Numurkah Floodplain Management Study and Plan

Study Report

November 2017

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PROJECT DETAILS

Project Name	Numurkah Floodplain Management Study and Plan
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Cover Photo: Melville St, Numurkah during the March 2012 event

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21 November 2017

THE NUMURKAH FLOODPLAIN MANAGEMENT STUDY & PLAN

COMMUNITY REFERENCE GROUP SUMMARY & RECOMMENDATION

The Numurkah Floodplain Management Study and Plan was initiated in October 2012 after a major rainfall event in late February and early March 2012 which severely impacted on the town of Numurkah. This event saw some 200 to 300mm of rain fall across the Broken, Muckatah and Nine Mile Creek Catchments, an area of approximately 2500 square kilometres which stretches from the Midland Highway to the south, across to the Warby Ranges and Peechelba in the east and to Yarrawonga and Cobram to the north.

The topography of the catchment naturally flows to the west, with an estimated 200,000 to 250,000 megalitres of flood water runoff, all having to pass through and around the township of Numurkah, on its route to the Murray River.

As the main bridge on the Broken Creek, the Melville Street Bridge in Numurkah is restricted by a design capacity of just 800 megalitres per day. It was no match for the peak flow of 25,000 to 30,000 megalitres of water per day; subsequently the bridge structure and creek banks were rapidly overtopped. When floodwater from the east combined with flood water entering the town from the south, via the Hospital Depression, it resulted in unprecedented flood levels and extensive damage being recorded across what were previously considered by the community as “safe residential areas”.

In the absence of prior safeguards in place, the ultimate casualty was the inundation of the Numurkah Hospital in the early hours of Sunday the 4th of March. This traumatised both staff and patients alike. Many community residents and business houses were also severely impacted and paid a heavy price both emotionally and financially, many of them still struggling to recover. A lingering consequence of this is that any reports of a major rainfall event in any of the upper catchments immediately raises the stress and anxiety levels of the Numurkah community to a state of high alert for the days following as they grapple with the possibility of another major flood event heading towards the town.

As a result of extensive community feedback, the Community Reference Group resolved that anything short of permanent protection for both north and south Numurkah would not be acceptable. To that end, extensive studies of up to 15 different options have been modelled ranging from a small floodway through the Train Park to a large whole town levee and Box Creek bypass.

The Community Reference Group, and the supporting agencies involved, are determined to finally overcome Numurkah’s long-term vulnerability to major floods which have occurred almost every second decade.

Working through the results of each option modelled made it quite clear that with Numurkah’s relatively flat topography finding a practical solution would be challenging and difficult.

Mitigation Option (A) which is explained in greater detail within the attached report was by design, the final model run. After detailed assessment it has been determined by the Community Reference Group that this option best meets the needs of the Numurkah community and your endorsement of Mitigation Option (A) is favourably encouraged.

THE COMMUNITY REFERENCE GROUP RECOMMENDATION & EXPLANATION

Mitigation Option Package (A) - a brief overview:

Offers protection to all homes, businesses and community facilities within the Levee system, both north and south of the Broken Creek. The larger residential blocks in south Numurkah, between Corke Street and Powell Road are not included within the Levee system because the flood passage through these blocks needs to be maintained. The homes on these blocks, and other houses outside the levee system but being deemed at risk will be part of the Operating Flood Plan and will be individually protected as the need dictates. The planning and design of protection for these properties such as the quantity and placement of sandbags and other infrastructure, will need to be part of the Moira Shire Municipal Emergency Flood Sub Plan. This Plan will be assisted by the permanent installation of "In Stream Monitoring Stations" placed upstream of Numurkah, which will provide for more informed and timely management of future events.

The Numurkah Recreation Reserve and a portion of the Numurkah Golf Course are inside the levee system as a result of the need to take the Southern Residential Levee to its north-eastern tip in order to act as a 'Diversion Levee' in this area and to maximise flow through the creek itself.

Permanent levees are a necessity as Numurkah has limited time available to prepare for any rapidly approaching flood event.

Flood water passing through the central town area will be contained within the creek reserve.

The northern levee in the initial mitigation package presented to the Community in June of 2015 and rejected by both the community and the Community Reference Group as a "Stand Alone" package, is an important component of the recommended package.

The Community Reference Group believes that dry road access to south Numurkah and thus the Numurkah and District Health Service and Ambulance Victoria Station needs to be maintained. Access will be via Katamatite Road and the Goulburn Valley Highway or possibly an improved Melville Street Bridge however, how this is achieved is to be determined in the planning and design phase.

A large portion of the levees would not be constructed in 'built up' areas and generally where possible would follow the creek reserves.

Although not a component of this Flood Study, the Community Reference Group would like to see the old Numurkah Cemetery's flood protection reinstated to cope with a 1974 type flood event. Larger events would require the flow path to remain open through this area.

We present this report to the community and urge your support of package (A).

The Community Reference Group wish to acknowledge Water Technology Consultants, Moira Shire Staff, Government Support Agencies and our local politicians, both State and Federal, for their expertise, assistance and encouragement throughout this project.

As Chairman, and Councillor Representative, I would like to extend my sincere thanks to the Numurkah Community for supplying information and taking ownership of this plan.

My sincere thanks and gratitude also goes to the relatively small but very dedicated team of the Numurkah Flood Study Community Reference Group, who have spent many hundreds of hours of researching, fact finding and negotiation in order to reach this very comprehensive and positive outcome.

Cr Kevin Bourke

Chairman - Numurkah Floodplain Management Study & Plan Community Reference Group

GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Existing Conditions	Refers to modelling of the current situation in Numurkah with respect to topography (lay of the land) and key structures such as bridges and culverts.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.

Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Probable Maximum Flood	The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

EXECUTIVE SUMMARY

Overview

North-East Victoria and the New South Wales Riverina was subject to widespread heavy rainfall and flood events in March 2012. Numurkah was one of the towns hit hardest during this period, with large parts of the township inundated in that event. It is estimated that over 90 residential and commercial properties were inundated above floor level in the March 2012 event. Prior to March 2012 another significant flood event occurred in October 1993 which was smaller in magnitude. Many other historic floods have also occurred in Numurkah.

The Victorian Minister for Water, Peter Walsh, announced funding to undertake the Numurkah Floodplain Management Study and Plan in October 2012. The Moira Shire Council, in conjunction with Goulburn Broken CMA and the community, has developed the Numurkah Floodplain Management Study and Plan. This study builds on the work that Water Technology previously completed during the Numurkah Flood Study (Water Technology, 2011).

Community Consultation and Feedback

A key objective of the Plan was to ensure community engagement and to demonstrate community support for the final Plan. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and one-one-sessions and through more formal feedback methods such as surveys.

A community-based reference group (CRG) was involved in all stages of the study, including the development of flood mitigation options for testing in the flood modelling.

A public meeting held in August 2015 was strongly attended with approximately 150 community members present. Following the public meeting a series of 'one on one' discussions were also well attended, with 19 community members making appointments to speak with Council and CMA staff. Community feedback was also received through 74 written submissions to Council. Feedback from the period of community consultation guided the development of the Plan and the final recommended package of mitigation works.

Three final mitigation packages are presented in this report and it is recommended that these options are presented to the community through an additional period of community consultation. This will aim to seek feedback on the options and determine a preferred package. It is imperative that the adopted package of mitigation works has strong community support.

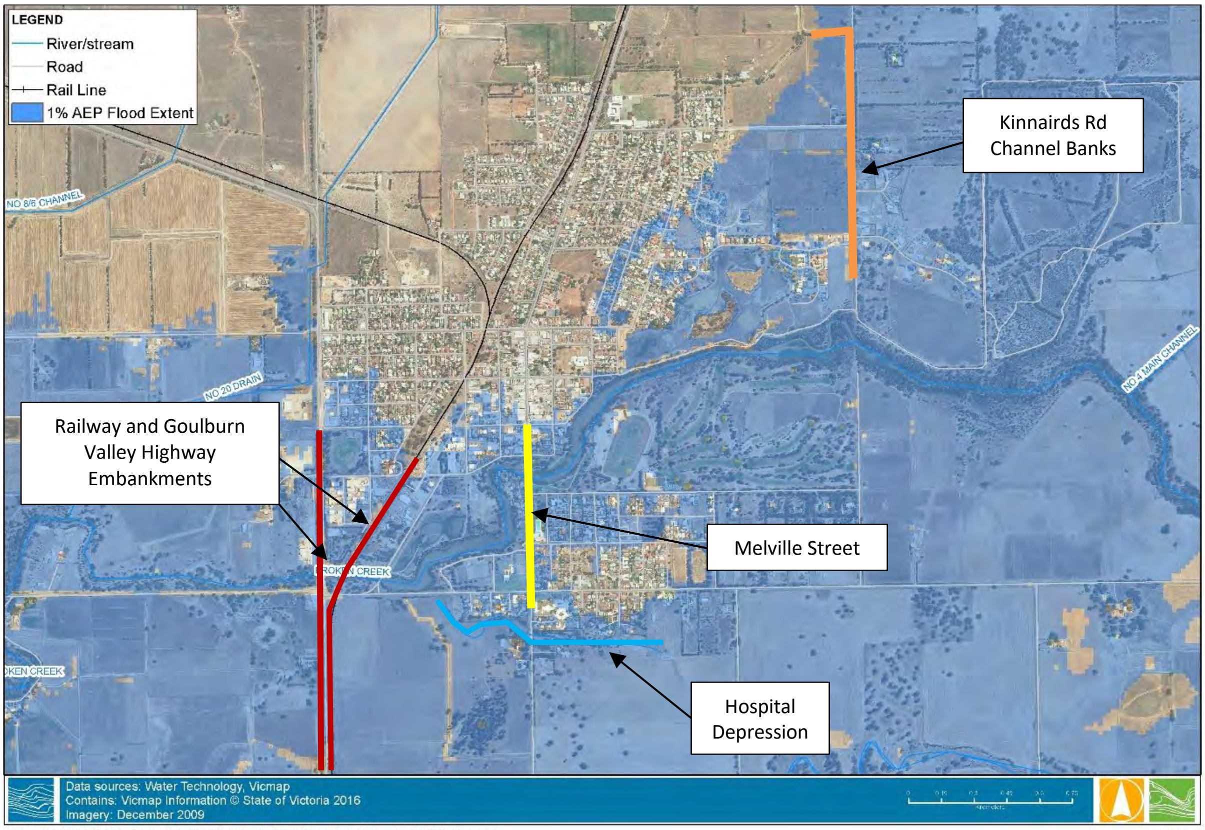
Flood Mapping and Intelligence

A 1D/2D Mike FLOOD hydraulic model was constructed and calibrated to the March 2012 and October 1993 historic events. An excellent calibration was achieved for the March 2012 event and a very good calibration achieved for the October 1993 event. The modelling demonstrated that the events were quite different in nature which correlates with observations that the March 2012 was a much larger and more damaging event. Overall the hydraulic models provided a very good representation of the historic events which impacted Numurkah.

A full range of design events were then run using the flows determined in the hydrology phase of the project. The key findings form the hydraulic modelling were:

- Under existing conditions approximately 125 commercial and residential properties are flooded above floor in the 1% AEP event. This assumes no temporary protection measures are in place such as sandbagging. Extensive sandbagging would be required to significantly reduce above floor flooding in the 1% AEP event, as occurred in the March 2012 event.

- Approximately 25% of flow passes through the central township in the 1% AEP event while the remainder flows through the hospital depression and across the floodplain to the south of Numurkah.
- It is not until the 2% AEP flood event and greater, that significant numbers of properties are flooded above floor.
- The 1% AEP event is slightly smaller in magnitude then the March 2012 event, with flood levels generally 20 to 30 mm lower around central Numurkah.
- The modelling has confirmed that the irrigation channel banks which run parallel to Kinnaird’s Road have an important role in protecting properties in the northern residential areas of Numurkah in large flood events particularly when combined with temporary measures such as sandbagging.
- The modelling demonstrated that the railway line and Goulburn Valley Highway embankments have a local impact on upstream flood levels but this impact only extends as far upstream as Melville St. Upstream of Melville Street flood levels are controlled by Melville Street and the higher ground around the football club and southern residential area.
- It was found that increasing the culvert capacity on Broken Creek under the railway and Goulburn Valley Highway had a very minor impact in reducing upstream flood risk. It had a local impact on reducing upstream flood levels but that impact only extended for a short distance upstream and not to residential and commercial areas.



