth of flooding.

Land in Nathalia is used for a variety of purposes, such as residential, commercial, industrial and recreation. Flood damage varies with land use.

The amount of damage that occurs on a particular piece of land tends to increase with the "size" or "scale" of the operations undertaken with, other factors remaining constant. Measures of property size can include annual assessed value ($) as the measure of size for residential and recreational property and floor area (m^2) for all other types of property.

For this study, damages for commercial properties were based on an extensive database of actual and potential damages from previous studies undertaken (Upper Nepean, SMEC 2001; Gunnedah, SMEC 1999, Wollondilly River SMEC 2002). This information was analysed and estimates of damage for various components of each business was made e.g. stock, fittings, fixed or moveable machinery, etc and a flood level at which this damage would be sustained was assigned. All commercial properties were divided according to a business category, and by summarising the above data, an estimate of average damage made for each category based on a flood level.

For this study, the damage estimates applicable to residential properties were based on published data relating to flood damages and survey of properties in Nathalia. A damage curve was assigned to each residential property, which estimates the structural, contents and external costs. These curves were taken from previous studies.

A total of 743 properties were surveyed and the data collected included:

- type of property (house, unit, etc);
- height of floor;
- construction type;
- age of building;
- size of building;
- value of building (CIV).

Some of this information was gathered by LICS with most obtained from Hann McKenzie Valuers who had undertaken an extensive financial survey of Nathalia. This information was to ascertain the local property values that could be applied to factor each value code.

8.7 AVERAGE ANNUAL POTENTIAL DAMAGES

Average Annual Potential Damage (AAD) is equal to the total damage caused by all floods over a long period of time divided by the number of years in that period and assumes that development is constant over the analysis period.[1] It has been calculated using the total financial potential damages (direct and indirect costs) for a range of flood events and the probability of the event's occurrence. Effectively, AAD is the area under the curve when these two variables are graphed.

Flood damages for existing conditions in Nathalia to residential properties are given in Table 8.1, damages to commercial/industrial properties are given in Table 8.2 and damages to infrastructure are given in Table 8.4. A summary of the AAD for each sector is given in Table 8.4.

[1] Floodplain Management in Australia, Best Practise Principles and Guidelines, CSIRO, 2000

Based on these calculations, the total AAD for the existing Nathalia township is estimated to be $508,000 (in round terms).

Table 8.1: Potential Flood Damages, Existing – Residential

Average Recurrence Interval (years)	Damage ($)	Number of Houses Affected
20	$12,500	1
50	$3,556,400	455
100	$7,265,700	515
500	$8,005,445	515
Average Annual Damage	**$169,000**	

Table 8.2: Potential Flood Damages, Existing – Commercial/Industrial

Average Recurrence Interval (years)	Damage ($)	Number of Buildings Affected
20	$0.00	0
50	$5,522,100	80
100	$15,266,700	94
500	$17,261,300	94
Average Annual Damage	**$317,000**	

Table 8.3: Potential Flood Damages, Existing – Infrastructure

Average Recurrence Interval (years)	Damage ($)
20	$16,000
50	$580,200
100	$783,200
500	$783,200
Average Annual Damage	**$22,400**

Table 8.4: Average Annual Potential Damages

Sector	AAD
Residential	$169,000
Commercial/Industrial	$317,000
Infrastructure	$22,400
TOTAL	$508,400

It should be noted that these estimates are potential damages and do not necessarily reflect actual damages that may occur during a flood. Community awareness and the actions of emergency services, the evacuation of residents and their property and, most especially, the evacuation of goods and equipment from commercial properties in the flood-affected areas will significantly reduce the level of flood damage.

8.8 IMPACTS OF FLOODPLAIN MANAGEMENT MEASURES

The full range of floodplain management measures are identified and assessed in Section 10. Those identified as appropriate for detailed investigation were considered further and their impacts, including any reduction in flood damages, are discussed in Section 11.

8.9 RESULTS OF SENSITIVITY ANALYSIS ON FLOOD DAMAGES

As mentioned in Section 6.5 three additional models were run to determine the impact of various flows on flood risk at Nathalia. Table 8.5 and 8.6 shows the potential flood damages for residential and commercial areas for various ARI events.

Table 8.5: Potential Flood Damages, Existing – Residential

Average Recurrence Interval (years)	Damage ($)
100	$7,265,700
50 Broken Ck 100 Broken River	$6,619,000
100 Broken Ck 50 Broken River	$7,389,800
100 Broken Ck 100 Broken River	$7,446,000

Table 8.6: Potential Flood Damages, Existing – Commercial/Industrial

Average Recurrence Interval (years)	Damage ($)
100	$15,266,700
50 Broken Ck 100 Broken River	$13,453,400
100 Broken Ck 50 Broken River	$15,481,300
100 Broken Ck 100 Broken River	$15,839,000

The tables show that the model is relatively insensitive and the 100-year ARI chosen is a reasonable estimate.

9 Risk Assessment Outer Study Area

For the outer study area an assessment of AAD was undertaken using the RAM. The outer study area includes the remainder of the study area excluding the Nathalia township.

To calculate the AAD using the RAM a number of assumptions were made. The commencement of damages was assumed to correspond to a 5-year ARI. The number of buildings damaged during each flood event was calculated by overlaying the inundation extents for each ARI event over the topographic and aerial information. Building within the inundation extents were assumed to be affected, all buildings were defined as residential.

The flood warning ratio was assumed to be 0.7 based on a greater than 12 hour warning time with an inexperienced community. An inexperienced community is defined as a community that has not experienced a flood for five (5) years.

The landuse map of Victoria (NRE 1991), places the study areas land use as irrigated. For the RAM it was assumed that the outer study area was irrigated pastures and the land was inundated for greater than a week. For the clean up costs it was assumed that the land inundated fitted into the category of pastures and broadacre crops for low velocity flood events.

The length of road inundated for each ARI event was taken from the topographic information with the inundation extents overlaid.

The indirect damage was assumed to be 30% of the direct damages.

The AAD calculated for the outer study area from the RAM was $1,524,000

10 Floodplain Management Measures

10.1 General

There are three generally recognised ways of managing floodplains to reduce flood losses:

- by modifying the behaviour of the flood itself (Flood Modification);
- by modifying (e.g. house raising) or purchasing existing properties and/or by imposing controls on property and infrastructure development (Property Modification); and
- by modifying the response of the population at risk to better cope with a flood event (Response Modification).

The first two activities are generally referred to as “Structural Measures” and the third “Non-structural Measures”. The need to include flood preparedness and response measures in the overall Floodplain Management Plan is a new and effective method of minimising the affect of floods. Examples of the range of measures are shown in Table 10.1 below:

Table 10.1 Floodplain Management Measures

Structural Measures (Flood Modification)	Land Use Planning Measures (Property Modification)	Flood Emergency Measures (Response Modification)
Retarding Basins	Land Use Zoning	Community Awareness
Levees	Voluntary Purchase	Community Preparedness
Bypass Floodways	Building Lines	Flood Prediction and Warning
Channel Improvements	Floor Level Controls	Emergency Response Plans
Flood Gates		Emergency Recovery Plans
House Raising		Insurance
Flood Proofing Buildings		

Flood Modification Measures are a common and proven means of reducing damage to existing properties at risk. Property Modification Measures, such as effective land use controls, are essential if the growth in future flood damage is to be contained and managed. Response Modification Measures, such as flood awareness, are the most effective means of dealing with the continuing flood problem, which is the risk that remains from floods after other measures are in place.

A fundamental principle of sound floodplain management is that management measures should not be considered either individually or in isolation. They should be considered collectively so that their interactions, their suitability and effectiveness, and their social, ecological, environmental and economic impacts can be assessed on a broad basis.

The Nathalia Floodplain Management Plan needs to consider all three types of management measures and adopt an integrated and effective mix that is appropriate to the specific circumstances of the flood prone community. The options suggested to form part of the Floodplain Management Plan are summarised in Table 10.3 following the discussion.

The Floodplain Management Options discussed were developed by SMEC in co-operation with the Nathalia community through the information questionnaire. The priority of options put forward by the Community is summarised in Table 10.2 below. A full list of response is shown in Appendix E. These options were considered in the development of the overall floodplain management approach adopted in the resultant Floodplain Management Plan.

Table 10.2 Floodplain Management Measures

Mitigation Option	Priority (1 being highest 8 being the lowest)
Clear exotic vegetation from creeks and the floodplain	3
Increase the number of floodways i.e. create or re-establish old floodways or by-pass channels	1
Increase height and or increase number of levees or floodwalls	4
Flood proofing or raising of individual buildings	8
Improve management of land in floodplains i.e. remove levees	2
Planning controls for conversion of land to floodplain	5
Community education and awareness programs on how to respond during a flood	7
Implement flood warning systems	6

10.2 Flood Modification Measures

The purpose of flood modification measures is to modify the behaviour of a flood by reducing flood levels or velocities or by excluding floodwaters from areas at risk. Flood modification measures, by their structural nature, may have environmental and ecological impacts (positive or negative) and so any proposal for such works must be subject to strict and detailed assessment in accordance with the existing planning and assessment legislation.

10.2.1 Retarding Basins

A retarding basin is a small dam that provides temporary storage for floodwaters. It behaves in the same way as a flood mitigation dam, but on a much smaller scale. In urban areas, retarding basins are most suitable for small streams that respond quickly to rapidly rising flooding.

Retarding basins have a number of inherent disadvantages that must be carefully evaluated for each particular situation, for example:

- they require a substantial area to achieve the necessary storage;
- where they involve multi-purpose uses, safety aspects during flooding need to be addressed;
- long duration or multi-peak storms (when the basin is filled from a previous peak) can increase the risk of overtopping or breaching and the resulting hazard and damage;
- they may have adverse impacts on riparian vegetation and connectivity for some flora and fauna species;
- they may increase the duration of flows in the stream; and
- they provide little attenuating effect when overtopping occurs.

Retarding basins are not a viable flood modification measure when addressing the river-sourced flooding in Broken Creek. Accordingly retarding basins are not a recommended flood mitigation measure for the Broken Creek system. However, with suitable design that takes into account flooding, social, economic and environmental issues, may be appropriate for local runoff within town.

10.2.2 Levees

The Nathalia township is already protected by a levee system up to approximately a 20-year ARI flood event. Levees are frequently the most economically attractive measure to protect existing development in flood prone areas. The height or crest level of a levee is determined by a variety of factors including:

- the economics of the situation (including the nature of development requiring protection);
- the physical limitations of the site; and
- the level to which floods can rise relative to the ground levels in the area (important in safety considerations).

If a levee fails because of inadequate design, improper construction or poor maintenance, the money spent on its construction has largely been wasted and the flood damages that had been "saved" were, in all probability, significantly increased. Even if design, construction and maintenance is exemplary, all levees will ultimately be overtopped by an 'overwhelming' flood (unless designed for the Probable Maximum Flood event). It is not a question of if overtopping will occur, but of when and what the consequences will be.

In raising the levees to provide for greater flood mitigation, the following precautions need to be noted:

- the likelihood and consequences of catastrophic damage and unacceptable hazard levels when the levee is overtopped;
- appropriate design of the levee and provision of spillways to avoid uncontrolled high velocity flows or even failure when the levee is overtopped;
- proper maintenance of the levee crest level, grass cover and spillways, and the avoidance of damage from traffic or animals;
- development control measures for protected development behind the levee;
- provision for local runoff from behind the levee into the main stream;
- emergency response plans for levee overtopping and evacuation;
- analysis of flow conditions that may develop when overtopping occurs and the flood continues to rise. In some situations high hazard conditions can develop in protected areas;
- on-going community education to ensure that the population is aware of the risk of overtopping, is informed about emergency response plans and does not suffer a false sense of security simply because a levee has been constructed and raised; and
- levees may prevent the flow of water to valuable ecological areas, such as wetlands. The consequences of this need to be considered especially for threatened species and the ecological community as a whole.

Some of the foregoing precautions do not apply when the probable maximum flood is adopted as the design event for levees. In such cases, important factors to consider include the maintenance of the levee and the provision of adequate freeboard against wave action and subsidence.

The raising of levees may be a feasible option to increase the level of protection of the township of Nathalia however, they could have the following negative impacts:

- the raised levees could have to be very large earth and/or concrete structures that would cut the protected areas off from their view of the river and the floodplains;
- the cost of construction could outweigh the flood damages saved, reducing the economic return to minimal values;
- the construction could impact on the local infrastructure such as roads;

- should the levee fail or be overtopped, the flood level rise would be sudden and rapid and the cost impacts would be far higher than that currently estimated; and
- flood levels could be raised upstream of town which could impact on the rural areas.

With the above issues in mind levee raising is considered a viable management option for the Nathalia township and will be investigated further.

10.2.3 Bypass Floodways

Bypass floodways redirect a portion of the floodwaters away from areas at risk, and so reduce flood levels along the channel adjacent to the diversion. However, bypass floodways may exacerbate downstream flood problems.

The topography of the Broken Creek floodplain surrounding Nathalia has a number of bypass floodway options, the southern, western and northern floodway. All of these floodways are obstructed, to varying degrees by the local infrastructure. Figure 10.1 illustrates the location of these floodways. To reopen bypass floodways the following issues need to be considered:

- possible extensive (and expensive) purchase of land and the total disruption of existing land uses on the floodplain;
- the extraction of vast amounts of sand, soil and other material to create the new channel; and
- the subsequent destruction of large areas of existing vegetation, impacting on the existing environment.

With these issues in mind bypass floodways are considered a viable option for Nathalia and will be investigated further.

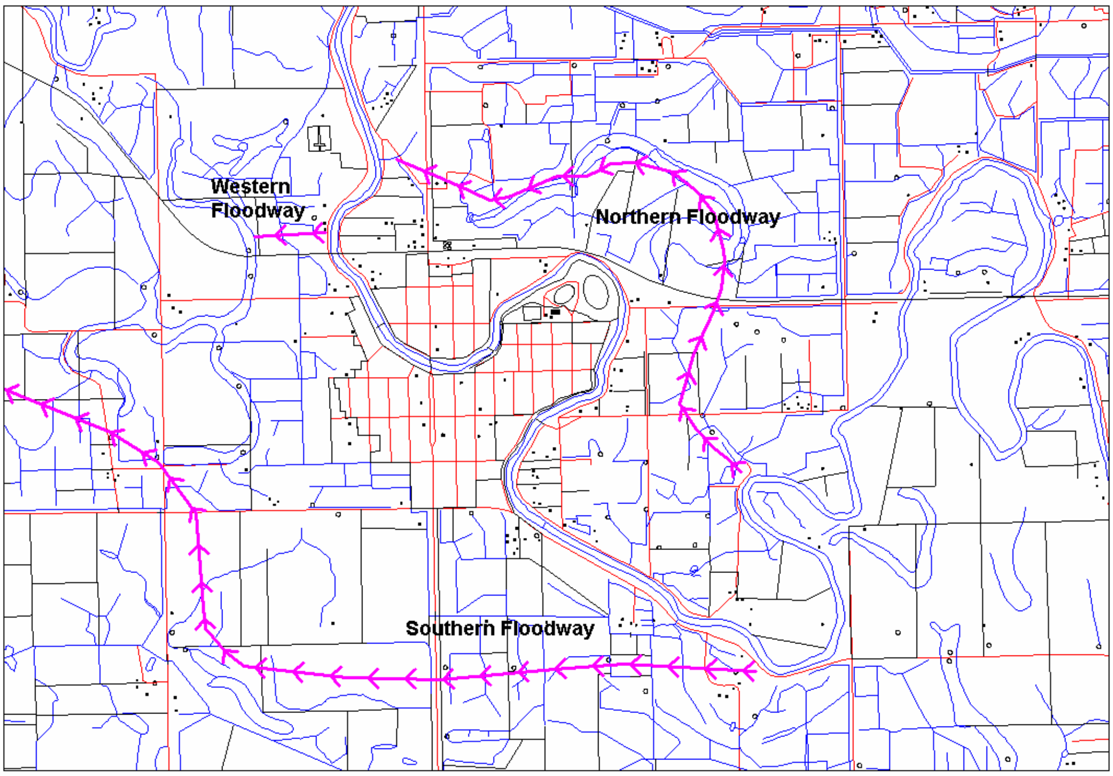

Figure 10.1: Location of Bypass Floodways

10.2.4 Channel Improvements

The capacity of a river channel to discharge floodwater can be increased by widening, deepening or re-aligning the channel, and by clearing the channel banks and bed of obstructions to flow. The effectiveness of channel improvements depends upon the characteristics of the river channel and the river valley.

As a mitigation measure, channel improvements have several potential disadvantages. First, they facilitate the transfer of floodwaters downstream and can accentuate downstream flooding problems. Other disadvantages include the cost of maintenance, the potential to adversely impact on natural channel morphology, the destruction of riverine habitat and the visual impact of replacing naturally varying channel sections with a section of more uniform geometry.

Channel improvements are likely to be most effective (including reducing the need for other structural works) on steeper smaller streams with overgrown banks and narrow floodplains. Channel improvements would have a minimal effect in flooding situations where there are extensive areas of over bank flooding, such as at Nathalia.

Accordingly, it is recommended that channel improvement works do not form part of a Floodplain Management Plan for Nathalia and surrounds.

10.3 House Raising and Flood Proofing

10.3.1 Basis for House Raising and Flood Proofing

House raising achieves three important objectives:

- a reduction in personal loss;
- a reduction in risk to life and limb and in the costs of servicing isolated people who remain in their homes to protect possessions; and
- a reduction in stress and post-flood trauma.

Not all houses are suitable for raising. Houses of single or double brick construction or slab-on-ground construction are generally either impossible or very expensive to raise, however the decision on this latter issue is very site specific. The principal issues to be addressed with such houses are the quality of the foundations and the state of the brickwork. Houses best suited to raising are timber-framed and clad with non-masonry materials.

While raising a house may achieve the objectives described previously, care must be exercised in implementing this measure by considering the implications of a slightly higher than design flood. The new construction may be isolated for long periods during floods, necessitating an increased load on emergency services should they be required. The isolated house would also have to be capable of self-support during flooding, e.g. adequate food supplies must be stocked. Thus, it is essential that both the benefits and disadvantages of house raising are considered in the floodplain management planning process and any subsequent community education campaign.

Another method for reducing flood damage, particularly in two-storey houses or where flood levels are low, is to flood proof the residence through structural adjustment to the existing walls, doors, etc.

With either method, or when a two-storey house is required by the development controls, it is standard practice to have non-habitable rooms on the lower level. This not only limits flood damage, it obviates the need for moving furniture or other bulky goods during the onset of a flood. It is essential that this practice be enforced and, where open spaces are filled, that Council ensures that such action will not be detrimental to adjoining properties.

10.3.2 Nathalia Township

Given the nature of flooding in Nathalia i.e. for the 100-year ARI event the levees are breached house raising and flood proofing will likely be expensive and extensive. Within Nathalia a total of 515 residential and 93 commercial properties are inundated during a 100-year ARI event. In other words for the 100-year ARI event a large number of residences within town are inundated. With this in mind this option will be investigated further to determine if it is viable or not.

In any case, the decision on whether house raising or flood proofing will be implemented must be assessed on the merits of each case. Such an assessment will include detailed internal and external examination, a structural examination and a check of whether any lower storey rooms are habitable. Any illegal development, such as habitable lower storey rooms contrary to development approval, will need to be addressed before implementation of the scheme.

10.4 Property Modification Measures

10.4.1 General

Planning controls and building regulations provide mechanisms for ensuring suitable use of land and building construction given the physical constraints of flooding from rivers and streams. To address these issues the State Government has introduced a consistent planning scheme across the State named, The Victoria Planning Provisions (VPPs).

In Victoria, there are Building Regulations which specify that floor levels should be 300mm above the 100-year ARI flood. If the 100-year ARI flood has not been determined for a particular area a level is nominated by the floodplain management authority usually on the basis of historical flood events. If land is subject to flooding, the council may set conditions that require particular types of construction or particular types of construction material.

10.4.2 Victoria Planning Provisions

The VPP aims to achieve consistency in the application of planning controls for areas subject to flooding throughout the state of Victoria. The stated aims are to protect life, property and community infrastructure from flood hazard, and to preserve flood conveyance, floodplain storage and areas of environmental significance.

Under the VPP there is provision for overlays associated with mainstream flooding which is relevant to Nathalia, these are:

- Land Subject to Inundation Overlay (LSIO),
- Floodway Overlay (FO)
- Urban Floodway Zone (UFZ)

Generally the LSIO identifies land in flood storage or flood fringe areas which are subject to inundation during a 100-year ARI event, or some other nominated flood if the 100-year ARI flood has not been determined. For Nathalia the 100-year ARI flood has been adopted to delineate the LSIO.

The floodway zone and overlay (UFZ and FO) identify main flood paths and flood storage areas and/or flood prone areas which are high hazard. Such areas are usually areas with significant flood depths and/or velocities, frequent flooding, or are important for conveying significant flood flows or storing significant flood volumes.

In general, development within flood affected areas should be regulated by the system of building and planning permits. All floor levels should be set at least 300mm above the nominated building, works and structures within floodways should be discouraged by the relevant planning authorities, in this case Moira Shire Council. The Moira Shire Council may specify exemptions in some instances, for specific conditions which apply to the locality.

The VPP detail for each overlays the appropriate types of land uses and developments which are to be regulated through a system of permits.

The VPP also stipulate numerous decision guidelines that must be considered by the responsible authority, Moira Shire Council, when deciding on applications for permits. For UFZ and FO, unless the Moira Shire has adopted a local floodplain development plan, the applicant is required to prepare a flood risk report. This report is to help identify the flood impacts at the site and on the adjoining areas. The flood risk report (or the local floodplain development plan where applicable) is incorporated into the decision guidelines.

For LSIO a flood risk report is not required. However, the Moira Shire is required to assess each application having regard to the same considerations required for the flood risk reports for the floodway zone and overlay, and the application has to be consistent any local floodplain development plan approved for the area.

Applications must be referred to the relevant floodplain management authority, is this instance the Goulburn Broken Catchment Management Authority for independent assessment.

10.4.3 Planning Controls for Nathalia

Flood delineation option maps have been produced to assist Moira Shire Council (MSC) and the Goulburn Broken Catchment Management Authority (GBCMA) in the definition of land use flood zones and overlays, and the designation of flood levels. These maps have been prepared for existing conditions for Nathalia. From these maps MSC and GBCMA have developed the planning maps in accordance with the VPP. The planning map has been included in a separate volume with an A3 copy included in Appendix C. The flood mapping from this study should be used to update the Moira Planning Scheme.

10.4.4 Building Regulations on the Floodplain

Building development on floodplains must be managed in a controlled and coordinated way to maintain the natural flow patterns and the environmental values of the floodplains but also to minimise the risk to life, health and safety of occupants. In general any building development on the floodplain requires a planning permit from the Moira Shire Council. These are broken down into two main categories, residential buildings and commercial/industrial buildings. There are a few exemptions from planning permits which are detailed in the VPP.

Residential Buildings

All new residential dwellings and extensions must be built at least 300mm above the 100-year ARI flood level. For extensions that are permitted to be built at the existing floor level, the building permit should require water resistant materials are to be used up to 300mm above the 100-year ARI flood level or to a level specified by the floodplain management authority.

Generally the floodplain management authority will be required to provide flood level advice, although for some areas MSC can perform this role in accordance with written agreement between the MSC and GBCMA or by Local Floodplain Development Plans.

Commercial and Industrial Buildings

To allow buildings to be constructed in land liable to flooding, municipal councils must comply with Regulations 6.2 (4) of the Building Regulations, 1996. This requires the relevant municipal council to refuse consent unless there is no significant danger to life, health or safety of the occupants of the buildings due to flooding of the site.

Wherever possible buildings should be located on flood free land. However there are instances where this is not possible. In such cases buildings should be located as far as practicable on land where the risk of property damage and harm to occupants is low, and where building development has minimal impacts on adjoining properties. Generally, the minimum floor level of industrial and commercial buildings shall be at least 300mm above the 100-year ARI flood level.

There are some instances where relaxing this floor level requirement is warranted. However, these instances are assessed on a case by case basis, in conjunction with the GBCMA.

10.5 Voluntary Purchase

In certain high hazard areas of the floodplain, it may be impractical or uneconomic to mitigate flood hazard to existing properties at risk, or flood modification measures may significantly increase hazard to a property unable to be protected. In such circumstances it may be appropriate to cease occupation of such properties in order to free both residents and potential rescuers from the danger and cost of future floods.

This is generally achieved by the purchase of the properties and their removal or demolition as part of a floodplain management plan. Under such circumstances, the property should be purchased at an equitable price (a price that reflects the value of the property without flood prone encumbrance) and only where voluntarily offered. Such areas should ultimately be rezoned to a flood compatible use. However, special treatment may be required if the property is constrained by orders such as a Heritage Listing and suitable uses may have to be determined for these properties that satisfy the general objectives of the Floodplain Management Plan.

In consideration of a voluntary purchase scheme, it is relevant to understand the social and economic costs of flooding on those in areas of high flood impact to ascertain whether this measure provides the optimum flood plain management solution.

10.6 Response Modification Measures

10.6.1 General

Response modification measures encompass various means of modifying the response of the community to the flood threat. Such measures include flood warning, plans for the defence and evacuation of an area, for the relief of evacuees and for the recovery of the area once the flood subsides. Planning for these measures is incorporated as part of the Municipal Emergency Management Plan in the Flood Sub-Plan (2002) for the area.

The importance of flood preparedness and response measures has become apparent in recent years, and was confirmed by the Victorian floods of 1993. Unless the probable maximum flood is adopted as the design flood, all flood and property modification measures will ultimately be overwhelmed at some time by a flood larger than that designed for. The development and implementation of effective response plans are a significant means of reducing flood related damages.

Response measures, such as flood warning and evacuation procedures, can be of substantial benefit in their own right. Flood warning and evacuation plans can be very cost effective. In fact, they may be, in some cases, the only economically justified management measures.