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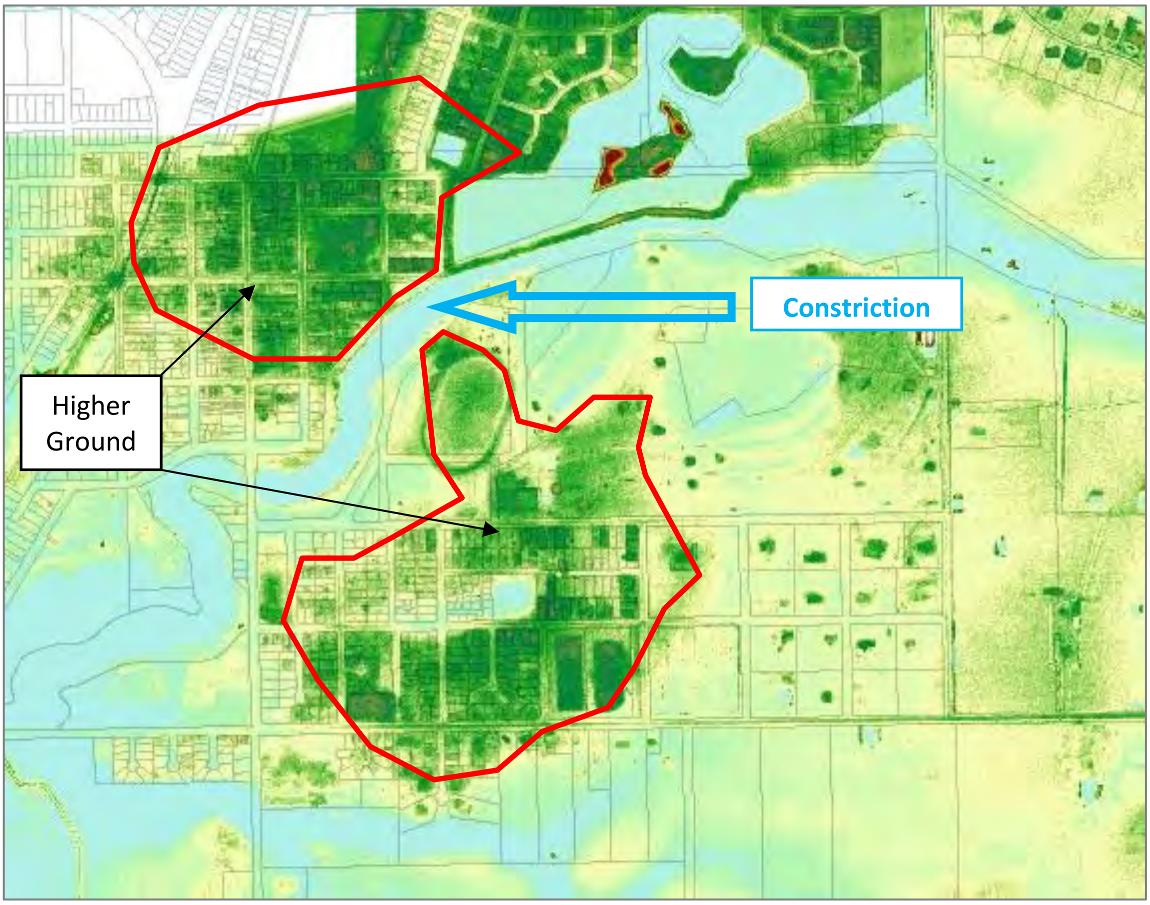
1% AEP Flood Extent and Key Hydraulic Features



Topography of central Numurkah demonstrating the natural constriction that occurs through the township

Final Mitigation Packages

A large number of mitigation options and packages of options were considered and modelled prior to development of the final mitigation packages presented in the Plan. These packages were developed following extensive consultation with the community-based reference group (CRG) and agency stakeholders, and consist of three alternative arrangements for the town.

The three final mitigation packages were modelled to fully understand the benefits, costs and impacts of each. The three packages consist of:

- **Final Mitigation Package A** – formalisation of the northern levee combined with a large southern ring levee and hospital depression levee protecting the northern and southern residential areas, excluding the large, southern, residential lots and sections of the golf club. This package results in a very significant reduction in flood damages. The scheme has some moderate impacts upstream of the levee systems which extend for several kilometres across the floodplain. This package of works has been costed at slightly less than $17 million and has a low benefit-cost ratio of 0.3. This option also includes channel enlargement works along Broken Creek. This package reduces the number of properties flooded above floor in the 1% AEP event from 125 to 6. This package is the preferred package of the community-based reference group (CRG).
- **Final Mitigation Package B** – formalisation of the northern levee combined with a southern ring levee and three smaller ring levees in the south of Numurkah thus providing protection to both the northern and southern residential areas of Numurkah, excluding the larger,

southern, residential lots. This package results in a very significant reduction in flood damages. The scheme has some moderate impacts upstream of the levee systems. This package of works has been costed at slightly more than $23 million and achieves similar benefits to Package A.

- **Final Mitigation Package C** – formalisation of the northern levee combined with a southern ring levee and three smaller ring levees in the south of Numurkah thus providing protection to both the northern and southern residential areas of Numurkah, including the larger, southern, residential lots. This package results in a very significant reduction in flood damages. The scheme has some very significant impacts upstream of the levee systems which extend for several kilometres across the floodplain and are more severe than Packages A and B. This package of works has been costed at slightly less than $25.5 million and achieves slightly more benefit than Packages A and B in that the larger, southern residential lots are also protected by the southern ring levee.
- It is recommended that the three final mitigation packages are presented to the community through a period of community consultation in order to seek community feedback on the preferred mitigation package.
- If any of the above packages of works are implemented the next step will be for the package to undergo functional and detailed design.
- Some of the packages have been noted to have impacts on a significant number of upstream and downstream properties, including the larger residential lots in the south of the Numurkah, and local mitigation works where appropriate will need to be investigated as part of the functional and detailed design phase.

The above mitigation packages all include removal of some earthen embankments to the east of Numurkah near the Numurkah Go Kart track, channel enlargement works on Broken Creek, non-return valves on stormwater infrastructure which intersect the levees and environmental and cultural heritage management plans.

Mitigation Package A was found to have a low benefit-cost ratios of 0.3. This is a reflection of the high costs associated with levee construction, particularly sections likely to require retaining or flood walls, as well as very significant acquisition costs. The low benefit cost ratio is also due to the benefits of the schemes not being realised until relative large flood events. Package B and C did not undergo full benefit cost analysis but given they are more expensive to construct and achieve similar benefits they would have a lower benefit-cost ratio than Package A.

Original Mitigation Package

The original mitigation package below was presented to the community at a period of community consultation in February 2016. One of the key areas of feedback from the community option was that it did not include any structural mitigation for the southern residential areas of Numurkah. Based on this feedback the additional modelling was undertaken which led to the final packages described above. It should be noted that this option does not have the support of the community reference group and generally received poor feedback from the broader community.

- **Original Mitigation Package** – formalisation of the northern levee in order to provide protection to properties located to the north of Broken Creek. This package predominately benefits the northern portion of the township and results in a significant reduction in flood damages. This package reduces the number of properties flooded above floor in the 1% AEP event from 125 to 31. This package of works has been costed at slightly less than $3.5 million and has a modest benefit-cost ratio of 0.4.

Plan Recommendations

After significant consultation with the community-based reference group and agency stakeholders, the Plan presents three packages of works that all provide significant protection to Numurkah up to and including a 1% AEP event. The three packages of works consist of three varying levee arrangements for the town. A number of smaller mitigation packages were also investigated and costed, but these did not receive community support as they did not offer full protection to the township south of Broken Creek.

The following points detail the key findings and recommendations of the study:

- Design flood levels were determined and can be used to guide future planning decisions in Numurkah.
- Three final packages of mitigation works were identified which significantly reduce flood risk for Numurkah. It is recommended that the three final mitigation packages are presented to the community through a period of community consultation in order to seek community feedback on the preferred mitigation package.
- If through community consultation a package of works has strong support and this aligns with agency stakeholders, it is recommended that this be taken to functional and detailed design phases prior to construction. Some of the works have been noted to have impacts on a significant number of properties upstream of Numurkah, including the larger residential lots in the south of the town, and local mitigation works and landholder consultation will need to be investigated as part of a functional design phase.
- It is recommended that any future decommissioning of irrigation channels must consider the impact on flood risk to Numurkah and surrounds. In particular, the study has highlighted the importance of the irrigation channel to the east of Numurkah which runs parallel to Kinnairds Road and has a significant role in protecting the township in large flood events. Any future decommissioning works of the Kinnairds Road channel must consider these impacts and replace the channel banks with a formal levee.
- The community-based reference group requests that culverts along Broken Creek are upgraded in the future to improve drainage around Numurkah. In particular, when funding permits, the committee wishes to see the Goulburn Valley Highway and Railway culverts be upgraded with increased capacity to reduce water banking up on the upstream side in large flood events. It is acknowledged by the committee that funding is unlikely to be available in the short-term but it is recommended that the works be implemented as part of a long-term drainage plan for Numurkah.
- The community-based reference group requests that VicTrack be notified that damage to the railway line in the vicinity of Numurkah from large flood events is likely to continue periodically into the future. The CRG would like VicTrack to consider that when funding permits, the culverts under the railway line be upgraded with either an increased number of culverts or bridged sections to increase the capacity of flow under the line. Such works will reduce the frequency of overtopping and are likely to reduce the long-term cost associated with flood damage to the railway line along with the associated economic losses to the greater community. It is acknowledged that funding is unlikely to be available in the short-term but it is recommended that the works be implemented as part of a long-term drainage plan for Numurkah. A copy of the draft report will be forwarded to VicTrack at the completion of the project with these points highlighted to them.
- It is recommended that future road maintenance and upgrade programs by both Council and VicRoads must consider the impact of flooding in completing such works. It is noted that roads can have a significant impact on floodplain behaviour, particularly in areas of flat terrain such as Numurkah. Floodplain behaviour must not be altered or made worse around Numurkah through the raising of road crest levels that often occurs in road maintenance programs.

- VICSES, Moira Shire Council and Goulburn Broken CMA should explore further the recommendations for enhanced flood response through utilising the flood inundation maps and flood intelligence tools included in the Municipal Flood Emergency Plan (MFEP).
- The study has recommended a flood warning system for Numurkah which includes additional permanent rainfall and streamflow gauges. A firm commitment has been made by Goulburn Broken CMA, DELWP, BOM and Moira Council to implement the recommendations and planning for the warning system has commenced. The flood warning system should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system.
- The CRG strongly support permanent gauges being installed on the Broken Creek between Katamatite and Numurkah and in the Muckatah Channel. They feel that this would reduce the reliance on temporary gauges that may not be available in a flood situation. It is recommended that Moira Shire Council and Goulburn Broken CMA explore the opportunity with Bureau of Meteorology what the benefit of permanent gauges would be for any future flood warning system upgrade, and identify locations that would be suitable. As part of this process consultation should also occur with Goulburn Murray Water who also have preferred permanent gauging sites. As stated above a firm commitment has been made by Goulburn Broken CMA, DELWP, BOM and Moira Council to implement the recommendations and planning for the warning system has commenced, including consideration for permanent gauges.

Next Steps

It is recommended that The Numurkah Floodplain Management Study and Plan now be presented to the community through a period of consultation in order to present the final mitigation packages and allow a preferred package to be determined.

Following this process, and the determination of a preferred scheme, the Plan will seek endorsement from both the Goulburn Broken Catchment Management Authority and the Moira Shire Council prior to sending to the Victorian Government for consideration for funding in a staged manner. Initial funding requests will comprise functional and detailed design of the proposed structural mitigation works. Other actions will include updating of the Emergency Response Plan, implementation of updated planning scheme layers, and implementation of the flood warning recommendations.

Acknowledgements

The Numurkah Floodplain Management Study and Plan was led by the Numurkah Floodplain Management Study and Plan Community Reference Group. The study team would like to thank the community members which volunteered their time to be on the CRG, and all others who contributed to the Plan, for their commitment to what has been a long study, but which offers solutions to reduce the flood risk for the Numurkah community.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Moira Shire Council in conjunction with Goulburn Broken Catchment Management Authority commissioned Water Technology to undertake the Numurkah Floodplain Management Study and Plan. This study builds on the work that Water Technology previously completed during the Numurkah Flood Study (Water Technology, 2011). Figure 1-1 displays the study area and the contributing catchment.

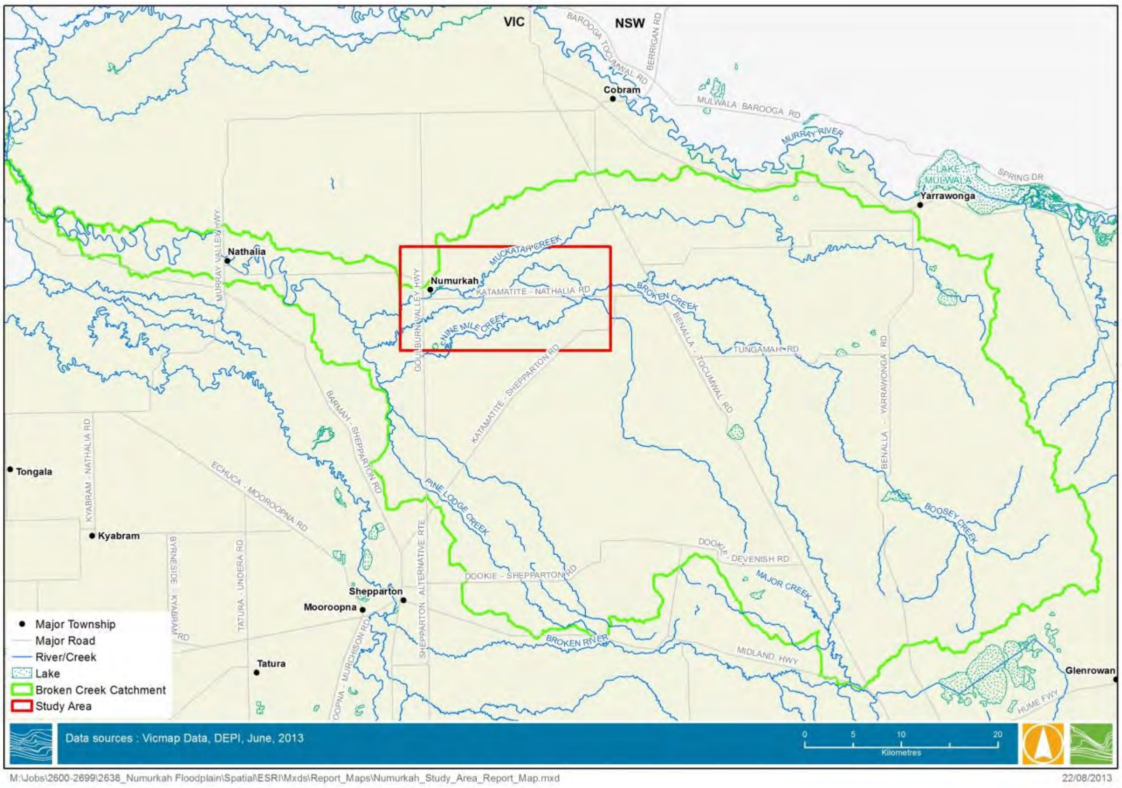


Figure 1-1 Map of Broken Creek catchment and study area

2. DATA REVIEW

2.1 Overview

This section identifies and briefly reviews relevant available data and information collated. Sources of background data and information collated included:

- Streamflow and rainfall data
- Topographic Data
- Existing Structure Information
- Previous hydrologic analysis studies and investigations

2.2 Observed Streamflow and Rainfall Data

Table 2-1 displays the relevant streamflow gauges within the study area with Figure 2-1 showing a map of their locations.

Table 2-1 Streamflow gauges

Gauge Station (No.)	River/Creek, Location	Period of Observation
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

A number of daily and pluviographic rainfall stations are located within or adjacent to the Broken Creek catchment. Figure 2-2 show the location of both the pluviographic and daily rainfall stations.

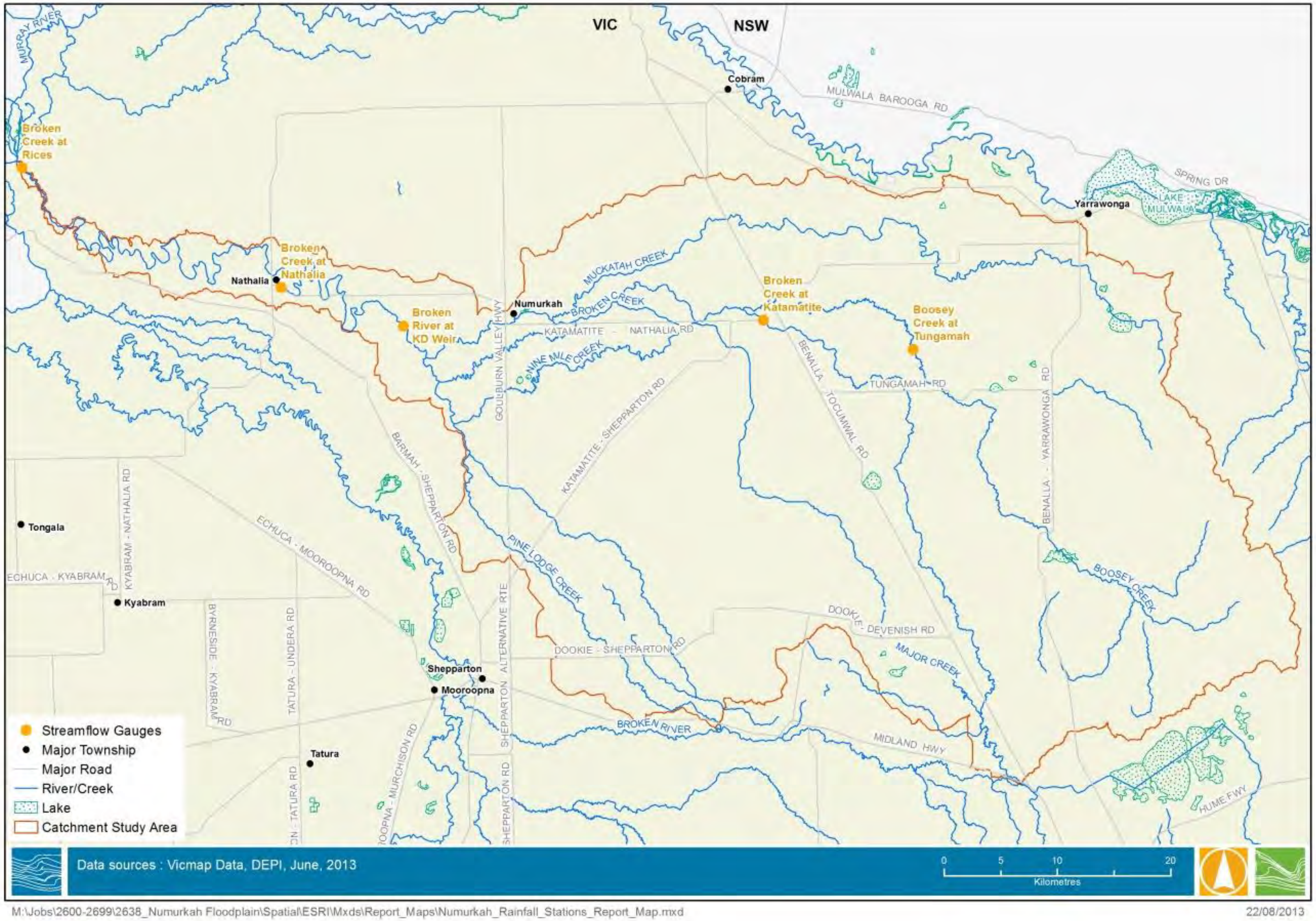


Figure 2-1 Stream gauge locations

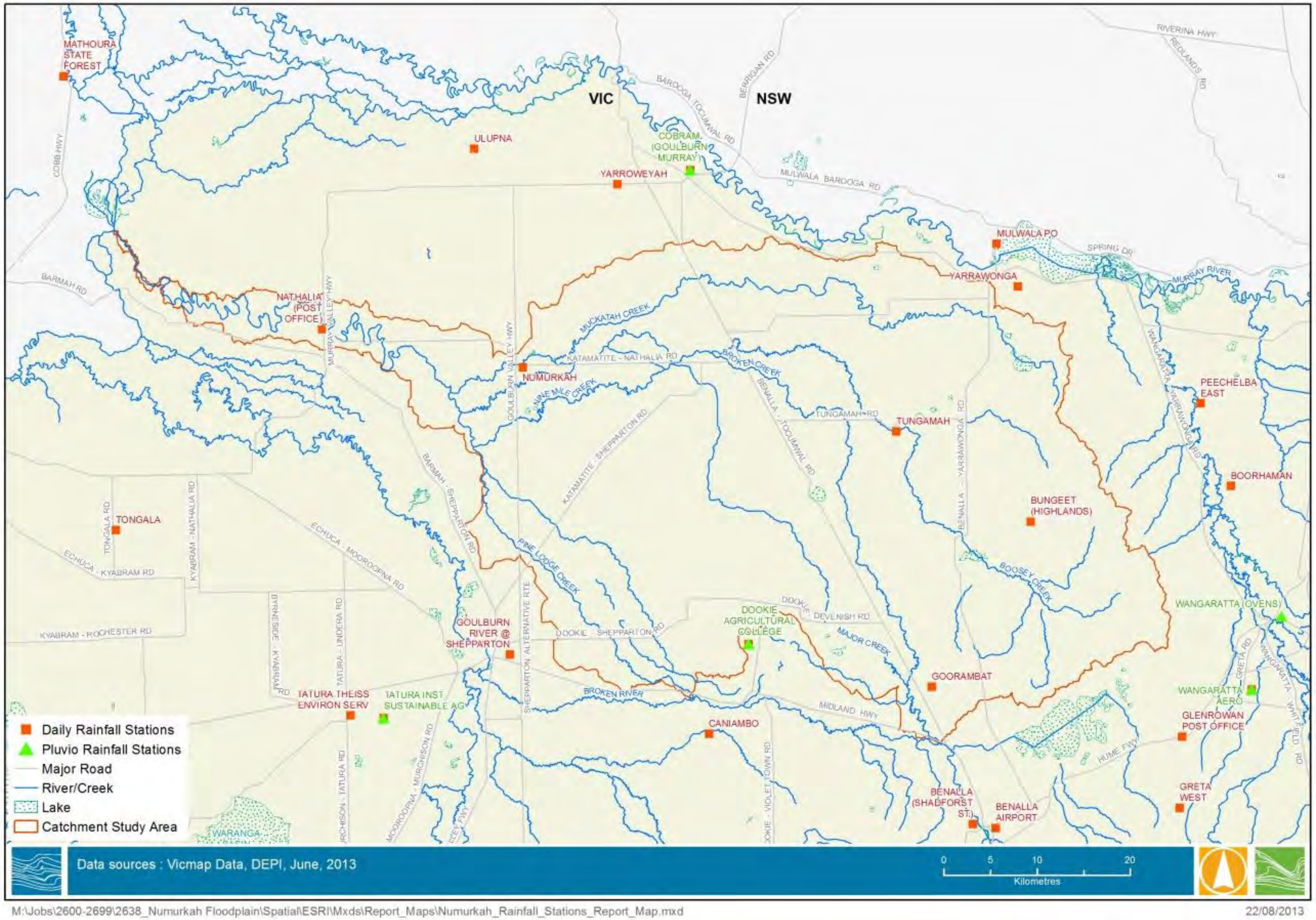


Figure 2-2 Daily and Pluviograph Rainfall Stations

2.3 Topographic Data

2.3.1 LiDAR

Detailed accurate topographic data provides the basis for any hydraulic model. For the present study a LiDAR dataset of the study area was provided by the Goulburn Broken Catchment Management Authority.

The LiDAR was flown by Fugro and provided in tiles of 1m xyz grid text files. These tiles were converted into 1m rasters and stitched together to form a large grid which covered the Numurkah floodplain. Additional LiDAR was flown at a later date, and these new tiles were stamped onto the original grid to update it.

For hydraulic modelling purposes, the large floodplain wide grid needed to be resampled to a 20m grid. While this incurs a loss of data, it is necessary for the model to run at a reasonable speed. The loss of data is considered negligible given the size of most floodplain features. Smaller features such as levee banks and river inverts were stamped onto the grid to ensure the most important hydraulic controls would still be picked up in the model.

The hydraulic model study area is limited by the extent of the available LiDAR, particularly for the areas immediately to the north of Numurkah.

2.3.2 Field Survey

To supplement the LiDAR data additional field survey was captured by Price Merritt surveyors and included in modelling. The survey primarily captures the crest height of levees and banks adjacent to Broken Creek within the township. Details of the survey are shown Figure 2-3.