The Moira Shire Flood Sub-Plan (2002) states a Flood Plan Sub Committee will be made up of representatives from the following agencies and organisations:

- Moira Shire
- The Victoria Police
- The Victoria State Emergency Service
- The Goulburn Murray Water Authority
- The Lower Goulburn Catchment Management Authority
- The Country Fire Authority
- Community Representatives (1 per area)

10.6.2 Flood Warning

The purpose of flood warning is to enable and persuade the community to take the appropriate actions to increase safety and reduce the damages associated with flooding. When properly developed and communicated, accurate and timely flood warnings are one of the most effective tools in the management of flooding, the reduction of damage and the maintenance of safety of the community.

Flood Warning (Australian Emergency Manuals Series, Volume 3, Guide 5, Emergency Management Practice Guidelines) describes a Total Flood Warning System, comprising the following stages:

- Prediction of flood severity and time of onset of particular levels of flooding;
- Interpretation of the prediction to determine flood impacts on the community
- Construction of warning messages describing what is happening, the expected impact and what action should be taken;
- The dissemination of such messages;
- Response to the warnings by the agencies involved and the community; and
- Review of the warning system after flood events.

These components, as they apply to the Nathalia, are discussed below and recommended actions within the Floodplain Management Plan are highlighted.

The Bureau of Meteorology is the lead agency in the provision of flood warning services to Nathalia. Where the Bureau of Meteorology believes weather patterns show a potential for flooding, Flood Watches will be issued. Where the flood data collection network shows flooding is imminent a Flood Warning will be issued. For the purposes of dissemination, both Flood Watches and Flood Warning will be treated as flood warning. Apart from the normal media announcements, warnings are transmitted to a range of Government Agencies, Police, Local Government and the State Emergency Service. These bodies in turn further disseminate the information to local organisations and groups.

A flood warning issued by the Bureau of Meteorology will outline the likely indicative flooding consequences. For each flood warning a flood warning category is issued in terms of minor, moderate or major. The definitions of the flood warning categories are as follows:

Minor Flooding – Causes inconvenience. Low lying areas adjacent to watercourses are inundated requiring the removal of stock and equipment. Minor roads may be closed and low level bridges submerged.

Moderate Flooding – In addition to the above, may necessitate the evacuation of some houses. Main traffic routes may be covered and the area of inundation is substantial in rural areas.

Major Flooding – In addition to the above, causes inundation of extensive rural areas and appreciable urban areas. Properties and towns are likely to be isolated and major traffic routes closed. Large numbers of evacuations may be required.

For the Nathalia township the Moira Shire Flood Sub-Plan (2002) provides the following advice on trigger data flood levels for the township of Nathalia. The Flood Sub-Plan (2002) states that, the key guide to flooding at Nathalia is at Walsh's Bridge. The only key reading given at Walsh's Bridge is for the 1993 flood of 104.45 metres. This is stated as approximating the 100-year ARI event. It is also stated that the Nathalia gauge usually peaks about 2 days after Walsh's Bridge and "major event readings for this gauge in the past are, 1993 Flood 102.08 metres which approximates the 100-year ARI flood level at this location."

As discussed in Section 7 the flood inundation mapping for flood response have been prepared for the 5, 10, 20, 50, 100 and 500-year ARI flood events. From Table 7.1 the gauge heights at Walsh's Bridge vary from 2.96m to 3.79m for the 5 to 500-year ARI flood events. Table 10.3 outlines the flood behaviour, properties and infrastructure affected for a range of gauge heights up to the gauge height of 3.63m (100-year ARI). Figure 10.2 shows the locations of the areas identified in Table 10.3.

The Bureau of Meteorology has reported that a flood event in 1995 on the Broken Creek should be classified as a moderate event. The level which was reported at Walsh's Bridge for this event was 2.58m, which according to the hydraulic modelling is less than a 5-year ARI event. SMEC has chosen the 20-year ARI event as the trigger for a major event as this is when the levees at Nathalia would be under treat of overtopping. A minor event has been taken as the level when flood waters would be over topping the river bank at Walsh's Bridge. Using the definition of the flood warning categories outlined above, SMEC recommends the following trigger levels at Walsh's Bridge:

- Minor: 1.5m
- Moderate: 2.58m
- Major: 3.34m

With in the Broken Creek system, upstream of Nathalia, there are currently stream gauges at Tungamah, Katamatite and the Broken Creek (channel) at Casey Weir. Also there are manually read flood level gauges at Walsh's Bridge and Nathalia upstream of the Murray Valley Highway Bridge.

Historically there have been two different flow regimes which have resulted in flooding at Nathalia. In 1974, more of the flow was reported to have derived from the upper Broken Creek catchment passing down Boosey Creek, an anabranch of the Broken Creek, through Tungamah. In 1993 more of the flood flow at Nathalia was derived from the breakaway flows from the Broken River which arrived down Pine Lodge Creek, Congupna Creek and the Broken Creek.

Past arrangements has generally relied on Goulburn-Muray Water to manually read streamflow gauges within the Broken Creek catchment as data in currently not available remotely. However, future arrangements are unlikely to continue, particularly as Goulburn-Murray Water is not responsible for the collection or the dissemination of flood warning data.

The streamflow gauges on the Broken Creek at Katamatite and Boosey Creek at Tungamah could be telemetered (preferably using Event Reporting Real-time Telemetry (ERTS)) which would provide advanced flood warning capability to Walsh's Bridge gauge (which should also be telemetered) and subsequently Nathalia. Access to real time streamflow data for these sites is important given that there are two clearly different mechanisms for flooding.

Broken Creek at Nathalia would also benefit from upgrade to ERTS to verify relationship between the Walsh's Bridge and Nathalia streamflow gauges.

The recommendations for the warning process are:

- Undertake a calibration of the Casey Weir gauge during a large flow event.
- Replace existing flood level boards at Walsh's Bridge and Nathalia with a single flood level gauge. Also places the flood boards downstream of Walsh's Bridge.
- Add a telemetry (ERTS) stream gauge and link to the Bureau of Meteorology at the following sites:.
    - Broken Creek at Nathalia (optional)
    - Broken Creek at Walsh's Bridge
    - Broken Creek and Katamatite
    - Boosey Creek at Tungamah
- Telephone alerting arrangements to communicate impending floods to the affected community (Expedite System as used for Benalla and Shepparton-Mooroopna.
- Develop and prepare flood education information and community flood response guidelines.

The capital cost for ERTS stream gauge installations at the above three sites require approximately $40,000 and approximately $4,000 per annum for maintenance costs. Based on preliminary advice from Thiess Services, the description of the existing site and upgrade and maintenance costs are detailed as follows:

Broken Creek at Katamatite

Capital

The site currently monitors both river level and rainfall. Proposed to install a separate water level monitoring encoder and connect to the existing rain gauge. The upgrade of the site is to include ERTS canister, mast, aerial, solar panel, encoder and all other associated materials for the flood alert site. Capital cost **$9,250**

Annual Recurrent

This is an approximate Operation & Maintenance cost over and above the current costing for this site. If eventually included in the DSE contract (i.e. the regional partnership contract) this figure will need to be looked at from that point of view. In any case this figure could be regarded as the maximum. O&M cost **$611 per annum**

Boosey Creek at Tungamah

Capital

The site currently monitors both River level and Rainfall. We propose to install a separate water level monitoring encoder and connect to the existing rain gauge. The upgrade of the site is to include EERTS canister, mast, aerial, solar panel, encoder and all other associated materials for the flood alert site. Capital cost **$9,250**

Annual Recurrent

This is an approximate Operation & Maintenance cost over and above the current costing for this site. If eventually included in the DSE contract this figure will need to be looked at from that point of view. In any case this figure could be regarded as the maximum. O&M cost **$611 per annum**

Broken Creek at Walsh's Bridge

The site currently consists of a bank of staff gauges only. (No instrumentation for recording of water level or rainfall.) It is proposed to install water level instrumentation housed in a concrete shelter for protection from anticipated vandalism. As this is also a low lying area, we have included costs to raise the shelter approximately 500mm above natural surface level to keep instrumentation above any likely flood level. This site will be used to collect data on water level only.

The CMA should note that due to the general conditions and characteristics of this waterway and proposed site, with its numerous variable controls, seasonal variations in vegetation within the waterway and minimal grade, the development of a stable stage discharge would not be possible. If flow is required we would need to consider the quite expensive and somewhat 'fragile' (in some instances) option of direct velocity measurement at the site. However as it is proposed for flood warning only, this may not be of concern.

Capital

As indicated above, it is proposed to install a raised walk-in concrete instrument housing to secure instrumentation and equipment including an ERRTS canister, water level transducer (model 6100 Gas System) and dry bubbler system. The costing also includes a solar panel, aerial mast and all other associated materials for a flood alert site. Capital cost **$16,560**

Annual Recurrent

This is an approximate Operation & Maintenance cost for this site. If eventually included in the DSE contract, this figure will need to be looked at from that point of view. In any case this figure could be regarded as the maximum. O&M cost **$2,510 per annum**

Total Capital (Three sites)	**$35,060**
Total Annual Recurrent (Three sites)	**$3,732**

In the past funding for flood warning capital has been provided equally by the Australia and State governments with the on-going maintenance provided from the local beneficiaries, via local municipalities or CMAs.

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Table 10.3: Flood Behaviour in Nathalia for a Range of Gauge Heights At Walsh's Bridge

Gauge Height at Walsh's Bridge	Flood Behaviour and Properties/Infrastructure Affected							
	1) Start of Levee Approximately 300m south of Nathalia Weir	**2) Southern End of Barry Street**	**3) Northern End of Bindon Street**	**4) Northern End of Mitchell Street**	**5) Western End of North Street**	**6) Railway Street**	**7) Murray Valley Highway (Southern)**	**8) Murray Valley Highway (Northern)**
2.96m (5-year ARI)	Water level approximately 400mm below low point in levee. No flooding of town	Water level approximately 500mm below low point in levee. No flooding of town	Water level approximately 500mm below low point in levee. No flooding of town. Show ground reserve inundated	Water level approximately 400mm below low point in levee. No flooding of town. Buildings located in the floodplain to the north of levee are inundated. Access to these buildings is also inundated	Water level approximately 380mm below low point in levee. No flooding of town	Levee needs to be closed with road inundated to a depth of approximately 50mm. Water level approximately 490mm below low point in levee. No flooding of town	Water level below high ground along Weir street, monitor situation	Levee needs to be closed with the Highway inundated to a depth of approximately 700mm

Table 10.3 (cont.): Flood Behaviour in Nathalia for a Range of Gauge Heights At Walsh's Bridge

Gauge Height at Walsh's Bridge	Flood Behaviour and Properties/Infrastructure Affected							
	1) Start of Levee Approximately 300m south of Nathalia Weir	**2) Southern End of Barry Street**	**3) Northern End of Bindon Street**	**4) Northern End of Mitchell Street**	**5) Western End of North Street**	**6) Railway Street**	**7) Murray Valley Highway (Southern)**	**8) Murray Valley Highway (Northern)**
3.18m (10-year ARI)	Water level approximately 170mm below low point in levee. No flooding of town	Water level approximately 240mm below low point in levee. No flooding of town	Water level approximately 210mm below low point in levee. No flooding of town. Show ground reserve inundated	Water level approximately 140mm below low point in levee. No flooding of town. Buildings located in the floodplain to the north of levee are inundated. Access to these buildings is also inundated	Water level approximately 110mm below low point in levee. No flooding of town	Levee needs to be closed with road inundated to a depth of approximately 300mm. Water level approximately 230mm below low point in levee. No flooding of town	Water level starting to threaten weir street, monitor situation	Levee needs to be closed with the Highway inundated to a depth of approximately 1000mm

Table 10.3 (cont.): Flood Behaviour in Nathalia for a Range of Gauge Heights At Walsh's Bridge

Gauge Height at Walsh's Bridge	Flood Behaviour and Properties/Infrastructure Affected							
	1) Start of Levee Approximately 300m south of Nathalia Weir	**2) Southern End of Barry Street**	**3) Northern End of Bindon Street**	**4) Northern End of Mitchell Street**	**5) Western End of North Street**	**6) Railway Street**	**7) Murray Valley Highway (Southern)**	**8) Murray Valley Highway (Northern)**
3.34m (20-year ARI)	Water level approximately 50mm below low point in levee. No flooding of town however situation would need to be monitored with sand bags required.	Water level approximately 130mm below low point in levee. No flooding of town	Water level approximately 100mm below low point in levee. No flooding of town. Show ground reserve inundated	Water level approximately 40mm below low point in levee. No flooding of town however situation would need to be monitored with sand bags required. Buildings located in the floodplain to the north of levee are inundated. Access to these buildings is also inundated	Water level approximately 50mm below low point in levee. No flooding of town however situation would need to be monitored with sand bags required.	Levee needs to be closed with road inundated to a depth of approximately 400mm. Water level approximately 140mm below low point in levee. No flooding of town	Water level beginning to overtop weir street, monitor situation with sand bags required.	Levee needs to be closed with the Highway inundated to a depth of approximately 1050mm

Table 10.3 (cont.): Flood Behaviour in Nathalia for a Range of Gauge Heights At Walsh's Bridge

Gauge Height at Walsh's Bridge	Flood Behaviour and Properties/Infrastructure Affected							
	1) Start of Levee Approximately 300m south of Nathalia Weir	**2) Southern End of Barry Street**	**3) Northern End of Bindon Street**	**4) Northern End of Mitchell Street**	**5) Western End of North Street**	**6) Railway Street**	**7) Murray Valley Highway (Southern)**	**8) Murray Valley Highway (Northern)**
3.51m (50-year ARI)	Levee overtopped. Southern section of town inundated up to approximately 1m	Water level at top of levee. Sand bagging required	Water level at top of levee. Sand bagging required. Show ground reserve inundated	Levee overtopped. Southern section of town inundated up to approximately 1m	Water level approximately 20mm below low point in levee. No flooding of northern section of town however situation would need to be monitored with sand bags required.	Levee needs to be closed with road inundated to a depth of approximately 500mm. Water level approximately 50mm below low point in levee No flooding of northern section of town however situation would need to be monitored with sand bags required.	Water level overtopping Weir Street. Southern section of town inundated up to approximately 1m	Levee needs to be closed with the Highway inundated to a depth of approximately 1100mm

Table 10.3 (cont.): Flood Behaviour in Nathalia for a Range of Gauge Heights At Walsh's Bridge

Gauge Height at Walsh's Bridge	Flood Behaviour and Properties/Infrastructure Affected							
	1) Start of Levee Approximately 300m south of Nathalia Weir	**2) Southern End of Barry Street**	**3) Northern End of Bindon Street**	**4) Northern End of Mitchell Street**	**5) Western End of North Street**	**6) Railway Street**	**7) Murray Valley Highway (Southern)**	**8) Murray Valley Highway (Northern)**
3.63m (100-year ARI)	Levee overtopped. Southern section of town inundated up to approximately 1.2m	Levee overtopped. Southern section of town inundated up to approximately 1.2m	Levee overtopped. Southern section of town inundated up to approximately 1.2m. Show ground reserve inundated	Levee overtopped. Southern section of town inundated up to approximately 1.2m	Levee overtopped. Northern section of town inundated up to approximately 1.2m	Levee needs to be closed with road inundated to a depth of approximately 640mm. Levee overtopped. Northern section of town inundated up to approximately 1.2m	Water level overtopping Weir Street. Southern section of town inundated up to approximately 1.2m	Levee needs to be closed with the Highway inundated to a depth of approximately 1200mm

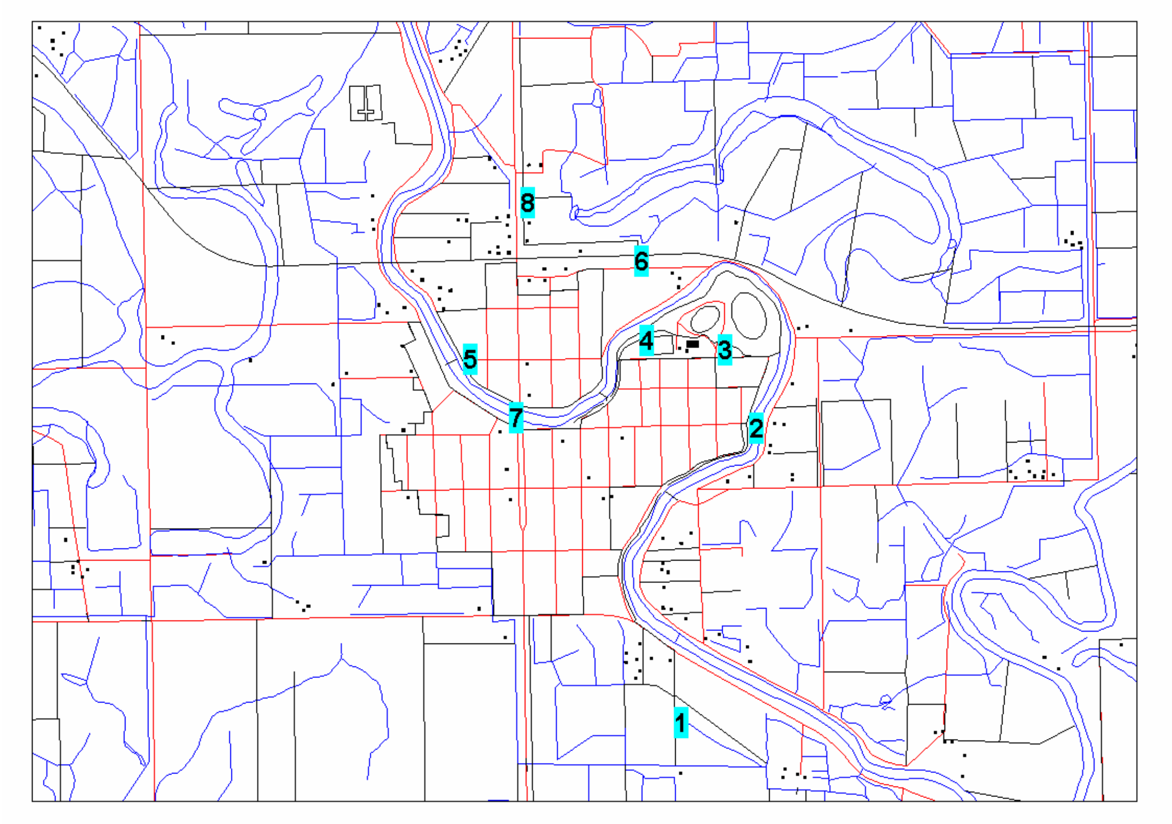


Figure 10.2: Locations of Areas Mentioned in Table 10.3

10.6.2.1 Construction of warning messages

A "warning message" converts the technical information of the prediction and its interpretation into news and advice for the community at risk. It is the critical step between flood prediction and interpretation on the one hand and protective action by the community.

Flood warning provides a guide for effective message design, the message should:

- describe the flood;
- say what is happening currently, what is expected to happen and when it will occur; and
- indicate how people should act.

It is also essential that Council works in co-operation with the SES in the design of the messages.

10.6.2.2 The dissemination of messages

The Moira Shire Flood Sub-Plan (2002) provides a number of points for the dissemination of flood warnings. These are as follows:

- Routine flood warnings and updates, as issued by the Bureau of Meteorology, will be disseminated by the Victorian SES North East Region
- Moira Shire will develop a distribution list to enable broadcast fax forwarding of information as required throughout the Shire
- Information and reports from the public and other agencies must be recorded and passed directly to Incident Controller at the Municipal Emergency Coordination Centre (MECC) for collation, confirmation and response
- Regular reports will be issued to the Public Information Centre

- The Public Information Centre will be located at various Moira Shire Centres depending on the nature and location of the event
- Moira Shire shall staff and manage the Centre, prepare public information material and attend to public enquires
- VICSES will attend to Media needs in conjunction with Moira Shire and the Victorian Police
- The Centre will send public advice/relevant reports to the MECC
- Public information bulletins are to be prepared and printed for handing out to the community and rural areas of Moira Shire
- Moira Shire Staff will be tasked to contact/door knock residents that may be in flood prone areas and keep them informed of the situation either verbally or via news letters
- Moira Shire will arrange for the installation of dedicated tape message answering machines at the Cobram Service Centre during an emergency to provide up to date Public Information on the emergency.

Two general categories describe message dissemination methods, general and specific. General methods are usually the “mass media”, in particular the broadcast media. Specific methods provide information and warnings to particular, pre-identified individuals, groups or organisations. These two methods should be complementary, with specific warnings reinforcing the general.

An issue facing the community of Nathalia in message dissemination is the ability to make the best use of the broadcast media, particularly radio and television. Radio station ABC has a specific arrangement to broadcast flood information in the event of a significant flood. Television in Nathalia is sourced from the major networks and it is likely that the SES could have difficulty in arranging a break in to the networks to broadcast the warning messages.

As indicated above, specific messages must be used to complement the general messages that are sent on the broadcast media. This is very labour intensive with the responsibility of this task stated as Moira Shire staff in the Flood Sub-Plan (2002). It is essential that each the Moira Shire and the VICSES co-ordinate their resources with a data folder, held in the VICSES office and the Moira Shire office, that defines the duties and tasks of each organisation and details properties to be contacted. It is essential that these folders are kept as up-to-date as possible and that the residents with special needs are noted.

While a personalised system may be successful in relatively low floods there always remains the risk that, when a major flood occurs, the personalised system will fail and there is a need to ensure back-up procedures and even redundancy in the process. The warning message must get through. The added complication with Nathalia is once the levees are breached there is a risk of the whole town being inundated during a 100-year ARI flood.

10.6.2.3 Flood Response

Flood response refers to activities to be undertaken when flooding is likely to occur. The main tasks and responsibilities for these tasks are provided in Table 10.4 below.

Table 10.4: Flood Response – Tasks and Responsibilities

Main Task	Responsibility: Municipal Level	Responsibility: Regional Level
Erect barriers, signs, close roads and highways	Moira Shire Victoria Police VicRoads	VicRoads
Evacuation	Police in consultation with Control Agency (VICSES) and Moira Shire	Police
Managing Welfare Centres	Moira Shire	VICSES
Rescue	Police & VICSES	Police & VICSES
Advice on drainage and pumping	Moira Shire	Goulburn-Murray Water
General assistance to Public e.g. Sandbagging, lifting furniture etc. (Subject to available resources)	VICSES local units and Moira Shire	VICSES
Media Releases	VICSES Police Moira Shire	VICSES Police

The VICSES is the designated control agency for response to floods within the State. VICSES will control all flood response activities within the Moira Shire.

VICSES, Municipal Emergency Response Coordinator and the Municipal Emergency Resources Officer will meet at designated times during the flood events to discuss the ramifications of warnings and to plan appropriate actions.

At the request of the Municipal Emergency Resources Officer, VICSES Controller or the Municipal Emergency Response Coordinator, the Municipal Emergency Coordination Centre will be opened.

The primary support agencies for flood events will be the Moira Shire, Victoria Police, Bureau of Meteorology, Goulburn-Murray Water, Goulburn Broken Catchment Management Authority and the Country Fire Authority, however all agencies named in the Flood Sub-Plan (2002) may be asked to provide assistance.

To ensure effective control is maintained, agencies directly supporting the response effort must advise VICSES of all relevant information, all requests for assistance received and directly by them and accept the overall direction of VICSES.

VICSES, Police and the Municipal Emergency Resources Officer will identify the need to evacuate any residents in flood threatened areas. Victoria Police and VICSES will implement the evacuations, assisted by other agencies on a needs basis. Moira Shire will manage welfare centres, supported by VICSES.

SMEC recommends the flood inundation maps for emergency response, as discussed in Section 7, be incorporated into the Moira Shire Flood Sub-Plan (2002) together with Table 10.2 and Figure 10.2. The emergency response flood inundation maps provide details of the flood behaviour and flood affected properties for a range of gauge heights at Walsh's Bridge.

10.6.2.4 Review of the warning system after flood events.

A post-flood review of the warning system and the response of all parties is an essential part of an effective floodplain management plan. Its aim is not to criticise or shift blame for problems that may arise. Rather, the purpose of the review is to allow constructive discussion of issues and to seek and implement improvements in the existing plans.

10.6.3 Community Awareness and Preparedness

A first step towards modifying the community's response to a flood event is to ensure that the community is fully aware that floods are likely to interfere with normal activities in the floodplain. This must be done purposefully because awareness of flooding and its consequences cannot be assumed.

Flood awareness can be enhanced by various simple means such as

- advice about flooding to ratepayers and tenants/residents from time to time;
- articles in local newspapers;
- displays of flood photographs and newspaper articles in the Council Chambers or in shopping centres;
- videos of historic floods in the area; and
- erecting signs showing where flood waters have come to in previous flood events.

The major factor determining the degree of flood awareness of a community is usually the frequency of moderate to large floods in the recent history of the area. The more recent the flooding, the greater the community flood awareness is likely to be.

Even when residents have a high level of flood awareness, such as at Nathalia, there will always be people moving into an area who have not experienced flooding even in the areas from which they originated. Such people must be expected to be unaware of basic flood preparedness activities as well as of the nature of the flood hazard in their new location. Awareness raising activities must be devised to ensure that the newcomers become aware and the long-term residents do not forget. These activities must be repeated from time to time to maintain consciousness of the hazard.

Sustaining an appropriate level of flood awareness is not easy. It involves a continuous effort by Council in cooperation with the VICSES.

Community awareness of floods needs to be used to create community preparedness for floods. Effective flood plans need to be developed, and the community must be made aware - and remain aware - of the role of each individual in mitigating flood impacts.

Flood preparedness is the ability of flood-affected people to defend their communities from flood threat and to minimise the flood damages, both actual and potential, by appropriate preparatory and evacuation measures. Preparedness involves deciding, or at least considering, what goods and possessions to move, and how, and where to put or take them.

It is important that preparation should not be solely for the more common and/or less severe floods. The community needs also to be prepared for the flood that is quite outside the experience of anyone in the floodplain. Eventually, there will be a flood which overwhelms the access routes used at flood time, overtops levees which have not been overtopped before and which inundate areas, both rural and urban, that have not previously been affected.

Strategies to facilitate community education and awareness raising need to be implemented on a systematic basis and targeted towards particular sections of the community, with a focus on commercial property owners, affected residents and school children.

Although regular newspaper features and general information circulation are important, these traditional approaches have been found to be wanting in the past.

It is recommended that a systematic flood awareness strategy be implemented, having regard to the following potential initiatives:

- Development of a local schools campaign, run at both primary and high school level
- Occasional major events, possibly around the anniversary of a major flood. Such events have been very successful elsewhere and provide an opportunity for a multi-faceted approach, which could include an ‘awareness day/week’, parade or festival, competitions and general information distribution
- Some focus on property management initiatives, for both commercial and residential properties, including the development of flood plans for individual properties, flood proofing initiatives for commercial properties and review of property safety (eg under-house wiring problems).

In the Moira Shire Flood Sub-Plan (2002) it is mentioned that the Moira Shire supports pro-active community education and awareness programs.

10.6.4 Flood Recovery

Flood recovery activities commence when people, property or the community are affected by flooding. The main tasks and responsibility for flood recovery are provided in Table 10.5 below.

Table 10.5: Flood Recovery – Task and Responsibilities

Main Tasks	Responsibility	
	Municipal Level	Regional Level
Temporary Accommodation	Moira Shire	Dept. Human Services
Emergency Grants	Dept. Human Services	Dept. Human Services
Establish centre for recovery information and services	Moira Shire	Dept. Human Services
Maintain continuous updates on flood information and recovery	Moira Shire	

In general, the recovery arrangements detailed in the Municipal Emergency Management Plan will be applied to flood events.

10.6.5 Recommended Revisions to Flood Sub-Plan for Nathalia

This section details the recommendations for Nathalia arising from the review of the Moira Shire Flood Sub-Plan (2002). In general this document should be reviewed and updated annually.

Flood Warning

SMEC recommends that the following trigger levels are included for the township of Nathalia. With the levels shown at Walsh's Bridge:

- Minor: 1.5m
- Moderate: 2.58m
- Major: 3.34m

The recommendations for the warning process are:

- Undertake a calibration of the Casey Weir gauge during a large flow event.
- Replace existing flood level boards at Walsh's Bridge and Nathalia with a single flood level gauge. Also places the flood boards downstream of Walsh's Bridge.
- Add a telemetry (ERTS) stream gauge and link to the Bureau of Meteorology at the following sites:.
    - Broken Creek at Nathalia (optional)
    - Broken Creek at Walsh's Bridge
    - Broken Creek and Katamatite (streamflow and rain gauges already operating)
    - Boosey Creek at Tungamah (streamflow and rain gauges already operating)
- Telephone alerting arrangements to communicate impending floods to the affected community (Expedite System as used for Benalla and Shepparton-Mooroopna.
- Develop and prepare flood education information and community flood response guidelines.

The capital cost for all the above flood warning arrangements would require approximately $60,000 and approximately $5,000 per annum for maintenance costs. In the past funding for flood warning capital has been provided equally by the Australia and State governments with the on-going maintenance provided from the local beneficiaries, via local municipalities or CMAs. Note Nathalia gauge would require additional capital of $17,000 and $2,500 for annual maintenance.

Dissemination of Flood Warning

In general the flood warning dissemination detailed in the Moira Shire Flood Sub-Plan is adequate. However, it is recommended that dissemination channels are made clearer, perhaps with a diagram detailing the steps undertaken and the ways that the message is to be delivered to the community.

Also there is considerable dependence on telephone landlines or mobile coverage for the successful passage of information and directions. Many components of the telephone system are subject to flooding or, in the case of overhead lines, breakage during floods. In addition, floods cut normal access routes to many sections, so sound communications links are vital to a successful flood operation. If telephone lines are inoperable and mobile coverage is not available other forms of communication such as radio linkages should be incorporated into the plans.

The Moira Shire may also explore the viability of automatic telephone dialling as an alternative to deliver flood warnings to individual properties. Telephone alerting arrangements to communicate impending floods to the affected community are now in place including the Expedite System as used in Benalla and Shepparton-Mooroopna.

Flood Response

The flood inundation maps for emergency response, as discussed in Section 7 should be incorporated into the Moira Shire Flood Sub-Plan (2002).

Also the Moira Shire Sub-Flood Plan (2002) details three local VICSES units within the Moira Shire, Yarrawonga, Cobram and Numurkah. The plan for Nathalia should state which unit is the first point of contact for Nathalia and where the office which co-ordinates activities for Nathalia is located. If a site is established for use in Nathalia it is important that an alternative location is established outside of town if the levees become overtopped and the town is inundated.

Access to and from Nathalia during a large flood event should also be addressed in the Moira Flood Sub-Plan (2002). The main access road to Nathalia, the Murray Valley Highway, is inundated during a significant event. The section of the road to the north of town could be raised above the flood level however, adequate provision would need to be made to pass flood flows. This could be achieved through the use of culverts or a bridge.

Accordingly, raising a section of the Murray Valley Highway is recommended for consideration as a floodplain management option for the Nathalia township.

Access during flood events is not only by roads. Consideration should be given in the emergency planning activity to where boats can be launched or berthed in quiet floodwaters. This approach should be considered as a last resort due to the risks involved in operating boats during floods. Development planning should also consider where helicopters could safely land in flood time.

Access also covers the continued operation of essential services, e.g. water supply, sewerage and power. The need to be able to shut down critical facilities, such as pump stations, by physical presence at the site, or by remote control is a flood access issue that must be included in flood plans.

Community Awareness and Preparedness

It is recommended that the Moira Shire in conjunction with the VICSES and the GBCMA develop a program to increase community awareness of existing flood risks, flood emergency response and flood warning arrangements. The program should at least outline contact phone numbers, context of local flooding issues, flood warning arrangements and tips for reducing damage and enhancing safety.

Flood Recovery

The location of evacuation centres and how well they are fitted out to cater for relatively large numbers of people of all ages is an essential item to be addressed in the Moira Shire Sub-Flood Plan (2002) for Nathalia. It is essential that these centres are above all risk of flooding which for Nathalia is out of town.

The importance of such centres, and the community's knowledge of their existence, cannot be overstressed. It is essential that the Moira Shire Sub-Flood Plan (2002) clearly establishes the location of evacuation centres, what facilities they have and what and where are alternative sites in the event of either overcrowding or threat of greater depths of flooding.

The sites should be chosen on the basis of:

- the available space for short term sleeping accommodation;
- the available space for storage of belongings;
- the capacity of the site to supply sufficient hygiene facilities; and
- the capacity of the site to service the food and beverage requirements of the evacuees.

10.7 Summary

The recommended floodplain management measures for further consideration are summarised in Table 10.6 below. The impacts of these measures on the Nathalia are discussed in Section 11.

Table 10.6: Assessment of Potential Floodplain Management Measures

Floodplain Management Measures	Comment	Recommended for Floodplain Management Plan
Flood Modification Measures		
Retarding basins	Not a suitable measure for Broken Creek	No
Levees	May be viable need to carefully consider height.	Yes
Bypass Floodways	Can open up northern, southern and western floodways	Yes
Channel Improvements	Changing channel geometry not viable; addressing floodplain and riverine vegetation will have no significant impact on flooding characteristics.	No
House Raising	Maybe viable, issue maybe suitability of houses.	Yes
Property Modification Measures		
Land Use Zoning	Needed to address existing and future flood problems. Covered under VPP.	Yes
Voluntary Purchase	Maybe viable, particularly in high hazard areas	Yes
Building and Development Controls	Building regulations apply	Yes

Table 10.3: Assessment of Potential Floodplain Management Measures (cont.)

Floodplain Management Measures	Comment	Recommended for Floodplain Management Plan
Response Modification Measures	**Will require close liaison with VICSES**	
Flood Warning	Essential part of overall floodplain management plan.	Yes
Community Awareness & Preparedness	Urgent need, especially for new residents.	Yes
Flood Response	The flood inundation maps devised as part of this report should be incorporated The access during flood should be addressed with the Murray Valley Highway inundated during significant events and the town is isolated	Yes
Flood Recovery	Essential part of overall floodplain management plan. Will require close liaison with VICSES and welfare agencies.	Yes

11 Assessment of Management Options

11.1 Introduction

The proposed flood mitigation measures recommended by the study for further review include:

- Raising levees;
- Opening up floodways;
- Land use zoning and development control;
- Co-ordination and upgrading of flood warning and related emergency plans;
- Improve flood access;
- Voluntary purchase of properties; and
- Voluntary house raising.

The assessment of options recommended for further investigation was undertaken using a multi-criteria procedure that considers relevant issues for the study area. Table 11.1 lists the issues considered.

Table 11.1: Assessment issues for management measures

Category	**Issues**
Social	Does the measure reduce trauma to individuals during floods
	Does the measure increase or decrease the disruption/access in and around the city during a flood
	Does the measure have an impact on community growth
	Does the measure affect property values
	Does the measure have a visual impact
Economic	Cost of mitigation measures
	Savings in potential flood damages
	Can the project be funded
Environmental	Will the measure result in increased erosion of river banks?
	Does the measure maintain or improve riverine habitat that encourages diversity of species?
	Does measure enhance or degrade water quality?
	Does the measure improve habitat and vegetation of the floodplain environs?
Flooding behaviour	Does the measure increase or reduce the hazard to the community?
	Does the measure reduce the potential for inundation in the town?
	Does the measure improve or worsen the impacts of a flood event larger than the design flood?
	Does the measure change velocities or water levels downstream?
	Does the measure change water levels and extent of inundation upstream?

Each measure was assessed against these issues using a five point system:

1 – major negative impact

2 – minor negative impact

3 – no impact / negligible

4 – minor positive impact

5 – major positive impact

The social and environmental assessment is qualitative only, while the flood behaviour and economic assessments are arrived at based on hydraulic model results where applicable and benefit and cost estimates where available.

Each of the viable options listed in Table 10.3 were assessed. Table 11.2 below details the score of each item.

Table 11.2: Multi Criteria Assessment of Each Option

Option No.	Management Option	Average Score	Comments
1	Raising Levee for 100-year ARI event (300 mm)	58	Provide positive growth opportunities Problems with false sense of security.
2	Raising Levee for 100-year ARI event (traditional way-600 mm)	54	Poor socially* due to visual impacts. Provide positive growth opportunities Problems with false sense of security.
3	Remove levees to north of town	58	Waste Water Treatment Plant may need to be protected
4	Open up northern floodway	53	
5	Remove levee to north of town and open up northern floodway	58	
6	Direct flow into the Deep Creek catchment	61.5	Diverting flow into Deep Creek catchment. Requires the Lower Goulburn scheme to be successful. Problems with cross catchment transfers
7	Install a siphon in Channel 38/12	53	
8	Remove levee to north of town and open up northern floodway and install a siphon in Channel 38/12	57	
9	Remove the railway embankment to the north of town	53	
10	Re-zoning land liable to flooding and appropriately zoning new areas	51.5	Standard measure and highly desirable
11	Flood Warning and Emergency Plans	54	Standard measure and highly desirable
12	Improve flood access upgrade the Murray Valley Highway	45	Costly
13	Voluntary purchase	56	
14	Voluntary house raising	54	Significant cost and disruption to community

*Based on providing 600mm freeboard above the ARI flood event.

Based on Table 11.2 the ranking is:

High Scores (54 or greater):

- Option 6 - Direct flow into the Deep Creek catchment
- Option 3 – Remove levee to north of town
- Option 5 – Option 3 and 4 combined
- Option 8 – Combine option 3, 4 and 7
- Option 1 & 2 - Raise Levees for 100-year ARI event
- Option 13 - Voluntary purchase
- Option 14 - Voluntary house raising
- Option 11 - Flood Warning and Emergency Plans

Medium Score (between 46 and 54):

- Option 9 – Remove railway levee to the north of town
- Option 4 – Open up northern floodway
- Option 7 – Install a siphon in Channel 38/12
- Option 10 - Re-zoning land liable to flooding and appropriately zoning new areas

Low Score (45 or less)

- Option 12 - Improve flood access upgrade the Murray Valley Highway

Detailed investigation of each of the options is discussed below. Where possible for each item a benefit cost ratio was calculated. A benefit cost ratio greater than one (1) indicates that costs outweigh benefits. A benefit cost ratio below one (1) indicates that costs outweigh benefits. In the latter case the option becomes difficult to justify. The ratio provides a means by which the options can be ranked on economic grounds. For the economic analysis, a 30 year project life and 6% discount rate were assumed. The steps taken in computing benefit cost ratio are:

B = average annual benefit ($)

= average annual damage for existing situation – average annual damage for a given mitigation option.

N = net annual benefit ($)

= *B* – annual maintenance cost for a given mitigation scheme

P = present value of benefits ($). This is a capitalised value computed by discounting *N* over the life of the works (*Y* years) at a discount rate of *i,* such that:

$$P = \left(\frac{(1+i)^Y - 1}{i(1+i)^Y} \right) N = 13.7648 \times N$$

Benefit cost ratio = *P/C*

11.2 Raising Levees

Currently there is a levee system protecting Nathalia which begins south of town at approximately Nathalia weir moving north along the Broken Creek until Park Street where it turns in an easterly direction towards the eastern bank of the Broken Creek. From there the levee continues along the banks of the Broken Creek in a south westerly direction to approximately the intersection of Bromley and Kostadt Street. At this intersection high ground continues along the banks of the Broken Creek until the levee continues along the banks of the Broken Creek at approximately Phillip Street in a north westerly direction until it meets the old railway line. Another levee is a ring levee starting on the northern banks of the Broken Creek it goes in an easterly direction along Muntz Ave following the Broken Creek. At approximately 100m east of Martin Street the levee goes north until approximately 100m north of Railway Street where the levee goes in a westerly direction weaving its way to the old railway north. From there it turns south west along Scott Ave until it hits the Murray Valley Highway. The levee is not continuous across some roads. These are Railway Street and the Murray Valley Highway. During times of flood these breaks in the levee need to be closed through the use of sandbags or soil.

The location of the levees are shown in Figure 11.0a and Appendix F shows the location and the current height of the levees from the Levee Audit Report (1996).

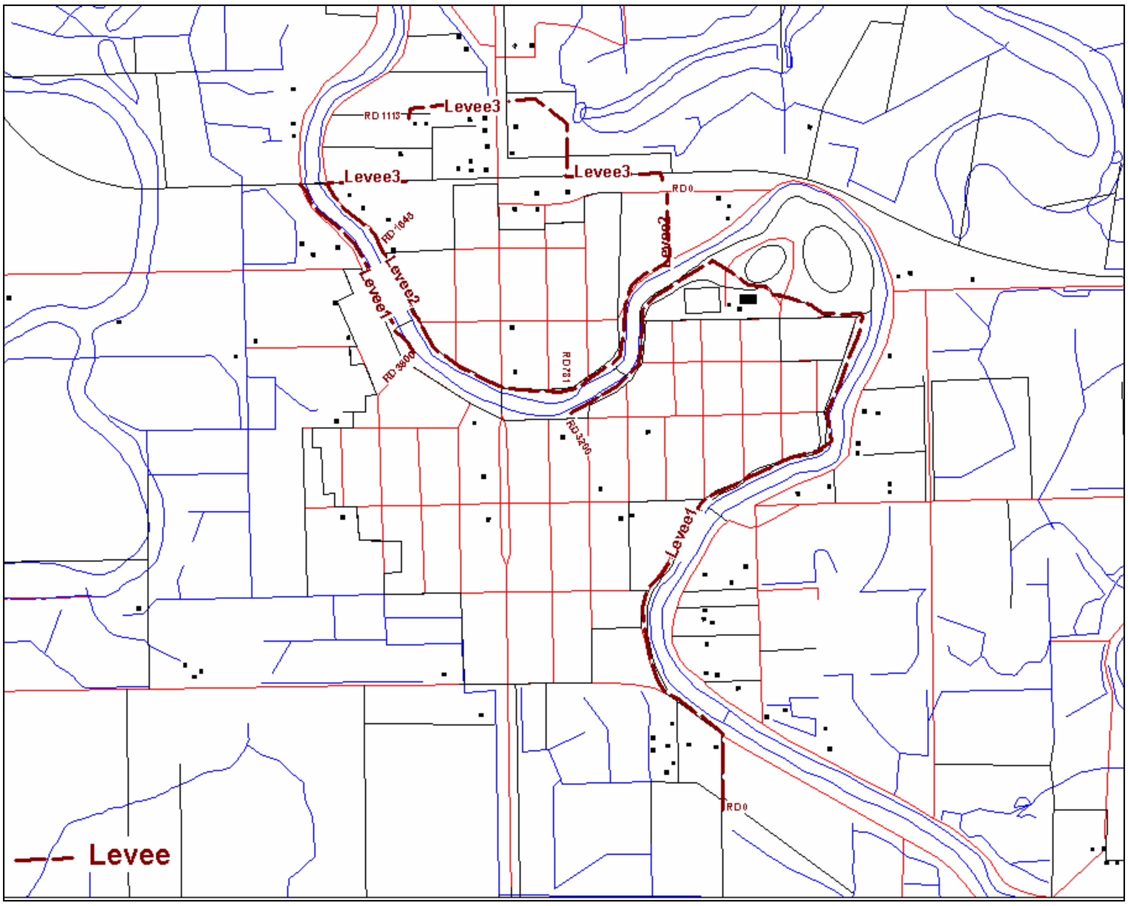


Figure 11.0a: Location of Levees at Nathalia Township

The town levees were designed by the State Rivers & Water Supply Commission (SR&WSC) in 1978 and constructed in the early 1980s. The impetus for these levees resulted from the 1974 flood where some 250,000 sandbags were used to protect the Town.

The 1978 levee crest height design, the 100-year ARI flood profile and the existing levee crest for levee 1 has been plotted in Figure 11.0b. This figure illustrates the variability of the existing levee and the vulnerability for overtopping during major floods. Interestingly, the 1978 levee crest design profile plots on a steeper grade compared with both the 100-year ARI flood profile and the general grade of the existing levee. Also, the amount freeboard above the 100-year ARI flood profile provided by the 1978 design diminishes to zero at the downstream end of the levee. This may be explained based 1978 design assumption that the floodways would be opened, which has been investigated as Option 4.

Figure 11.0b also provides two additional profiles relating to 300mm and 600mm freeboard above the 100-year ARI flood profile. The usual practice in Victoria is to provide 600mm freeboard to allow for settlement, uncertainty, tolerance limits, wave action, etc.

Following review of the 14 Options by the technical and community reference group, a further option of providing levee upgrade to a 100-year ARI standard with 300mm was investigated.

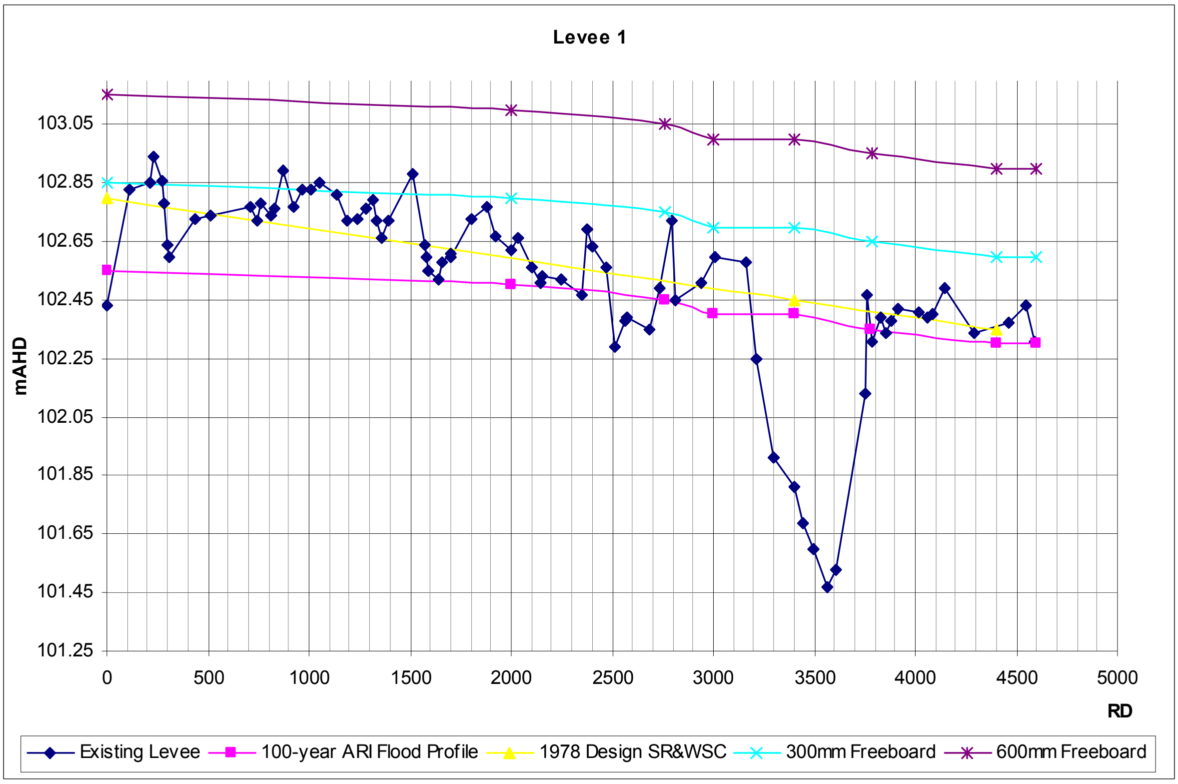


Figure 11.0b: Location of Levees at Nathalia Township

During the 1993 flood these levees protected the town from serious flooding. The flood in 1993 came close to overtopping the levee in a number of locations with sand bags used to protect the town.

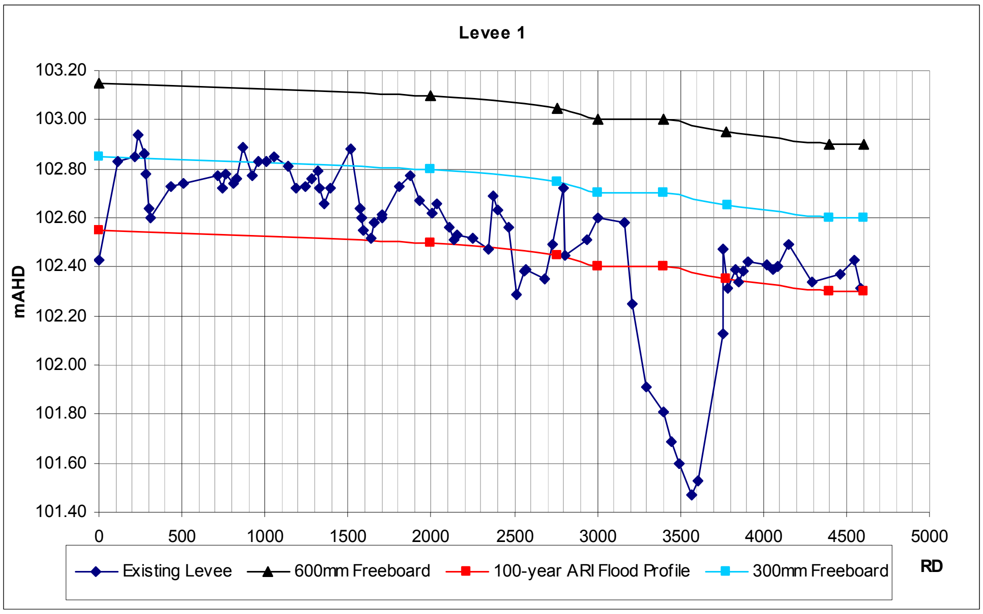
Two levee raising options were considered. One to protect the town against flooding for the 50-year ARI event the other for the 100-year ARI event. The two different flows were put into the hydraulic model and the levees raised until the town did not flood.

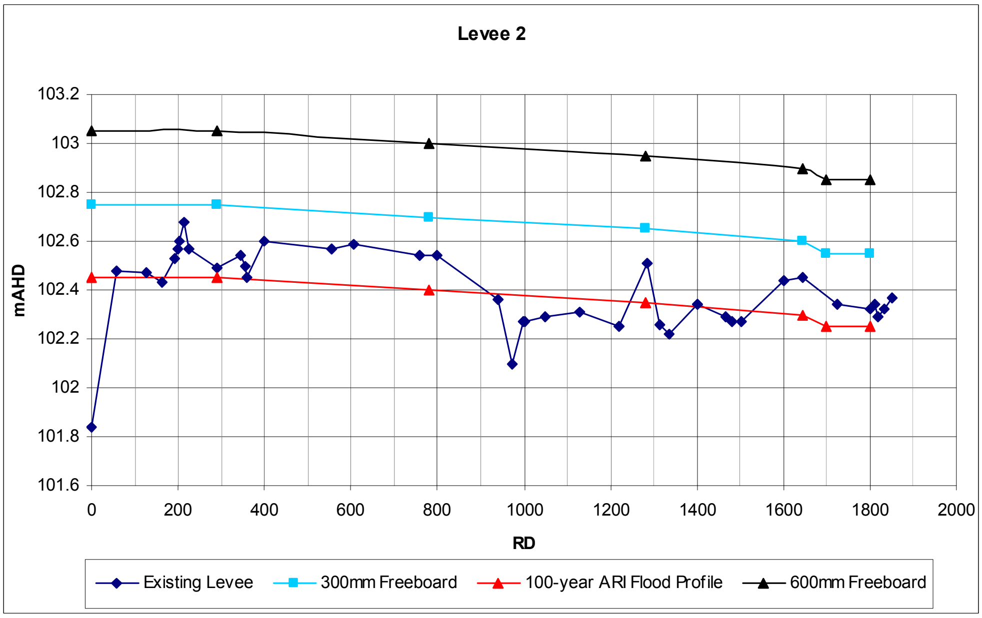
11.2.1 Option 1 & 2 - 100-year ARI Event

Table 11.4 summarises the modelling results for the 100-year ARI event. The chainage indicated is that on the drawings in Appendix F and summarised in Figure 11.0a. Note the levels which the levee needs to be raised including 300/600mm freeboard. Figure 11.3 shows a long section of the existing levees and the level required (including 600mm freeboard) to protect the town against a 100-year ARI event.