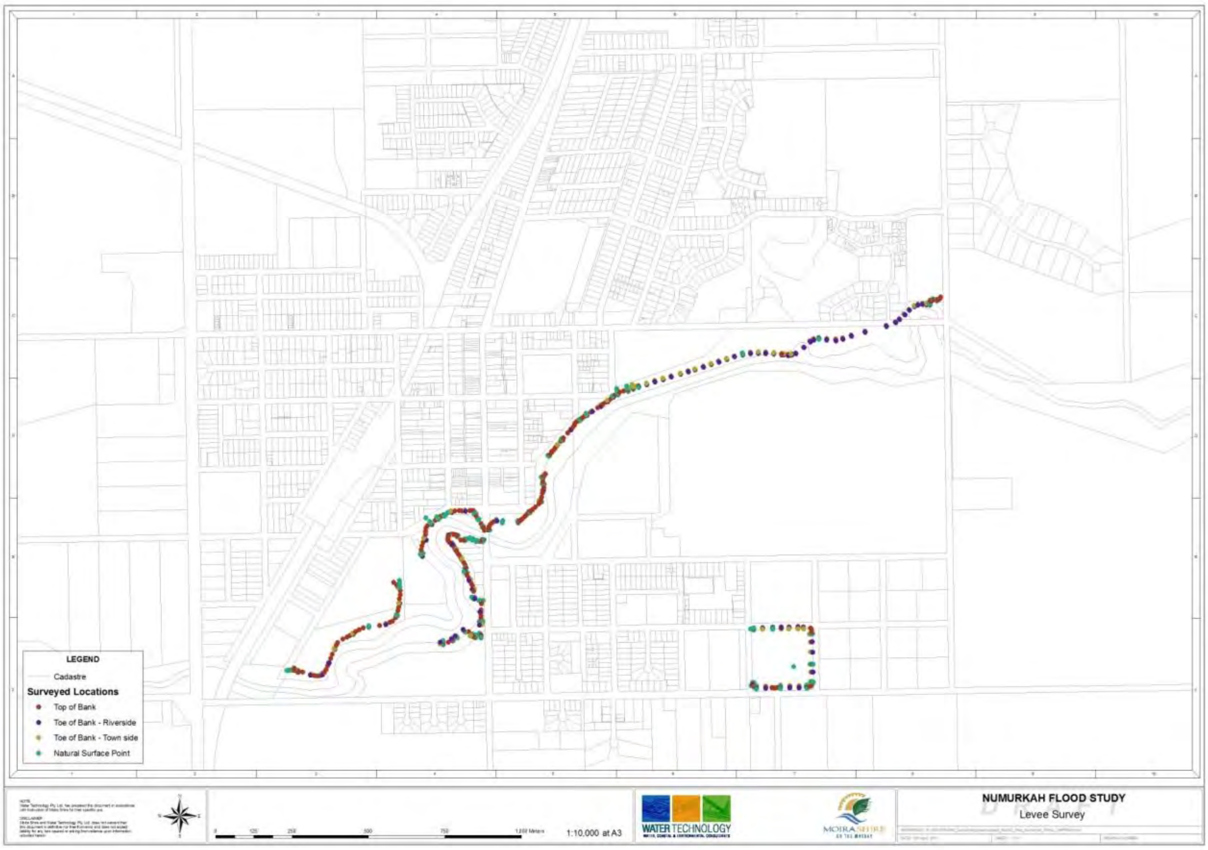


Figure 2-3 Additional field survey captured by surveyors

2.4 Existing Structure Information

Details of the existing structures within the study area, including culverts, bridges and floodways, were provided by Moira Shire Council. Key structures were identified during initial modelling, and depending on their impacts on flooding in the study area they were included in the model. A total of ten bridges and culverts were incorporated into the final hydraulic model. The culverts or bridges are referred to by their asset number, as provided by Moira Shire Council unless noted otherwise.

- Bridges
  - Station Street
  - Goulburn Valley Highway
  - Railway Bridge
  - 51663 - Follets Bridge
  - 45761 - Melville Road Bridge
  - Sloleys Bridge
- Culverts:
  - 47451 (Kelly's Road)
  - 46567 (Labuan Rd)
  - 46137 (Lukies Road - east)
  - 46138 (Lukies Road – west)

2.5 Previous Hydrological Investigations

This section discusses the previous hydrologic analysis undertaken in the Nathalia Floodplain Management Plan (SMEC 2005) and the Numurkah Flood Study (Water Technology 2011). A summary of the previous investigations is provided below.

2.5.1 Nathalia Floodplain Management Plan (SMEC 2005)

The Nathalia Floodplain Management Plan (SMEC 2005) included a hydrological analysis to assess required historical and design flood hydrographs at Nathalia. Nathalia is located 22 kilometres downstream from Numurkah along Broken Creek.

The RAFTS model was employed as the principal hydrological tool for the study. The model employed by SMEC (2005) built on previous RAFTS models from the 'Broken Creek Management Strategy' (SKM, 1998). SMEC (2005) further developed this RAFTS model by refining storage areas and including provision for overflows from the Broken River. Figure 2-4 shows the RAFTS (SMEC 2005) model structure.

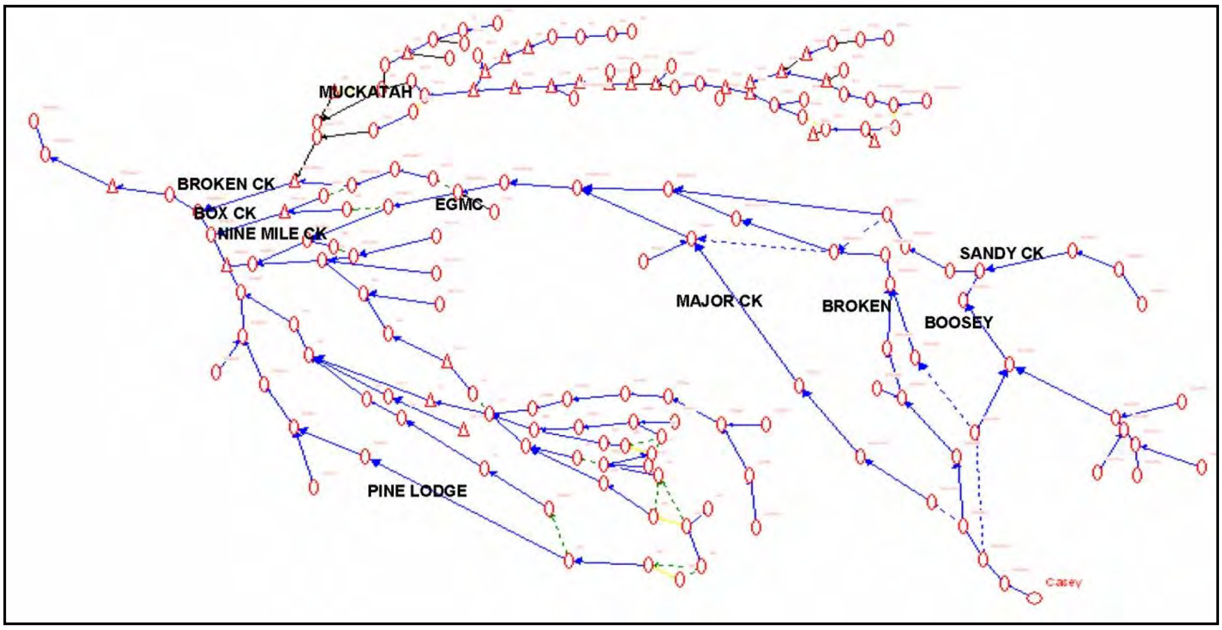


Figure 2-4 RAFTS model Structure (SMEC 2005)

The SMEC (2005) model was calibrated using the 1993 flood event and verified using the 1974 flood event at Katamatite on the Broken Creek and at Tungamah on the Boosey Creek.

The calibration data available for the 1993 and 1974 flood events was limited but as detailed in the SMEC (2005) report a reasonable calibration was achieved. Figure 2-5, Figure 2-6 and Figure 2-7 display the observed and RAFTS modelled hydrographs for the October 1993 event at Katamatite, Tungamah and Walsh's Bridge respectively. Figure 2-8 shows the May 1974 calibration at Walsh's Bridge. Gauged hydrographs were not available for 1974 at Katamatite and Tungamah but peak flow estimates of 85 m^3/s and 220 m^3/s respectively, were obtained from previous studies. The model replicated these peak flows very well, 85 and 215 m^3/s for Katamatite and Tungamah respectively but the shape and volume differed significantly.

Design hydrographs were generated using the calibrated RAFTS model and design rainfall from Australian Rainfall and Runoff, (Institution of Engineers Australia, 1997). For the design flood estimation, the following model parameters and assumptions were applied:

- Rainfall losses: initial losses of 18 and 30 mm for irrigation land and dryland respectively, and a continuing loss of 1 mm/h.
- Zone 1 design rainfall temporal patterns from Australian Rainfall and Runoff (1997). The catchment is in Zone 2 but it was found that Zone 1 patterns best represent rainfall patterns for the catchment.
- Uniformly distributed spatial pattern.
- Areal reduction factors from Siriwadena and Weinmann (1996).

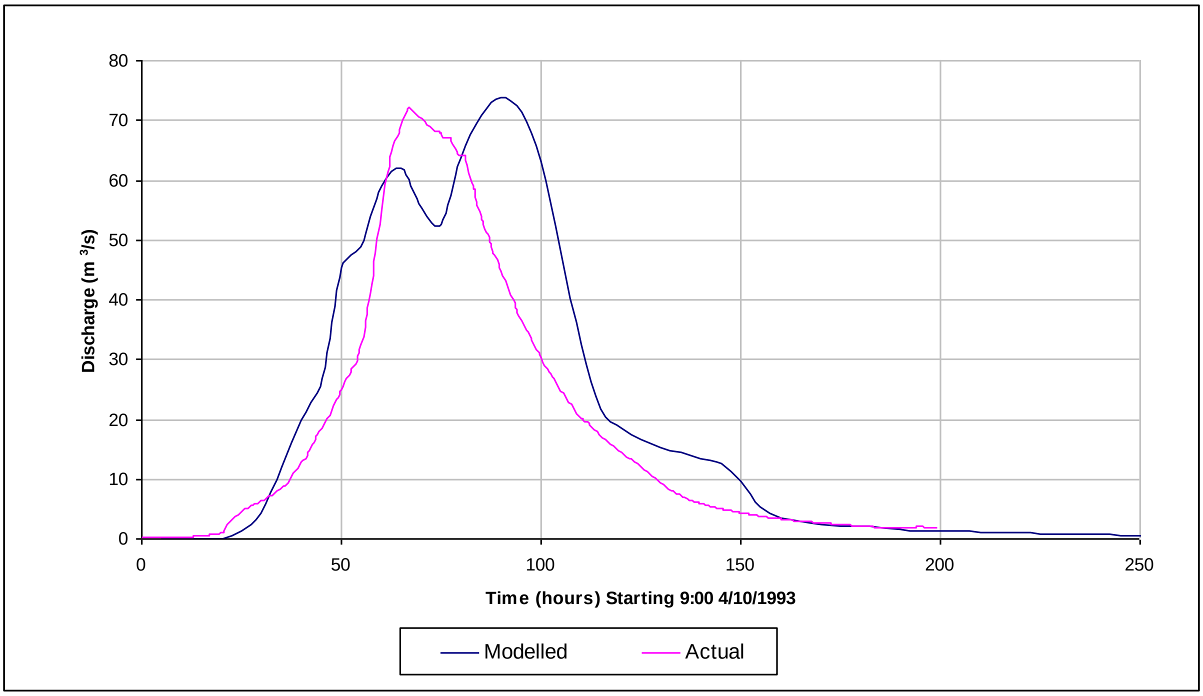


Figure 2-5 RAFTS Calibration – October 1993 at Katamatite (taken from SMEC 2005 report)

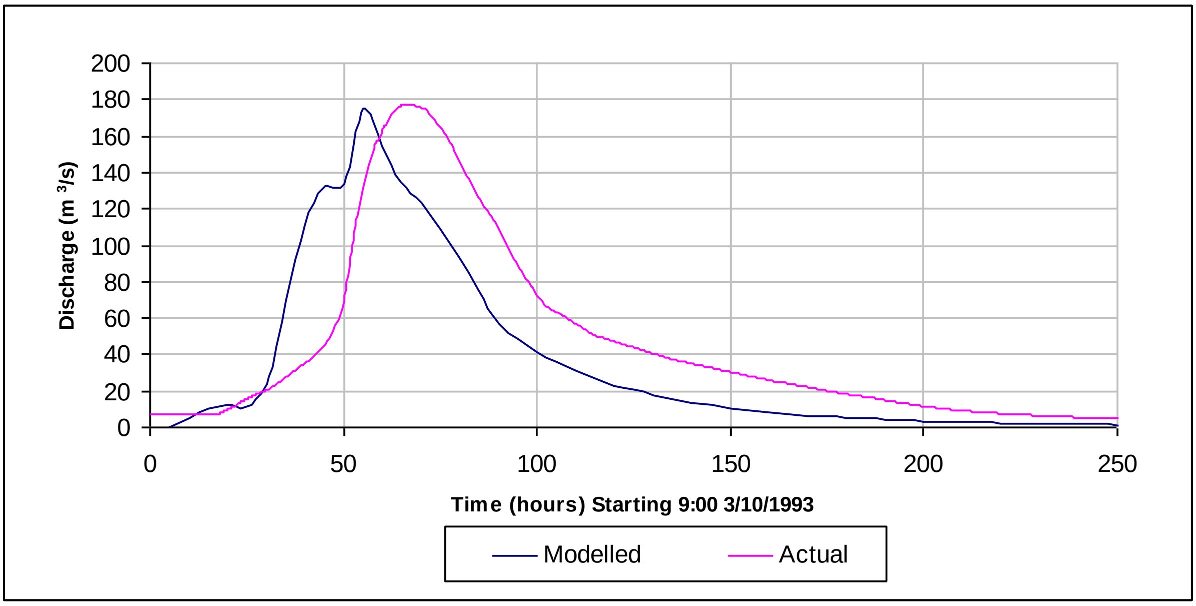


Figure 2-6 RAFTS Calibration – October 1993 at Tungamah (taken from SMEC 2005 report)