Table 11.4: Summary of Levee Raising Required for 100-year ARI Event with 300/600mm Freeboard

Chainage	Current Levee Height (m AHD)	100-year ARI flood level (m AHD)	Level Required (including 300/600mm freeboard) (m AHD)
Levee 1			
0 - 220	102.43	**102.55**	102.85/103.05
235 - 870	102.6	**102.55**	102.85/103.05
875 - 1490	102.66	**102.55**	102.85/103.05
1550 - 2800	102.29	**102.5 - 102.4**	102.8/103.1 – 102.7/103.0
2800 - 4588	101.47	**102.4 - 102.2**	102.7/103.0 – 102.5/102.8
Levee 2			
0 – 1850	101.84	**102.45 - 102.25**	102.75/103.15 – 102.55/102.85
Levee 3			
0 - 1180	102.29	**102.4 - 102.35**	102.7/103.0 – 102.65/102.95
1230 - 1546	102.19	**102.35**	102.65/102.95





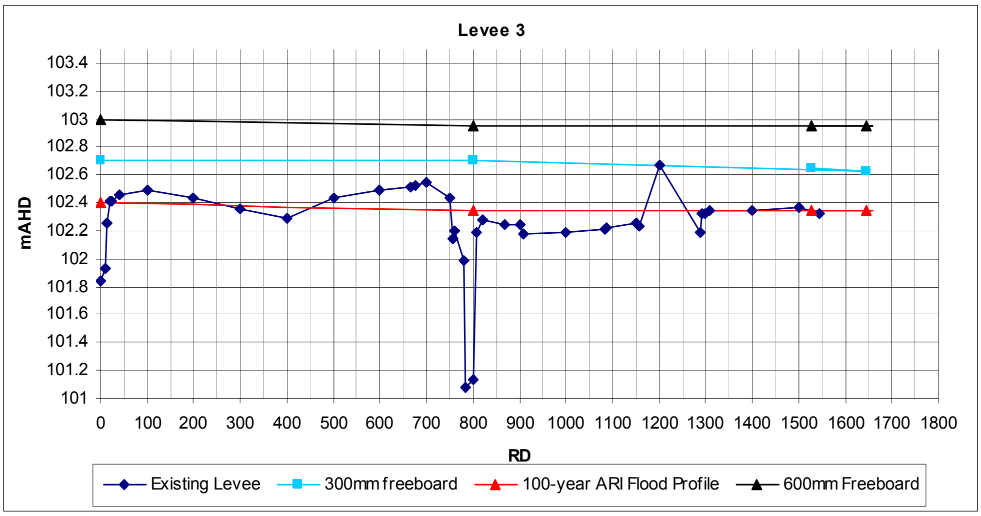


Figure 11.3: Levee Raising Required to Protect Nathalia Against 100-year ARI Event with 300/600mm Freeboard

The hydraulic model indicates that there is a potential for an increase in flood levels of approximately 40mm within the Broken Creek through out town and between 10 to 30mm upstream of town. The area of influence extends approximately 1km upstream of town. This is a minor hydraulic impact. Figure 11.4 shows the difference in the 100-year ARI water surface between Option 2 and existing conditions.

A preliminary estimate of the cost to raise the levee was prepared. Space is limited so the levee was assumed to be raised using a retaining wall structure.

Allowing for 600mm freeboard (Option 2), the preliminary cost estimate was $4.8 million, which included site clearance, importing fill, construction of retaining wall, finishing, landscaping and capping.

As discussed in Section 8 the total AAD calculated for the existing Nathalia township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the town protected against a 100-year ARI event the AAD damages is reduced to $103,000 (in round terms) a reduction of $405,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event.

The Benefit/Cost Ratio was calculated as 1.2.

Allowing for 300mm freeboard (Option 1), the preliminary cost estimate was $1.5 million, which included

- temporary barrier system for 500m for Weir Street and Murray Valley Highway;
- provision of recreational concrete foot path along the existing levees for some 4,900m along levees 1 and 2;
- earthen strengthening along 2060m of levee 3 and portion of levee 2; and
- Lift and extend Levee 1 by 200m.

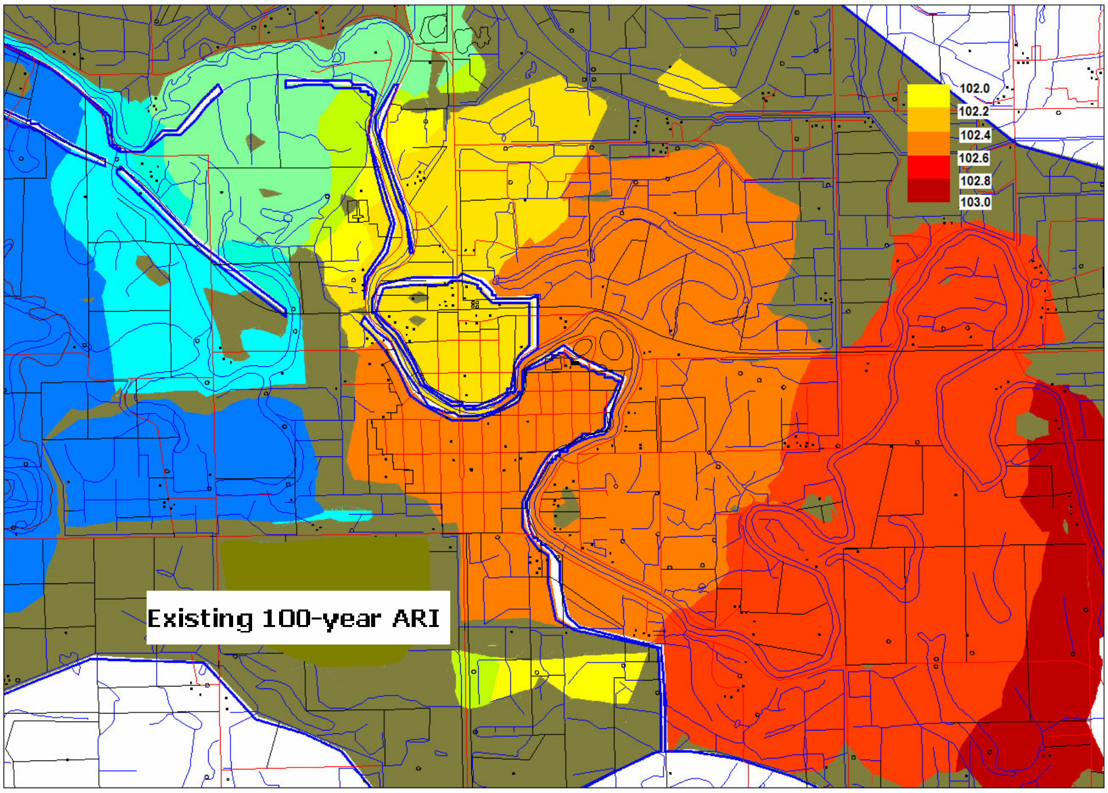
This option has been looked at in some detail by the Goulburn Broken Catchment Management Authority and Moira Shire Council with assistance from John Webb Consulting in providing some detailed field work and cost estimates.

Given the structural integrity of providing a 1.2m wide concrete foot/bike pathway for the majority of the levees has brought about the review of reducing the freeboard requirement together with the lack of sensitively on flood levels for larger floods. Note other earthen treatments along the some 2km of levee 2 would require at least 450mm freeboard.

The advantage of providing flood protection up to and including the 100-year ARI standard which forms the bench mark standard for planning and building approvals is that floor level requirements may be relaxed and future subdivision would be allowed to continue. On the other hand, levees may lead to a false sence of security, which highlights the importance of flood awareness programs to neglect flood apathy and complacency.

As discussed in Section 8 the total AAD calculated for the existing Nathalia township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the town protected against a 100-year ARI event the AAD damages is reduced to $103,000 (in round terms) a reduction of $405,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event.

The Benefit/Cost Ratio was calculated as 3.7.



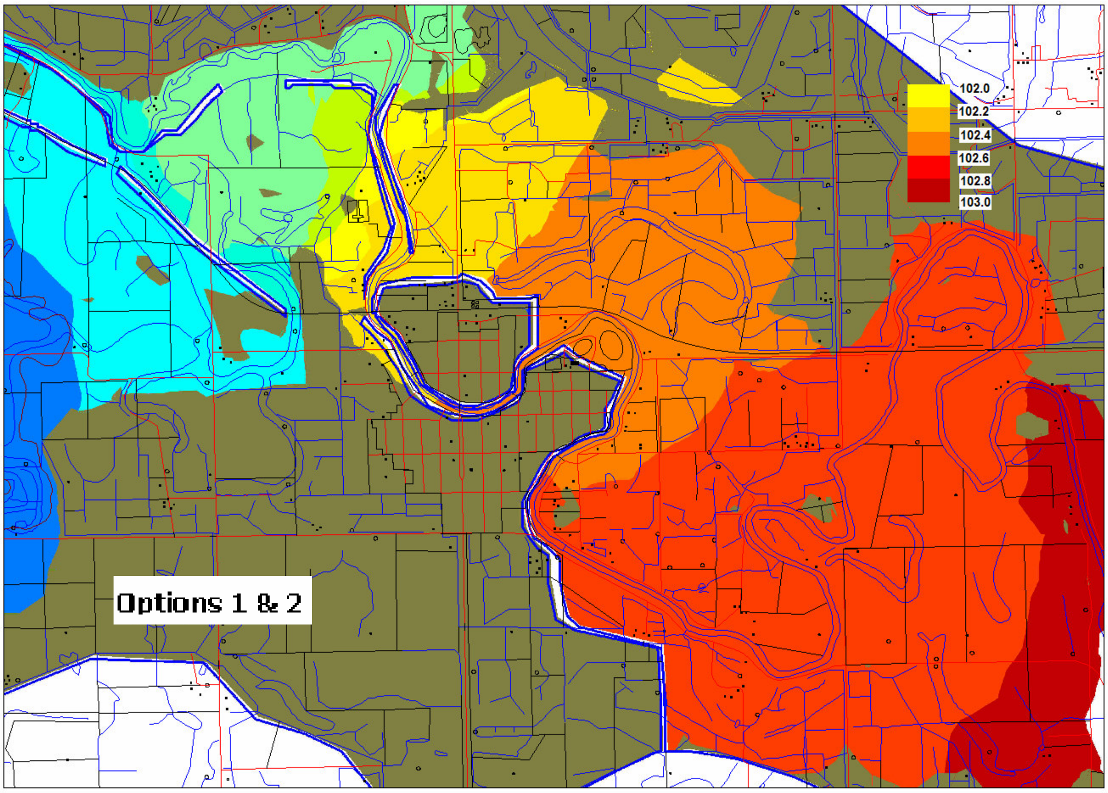


Figure 11.4: Difference in Water Surface Levels between Existing Conditions and Option 1 & 2

11.3 Bypass Floodways

11.3.1 Introduction

Within this mitigation option several options were investigated. These are summarised below.

Option 3 – Open up northern floodway by removing the levees on both the left and right banks between the old railway bridge and Drain 13.

Option 4 – Open up northern floodway by placing a 50m siphon on the farm channel to the north of the show grounds, lower the east-west road by 0.3m over 50m between Allotments 4B and 4K and reconstruction of the irrigation layout in Allotment 4B. Open up the western floodway by including a 50m siphon for Channel 38/12 adjacent to Chinamans weir. These works are based on the recommendations detailed in the 1978 flood mitigation report.

Option 5 – Option 3 and 4 combined.

Option 6 – Construct an overflow channel to the south east of town directing flow from the Broken Creek into the Deep Creek system.

Option 7 – Open up the southern floodway by placing a 100m siphon on channel 38/12.

Option 8 – Option 3, 4 and 7 combined.

Option 9 – Remove the railway embankment north of town located within the northern floodway

11.3.2 Option 3

Option 3 is opening up the northern floodway by removing the levees on both the left and right banks between the old railway bridge and Drain 13. Figure 11.5 shows the location of the levees removed in the investigation of this option. The hydraulic model indicated that for the 100-year ARI a significant reduction in levels was achieved within town. The northern section of the town did not flood and to the south the levels were reduced in the order of 600mm within the town levee. However, the reduction of flood levels adjacent to the levees are the greatest near the old railway in the order of 200mm but rapidly reduce to less then a few millimetres upstream of the Murray Valley Highway.

Figure 11.6 shows the difference in the 100-year ARI water surface between Option 3 and existing conditions.

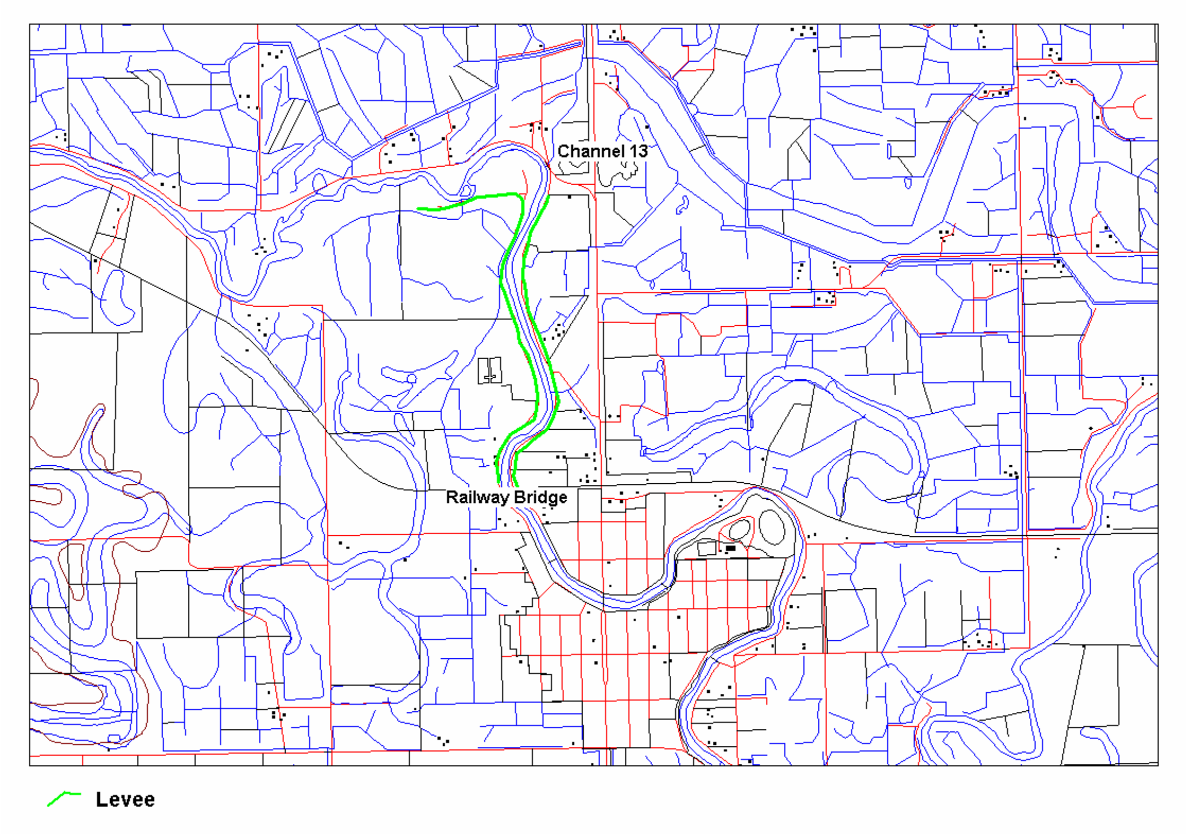


Figure 11.5: Location of Levees Removed

A preliminary estimate of the costs to remove the levees was made. SMEC has costed levee removal with the material dumped outside of the floodplain. The preliminary cost estimate was $280,000, which included excavation and dumping.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the northern section of the town protected against a 100-year ARI event the AAD damages is reduced to $141,000 (in round terms) a reduction of $367,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event and the town is protected for events less than a 50-year ARI event.

It is important to note that the model indicates that the northern section of town is just safe from flooding with no freeboard on the levees and therefore the reduction in flood damage is overestimated. In an actual event the levees could overtop.

This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the ‘Floodway Overlay’.

The Benefit/Cost Ratio was calculated as 18 assuming no freeboard allowances.

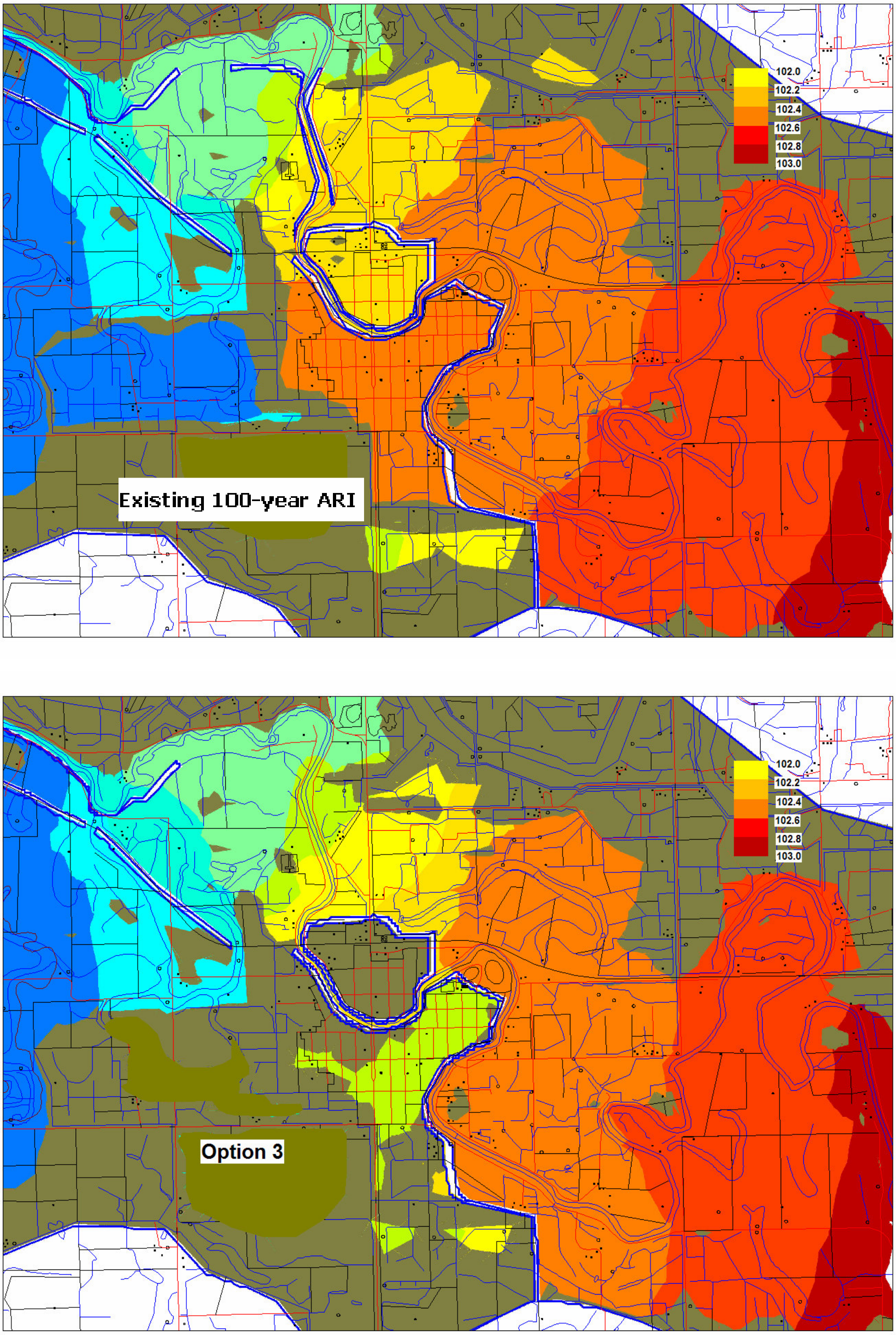


Figure 11.6: Difference in Water Surface Levels between Existing Conditions and Option 3

11.3.3 Option 4

Option 4 is opening up the northern floodway by placing a 50m siphon on the farm channel to the north of the show grounds, lower the east-west road by 0.3m over 50m between Allotments 4B and 4K and reconstruction of the irrigation layout in Allotment 4B. Open up the western floodway by including a 50m siphon for Channel 38/12 adjacent to Chinamans weir. These works are based on the recommendations detailed in the 1978 State Rivers & Water Supply Commission Flood Mitigation Report. Figure 11.7 shows the location of the works proposed to open up the northern and western floodway. For this option the levees to the north of town, as described in Option3 were still in place.

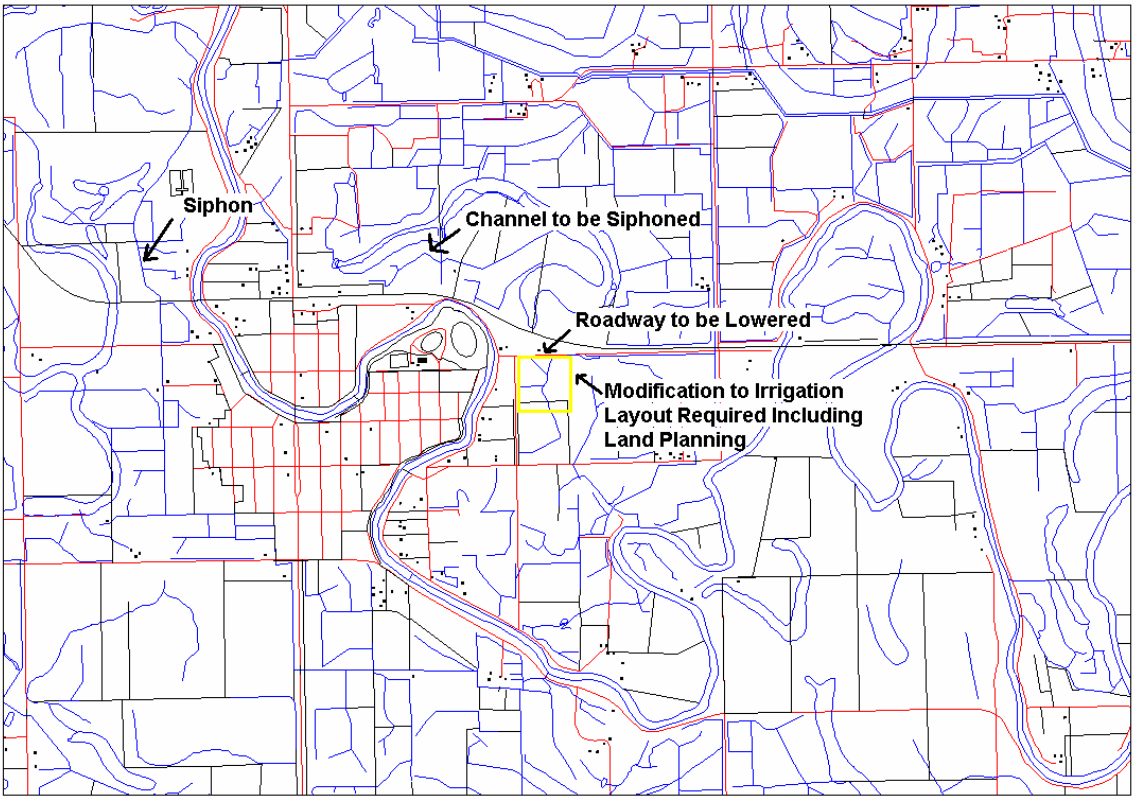


Figure 11.7: Location of Works for Option 4

The hydraulic model indicated that for the 100-year ARI the entire town is still inundated but there is a reduction in levels within town levees. In the northern section of the town flood levels are reduced by approximately 80mm and to the south the levels were reduced in the order of 100mm. The reductions of flood levels outside of the town levee have less impact.

Figure 11.8 shows the difference in the 100-year ARI water surface between Option4 and existing conditions.

A preliminary estimate of the costs to install two 50m siphons, lower a 50m section of road and some land planning was estimated at $230,000.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the northern and western floodway adjusted the levels in town are reduced for a 100-year ARI event and the AAD damages is reduced to $375,000 (in round terms) a reduction of $133,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event and for events less than a 50-year ARI event a decrease in flood level of the same proportion as the 100-year ARI event was assumed.

It is important to note that no allowance has been considered for levee freeboard and therefore the reduction in flood damage is overestimated.

This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the 'Floodway Overlay'.

The Benefit/Cost Ratio was calculated as 8.0 assuming no freeboard allowances.

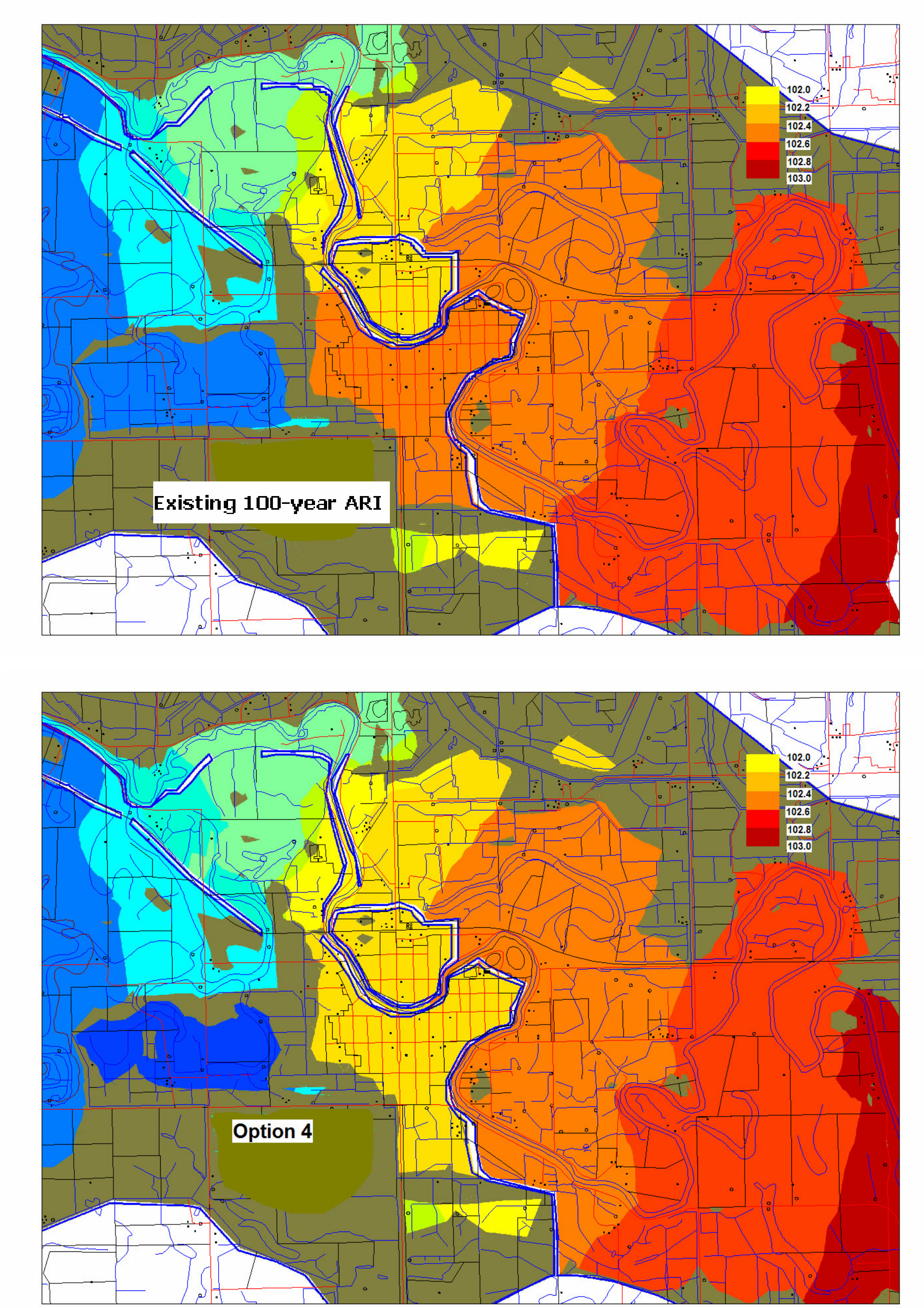


Figure 11.8: Difference in Water Surface Levels between Existing Conditions and Option 4

11.3.4 Option 5

Option 5 is combining Option 3 (remove levees to north of town) and Option 4 (open up northern and western floodway). The hydraulic model indicated that for the 100-year ARI the town is just protected. It is worth noting that there is no freeboard and the water would be lapping the top of the levees and in some locations without sandbagging it would even be just overtopping the levee. These locations are the low points, one of these is south of town at the very start of the levee approximately 300m south of the Nathalia weir. This needs to be fixed as water could threaten the town from the south. Other low points where water would be just overtopping the levee are the southern end of Barry Street, the northern end of Bindon Street and the northern end of Mitchell Street. In an actual event the levees could overtopped in more locations than these.

Figure 11.9 shows the difference in the 100-year ARI water surface between Option5 and existing conditions.

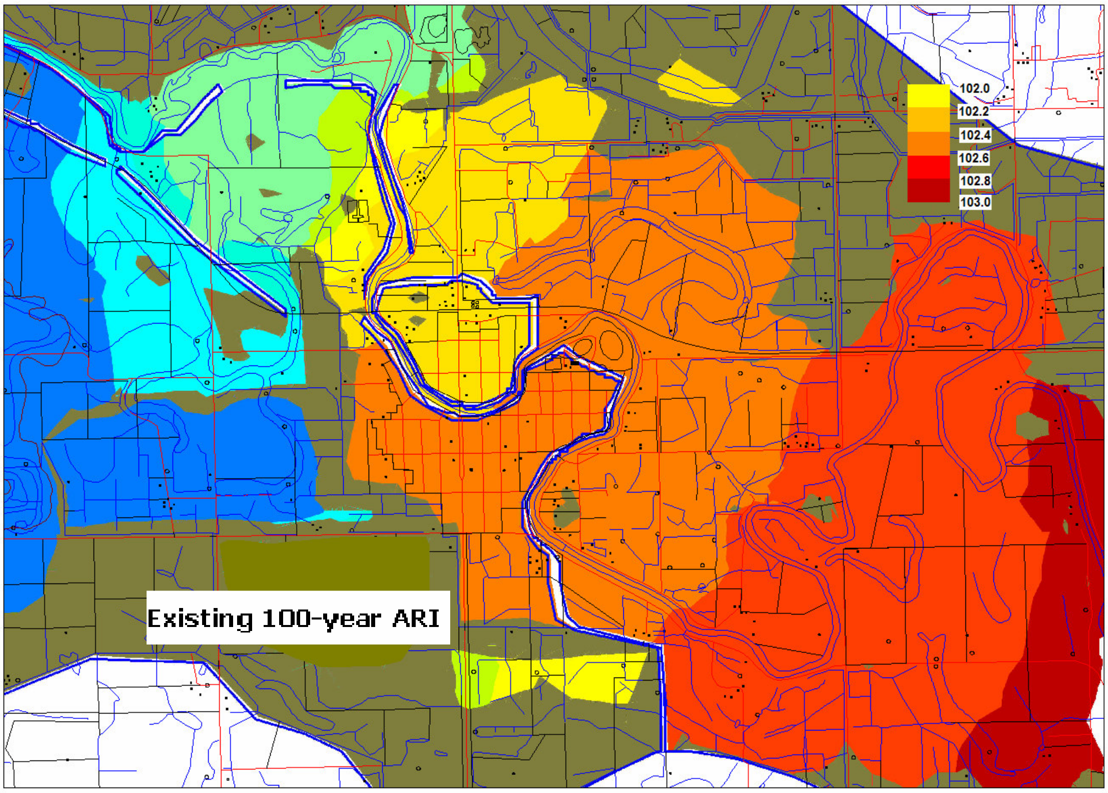
A preliminary estimate of the cost of the combined works was calculated as $510,000.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the town protected against a 100-year ARI event the AAD damages is reduced to $103,000 (in round terms) a reduction of $405,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event.

It is important to note that the reduction of flood damage has no allowance for levee freeboard and therefore the reduction in flood damage is overestimated.

This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the ‘Floodway Overlay’.

The Benefit/Cost Ratio was calculated as 10.9 with no allowance for levee freeboard.



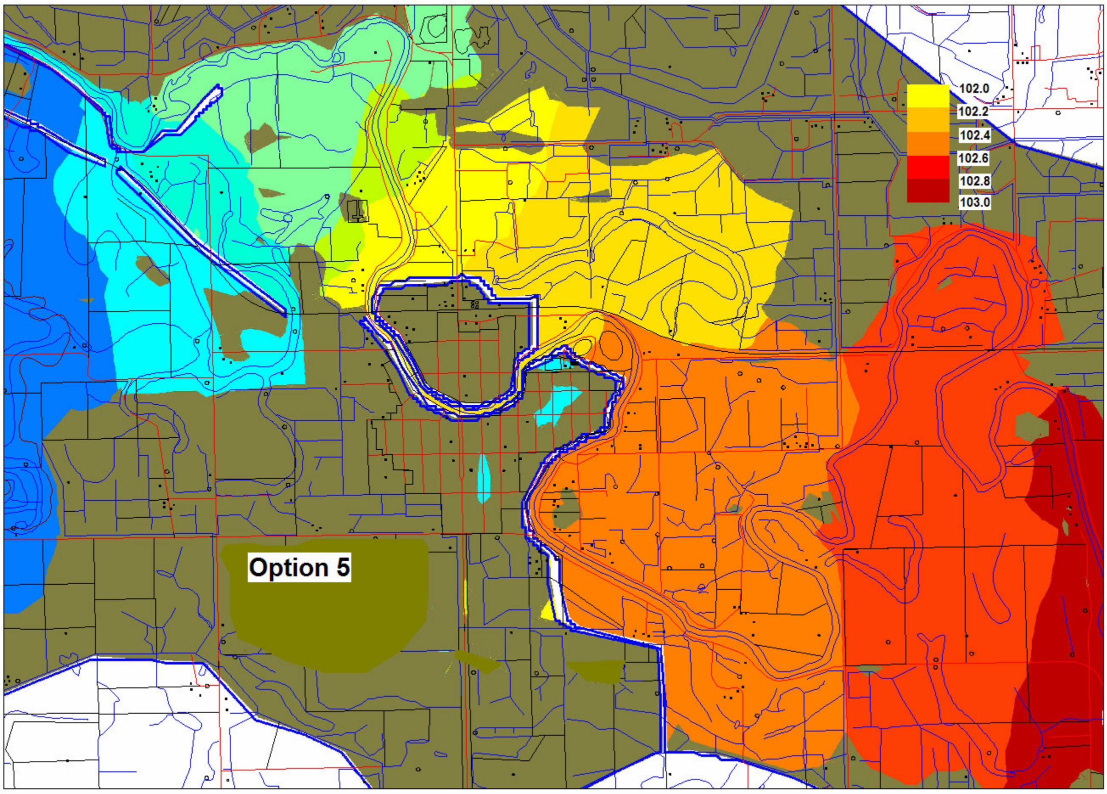


Figure 11.9: Difference in Water Surface Levels between Existing Conditions and Option 5

11.3.5 Option 6

Option 6 is constructing an overflow channel to the south east of town directing flow from the Broken Creek into the Deep Creek system. This option is dependant on the Lower Goulburn drainage scheme. This option is illustrated in Figure 11.10 below.

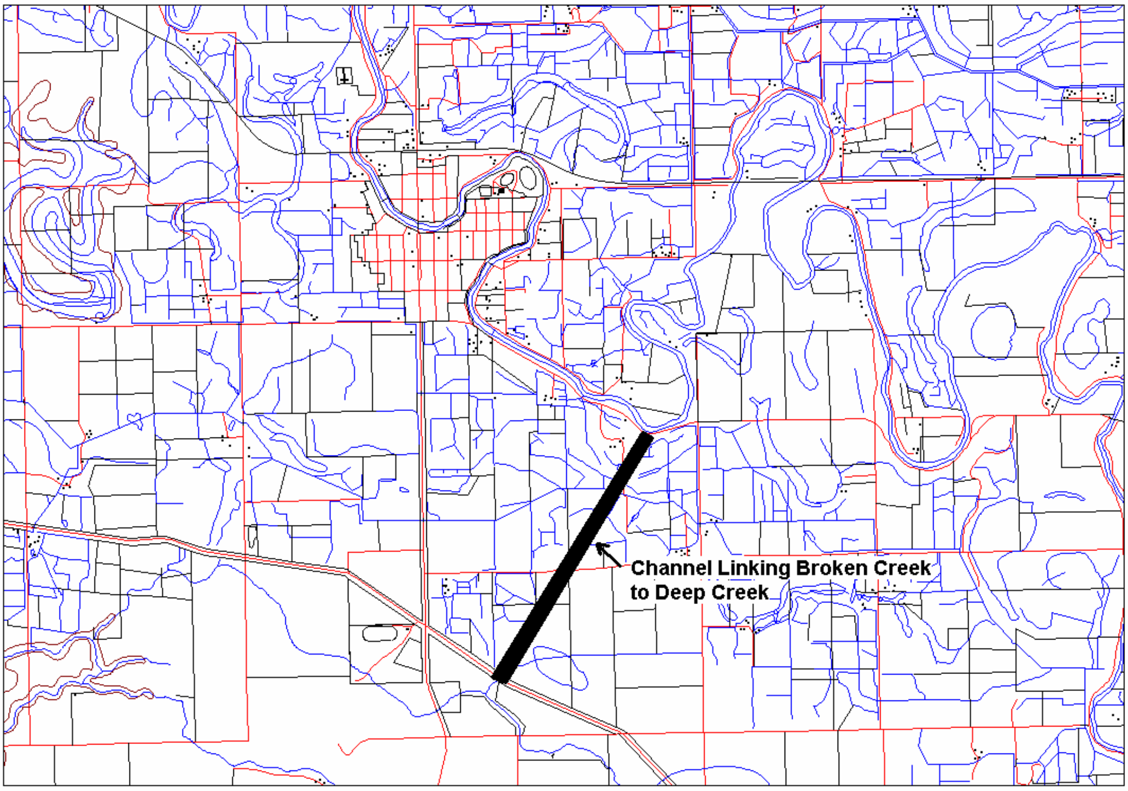


Figure 11.10: Location of Option6

The hydraulic model indicated that for the 100-year ARI the entire town remains flood free. The additional benefit is within the northern floodway where levels are lowered by some 200mm, this means that there would be some freeboard before the levees were overtopped. The freeboard varies as the levee has some low points. Figure 11.11 shows the difference in the 100-year ARI water surface between Option6 and existing conditions.

A preliminary estimate of the cost to construct a 100m wide and approximately 1.5m deep channel was undertaken. The preliminary cost estimate was $5.8 million, which included excavation and dumping of excess material, siphons and land acquisition.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the channel protecting against a 100-year ARI event the AAD damages was reduced to $103,000 (in round terms) a reduction of $405,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event and the town is protected for events less than a 50-year ARI event. The other advantage of this option is it would reduce social impacts on the community by reducing stress as there is some freeboard on the levees. While it is difficult to place an exact monetary value on these benefits it could be expected that it would amount to some $25,000 annually. Thus, the benefit of the recommended floodplain management measure is $430,000.

It is important to note the reduction in flood damage has not allowed for freeboard on the levees and therefore the reduction in flood damage is overestimated. Additional works on the levees would be required.

This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the ‘Floodway Overlay’.

In addition, the Broken Creek Management Strategy (SKM, 1998) has documented the principal of cross catchment transfers, which this option would create. This option present concerns at the final community reference group meeting.

An alternative overflow channel was mooted further upstream commencing near the corner of Prentices and Walsh’s Bridge Roads. The route of this overflow channel to the Deep Creek floodplain would be some 2 kilometres longer compared with the overflow channel option closer to Nathalia and would include an additional road crossing. The cost would be a least 70% more amounting to some $10 million making this option uneconomically unviable.

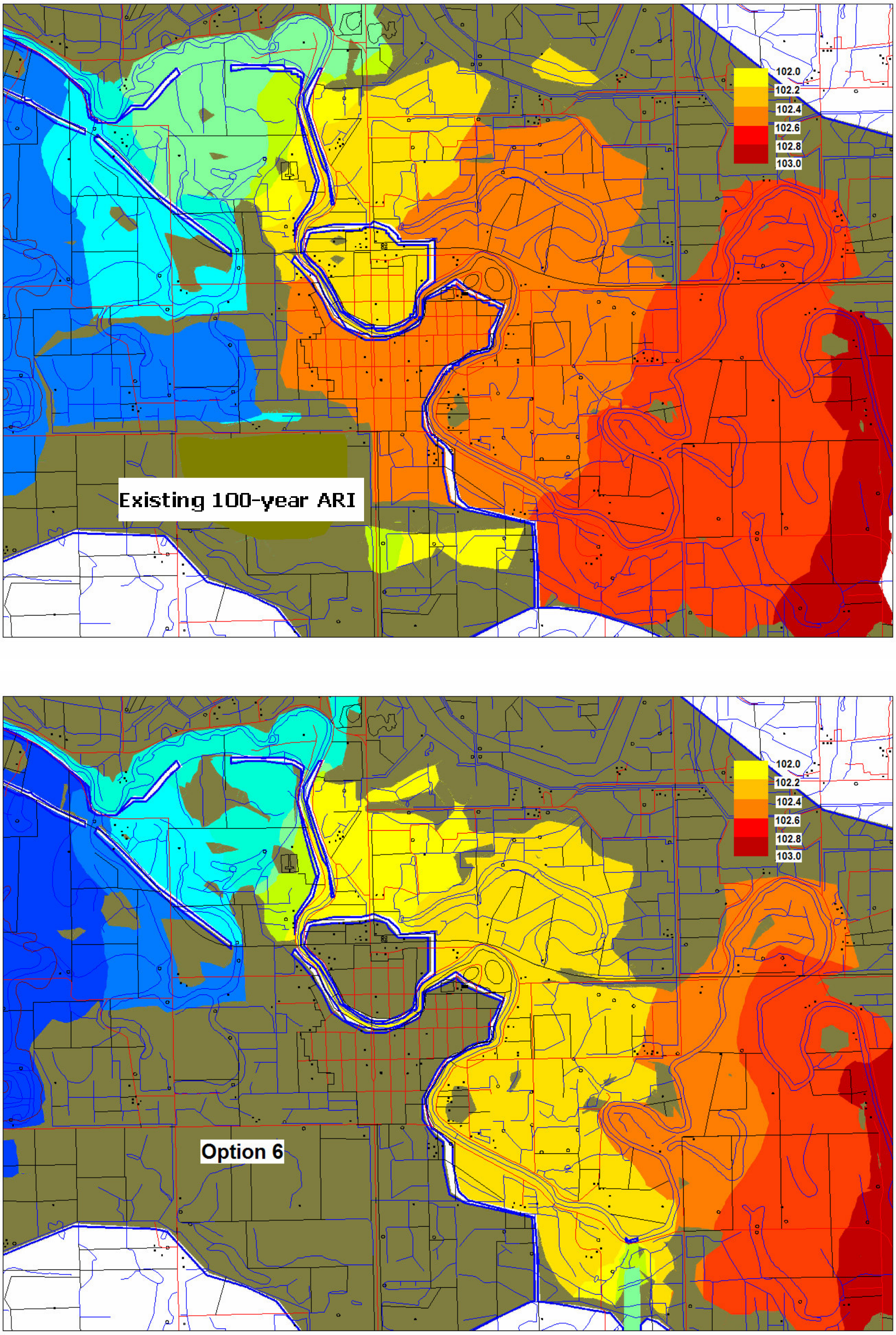


Figure 11.11: Difference in Water Surface Levels between Existing Conditions and Option 6

11.3.6 Option 7

Option 7 is opening up the southern floodway by placing a 100m siphon on channel 38/12. Figure 11.12 shows the location of the proposed siphon. The hydraulic model indicated that for the 100-year ARI the entire town is still inundated but there is a slight reduction in levels within town. In the northern section of the town the flood levels are reduced by approximately 60mm and to the south the levels were reduced in the order of 50mm. The reduction in flood levels outside of the town levees is only a few millimetres.

It is important to note no allowance for levee freeboard has been made and therefore the reduction in flood damage is overestimated. In an actual event the levees could overtop.

This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the 'Floodway Overlay'.

Figure 11.13 shows the difference in the 100-year ARI water surface between Option7 and existing conditions.

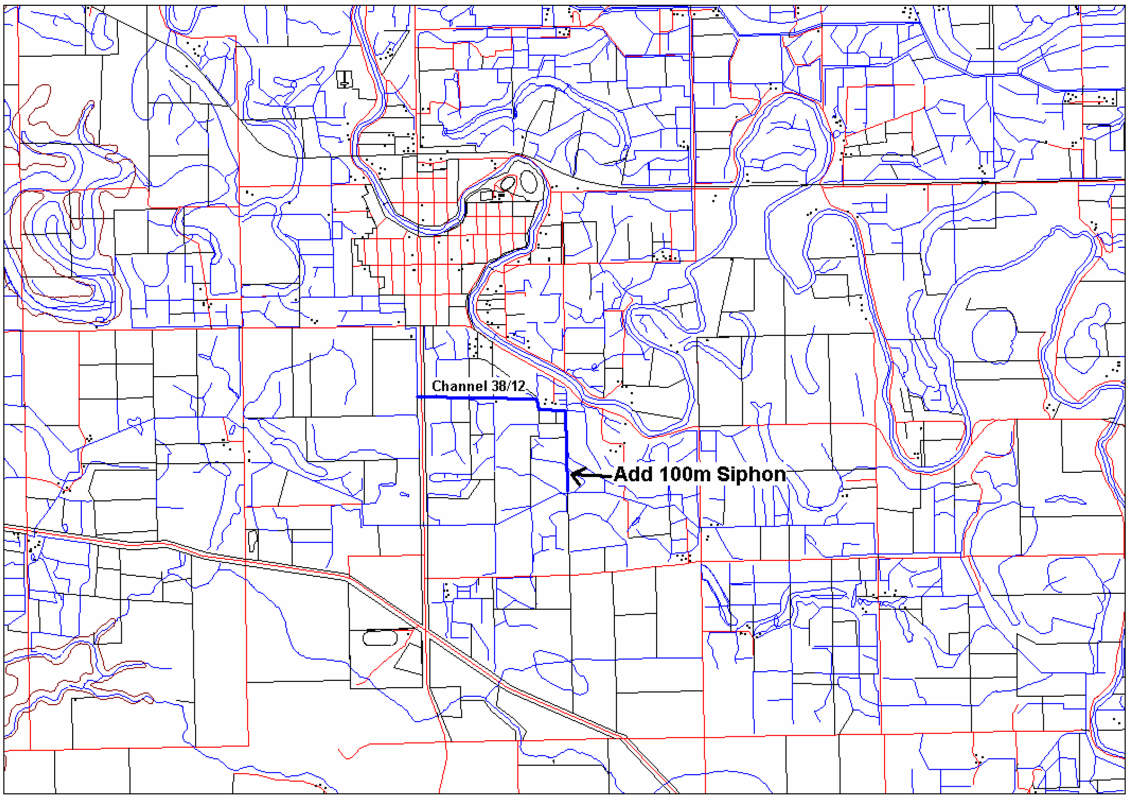
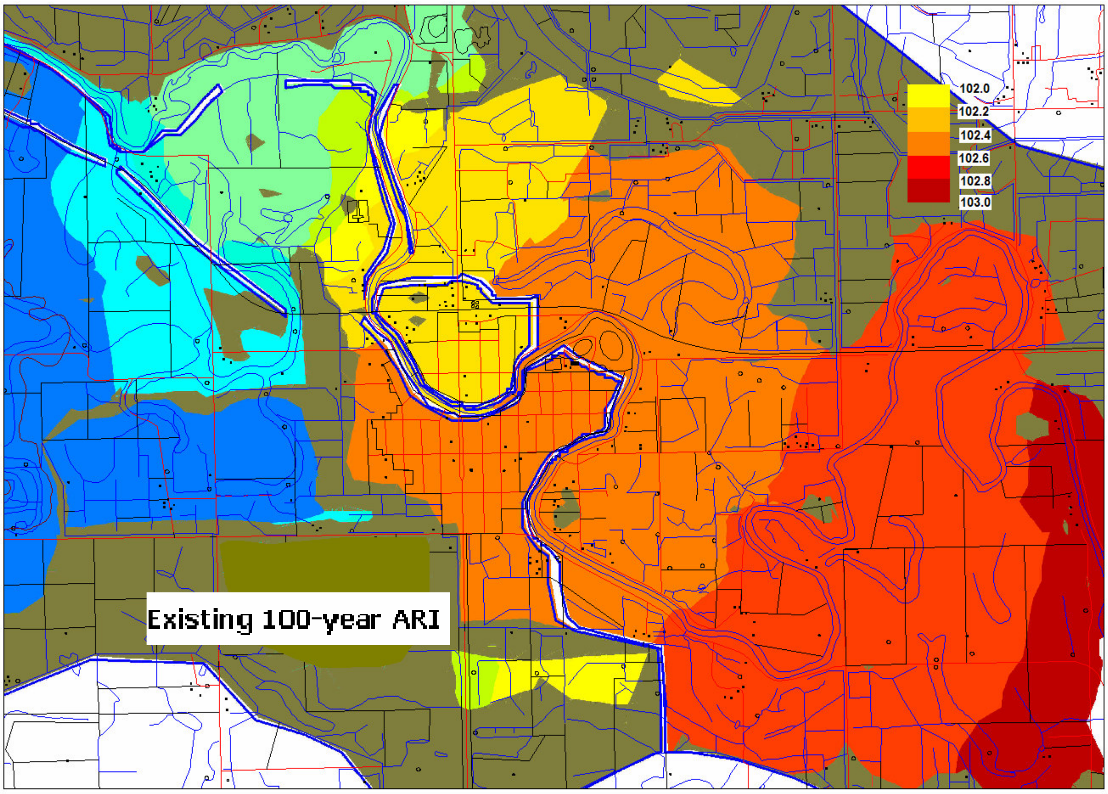


Figure 11.12: Location of 100m Siphon on Channel 38/12

A preliminary estimate of the costs to install a 100m siphon was estimated at $180,000.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the siphon added the AAD damages is reduced to $415,000 (in round terms) a reduction of $93,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event and for events less than a 50-year ARI event a decrease in flood level of the same proportion as the 100-year ARI event was assumed.

The Benefit/Cost Ratio was calculated as 7.1 with no allowances for levee freeboard.