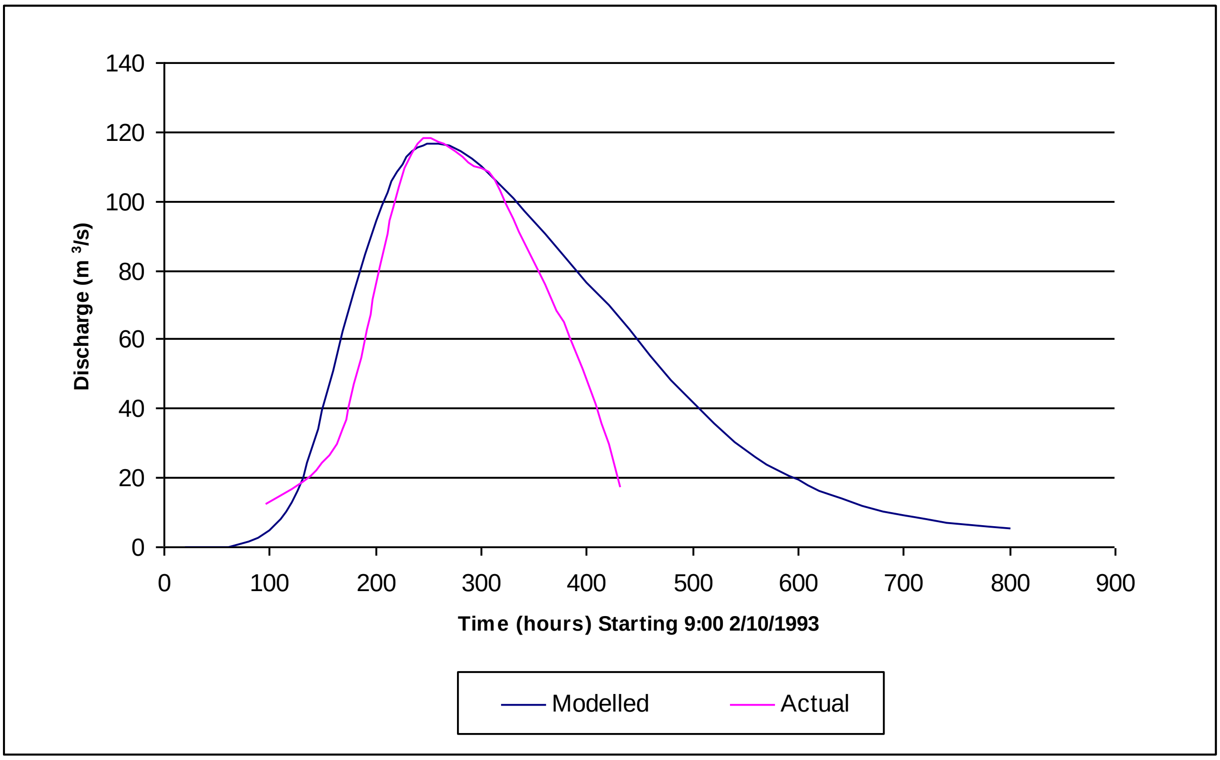


Figure 2-7 RAFTS Calibration – October 1993 at Walsh's Bridge (taken from SMEC 2005 report)

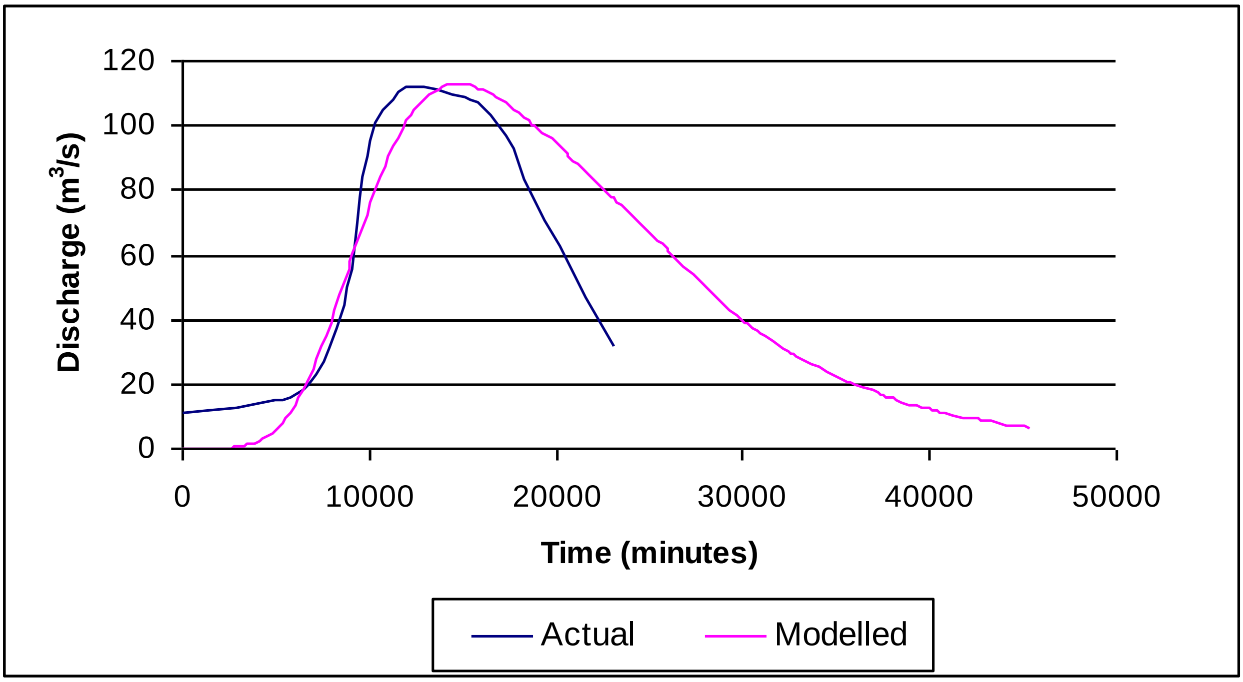


Figure 2-8 RAFTS Validation – May 1974 at Walsh's Bridge (taken from SMEC 2005 report)

2.5.2 Numurkah Flood Study (Water Technology 2011)

The Numurkah Flood Study was commenced in 2009 and was put on hold in early 2012 due to the significant flood events that were occurring across northern Victoria at that time. It was deemed that the flood events at Numurkah were sufficiently large to impact the flood study hydrology results and for that reason it was postponed so data could be collated from those events and utilised in a revised study.

The hydrological analysis in the Water Technology study involved a recalibration of the existing RAFTS model using the 1974, 1981, and 1993 flood events. In undertaking the analysis some inconsistencies were observed in the rainfall temporal patterns used in the original SMEC study. These were revised and a reasonable calibration was achieved which was approved by the Goulburn Broken CMA and adopted for design flood estimation.

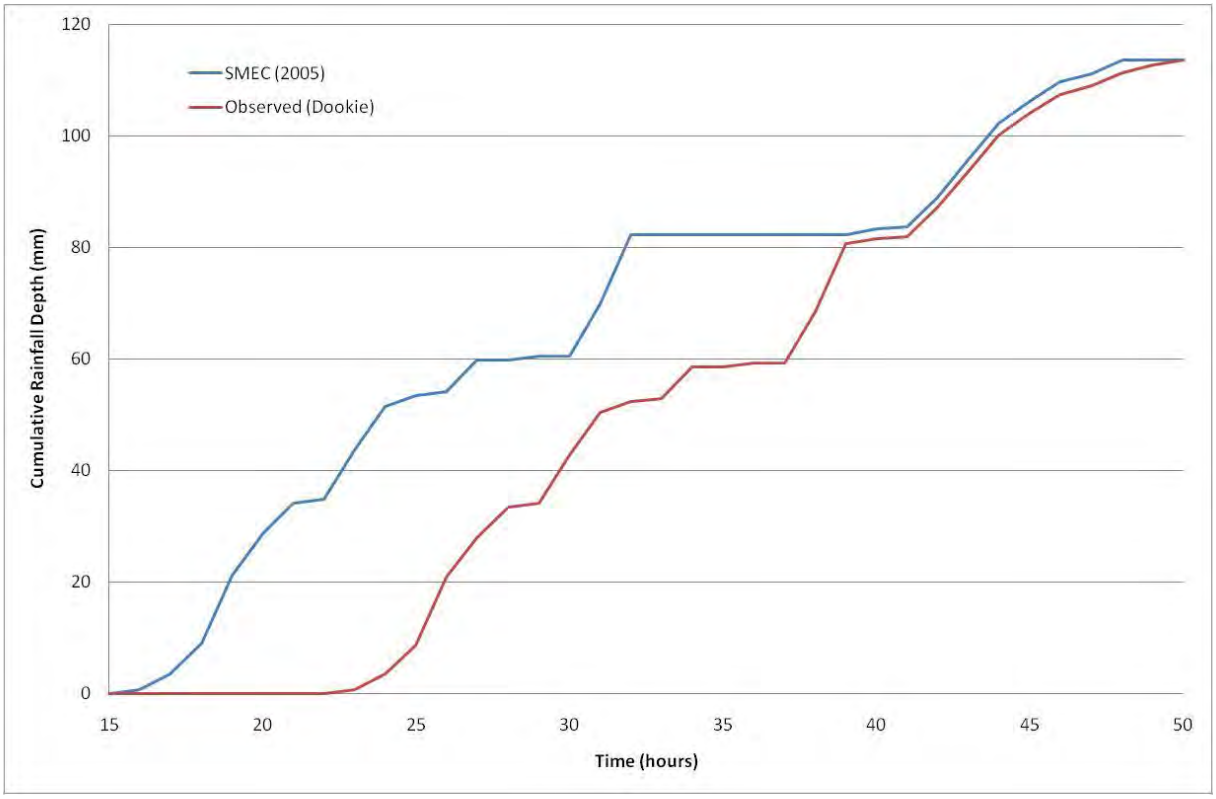


Figure 2-9 Comparison of temporal patterns from 1993

The RAFTS design peak flows were reconciled against flood frequency peak flow estimates. This reconciliation focused on the 10 and 20 year peak flow estimates, and was achieved by adjusting the rainfall losses in the RAFTS model. The resulting RAFTS design peak flows are shown in Table 2-2.

The 2009 study was placed on hold at the point at which hydraulic and hydrological models had been constructed and the final hydraulic calibration was occurring.

Table 2-2 Broken Creek catchment – RAFTS model design peak flows

Location	Design peak flow (m^3/s)					
	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI	500 Year ARI
Broken Creek immediately downstream of confluence of the Boosey and Broken Creeks (RAFTS Node Brok14)	72.5 (72h)	110 (72 h)	144 (72 h)	187 (48 h)	216 (48 h)	283 (48 h)
Major Creek immediately upstream of the Major and Broken Creek confluence (RAFTS Node Maj6)	15.9 (72 h)	28.5 (72 h)	35.9 (72 h)	42.1 (72 h)	40.2 (72 h)	50.4 (72 h)
Muckatah Depression	5.84 (72 h)	7.44 (72 h)	9.82 (72 h)	12.0 (72 h)	15.0 (72 h)	19.3 (72 h)

2.6 Other Background Data

Other background data available for the study included:

- High resolution (0.25 m) aerial imagery of the March 2012 flood events with a range of dates from 3rd to 17th March 2012 sourced from Goulburn Broken CMA
- A range of flood surveys from the March 2012 event completed by CPG Australia and ThinkSpatial and provided by Goulburn Broken CMA. Some of the datasets include a number of photographs of survey being recorded.
- Numerous photos of the March 2012 flood event taken by local resident Jack Richardson and provided by Goulburn Broken CMA;
- Several DSE/CFA linescan maps of the March 2012 event in Broken Creek annotated with flow directions and points of interest provided by Goulburn Broken CMA;
- Report and results of levels recorded by Portable Automated Logging System (PALS) during the March 2012 event at a number of locations in Broken Creek provided by Goulburn Broken CMA;
- Three documents from the Numurkah Flood Action Group discussing flooding and mitigation options in Numurkah provided by Goulburn Broken CMA;
- Map indicating flows and travel times through the Broken Creek catchment in the October 1993 flood event provided by Goulburn Broken CMA;
- Report of the 2012 North East Victoria Flood Review completed by the Office of the Emergency Services Commissioner and provided by Goulburn Broken CMA;
- Report detailing floor survey of the Numurkah Hospital completed in 1989 and provided by Goulburn Broken CMA;
- Emails detailing flood observations from local resident Kevin Hansen
- Asset and cadastral information sourced from the Goulburn Broken CMA and VicMap.
- A collection of articles, photographs and flood data relating to flooding in Numurkah provided by local resident Kerry Swann

3. HYDROLOGICAL APPROACH

The hydrology of the Broken Creek catchment is extremely complex due to a range of factors including the flat topography, slow travel times, a heavily-modified landscape and breakouts from the Broken River. For this reason a traditional approach to the hydrological approach was not possible and instead relied on a combination of RORB modelling, flood frequency analysis and hydraulic modelling to improve understanding of the catchment behaviour. In completing the analysis a number of difficult decisions had to be made regarding the adopted methodology and these were made based on the weight of evidence, significant sensitivity testing and using experienced engineering judgement.