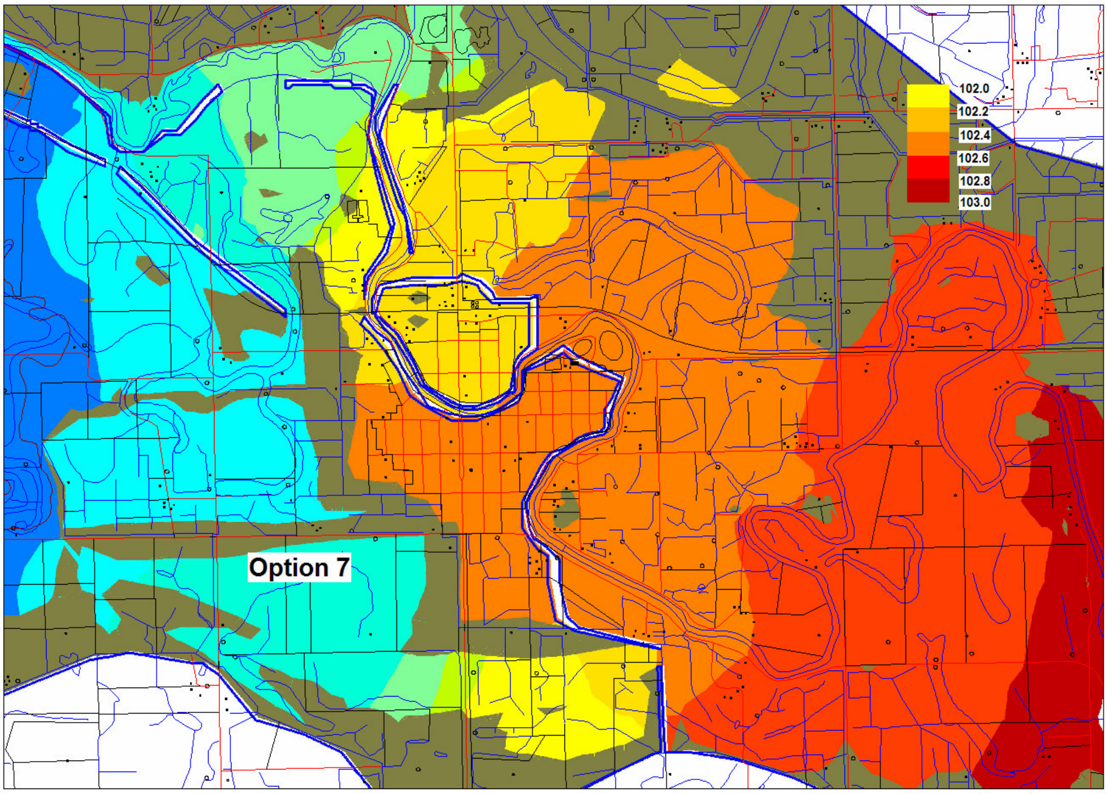


Figure 11.13: Difference in Water Surface Levels between Existing Conditions and Option 7

11.3.7 Option 8

Option 8 is combining Option 3 (remove levees to north of town), Option 4 (open up northern and western floodway) and Option 7 (100m siphon in channel 38/12). The hydraulic model indicated that for the 100-year ARI the town is protected. It is worth noting that there is no freeboard and the water would be lapping the top of the levees and in some locations without sandbagging it would even be just overtopping the levee. These locations are the low points, one of these is south of town at the very start of the levee approximately 300m south of the Nathalia weir. This needs to be fixed as water could threaten the town from the south. Other low points where water would be just overtopping the levee are the southern end of Barry Street, the northern end of Bindon Street and the northern end of Mitchell Street. In an actual event the levees could overtopped in more locations than these. Whilst there is a slight reduction in flood levels compared to Option 5 the difference is hydraulically insignificant. Figure 11.14 shows the difference in the 100-year ARI water surface between Option 8 and existing conditions.

A preliminary estimate of the cost of the combined works was calculated as $690,000.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the town protected against a 100-year ARI event the AAD damages is reduced to $103,000 (in round terms) a reduction of $405,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event.

It is important to note that no allowance has been made for levee freeboard and therefore the reduction in flood damage is overestimated. In an actual event the levees could overtop.

This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the ‘Floodway Overlay’.

The Benefit/Cost Ratio was calculated as 8.1

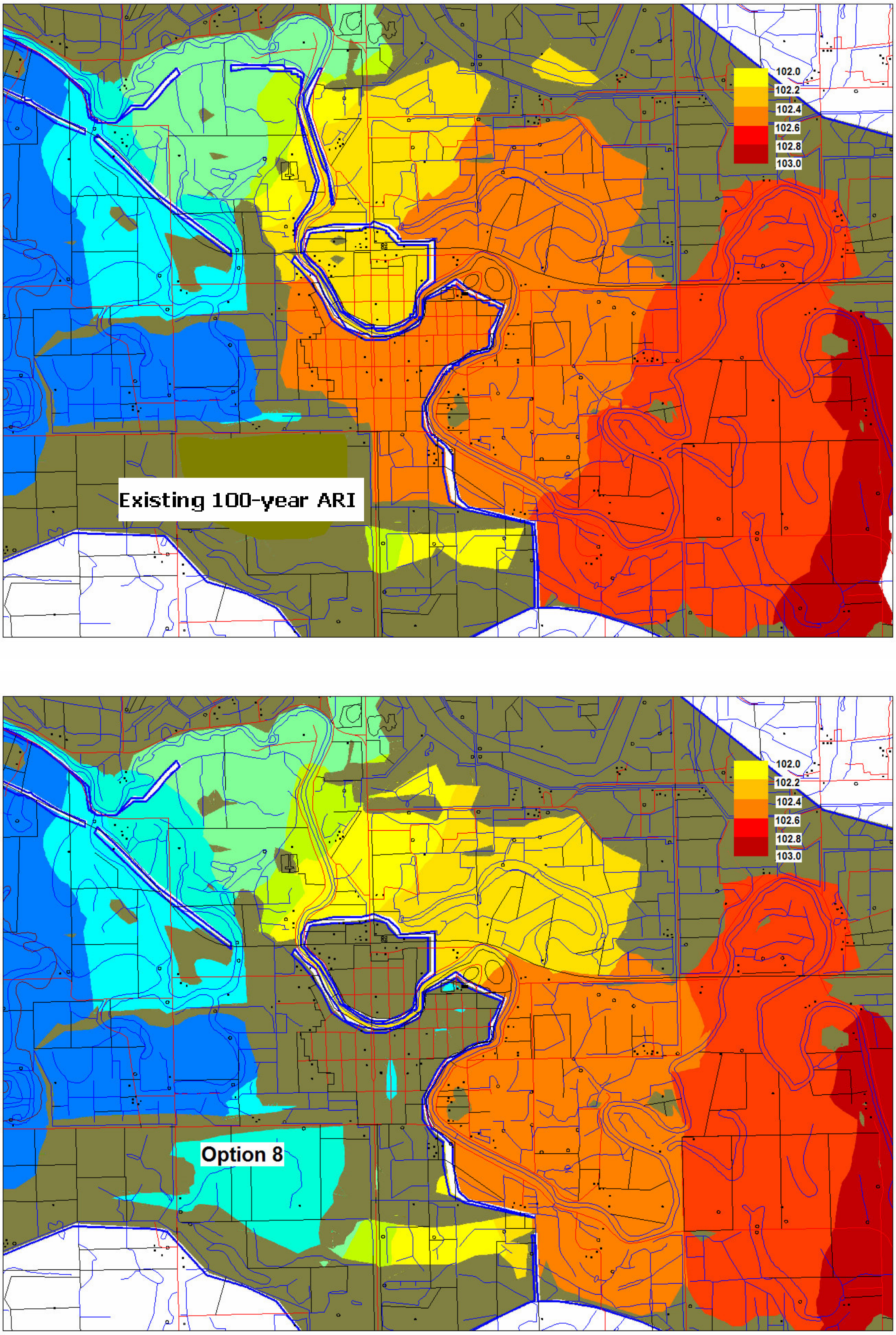


Figure 11.14: Difference in Water Surface Levels between Existing Conditions and Option 8

11.3.8 Option 9

Option 9 is removing the old railway embankment north of town which is located within the northern floodway. Figure 11.15 illustrates the section of railway removed in analysing this option. The hydraulic model indicated that for the 100-year ARI there is little improvement in the flood levels throughout town. There is a 10mm reduction in levels in the northern part of town and a reduction of approximately 60mm in the southern part of town. Reduction of flood levels outside of the town levees is only a few millimetres.

Figure 11.16 shows the difference in the 100-year ARI water surface between Option 9 and existing conditions.

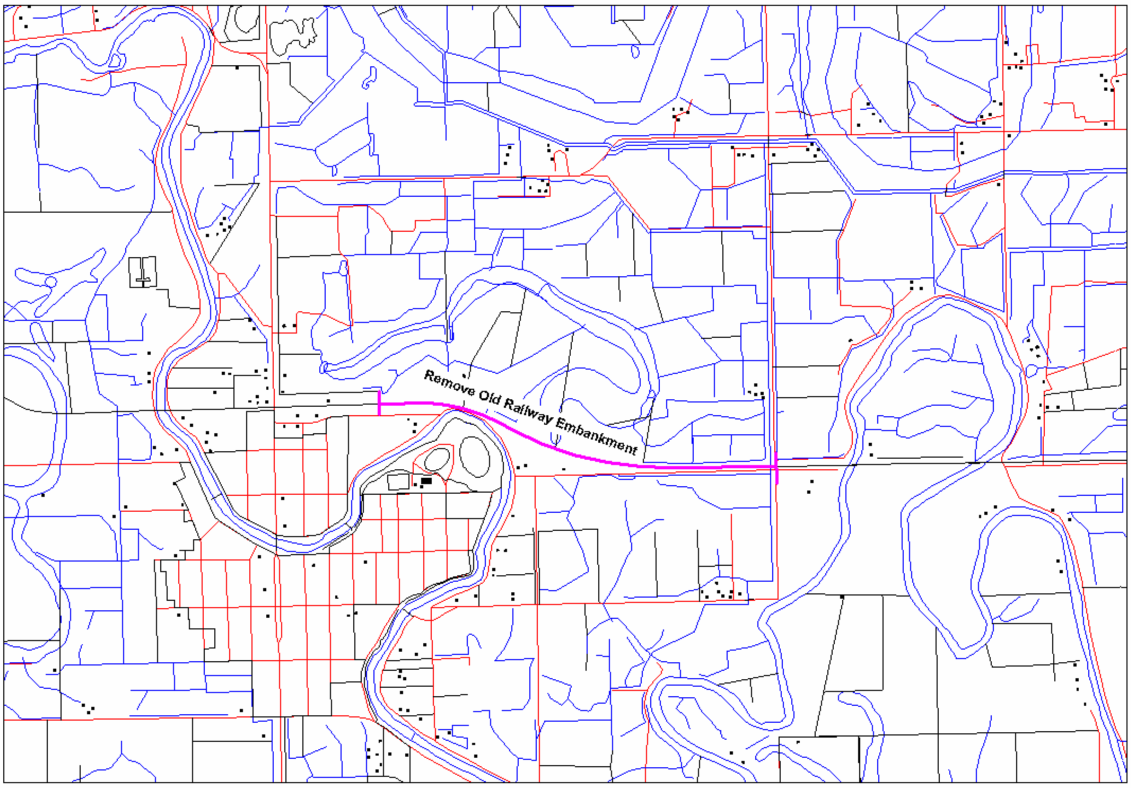


Figure 11.15: Railway Section Removed

A preliminary estimate of the costs to remove the levees was made. SMEC has costed levee removal with the material dumped outside of the floodplain. The preliminary cost estimate was $200,000, which included excavation and dumping.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the mitigation option in place the AAD damages is reduced to $413,000 (in round terms) a reduction of $95,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event and for events less than a 50-year ARI event a decrease in flood level of the same proportion as the 100-year ARI event was assumed.

It is important to note that no allowance has been made for levee freeboard and therefore the reduction in flood damage is overestimated. In an actual event the levees could overtop. This option would require new dwellings, retail and commercial type buildings to the constructed above the 100-year ARI flood level, which is generally 900 to 1,200mm above the ground level. Also, subdivision on land where the flood depth exceeds 500mm would be prohibited under the Victoria Planning Provision, as these areas would be placed within the 'Floodway Overlay'.

The Benefit/Cost Ratio was calculated as 6.5

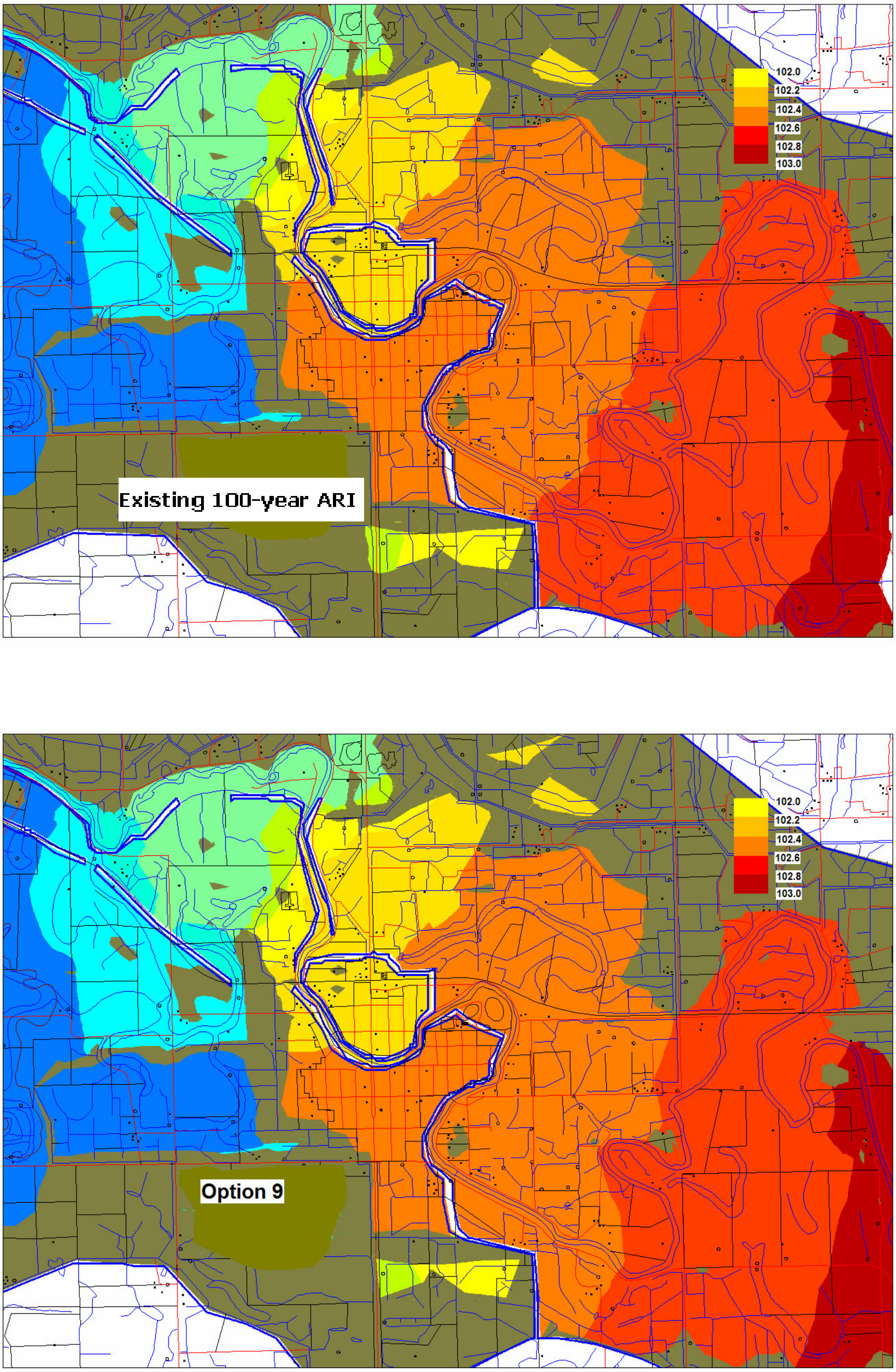


Figure 11.16: Difference in Water Surface Levels between Existing Conditions and Option 9

11.4 Voluntary Purchase

As mentioned in Section 10 in certain high hazard areas of the floodplain, it may be impractical or uneconomic to mitigate flood hazard to existing properties at risk, or flood modification measures may significantly increase hazard to a property unable to be protected. In such circumstances it may be appropriate to cease occupation of such properties in order to free both residents and potential rescuers from the danger and cost of future floods.

A depth of flooding of 2.5m has been adopted as a cut off point for voluntary purchase. This is approximately the additional height that may be provided by adding a non-habitable ground floor to an existing residence. Residential properties with depths less than 2.5m may be suitable for house raising, as discussed below. Within Nathalia for a 100-year ARI event the highest over floor flooding in the residential area is 1.5 meters. As a consequence voluntary house purchase is not considered to be a viable option for Nathalia.

Whilst voluntary house purchasing is not considered viable for Nathalia it does remove forever a high hazard situation, benefiting both the resident and the emergency services, but also allows the land to be put to flood compatible use.

11.5 House Raising and Flood Proofing

House raising and flood proofing is considered a possible floodplain management measure for Nathalia. Based on the criteria that if the flood level during a 100-year ARI event got to within 100mm of the floor level or 100mm above then flood proofing maybe appropriate anywhere where the level was above 100mm then the floor level would need to be raised. Based on this criteria there are 93 residential properties which could be flood proofed and 489 residential properties which would need to be raised

Based on an average cost of house raising of $40,000 the comprehensive implementation of this measure in Nathalia would cost up to $19,560,000. An additional $6.0M should be allowed for raising those that are brick walled.

Based on the estimated cost of flood proofing of $10,000 however, this is a very site specific measure and the price range could be ±50%. The comprehensive implementation of the proposed flood proofing measure in Nathalia would cost up to $930,000. An additional $465,000 should be allowed for complex flood proofing measures.

As with a Voluntary Purchase Program, it should be borne in mind that any adoption by Council of such an approach does not require the immediate expenditure of this amount. If a House Raising Program is adopted as a floodplain management measure, the Program can be implemented over as many years as is required.

As discussed in Section 8 the total AAD calculated for the existing Nathalia Township is estimated to be $508,000 (in round terms). The AAD damages was reassessed with the mitigation option in place. With the residential houses in town protected against a 100-year ARI event the AAD damages is reduced to $358,000 (in round terms) a reduction of $150,000. The assumption is that there is no change to the damages for any event greater than the 100-year ARI event.

The Benefit/Cost Ratio was calculated as 0.1

As mentioned in Section 10 in all cases, the decision on whether house raising or flood proofing will be implemented must be assessed on the merits of each case. Such an assessment will include detailed internal and external examination, a structural examination and a check of whether any lower storey rooms are habitable. Any illegal development, such as habitable lower storey rooms contrary to development approval, will need to be addressed before implementation of the scheme.

11.6 Planning Scheme Amendments (Land-Use Planning)

Amendments to the current planning scheme are designed to ensure that future land use and development are compatible with flooding risks as identified by this study. Section 10 outlines the approach adopted by this study in providing improved planning information to the Moira Shire and the GBCMA.

Improved land use planning does not immediately reduce flood damages for existing development, but does provide an effective means of reducing flood damages in the future.

The improved information, in particular the updated maps, will aid in more effective assessment of applications for development in the future.

11.7 Response Modification Measures

11.7.1 General

As discussed in Section 10 response modification measures encompass various means of modifying the response of the community to the flood threat. Such measures include flood warning, plans for the defence and evacuation of an area, for the relief of evacuees and for the recovery of the area once the flood subsides. Planning for these measures is incorporated in the Moira Shire Flood Plan (2000), which is part of the Emergency Management Plan.

Unless the probable maximum flood is adopted as the design flood, all flood and property modification measures will ultimately be overwhelmed at some time by a flood larger than that designed for. The development and implementation of effective response plans are a significant means of reducing flood related damages.

The recommendations for the warning process are:

- Undertake a calibration of the Casey Weir gauge during a large flow event.
- Replace existing flood level boards at Walsh's Bridge and Nathalia with a single flood level gauge. Also places the flood boards downstream of Walsh's Bridge.
- Add a telemetry (ERTS) stream gauge and link to the Bureau of Meteorology at the following sites:.
    - Broken Creek at Nathalia (optional)
    - Broken Creek at Walsh's Bridge
    - Broken Creek and Katamatite (streamflow and rain gauges already operating)
    - Boosey Creek at Tungamah (streamflow and rain gauges already operating)
- Telephone alerting arrangements to communicate impending floods to the affected community (Expedite System as used for Benalla and Shepparton-Mooroopna.
- Develop and prepare flood education information and community flood response guidelines.

The capital cost for the above would require approximately $60,000 and approximately $5,000 per annum for maintenance costs. In the past funding for flood warning capital has been provided equally by the Australia and State governments with the on-going maintenance provided from the local beneficiaries, via local municipalities or CMAs. Note Nathalia gauge would require additional capital of $17,000 and $2,500 for annual maintenance.

The estimated cost to undertake the additional works recommended above is shown in Table 11.6 below.

Table 11.6: Estimated Costs - Flood Warning & Prediction System

Item	Number required	Unit Cost	Total Cost
Stream Level Gauge with ERRTS (at Walsh's Bridge)	1	$17,000	$17,000
Flood Level Board (at Nathalia and Walsh's Bridge)	2	$2,000	$4,000
ERRTS (at Tungamah and Katamatite)	2	10,000	20,000
Expedite (voiceReach) telephone alert	1	5,000	5,000
Awareness program and brochures	1	15,000	15,000
		Total	**$61,000**

There will be ongoing maintenance costs for the system. This would be approximately $620 per stream gauge per annum. VoiceReach telephone alerting system operational cost is approximately $500 per annum.

11.7.2 Economic Benefit of Flood Prediction and Warning

Economic Impact

The impact of the implementation of the recommended Flood Warning and Prediction system was assessed through revision of the Average Annual Damage estimates for commercial and residential properties.

For commercial properties, the various types of items were assessed for whether they would be moveable given adequate warning time to undertake this task. For those that were assumed moveable, percentage reductions between 10% and 50% were made to the value of damage sustained during the flood event. For residential properties, warning time is accounted for through a factor which is included in the equations to account for a reduction in damages due to the available time. In the initial damage assessment, this factor was set at 0.7. To account for the warning system being in place, this factor was reduced to 0.4.

From the analysis, the implementation of the recommended Flood Warning and Prediction system will result in a reduction in the Average Annual Damage for residential and commercial properties in the Nathalia from $508,000 (in round term) to $359,000 (in round terms).

Benefit/Cost Ratio

It can be determined that the benefits of implementing the Flood Warning and Prediction would be some $149,000 annually. These benefits would be increased by a significant reduction in the social impacts on the community. While it is difficult to place an exact monetary value on this benefit, it could be expected that it would amount to some $25,000 annually. Thus, the benefit of the recommended response measure is $174,000.

From Table 11.6, the costs of implementing the total scheme are $61,000, plus there will be ongoing maintenance costs of approximately $5,000 p.a. From this the Benefit/Cost Ratio was calculated as 87.2.

11.8 Summary of Economic Impact

As detailed in Section 8, a detailed flood damages analysis was made for the residential, commercial and industrial areas of Nathalia that may be flood prone. The analysis established that the Average Annual Damage (AAD) in Nathalia is $508,000.

The recommended floodplain management measures, raising of levees, opening up floodways, house raising and flood warning were applied to the property database used to calculate the existing AAD. This was done by eliminating all damages for properties after the works were undertaken. For the levee raising options a conservative approach was taken. It was assumed that the measures only protected the town to the point they were designed for.

As shown in Table 11.7 below, the implementation of certain measures will result in a significant reduction in the Average Annual Damage for properties in Nathalia.

In addition, a component of the AAD will remain which represents the continuing flood problem due to floods greater than the 100-year ARI event. This is managed through the response modification measures outlined in Section 10.

Table 11.7: Potential Average Annual Damages for Residential Properties for Recommended Floodplain Management Options

Management Option Considered	Average Annual Damage	Cost of Construction	Benefit/Cost Ratio
No option implemented	$508,000	-	-
Raise Levee for 100-year ARI plus 300 freeboard (Option 1)	$103,000	$1,500,000	3.7
Raise Levee for 100-year ARI plus 600mm freeboard (Option 2)	$103,000	$4,800,000	1.2
Open up northern floodway by removing the levees on both the left and right banks between the old railway bridge and Drain 13 (Option 3)	$141,000	$280,000	18.0
Open up northern floodway by placing a 50m siphon on the farm channel to the north of the show grounds, lower the east-west road by 0.3m over 50m between Allotments 4B and 4K and reconstruction of the irrigation layout in Allotment 4B. Open up the western floodway by including a 50m siphon for Channel 38/12 adjacent to Chinamans weir (Option 4)	$375,000	$230,000	8.0
Option 3 and 4 combined (Option 5)	$103,000	$510,000	10.9
Construct an overflow channel to the south east of town directing flow from the Broken Creek into the Broken River system (Option 6)	$78,000	$5,800,000	1.0

Table 11.7: Potential Average Annual Damages for Residential Properties for Recommended Floodplain Management Options (cont.)

Management Option Considered	Average Annual Damage	Cost of Construction	Benefit/Cost Ratio
Open up the southern floodway by placing a 100m siphon on channel 38/12 (Option 7)	$415,000	$180,000	7.1
Option 3, 4 and 7 combined (Option 8)	$103,000	$690,000	8.1
Remove the railway embankment between north of town located within the northern floodway (Option 9)	$413,000	$200,000	6.5
House Raising	$358,000	$26,955,000	0.1
Flood Warning	$334,000	$66,000	87.2

11.9 Flood Mitigation Outside of Nathalia Township

Federal and State Governments have recognised existing urban communities which live with flooding risk through funding initiatives. These funding initiatives include structural measures such as the construction of levees. These funds have been directed to help communities where an existing problem to an urban population and its associated infrastructure exists, provided that the proposed works have no adverse impact on surrounding areas and are cost effective, socially acceptable and environmentally sound.

In hindsight, towns with existing flood risk would most likely be located away from active floodplain areas through the use of sound planning principles.

Funding initiatives to protect open rural type land is generally not supported in principle by governments. These areas are expected to continue to allow for flood conveyance and flood storage.

The rural surrounds of Nathalia has many constructed private levees which have been put in place over many years. These levees are generally recognised 'as of right' under the Moira Planning Scheme. The level of management for these existing rural private levees is to recognise their location and current height and not to introduce further levees.

A detailed survey of these private levees has been undertaken and a plan prepared showing both location and height to metres AHD. This plan is to form part of the floodplain management plan which provides a benchmark of what is deemed 'acceptable'.

Although the protection from flooding of rural open type lands is not generally supported, these areas will have greater protection through the implementation of on improved flood warning system providing up to two days warning of a flood event.

11.10 Environmental Impact Assessment

11.10.1 Visual Assessment

The only proposed flood management measures likely to have a significant visual impact upon the community is the raising of levees, with the traditional 600mm freeboard requirement. This would hinder views of the creek.

The recreational option of provided a structural treatment in term of a shared 1.2m wide foot/bike path would generally only require raising the levee by some 200mm, and would have little visual impact. Given the structure integrity, freeboard requirements have been reduced to 300mm.

11.10.2 Ecological Assessment

It is considered that the proposed management measures will not have an impact on the ecology of the floodplain. The only option which will have a direct impact on the flow regime of the river during flood will be the opening up of existing floodways. Currently the northern and western floodways are activated during flood and the only change would be an increase in the amount of water passing through the floodway. The southern floodway is currently blocked by channels if these were opened then flow would be increased into these areas. As these areas are natural floodways and the majority of land is pasture the environmental risk is considered to be low.

The only other measure that will have an indirect impact will be the land use re-zoning and development controls. These measures will have the effect of providing better management of the floodplain.