One of the significant problems encountered was low design IFD rainfall depths compared with historic events. It is suspected that the IFD rainfall in the upper Broken Creek catchment is not reflective of actual rainfall depths. There are a number of examples where IFD rainfall is known to vary significantly from observed rainfall patterns. Factors such as lack of rainfall stations, localised weather patterns can all lead to inaccuracies in IFD data. During the design event modelling it was found that even with the RORB model at zero losses, the RORB design hydrographs were much smaller in peak flow and volume than historic events known to be less than the design event being modelled.

The following steps detail the hydrological approach that was used:

1. Breakout flows from the Broken River were analysed and determined through construction of a hydraulic model at Casey's Weir and extraction of flows from existing TUFLOW modelling of the Broken River near Gowangardie.
2. Construction of a new RORB model of the entire Broken Creek catchment
3. Calibration of the RORB model using the March 2012 and October 1993 events as calibration events and the May 1974 event as a verification event
4. Verification of the flows in Muckatah Depression using a combination of RORB modelling, construction of a new hydraulic model of the lower Muckatah catchment, aerial flood imagery and Manning's calculations
5. Flood Frequency Analysis of both peak flows and flood volumes at the Boosey Creek at Tungamah and Broken Creek at Katamatite gauges
6. Determination of design hydrographs on the Broken Creek through transposing of the flood frequency results to the upstream boundary of the hydraulic model boundary. A decision was made to use the flood frequency analysis results in preference to the RORB model due to concerns around the accuracy of the IFD rainfall. There was a greater level of confidence in the flood frequency analysis compared to the RORB design modelling.
7. Determination of design hydrographs on Majors Creek and Muckatah Depression through design RORB modelling. Due to the lack of gauges on those waterways flood frequency analysis was not possible and so RORB modelling was the only option. Flows in Muckatah and Majors Creek are very small in comparison to those in Broken Creek and it was deemed that this was an acceptable approach given the lack of available data.

The table below summaries the method used to determine design hydrographs at each inflow point with the inflow locations shown in Figure 3-1.

Table 3-1 Summary of Hydraulic Model Design Inflow Methods

Inflow Location	Design Flow Method	Comments
Broken Creek	Transposing of Flood Frequency Analysis flows	Greater confidence in Flood Frequency Analysis than RORB modelling due to concerns around IFD rainfall
Majors Creek	RORB Design Modelling	Hydrographs determined from design RORB modelling. Ungauged catchment so FFA not an option
Muckatah Depression Primary Inflow	RORB Design Modelling	
Muckatah Depression Secondary Inflow	RORB Design Modelling	

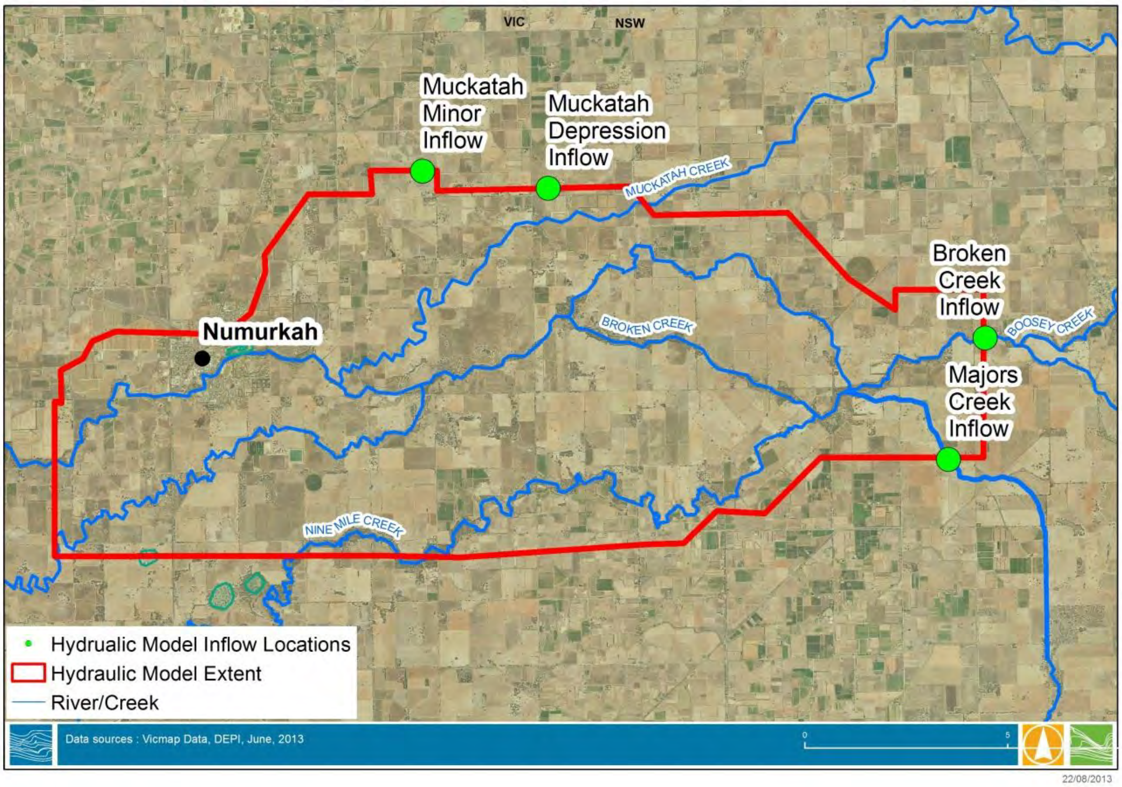


Figure 3-1 Hydraulic Model Extent and Inflow Locations

4. BROKEN RIVER BREAKOUTS

4.1 Broken River Breakout – Casey's Weir

During large flood events in Broken River a significant breakout occurs from Broken River into the Broken Creek catchment at Casey Weir's, located approximately 9 km north of Benalla. A relationship for the breakout was established in the original SMEC flood study using a 1D hydraulic model. It was decided to model the breakout in a 2D hydraulic model so the breakout relationship and its contribution to the Broken Creek flows could be better understood. A 2D MIKE FLOOD model was constructed with a 7 m grid resolution which was deemed fine enough to accurately establish a breakout relationship.

Topography

The 7m DEM was constructed by merging the 1 m ISC LiDAR and the 20 m VicMap dataset and then resampling the resulting grid. The 1 m ISC LiDAR covered the Broken Creek and Broken River watercourses with the 20 m dataset used on the extremities where there was no coverage from the 1 m LiDAR. The model topography is shown below in Figure 4-1.

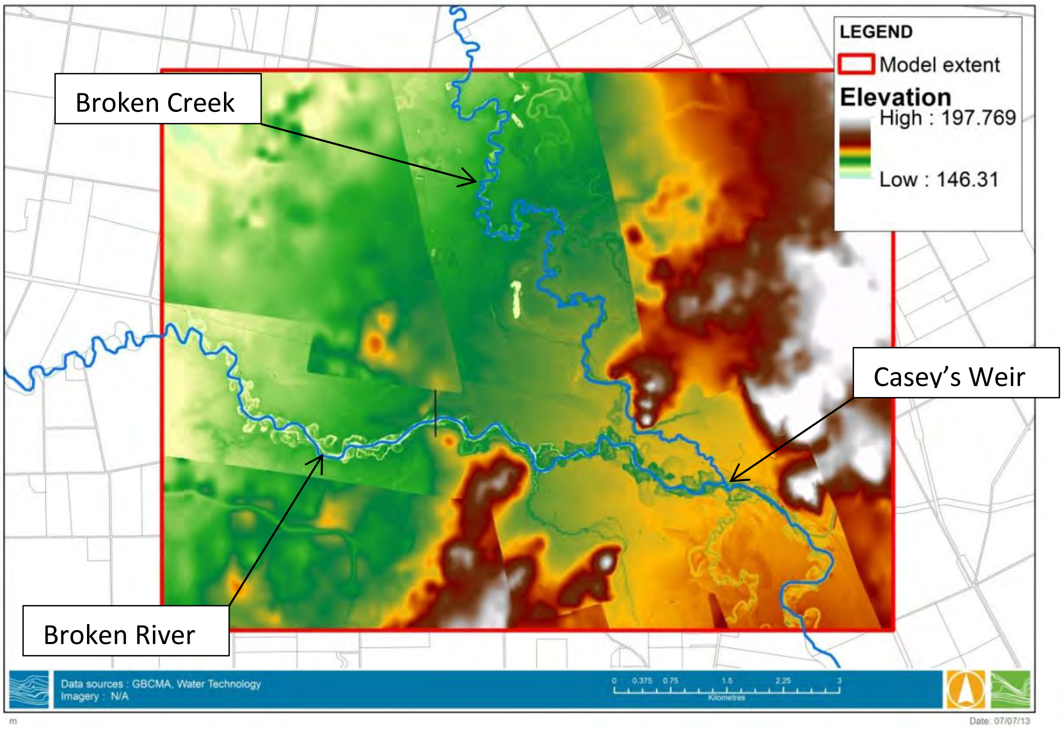


Figure 4-1 Casey's weir Hydraulic Model DEM and Extent

Parameters

The parameters of the 2D hydraulic model are described below:

- A uniform Manning's roughness of 0.035 was used across the model extent.
- An inflow flux boundary was used for Broken River at the upstream end of the model. A stepped inflow was created ranging from 50 m^3/s to 1,800 m^3/s with the model receiving a steady flow for 6 hours of simulation time before the next increment occurred.
- A constant water level boundary was used at the Broken River and Broken Creek outlets of the model at a sufficient distance downstream so as not to impact the hydraulics around the breakout.

Results

Following the model simulation flows and water surface elevations were extracted along Broken Creek for each inflow increment and flow split relationships were developed. Figure 4-2 shows the relationship established between discharge into Broken Creek and water surface elevation at Casey's Weir. The same relationship from the 2005 SMEC study is shown and it can be seen there are significant differences between the curves. The SMEC relationship generally reports lower breakout flows for the same water surface elevation. Figure 4-3 shows the new breakout relationship in terms of flows in Broken River and Broken Creek established from this study.

The results of the modelling indicate that breakouts occur when flows reach approximately 200 m^3/s in the Broken River or a water surface elevation of 158.73 m at Casey's Weir.

A review of the flow records for Broken River for the March 2012, September 1993 and May 1974 events indicate peak flows at Casey's Weir of 116 m^3/s, 1,216 m^3/s and 749 m^3/s. Based on the revised charts this suggest a breakout did not occur in the March 2012 event which is consistent with anecdotal reports.

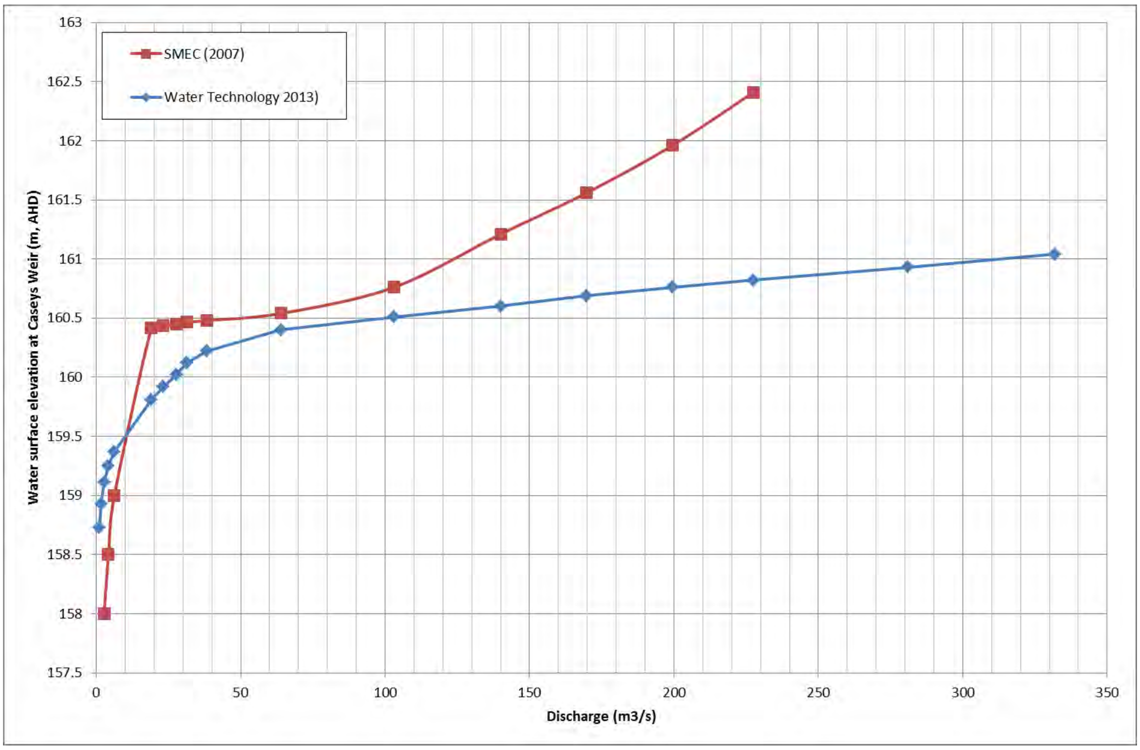


Figure 4-2 Comparison of water surface elevation/flow relationships developed by SMEC (2007) and Water Technology (2013)

The difference in results between the new 2D modelling and the original 1D modelling is likely to be a result of the assumptions made regarding flow paths in the original 1D modelling. The 2D model results indicate significant breakouts occur at multiple locations and the results are a very good example of where 2D modelling is superior to 1D modelling in that no assumptions have to be made regarding flow paths. Figure 4-4 displays a screen shot of the modelling results over an area of 5 km^2 and it can be seen where the Broken River has broken out at a number of locations in the vicinity of Casey's Weir. It is likely that a 1D model would not be able to accurately model the multiple breakouts.

It should also be noted that the revised breakout relationship is likely to be less accurate at lower flows due to the grid size used and the comparative size of the low flow channel at Casey's Weir. More detailed modelling would be required to improve the accuracy of the low flow relationship.

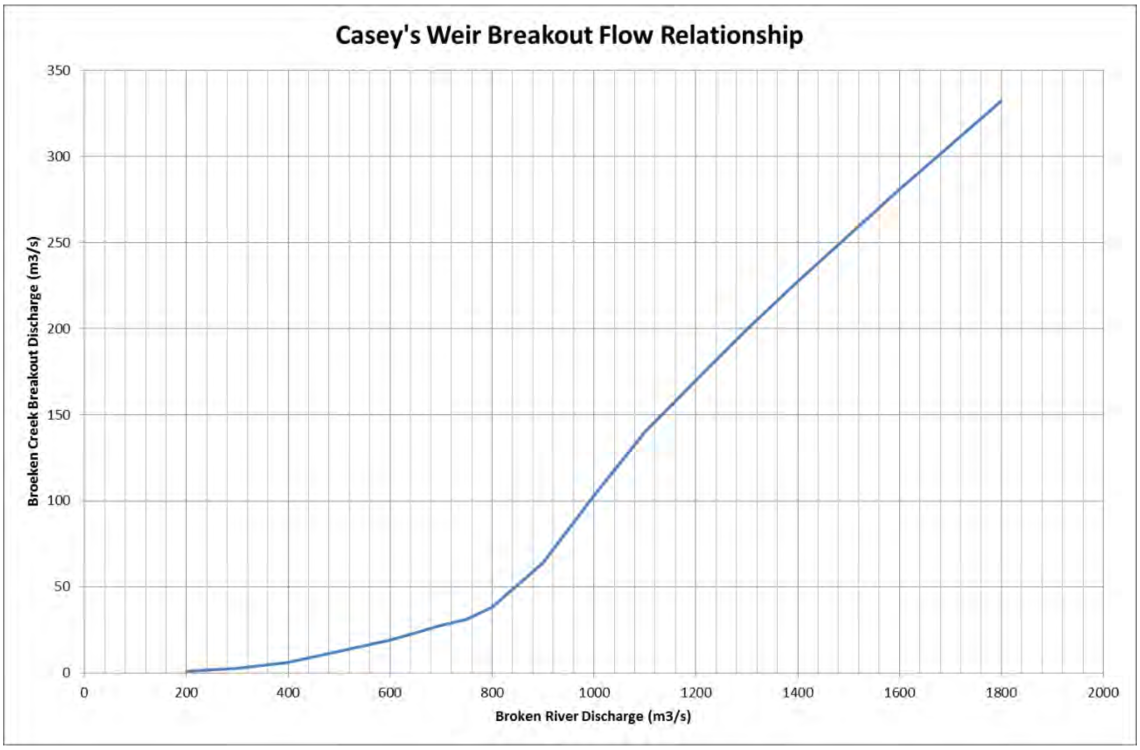


Figure 4-3 Casey' Weir Breakout Broken River/Broken Creek Flow Relationship

The Casey's Weir model was also run for the three calibration/validation events using the Broken River gauge records from those events. Broken Creek breakout flows were extracted and the results shown in Figure 4-1. As discussed above the modelling demonstrates that a breakout did not occur in the March 2012 event as a result of the comparatively low flows in Broken River despite the large event that occurred in the Broken Creek catchment.

Table 4-1 Casey's Weir calibration event breakout flows

Event	Broken River peak flow (m^3/s)	Broken Creek breakout peak flow (m^3/s)
March 2012	116	0
October 1993	1,216	275
May 1974	749	31.3

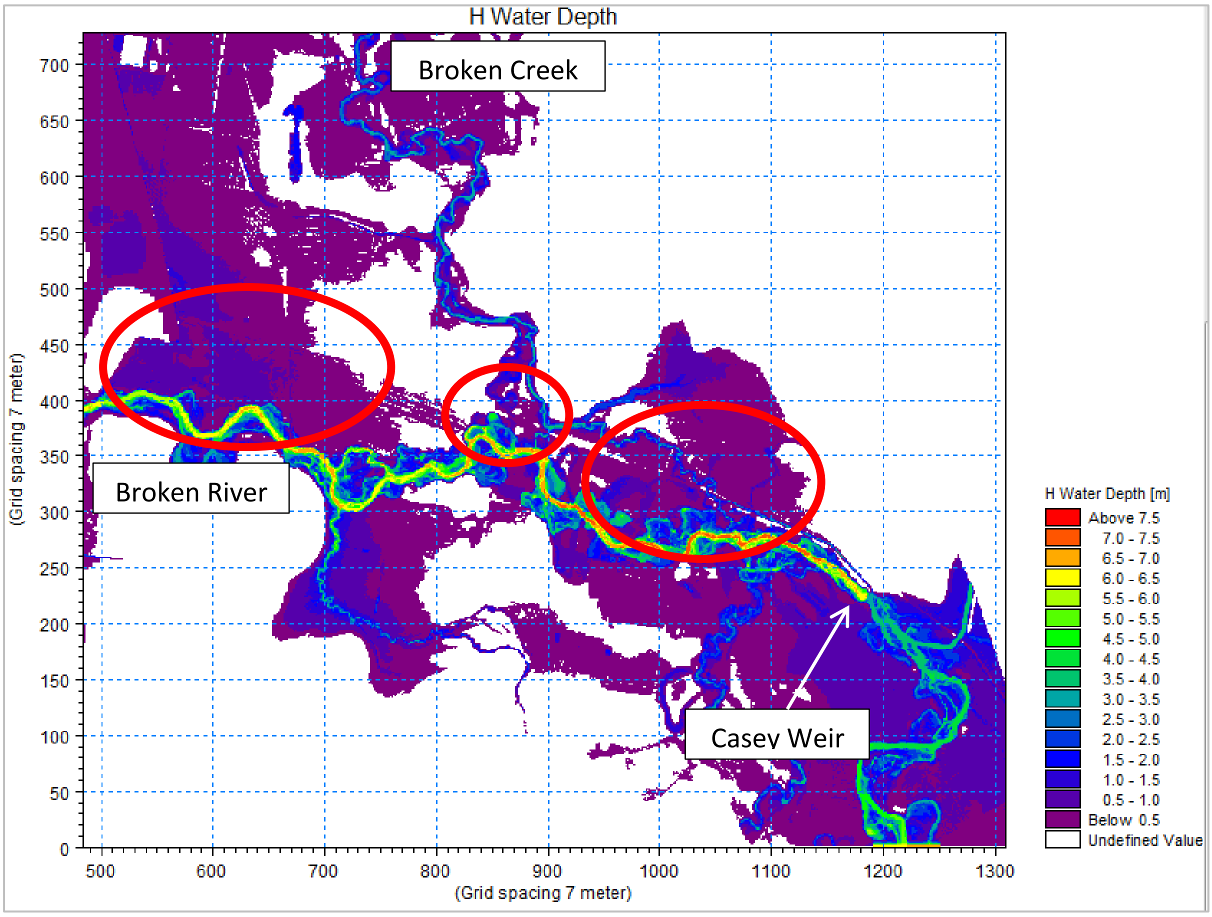


Figure 4-4 Screen shot of Casey Weir modelling results with breakouts indicated by red circles

4.2 Broken River Breakout – Gowangardie

A second breakout from Broken River occurs further to the west between Gowangardie and Shepparton. The Gowangardie breakout flows into the upstream end of Pine Lodge Creek and eventually into Broken Creek downstream of Numurkah.

The Shepparton Flood Mapping and Flood Intelligence Study is currently being undertaken by Water Technology and the extent of the hydraulic model developed in that study includes the Gowangardie breakout. Breakout flows were extracted from the model for the 1974 and 1993 event. As discussed previously flows during the March 2012 event were relatively small in Broken River and no breakouts occurred into the Broken Creek catchment. The Gowangardie breakout flows are shown below in Table 4-2.

Table 4-2 Gowangardie calibration event breakout flows

Event	Broken River at Gowangardie peak flow (m^3/s)	Gowangardie breakout peak flow (m^3/s)
March 2012	128	0
October 1993	690	55.2
May 1974	500 (estimated)[1]	39.0

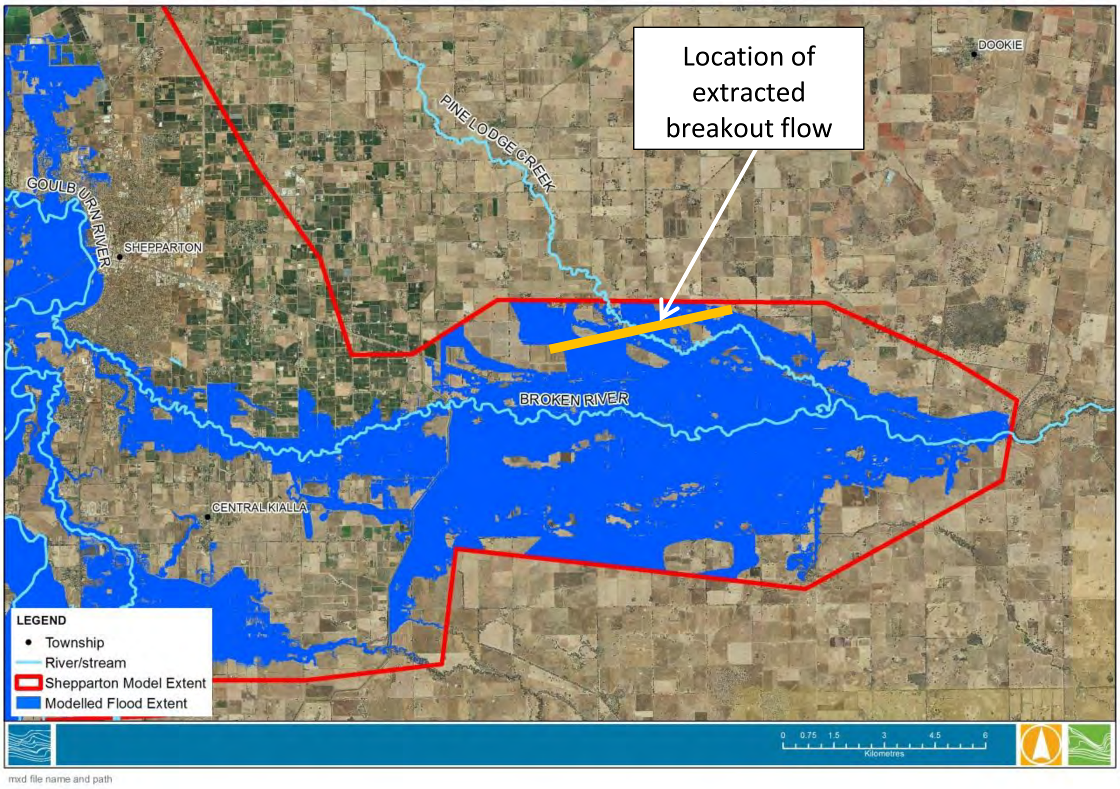


Figure 4-5 Shepparton model results and location of Gowangardie breakout flow

[1] Sinclair Knight Mertz, *Shepparton-Mooroopna Flood Study*, Sinclair Knight Mertz, Melbourne, 1982

5. RORB MODEL CONSTRUCTION

5.1 Overview

For this study a new hydrological model of the catchment was developed for the purpose of extracting flows to be used as boundary conditions in the hydraulic model. The rainfall-runoff program RORB was used for this study.

Following a review of the previous studies and existing RAFTS model it was deemed preferable to construct a new RORB model given a number of issues associated with the original RAFTS model. A new model was constructed which included the entire Broken Creek catchment downstream to the confluence with the Murray River.

RORB is a non-linear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reach storages. Observed or design storm rainfall is input to the centroid of each subarea. Specific losses are then deducted, and the excess routed through the reach network.