11.10.3 Ecologically Sustainable Development

Ecologically sustainable development (ESD) seeks to achieve the integration of environmental and economic considerations into the decision-making process. Ecologically sustainable development has been defined by the Commonwealth Government (1990) as 'using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased'. The concept of ESD has developed from the concern that insufficient weight has been placed on environmental considerations when making decisions about resource use.

The principles of ESD defined in the Protection of the Environment Administration Act 1991 and the Environmental Planning and Assessment Regulation 1994, are described below.

- The precautionary principle: This principle states that if there are any threats of serious or irreversible environmental damage, lack of scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.
- Inter-generational equity: This principle states that the present generation should ensure that the health, diversity and productivity of the environment are maintained or enhanced for the benefit of future generations.
- Conservation of biological diversity and ecological integrity: This principle is not described in the Regulation, although it means that the diversity of genes, species, populations and the communities, as well as the ecosystems and habitats to which they belong, must be maintained or improved to ensure their survival.
- Improved valuation and pricing of environmental resources: This principle is not described in the Regulation, although it is described in Harding (1990) as:

  "Traditionally pricing and resources have not reflected their scarcity, replacement costs in the long term, or future cost of irreversible and cumulative damage to natural systems. This principle requires that the true costs to the environment be factored into the cost of production or use of the resource. Those who pollute or degrade the environment should be held accountable for the restoration of the environment to its previous natural condition."

The proposed flood management measures are consistent with the objectives of ecologically sustainable development.

11.11 FINAL RECOMMENDATIONS

The final recommendations for floodplain management measures are summarised in Table 11.8 below.

Table 11.8: Summary of Recommended Floodplain Management Measures

Management Option	Objective	Recommended for inclusion in the FMP
Flood Modification Measures		
Raise Levee for 100-year ARI with 300mm freeboard (Option 1)	Protect town	Yes
Raise Levee for 100-year ARI with 600mm Freeboard (Option 2)	Protect town	No
Open up northern floodway by removing the levees on both the left and right banks between the old railway bridge and Drain 13 (Option 3)	Protect town	No (see option 5)
Open up northern floodway by placing a 50m siphon on the farm channel to the north of the show grounds, lower the east-west road by 0.3m over 50m between Allotments 4B and 4K and reconstruction of the irrigation layout in Allotment 4B. Open up the western floodway by including a 50m siphon for Channel 38/12 adjacent to Chinamans weir (Option 4)	Protect town	No (see option 5)
Option 3 and 4 combined (Option 5)	Protect town	No
Construct an overflow channel to the south east of town directing flow from the Broken Creek into the Deep Creek system (Option 6)	Protect town	No
Open up the southern floodway by placing a 100m siphon on channel 38/12 (Option 7)	Protect town	No
Option 3, 4 and 7 combined (Option 8)	Protect town	No
Remove the railway embankment between north of town located within the northern floodway (Option 9)	Protect town	No

Table 11.8: Summary of Recommended Floodplain Management Measures (cont.)

Management Option	Objective	Recommended for inclusion in the FMP
Property Modification Measures		
New flood maps	Show level of flooding and therefore development controls applying to property	Yes
Land Use Zoning	Ensures consistent, equitable, and compatible land management within flood prone areas.	Yes
Voluntary Purchase	Removes development and people from high hazard areas	No
House Raising	Raises development above flood planning levels in flood affected areas	No
Flood Proofing	Minimises the potential impacts of flooding	No
Response Modification Measures		
Flood Warning	Enable and persuade the community to take the appropriate actions to increase safety and reduce the damages associated with flooding	Yes
Community Awareness & Preparedness	Ensure that the community is fully aware that floods are likely to interfere with normal activities in the floodplain	Yes
Emergency Plans	Provide a sound basis for planning, preparation, response and recovery activities by VICSES and other emergency service providers during flood event The flood inundation maps devised as part of this report should be incorporated The access during flood should be addressed with the Murray Valley Highway inundated during significant events and the town is isolated	Yes

11.11.1 Discussion of Structural Mitigation Options

During a 100-year ARI type flood, the township of Nathalia is vulnerable to flooding for long periods of time, likely to be more than ten days. The level of over the floor flooding is extensive with more 80% of the buildings affected including dwelling, retail, office, commercial and industrial buildings.

Ideally, opening up floodways is desirable as it lowers the flood height. Hydraulic analysis has however shown small reduction is flood height outside the town levees, leaving the town still vulnerable to flooding during a repeat of a 100-year ARI type flood.

All options, except the levee treatment to the 100-year ARI standard, would require floor levels to be set 300mm above flood level within town, which would mean finished floor heights would be some 900 to1,200mm above ground. Also, subdivision would be prohibited with floodway areas as defined under the Victoria Planning Provisions.

Initially levees with 600mm freeboard above the 100-year ARI flood height were considered. To raise the levees with this amount of freeboard would raise concerns from the community. The previous refusal by sections of the residents to accept the visual intrusion caused by the levees, even at the existing height, resulted in the absence of any levee in sections of Weir Street, indicates that increasing the existing levee height to provide 600mm freeboard over significant lengths is likely to be strongly opposed.

There are sections of the levee system which are not obstructing the creek view from any residences, including the majority of levee 3 and short sections of levees 1 and 2. These sections could be raised as an earthen bank, with the remaining levee provided by a different solution. The Goulburn Broken Catchment Management Authority has advised, given the nature of flood flows, the freeboard could be reduced to 300mm if the existing levee is structurally capped or similar.

The recreational structural treatment of providing a 1.2m wide shared foot/bike path along the majority of the levee would provide sufficient 300mm freeboard above the 100-year ARI flood height. This in turn would offer protection to the planning and building standard, but must be complimented with awareness, flood warning, and alerting programs.

This option has support for both the Moira Shire Council and the Goulburn Broken Catchment Management Authority.

At an estimated cost of $1.5 million (including 40% contingencies) this option could be implement over a two year time frame with funding available on an equal basis from Australian, State and Local Governments.

12 Flood Effects from Gauge Height

Table 12.1 details the date and gauge height reached for the 1993 and the 1974 flood event, as listed in the 1995 HydroTechnology report.

Table 12.1: Flood Data - HydroTechnology

Date	Gauge Height (m)	Gauge Height (m AHD)	Flow (ML/d)	Location
12/10/93	1.895	104.45	10,100	Walsh's Bridge
14/10/93	2.20	102.08	9,700	Nathalia
17/5/74	1.60	-	-	Walsh's Bridge
17/5/74	2.01	-	9,700	Nathalia

Information on historical flood levels for the 1993 and the 1974 event, as supplied by Goulburn-Murray Water is detailed in Table 12.2.

Table 12.2: Flood Data – G-MW

Date	Gauge Height (m)	Location
12/10/93	3.95	Walsh's Bridge
14/10/93	2.20	Nathalia
22/5/74	3.66	Walsh's Bridge
22/5/74	2.01	Nathalia

Information on historical flood levels for the 1993 and the 1974 event, as supplied by Thiess is detailed in Table 12.3.

Table 12.3: Flood Data – Thiess

Date	Gauge Height (m)	Flow (ML/d)	Location
12/10/93	0.91	10,140	Walsh's Bridge
14/10/93	2.178	9,741	Nathalia
22/5/74	3.66	-	Walsh's Bridge
24/5/74	2.32	10,000*	Nathalia

Information on historical flood levels for the 1993 and the 1974 event, as supplied by the Bureau of Meteorology is detailed in Table 12.4.

Table 12.4: Flood Data – Thiess

Date	Gauge Height (m)	Location
12-13/10/93	2.95	Walsh's Bridge
15/10/93	2.2	Nathalia
22/5/74	2.69	Walsh's Bridge
24/5/74	-	Nathalia
24/7/95	2.58	Walsh's Bridge
27/7/95	1.75	Nathalia

The gauge heights shown above, although inconsistent can be used to reach a number of conclusions. Although approximately the same flow was recorded at Nathalia in 1974 as it was in 1993, changes along the river have increased flood levels for the same flow. This is clearly demonstrated in town where the addition of levees has increased levels by approximately 200mm. The second conclusion is the travel time between Walsh Bridge and Nathalia appears to be between 2 to 3 days. Thirdly, a single flood gauge should be placed at Walsh's Bridge and Nathalia such that a single reading of gauge height is taken.

From survey there are currently four (4) one meter gauge boards upstream of Walsh's Bridge with a zero gauge at 100.98mAHD and three (3) one meter gauge boards upstream of the Murray Valley Highway Bridge at Nathalia with a zero gauge at 100.01mAHD.

Modelling Results

From the hydraulic model the flood height for different ARI events was extracted at Walsh's Bridge and Nathalia (Murray Valley Highway). Table 12.5 summarises the results.

Table 12.5: Flood Levels from Hydraulic Model

ARI (years)	Gauge Level (m AHD)	Location
5	103.94	Walsh's Bridge
	101.87	Nathalia
10	104.16	Walsh's Bridge
	102.13	Nathalia
20	104.32	Walsh's Bridge
	102.22	Nathalia
50	104.49	Walsh's Bridge
	102.32	Nathalia
100	104.61	Walsh's Bridge
	102.39	Nathalia
500	104.77	Walsh's Bridge
	102.49	Nathalia

13 Community Consultation

Community input to the Floodplain Management Plan has been sought throughout the process of its development. The aims of the consultation were to:

- clearly articulate the study's aims and objectives to the community;
- establish and maintain the interest and enthusiasm of the community in the study;
- ensure that the community has ownership of the study by involving them in the decision making process;
- ensure that views of all target audiences are heard and there is a two-way communication process established;
- utilise established community networks and links to disseminate information to the wider community;
- utilise the forums as a commencement of the flood awareness program;
- ensure that all material presented is in a clear and concise plain English manner; and
- establish clear lines of communication between the community and the consultants at the outset of the project.

The key elements of the consultation undertaken were:

a) collection of data and community input through direct surveys

b) maintaining public awareness of the Study through a newsletter and newspaper articles

c) utilising the membership of the Community Reference Group (CRG) as a conduit for community views throughout the Study

d) obtaining informal community input through public forums in Nathalia following the development of mitigation options

e) presenting the draft Floodplain Risk Management Study and Plan for comment via a period of public exhibition.

13.1 Stage 1 Consultation

The key objective of the first stage of the consultation process was to collect information from the community. In order to assist in the collection of data a survey form was devised. This is provided in Appendix E. The focus of the information collected was to assist in understanding the nature of flooding within the study area.

A survey together with a newsletter was mailed to all residents within the study area, using Council's database. The objective of the newsletter was to raise the community awareness of the project; provide an opportunity for the community to forward feedback on flood history and form a Community Reference Group from community member interested in being part of the advisory group.

Council sent out during the month of June 2002. A total of 61 surveys were returned, from residents of various locations within the study area.

13.2 Stage 2 Consultation

The first public meeting with the CRG was held on the 31 July, 2003 in Nathalia. The objectives of the meeting were to:

- Inform the community on the process of the Floodplain Management Plan
- Discuss and verify the initial modelling results based on their experiences of flooding in the area

- Undertake a site inspection with members of the community.

13.3 Stage 3 Consultation

A second public meeting was held with the Community Reference Group in Nathalia on the 30 November 2004. The objective of this meeting was to discuss and inform the group of the risks of flooding and asking them to identify any ways that flood effects could be minimised in Nathalia.

Following this meeting a second survey was sent out during the month of December 2004 to the residents informing them of the risks of flooding and asking them to identify any ways that flood effects could be minimised in Nathalia. Various options were identified and have been discussed further in Section 10 of this report. A summary of the residents' responses is found in Appendix E

13.4 Stage 4 Consultation

The draft Floodplain Management Plan will be placed on public exhibition during the second week of December 2005 (08, December 2005). Following the exhibition period, comments on this report will be taken into account and the Reports finalised and submitted to the GBCMA, Moira Shire Council, DSE and the CRG.

14 Conclusions

The purpose of the study is to prepare a comprehensive Floodplain Management Plan for the township of Nathalia. The recommended plan comprises of a number of appropriate structural and non-structural flood mitigation measures, which will reduce the social and economic impacts of flooding within the Nathalia district up to the 100-year ARI flood standard.

As part of this study a comprehensive set of flood inundation maps for the study area have been prepared. These can be used by the Victoria State Emergency Service (VICSES), Moira Shire Council, Goulburn Broken Catchment Management Authority, Department of Sustainability and Environment and the community as part of a flood warning system as well as provide a basis for appropriate flood controls in the Moira Shire planning scheme.

The study has been undertaken using a risk management approach in accordance with AS/NZ code. The steps involved in formulating and implementing a Floodplain Management Plan are shown below.

Context ***complete***	➔	**Flood Study** ***complete***	➔	**Floodplain Management Study** ***complete***	➔	**Floodplain Management Plan** ***complete***	➔	**Implementation of Plan** ***To be done***

This report identifies and compares various management options, including a multi-criteria assessment of their social, economic and ecological impacts, together with opportunities to maintain and enhance river and floodplain environments.

This report also reports on the flood study which characterises the flooding behaviour of the catchment and the results from the hydraulic model produced. The results of the hydraulic model provided information on flood hazard and a means of assessing the impact of options emerging from the floodplain management studies on flooding behaviour and flood hazard.

Often, no single floodplain management option will suffice by itself. The determination of the optimum mix of measures, as undertaken in this study, involved extensive community consultation and the careful balancing of social, economic and environmental issues, as well as flooding issues. In assessing the impact of proposed developments on flooding behaviour elsewhere, it is incorrect to assess developments on an isolated and ad hoc basis. Their effects must be assessed on a cumulative basis within the context of the Floodplain Management Plan. This includes both the effect of development on flood behaviour and the number of people who may have to evacuate.

14.1 Floodplain Management Measures

14.1.1 General

A wide range of floodplain management measures were developed for the township of Nathalia and presented in Section 10. These measures are summarised in Table 14.1 below.

Table 14.1: Floodplain Management Measures Considered

Structural Measures (Flood Modification)	Land Use Planning Measures (Property Modification)	Flood Emergency Measures (Response Modification)
Retarding Basins	Land Use Zoning	Community Awareness
Levees	Voluntary Purchase	Community Preparedness
Bypass Floodways	Building Lines	Flood Prediction and Warning
Channel Improvements	Floor Level Controls	Emergency Response Plans
Flood Gates		Emergency Recovery Plans
House Raising		Insurance
Flood Proofing Buildings		

These options were presented to the Community in the form of a brochure in December 2004. Feedback was received and the multi-criteria assessment undertaken. The outcomes of this process indicated which options were considered appropriate for detailed investigation.

Section 11 presents the detailed investigations undertaken for each of these options and the final recommendations made for inclusion in the Nathalia Floodplain Management Plan.

14.2 Final Recommendations

The final recommendations for floodplain management measures are summarised in Table 14.2 below.

Table 14.2: Summary of Recommended Floodplain Management Measures

Management Option	Objective	Recommended for inclusion in the FMP
Flood Modification Measures		
Raise Levee for 100-year ARI with 300mm freeboard (Option 1)	Protect town	Yes
Raise Levee for 100-year ARI with 600mm freeboard (Option 2)	Protect town	No
Open up northern floodway by removing the levees on both the left and right banks between the old railway bridge and Drain 13 (Option 3)	Protect town	No (see option 5)
Open up northern floodway by placing a 50m siphon on the farm channel to the north of the show grounds, lower the east-west road by 0.3m over 50m between Allotments 4B and 4K and reconstruction of the irrigation layout in Allotment 4B. Open up the western floodway by including a 50m siphon for Channel 38/12 adjacent to Chinamans weir (Option 4)	Protect town	No (see option 5)
Option 3 and 4 combined (Option 5)	Protect town	No
Construct an overflow channel to the south east of town directing flow from the Broken Creek into the Broken River system (Option 6)	Protect town	No
Open up the southern floodway by placing a 100m siphon on channel 38/12 (Option 7)	Protect town	No
Option 3, 4 and 7 combined (Option 8)	Protect town	No
Remove the railway embankment between north of town located within the northern floodway (Option 9)	Protect town	No

Table 14.2: Summary of Recommended Floodplain Management Measures (cont.)

Management Option	Objective	Recommended for inclusion in the FMP
Property Modification Measures		
New flood maps	Show level of flooding and therefore development controls applying to property	Yes
Land Use Zoning	Ensures consistent, equitable, and compatible land management within flood prone areas.	Yes
Voluntary Purchase	Removes development and people from high hazard areas	No
House Raising	Raises development above flood planning levels in flood affected areas	No
Flood Proofing	Minimises the potential impacts of flooding	No
Response Modification Measures		
Flood Warning	Enable and persuade the community to take the appropriate actions to increase safety and reduce the damages associated with flooding	Yes
Community Awareness & Preparedness	Ensure that the community is fully aware that floods are likely to interfere with normal activities in the floodplain	Yes
Emergency Plans	Provide a sound basis for planning, preparation, response and recovery activities by VICSES and other emergency service providers during flood event The flood inundation maps devised as part of this report should be incorporated The access during flood should be addressed with the Murray Valley Highway inundated during significant events and the town is isolated	Yes

14.2.1 Discussion of Preferred Structural Mitigation Scheme

During a 100-year ARI type flood, the township of Nathalia is vulnerable to flooding for long periods of time, likely to be more than ten days. The level of over the floor flooding is extensive with more 80% of the buildings affected including dwelling, retail, office, commercial and industrial buildings.

Ideally, opening up floodways is desirable as it lowers the flood height. Hydraulic analysis has however shown small reduction in flood height outside the town levees, leaving the town still vulnerable to flooding during a repeat of a 100-year ARI type flood.

All options, except the levee treatment to the 100-year ARI standard, would require floor levels to be set 300mm above flood level within town, which would mean finished floor heights would be some 900 to1,200mm above ground. Also, subdivision would be prohibited with floodway areas as defined under the Victoria Planning Provisions.

Initially levees with 600mm freeboard above the 100-year ARI flood height were considered. To raise the levees with this amount of freeboard would raise concerns from the community. The previous refusal by sections of the residents to accept the visual intrusion caused by the levees, even at the existing height, resulted in the absence of any levee in sections of Weir Street, indicates that increasing the existing levee height to provide 600mm freeboard over significant lengths is likely to be strongly opposed.

There are sections of the levee system which are not obstructing the creek view from any residences, including the majority of levee 3 and short sections of levees 1 and 2. These sections could be raised as an earthen bank, with the remaining levee provided by a different solution. The Goulburn Broken Catchment Management Authority has advised, given the nature of flood flows, the freeboard could be reduced to 300mm if the existing levee is structurally capped or similar.

The recreational structural treatment of providing a 1.2m wide shared foot/bike path along the majority of the levee would provide sufficient 300mm freeboard above the 100-year ARI flood height. This in turn would offer protection to the planning and building standard, but must be complimented with awareness, flood warning, and alerting programs. The existing levees would require raising by generally 200mm.

This option has support for both the Moira Shire Council and the Goulburn Broken Catchment Management Authority.

At an estimated cost of $1.5 million (including 40% contingencies) this option could be implement over a two year time frame with funding available on an equal basis from Australian, State and Local Governments. The elements of the preferred structure mitigation scheme include:

- temporary barrier system for 500m for Weir Street and Murray Valley Highway;
- provision of recreational 1.2m wide shared concrete foot/bike path along the existing levees for some 4,900m along levees 1 and 2;
- earthen strengthening along 2060m of levee 3 and portion of levee 2; and
- Lift and extend Levee 1 by 200m.

14.2.2 Discussion of Non-Structural Mitigation Options Recommended

The recommended non-structural options to be implemented into the Nathalia Floodplain Management Plan are as follows.

Planning Scheme Amendment

- It is recommended that the Moira Shire Council amend its planning scheme to include the revisions to the planning zones and overlays as outlined in Section 7.
- It is recommended that the Moira Shire Council and the Goulburn Broken Catchment Management Authority adopt the 100-year ARI flood levels shown on the inundation maps as outlined in Section 7.

Flood Warning Arrangements

It is recommended that the Bureau of Meteorology continue to provide flood warning for Nathalia with the following trigger levels at Walsh's Bridge are included:

- Minor: 1.5m
- Moderate: 2.58m
- Major: 3.34m

The recommendations for the warning process are:

- Undertake a calibration of the Casey Weir gauge during a large flow event.
- Replace existing flood level boards at Walsh's Bridge and Nathalia with a single flood level gauge. Also places the flood boards downstream of Walsh's Bridge.
- Add a telemetry (ERTS) stream gauge and link to the Bureau of Meteorology at the following sites:.
    - Broken Creek at Nathalia (optional)
    - Broken Creek at Walsh's Bridge
    - Broken Creek and Katamatite (streamflow and rain gauges already operating)
    - Boosey Creek at Tungamah (streamflow and rain gauges already operating)
- Telephone alerting arrangements to communicate impending floods to the affected community (Expedite System as used for Benalla and Shepparton-Mooroopna.
- Develop and prepare flood education information and community flood response guidelines.

The capital cost for the above would require approximately $60,000 and approximately $5,000 per annum for maintenance costs. In the past funding for flood warning capital has been provided equally by the Australia and State governments with the on-going maintenance provided from the local beneficiaries, via local municipalities or CMAs. Note Nathalia gauge would require additional capital of $17,000 and $2,500 for annual maintenance.

Dissemination of Flood Warning

In general the flood warning dissemination detailed in the Moira Shire Flood Sub-Plan is adequate. However, it is recommended that dissemination channels are made clearer, perhaps with a diagram detailing the steps undertaken and the ways that the message is to be delivered to the community.

Also there is considerable dependence on telephone landlines or mobile coverage for the successful passage of information and directions. Many components of the telephone system are subject to flooding or, in the case of overhead lines, breakage during floods. In addition, floods cut normal access routes to many sections, so sound communications links are vital to a successful flood operation. If telephone lines are inoperable and mobile coverage is not available other forms of communication such as radio linkages should be incorporated into the plans.

The Moira Shire may also explore the viability of automatic telephone dialling as an alternative to deliver flood warnings to individual properties. Telephone alerting arrangements to communicate impending floods to the affected community are now in place including the Expedite System as used in Benalla and Shepparton-Mooroopna.

Flood Response

The flood inundation maps for emergency response, as discussed in Section 7 should be incorporated into the Moira Shire Flood Sub-Plan (2002).

Also the Moira Shire Sub-Flood Plan (2002) details three local VICSES units within the Moira Shire, Yarrawonga, Cobram and Numurkah. The plan for Nathalia should state which unit is the first point of contact for Nathalia and where the office which co-ordinates activities for Nathalia is located. If a site is established for use in Nathalia it is important that an alternative location is established outside of town if the levees become overtopped and the town is inundated.

Access to and from Nathalia during a large flood event should also be addressed in the Moira Flood Sub-Plan (2002). The main access road to Nathalia, the Murray Valley Highway, is inundated during a significant event.

Access during flood events is not only by roads. Consideration should be given in the emergency planning activity to where boats can be launched or berthed in quiet floodwaters. This approach should be considered as a last resort due to the risks involved in operating boats during floods. Development planning should also consider where helicopters could safely land in flood time.

Access also covers the continued operation of essential services, e.g. water supply, sewerage and power. The need to be able to shut down critical facilities, such as pump stations, by physical presence at the site, or by remote control is a flood access issue that must be included in flood plans.

Community Awareness and Preparedness

It is recommended that the Moira Shire in conjunction with the VICSES and the GBCMA develop a program to increase community awareness of existing flood risks, flood emergency response and flood warning arrangements. The program should at least outline contact phone numbers, context of local flooding issues, flood warning arrangements and tips for reducing damage and enhancing safety.

Flood Recovery

The location of evacuation centres and how well they are fitted out to cater for relatively large numbers of people of all ages is an essential item to be addressed in the Moira Shire Sub-Flood Plan (2002) for Nathalia. It is essential that these centres are above all risk of flooding which for Nathalia is out of town.

The importance of such centres, and the community's knowledge of their existence, cannot be overstressed. It is essential that the Moira Shire Sub-Flood Plan (2002) clearly establishes the location of evacuation centres, what facilities they have and what and where are alternative sites in the event of either overcrowding or threat of greater depths of flooding.

The sites should be chosen on the basis of:

- the available space for short term sleeping accommodation;
- the available space for storage of belongings;

- the capacity of the site to supply sufficient hygiene facilities; and
- the capacity of the site to service the food and beverage requirements of the evacuees.

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APPENDIX A – SURVEY LOCATION

Casey Weir

Bridges and Weirs Throughout Study Area (4 pages)

Levee Survey Throughout Study Area

APPENDIX B – RAINFALL CORRELATION

A relationship between the Broken River and the Broken Creek catchment would normally be estimated using stream flow gauging information on the catchments. This data was not available so an alternative approach was established. Initially it was assumed that these flows are dependent on the rainfall over the Broken River catchment. The key to estimating the break out flows is to understand what rainfall could be expected on the Broken River catchment when there is rainfall on the Broken Creek catchment. To estimate this SMEC assessed the correlation between rainfall stations in the headwaters of the Broken River and Broken Creek catchments. The analysis undertaken is detailed below.

Initially a correlation between Dookie (81013) in the Broken Creek catchment and Benalla (82002), Swanpool (82061) and Strathbogie North (82043) in the Broken River catchment was investigated. These stations were chosen as they indicate whether there is a change in the corresponding ARI of coincident rainfall across the Broken River catchment.

The procedure adopted was:

- Determine the period of concurrent rainfall at the 2 stations of interest.
- For the "base site" (Dookie (81013)), extract the maximum daily rainfall for each year of record.
- Develop the IFD curves for the "base site" (81013). For AEP's of greater than 1% CRC Forge rainfall depths were adopted.
- Determine the date (day, month, and year) when the maximum daily rainfall occurred at the "base site" (81013).
- For the corresponding site located in the Broken River catchment, determine the daily rainfall that occurred on the same day of the maximum daily rainfall on the Broken Creek.
- Determine the IFD curves for the corresponding site in the Broken River catchment.
- Plot AEPs of rainfall at the "base site" (81013) against the corresponding AEPs at the corresponding site in the Broken River catchment.
- Fit a trend line across the plotted values.

A similar procedure was adopted to determine the correlation between 3 day annual maxima at Dookie and concurrent corresponding rainfall at other specified rainfall stations.

The relationship between Dookie (81013) and Benalla (82002) was investigated first. These two sites where chosen as they have 120 years of overlapping data. These 2 rainfall stations are about 30km apart and it was assumed that the time distribution of rainfall at the stations is similar. The one day rainfall correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depths at Benalla in the Broken River catchment is shown in Figure A1.

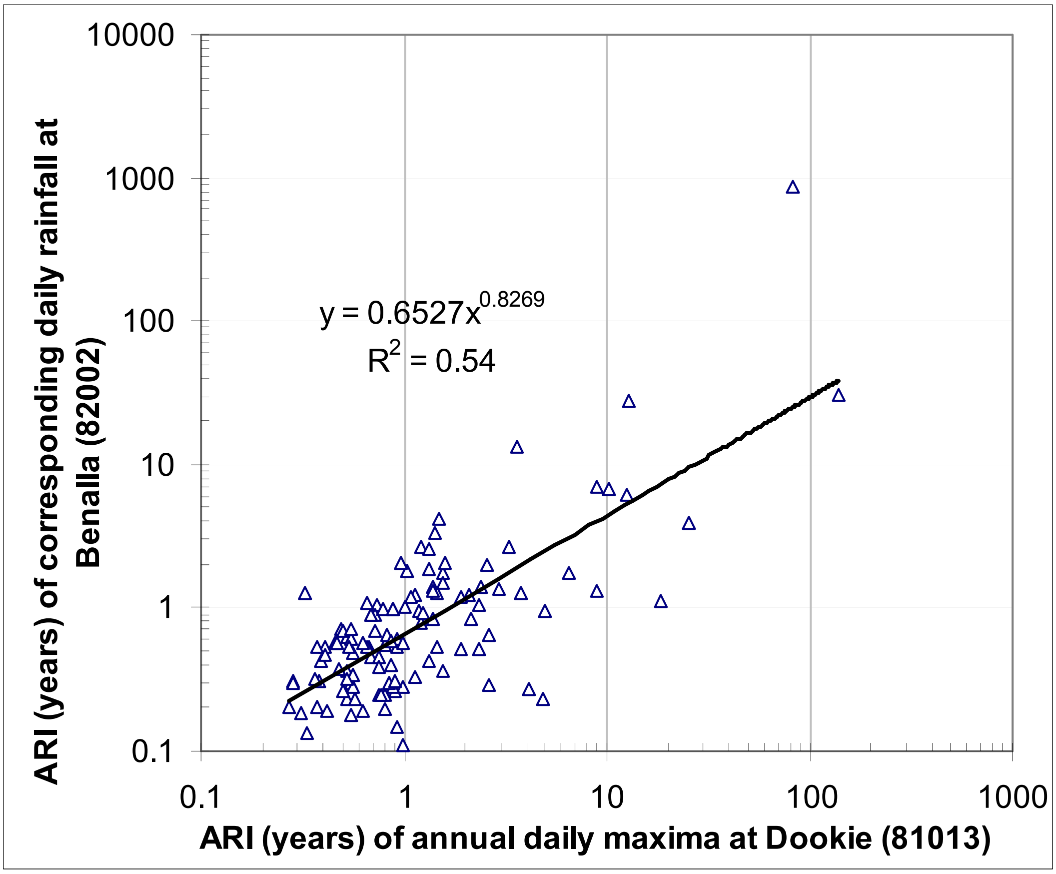


Figure A1: One day correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depth at Benalla in the Broken River catchment

As expected there is a high degree of scatter around the trend line, with the 1993 event at Benalla plotting as an ARI event of about 900 years.

The relationship between Dookie (81013) and Swanpool (82061) was also investigated. These two sites have 52 years of overlapping data and are about 50km apart. The one day rainfall correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depths at Swanpool in the Broken River catchment is shown in Figure A2.

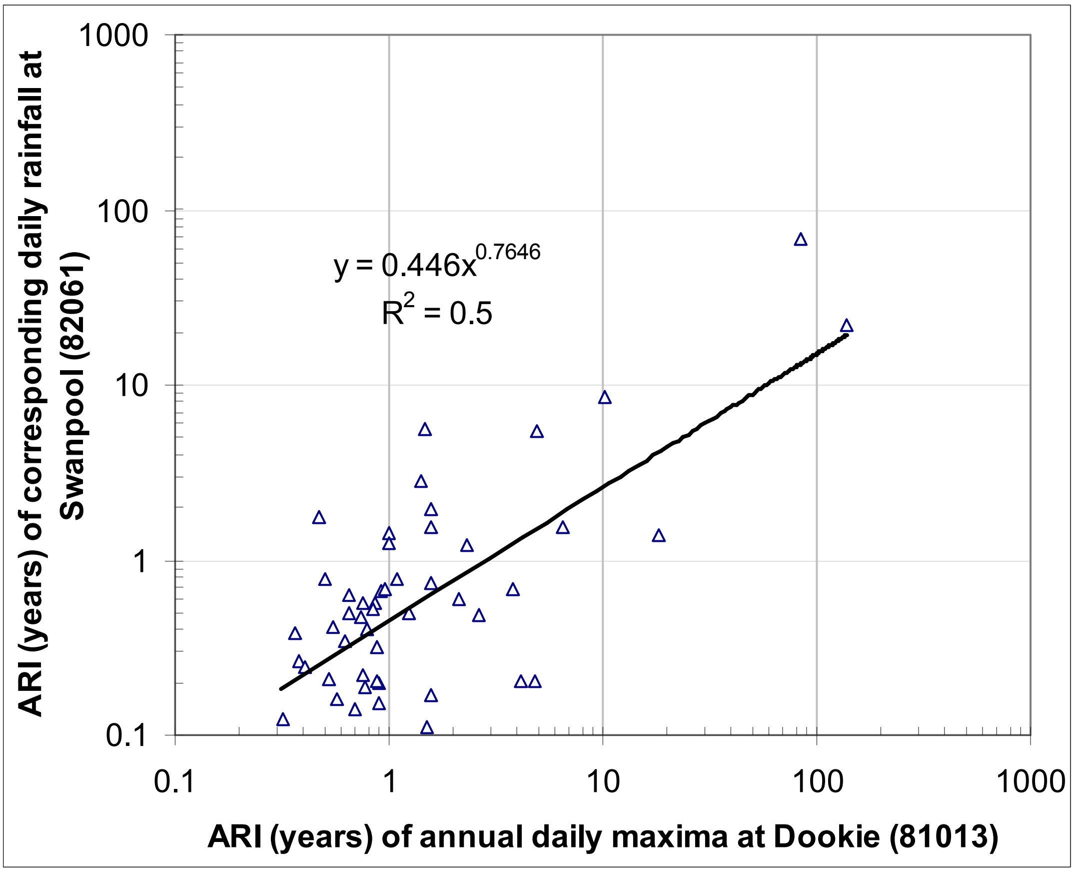


Figure A2: One day correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depth at Swanpool in the Broken River catchment

The amount of data available is less and the relationship indicates that for a certain ARI event in the Broken Creek catchment the ARI event in the Broken River is less than that achieved using Benalla.

The relationship between Dookie (81013) and Strathbogie North (82043) was also investigated. These two sites have 120 years of overlapping data and are about 60km apart. The one day rainfall correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depths at Strathbogie in the Broken River catchment is shown in Figure A3.

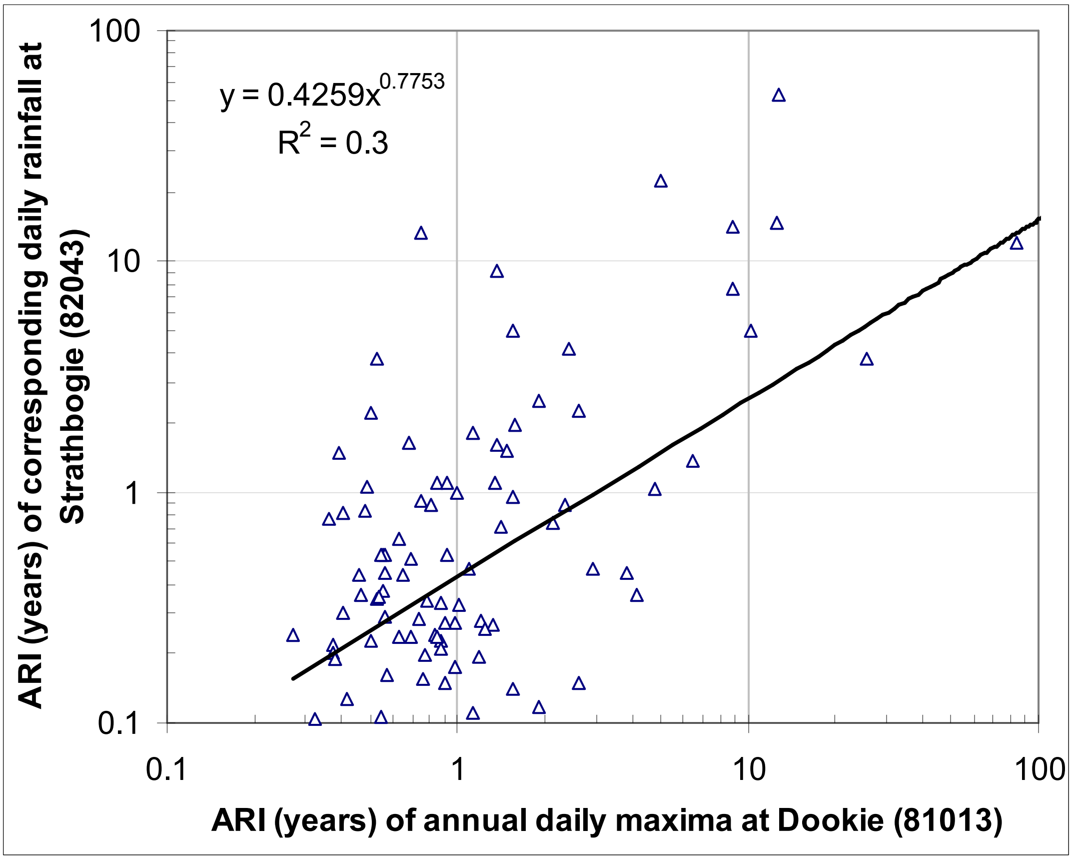


Figure A3: One day correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depth at Strathbogie in the Broken River catchment

The relationship between Dookie and Strathbogie was quiet poor. The further away the stations are from each other the less likely there is to be a relationship between the two stations.

The relationship developed between Dookie and Benalla indicates that if a 100 year event was to occur on the Broken Creek catchment on average a 30 year event could occur on the Broken River. The 95% confidence interval for this relationship means that the variation is approximately 15 years. Therefore, for a 100 year event on the Broken Creek a 45 year event could occur on the Broken River.

For the relationship developed between Dookie and Swanpool and Dookie and Strathbogie it indicates that if a 100 year event was to occur on the Broken Creek catchment on average a 18 year event could occur on the Broken River.

SMEC also undertook an analysis of the three day rainfall at Dookie compared with that at Benalla. It was thought that this may reduce the chances of “missing the peak rainfall” due to the spatial variation of a storm and the fact that large catchments of this type typically generate large flood events only after extended rainfall events. The three day rainfall correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depths at Benalla in the Broken River catchment is shown in Figure A4.

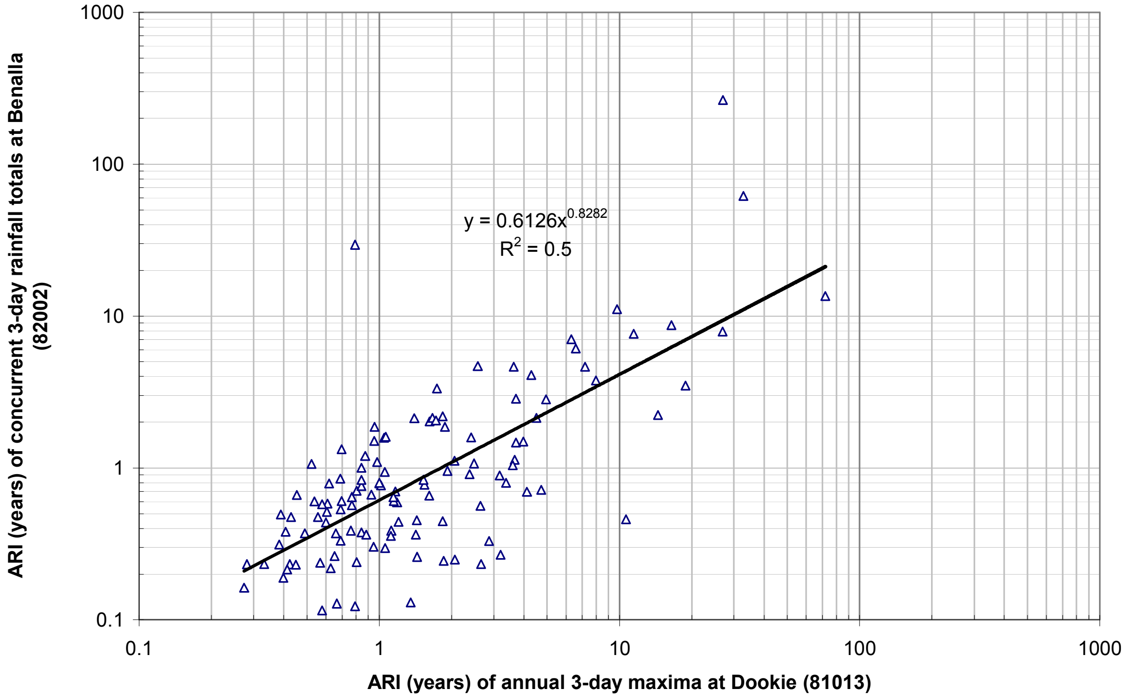


Figure A4: Three day correlation between the AEP of annual maxima at Dookie in the Broken Creek catchment and the AEP of the concurrent depth at Benalla in the Broken River catchment

From Figure A4 a similar result was achieved to that with one day totals i.e. if a 100 year event was to occur on the Broken Creek catchment on average a 30 year event could occur on the Broken River.

Given the uncertainty in the results and the limitation of representing the entire catchment at one rainfall station SMEC ran a sensitivity analysis on the breakout flows to give a range of results which are presented and discussed in section 5 of the report.

APPENDIX C – FLOOD MAPPING

APPENDIX D – FLOOD DAMAGES

1 INTRODUCTION

Flood damages for flood affected properties in Nathalia were computed using modules developed by SMEC. These modules can be used to compute damages for commercial, industrial and public utility properties. In the Nathalia study, damages for the residential sector were computed on a property by property basis using information collected during field visits, while damages for commercial properties were based on information collected on commercial properties in previous studies undertaken by SMEC.

To base damage estimates on data collected within the study area is usually the best approach, but the generalised procedure is used for studies that involve many commercial, industrial and utility properties where large surveys are not practical or where there is only a limited amount of information available. In Nathalia damage estimations for Nathalia used a combination of data collected and generalised procedures.

A description of the modules used to compute damages is given below.

2 GENERALISED PROCEDURE FOR DAMAGES

The procedures use information obtained from a detailed site survey. For the Nathalia study, the survey included all residential and commercial buildings located within in the inner study area. This survey was designed to establish the data necessary to establish the location and damage to property occupied by buildings, due to a particular flood event. The site survey was conducted by LICS and Hann McKenzie. The following data was obtained:

- addresses of buildings comprising property number, street number and street name as per site visits and Council records
- provision of a building description, i.e. flat, house, unit, cellar, workshop, etc;
- designation of building types between:
  - residential;
  - commercial/industrial; and
  - public institution;
- identification of the type of material used in the construction of external walls (residential only);
- the size of the floor area,
- an estimation of the floor level height above ground with a staff;
- an estimation of ground level at each building location, from topographic information;
- information on the capital improved value of the property;
- the age of the building;
- an easting and northing to locate the building.

The value of damages to all property occupied by buildings can be computed for the following categories for particular flood events:

- existing conditions; and
- proposed design conditions with different flood mitigation options.

An allowance for the additional cost of repairs and clean-up is included, together with a reduction factor to account for potential warning time. Vacant land is considered to contribute negligible damages overall and is normally excluded from the study. For each category above, total damages resulting from all flood events are plotted to produce a damage/frequency curve from which the Average Annual Potential Damage (AAD) is derived.

3 DATA PRESENTATION

3.1 BUILDING DATABASES

Building databases were established using excel, one for the commercial/industrial sector and one for the residential sector. The information held within the property spreadsheet included the following:

- Floor level (surveyed);
- Building type (residential, commercial/industrial, public institution);
- Building description (house, unit, storage shed/warehouse, workshop, garage, etc);
- Material type;
- Value of building (CIV).

3.2 BUILDING DAMAGE ASSESSMENT

The value of damages to residential buildings is estimated by assigning a value code to each property and incorporating the equations described in the following section into the spreadsheet database. Commercial properties were assessed using actual damage data collected through surveys of commercial property owners in previous studies undertaken by SMEC. The damage curves were developed for low, medium and high levels of flooding.

In the Nathalia study damages were estimated for all residential and commercial buildings subjected to floodwaters of 5%, 2%, 1%, 0.5% and 0.2% AEP for existing conditions. It is stressed that the results are estimates only and do not reflect actual damages in an actual flood. Only an actual flood can provide precise damages.

4 PROPERTY DAMAGE

4.1 RESIDENTIAL PROPERTIES

4.1.1 Evaluation

In evaluating property damage for residential landuse type the following equations are used:

For Depth of over floor flooding (H) < 1 m

$$D = D_2(0.06 + 1.42H - 0.61H^2)\ R\ (1 + ID) + D_{CLEAN} \quad (1)$$

For Depth of over floor flooding (H) ≥ 1 m

$$D = D_2\ (0.75 + 0.12H)\ R\ (1 + ID) + D_{CLEAN} \quad (2)$$

Where D = Value of damage to property ($)

D_2 = Assessed value of residential property damage at 2 m depth of flooding (H) ($)

H = Depth of over floor flooding (m)

R = Reduction factor by virtue of a flood warning provision. 0.7 was adopted in this study.

ID = Indirect damage factor. 0.25 was adopted for the Nathalia study.

D_{Clean} = Clean-up cost ($)

The values adopted for the current study are given below:

Residential Property Type	Internal	External	Structural
Low value property	$9,698	$1,062	$4,892
Medium Low value property	$11,625	$1,275	$6,330
Medium value property	$14,535	$1,575	$8,445
Medium High value property	$16,860	$1,845	$10,575
High value property	$20,055	$2,205	$13,725

4.1.2 Measures of "Size"

To make an allowance for the difference in comparable "size" between houses, flats and units, the following formulation was derived:

$$D_2 = X\ (Int + Ext) + (Y \times Struct) \quad (4)$$

D_2 = Annual assessed value of residential property at 2 m depth of flooding (H) or size (S) ($)

Where

X = Total number of units/flats located on title block

Y = Total number of buildings which contain X

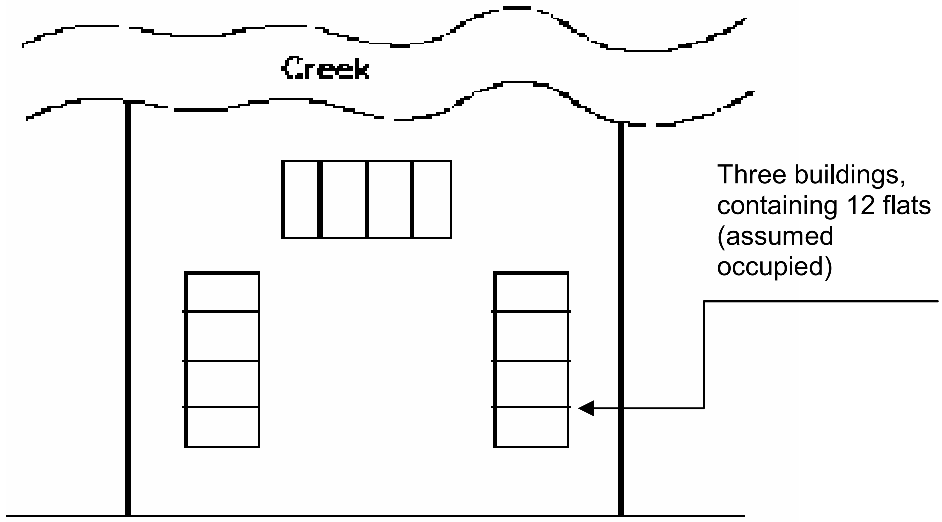
Int = Internal property value ($)

Ext = External property value ($)

$Struct$ = Structural property value ($)

An example of the use of Equation 4 is the case illustrated in Sketch C1 on the following page where 12 flats are assumed to have internal and external values of \$16 000 and \$1 750, respectively, and there are three buildings having a structural value of \$10 000 each.

Thus D_2 = 12 (16 000 + 1 750) + 3 x 10 000 = \$243 000



Sketch C1: Example of the Application of Equation (4)

4.1.3 Reduction Factor due to Flood Warning

The reduction factors or actual damage factors were determined from a review of previous studies (Upper Nepean (SMEC 2001), Gunnedah (SMEC 1999), Tamworth (PPK 1993), Wollondilly River (SMEC 2002), Cowra and Gooloogong (SMEC 2004)), and the history of flooding in Nathalia. A reduction factor of 30% was adopted.

4.1.4 Indirect Potential Damages

The indirect potential damages expressed as a percentage of direct damages were determined with the aid of previous studies and accounting for conditions in Nathalia. For residential properties, where clean-up costs were calculated as a separate item, a factor of 30% was allowed for the indirect potential costs.

4.1.4.1 Potential clean-up costs

To calculate the potential clean-up costs for residential properties, a clean-up equation was adopted as used in the 1980 SMEC study, River Torrens, Adelaide and adjusted to suit Nathalia conditions:

$$D_{Clean} = \text{Daily rate} \times Z \times \ln\left(\frac{H}{0.023}\right) \quad (5)$$

Where D_{Clean} = Potential clean-up costs (\$)

Daily rate = Earnings per day of one worker (\$/day)

H = Depth of over floor flooding (m)

Z = Factor accounting for sediment load and deposition

After consideration of other studies, Tamworth (PPK, 1993) and River Torrens (SMEC, 1980) and recent ABS data for Nathalia, a value of Z = 7 was adopted to account for sediment load and deposition and a daily rate of $70/day. This gave:

$$D_{Clean} = 490 \ln \left(\frac{H}{0.023} \right) \quad (6)$$

4.1.5 Special Conditions

Due to the inclusion of the natural logarithm function ln(A) in all equations used to evaluate damages, a value of 'A'< 1 would result in negative values creating instances of negative damages for small depths of over floor flooding ranges. Considering D_{Clean}, if D_{Clean} is to be greater than zero, h must be greater than 0.023 m.

Accordingly, for depths of flooding between zero and (0.023 + 0.01) m (=0.033 m), D_{Clean} was estimated from Equation (6) as if the depth, H, was in fact 0.033 m:

$$D_{Clean} = 490 \ln (0.033/0.023) = \$176.90$$

COMMERCIAL PROPERTIES

4.1.6 Evaluation

For commercial properties, damage curves were used for the following business types:

- agricultural/light industrial;
- hair/beauty;
- motel/b&b/caravan park;
- office;
- pub/hotel/RSL;
- restaurant/café;
- retail; and
- medical/dental services.

Damage estimates in this study for commercial properties were based on values provided by business operators in Australia from commercial surveys undertaken by SMEC in previous Floodplain Management studies (Gunnedah Floodplain Management Study (SMEC 1999); Upper Nepean River Floodplain Management Study & Plan (SMEC 2001), Wollondilly River and Mulwaree Chain of Ponds Floodplain Management Study and Plan (SMEC 2002) and Cowra and Gooloogong Floodplain Management Studies (SMEC 2004).

The damage curves for each business were collated from data on the estimated value of damage sustained through the various components of a business. These components were:

- Stock;
- Fittings;
- Fixtures;
- Wiring;
- Equipment;
- Electrical; and
- Other.

Using information supplied by the business operators, these components were categorised as being affected by a low, medium, or high flood and thus a curve was able to be developed to cover the spectrum of floods experienced for each type of business.

For each of the design flood levels, the depth of flooding experienced by a business was determined by subtracting the estimated flood level from the flood level. The depth of flooding was then looked-up on damage curve appropriate for the business type to determine the potential flood damage sustained for that depth of flooding.

4.1.7 Indirect Potential Damages

Indirect commercial damage may include costs of removal and storage, loss of business confidence and loss of trading profit. Smith's study of Lismore (1980) found that indirect costs were 18.5% of direct damage suffered by the commercial sector and 35% in the industrial sector. It is normal to include clean up costs as a direct damage. If it is incorporated into the equation as a percentage of indirect costs, then the indirect costs can be up to 25% of the total direct costs (Smith 1980).

The indirect potential damages expressed as a percentage of direct damages were determined with the aid of previous studies and accounting for conditions in Nathalia. For commercial properties a factor of 25% was adopted, which included the clean-up costs.

4.2 INFRASTRUCTURE / PUBLIC SECTOR

A major component of infrastructure damage is concerned with transport – damages to roads, bridges and culverts and locally to rail and air connections where applicable. Other losses are to services such as water, sewage treatment plants, gas, electricity and telephones. The variability in terms of location, the period of inundation, problems of sedimentation and erosion are such that no standard technique is possible. Australian and international literature suggests that infrastructure damage is normally within the range of 7% to 20% of that to the private sector. (DI Smith et al 1986).

In this study, data on previous flood damage to roads was not available so the Rapid Appraisal Method was adopted for damage to roads. The Rapid Appraisal Method (RAM) uses a total cost per kilometre for a major, minor and unsealed road. This single estimate of cost per kilometre of road inundated includes,

- Initial repair to roads
- Subsequent additional maintenance to roads
- Initial repairs to bridges; and
- Subsequent additional maintenance to bridges.

The costs listed in the RAM report are based on the 1993 flood in North Eastern Victoria and the 1998 floods in East Gippsland.

APPENDIX E – COMMUNITY CONSULTATION

APPENDIX F – SURVEY OF LEVEES