The following methodology was applied for the RORB modelling:

- The entire Broken Creek catchment area upstream of the Murray River delineated which includes Pine Lodge Creek and the Muckatah Depression;
- Catchment divided into subareas based on the site's topography and required hydrograph print (result) locations;
- RORB model constructed using appropriately selected parameters including reach types, slopes and subarea fraction impervious values;
- Storm files for the May 1974, October 1993 and March 2012 events were constructed;
- RORB model parameters were calculated based on the information available and regional prediction equations;
- The RORB model was calibrated to the October 1993 and March 2012 events
- The May 1974 was run through the model and used as a verification event
- Design loss parameters were adopted;
- Design flood events for the 5, 10, 20, 50, 100, 200 and 500 year ARI were run for multiple durations as well as the Probable Maximal Flood (PMF) event; and
- Hydrographs were extracted from RORB for use as inflow boundaries to the hydraulic model at Muckatah Depression and Majors Creek.

Flood hydrographs were required at the upstream boundaries of the hydraulic model for the 5, 10, 20, 50, 100 and 200 year ARI design flood events, as well as the May 1974, October 1993 and March 2012 historical flood events. The hydrographs will then be input into the hydraulic model to assess flood behaviour within the study area.

The upstream boundaries of the hydraulic model where flows were extracted from the RORB model were:

- Broken Creek downstream of the confluence with Boosey Creek
- Majors Creek upstream of the confluence with Broken Creek
- Muckatah Depression (primary inflow point to the north-east of Numurkah)
- Muckatah Depression (secondary inflow point to the north of Numurkah)

5.2 Model Construction

5.2.1 Subarea and Reach Delineation

The downstream outlet of the RORB model was on Broken Creek at the Murray River, covering the entire upstream catchment, an area of approximately 3,050 km^2 as shown in Figure 5-1. Upstream of Numurkah the combined catchment of Broken Creek, Majors Creek and Muckatah Depression have a combined catchment area of approximately 2,038 km^2, and individual catchments areas of 1,311 km^2, 510 km^2 and 217 km^2 respectively.

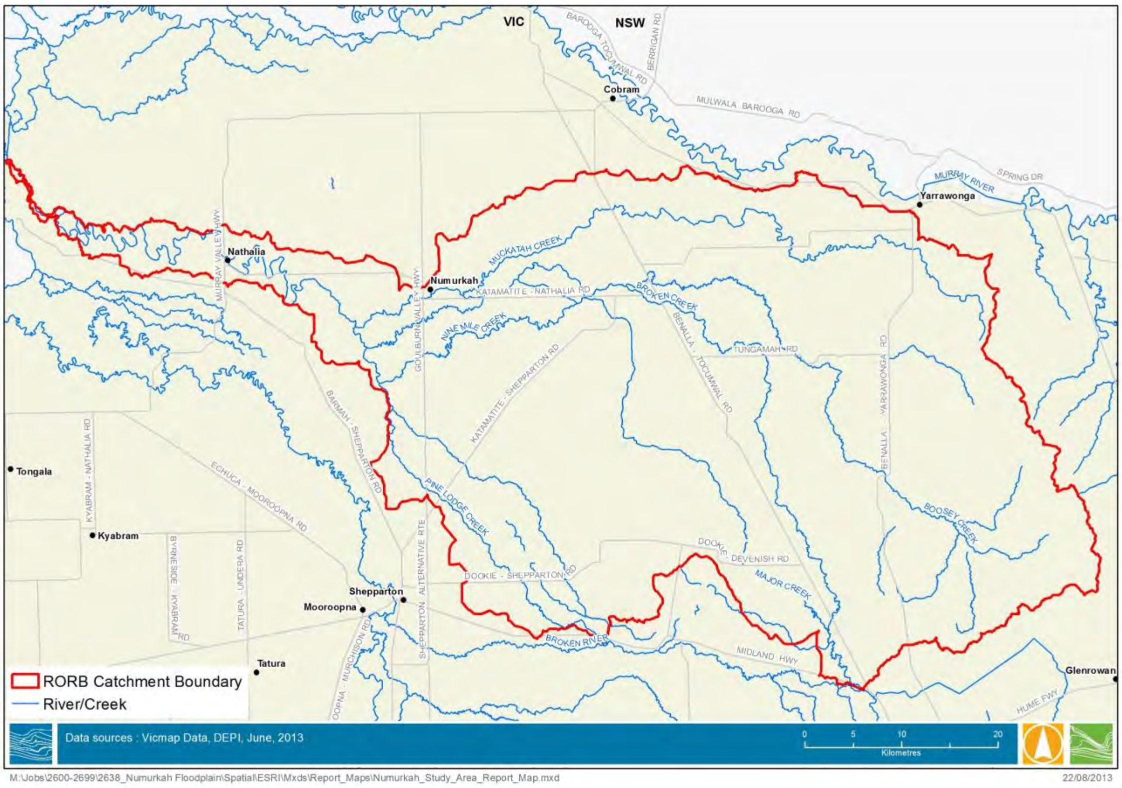


Figure 5-1 RORB model boundary and major watercourses

The RORB model was constructed using MiRORB (MapInfo RORB tools), RORB GUI and RORBWIN V6.15. A catchment boundary was delineated from the 20m Vicmap Elevation Digital Terrain Model (DTM) of the area. Sub-area boundaries were delineated using ARCHydro and revised as necessary to allow flows to be extracted at the points of interest. The RORB model was delineated into 87 sub-areas as shown in Figure 5-2.

It is important to note that a number of man-made features including roads, drains and irrigation channels have changed the topography and strongly influence the hydrology and hydraulics of the Broken Creek catchment. The sub-area delineation represents the current Broken Creek Catchment determined from the 20m topographical data. Higher resolution data such as LiDAR may change the sub-area delineation however such data is currently not available for the entire catchment.

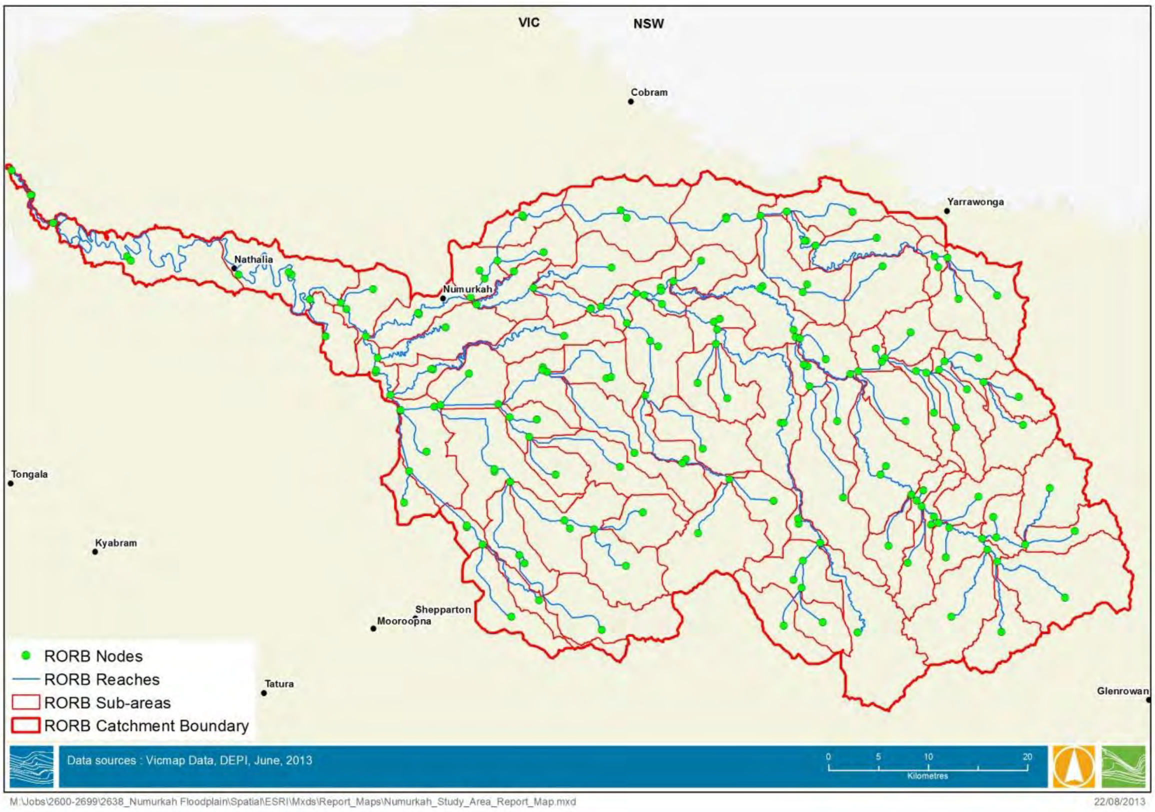


Figure 5-2 RORB model schematisation

Figure 5-3 shows a graphical representation of the RORB model in RORB GUI highlighting the location of sub-area nodes and reaches.

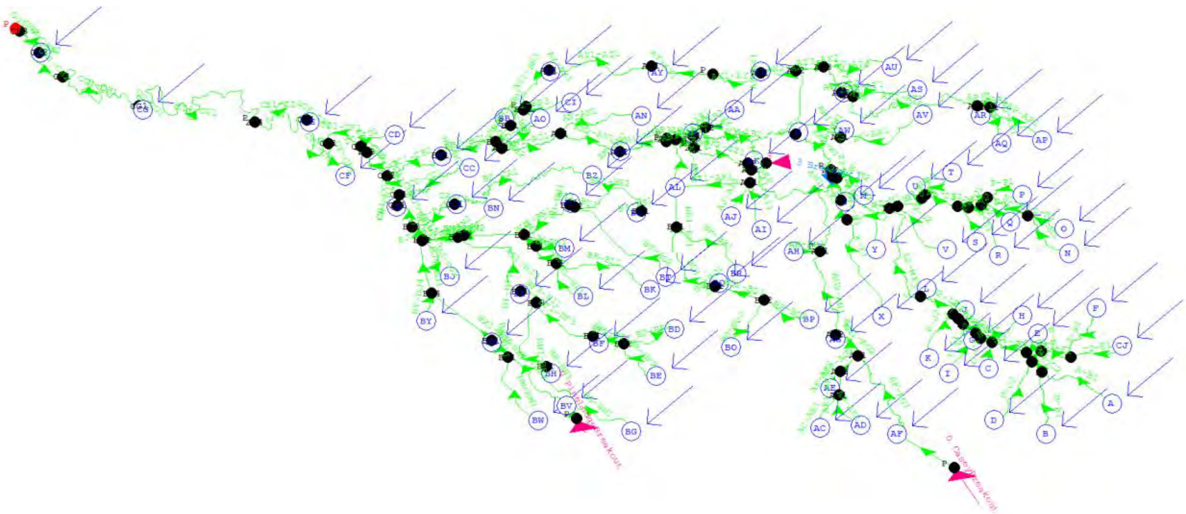


Figure 5-3 RORB Model GUI

Sub-area nodes

Nodes were placed at areas of interest, the downstream end of every sub-area and the junction of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type. Reach slopes were calculated using a digital elevation model (DEM) created from the 20m Vicmap Elevation DTM.

Reach types

Reach types in the model were set to be consistent with the land use across the catchment. Five different reach types are available in RORB (1 = natural, 2= excavated & unlined, 3= lined channel or pipe, 4= drowned reach, 5= dummy reach). Given the rural nature of the catchment, the reaches were set to natural. Reach slopes were calculated using the Vicmap 20m DEM dataset, but are not used within RORB for natural reaches.

Model print locations

Design hydrographs were extracted at the following locations:

- Broken Creek downstream of the confluence with Boosey Creek
- Major Creek upstream of the confluence with Broken Creek
- Muckatah Depression (to the north-east of Numurkah)
- Muckatah Depression (breakouts to the north of Numurkah)

There were also numerous other print locations throughout the model to assist in calibration and understanding of model behaviour. Print locations were also placed at all stream gauge locations within the catchment to assist with calibration.

5.2.2 Fraction Impervious Data

The RORB model requires Fraction Impervious (FI) values for the subareas. FI values were calculated using MiRORB. Default sub-area FI values were calculated based on the current Planning Scheme Zones (current June 2013) and then reviewed and amended as necessary based on recent aerial photos. The area weighted average FI of the Broken Creek catchment was calculated to be 0.06, reflecting the predominantly rural nature of the catchment. The different zones and their corresponding fraction impervious values used in the construction of the RORB model are shown below in Table 5-1 and Figure 5-4.

5.2.3 Storage Basins

There are no significant named storages within the Broken Creek catchment area. There are numerous small agricultural and recreational water bodies however they were deemed not large enough to have a significant impact on the hydrology of the catchment and were therefore not included in the RORB model.

Table 5-1 RORB Model fraction impervious values and zones[2]

Zone	Description	Typical Fraction Impervious
FZ	Farming Zone	0.05
PCRZ	Protection of natural environment or resources.	0.05
PPRZ	Main zone for public open space, incl golf courses.	0.1
PUZ1	Power lines, Pipe tracks and retarding basins	0.05
PUZ2	Schools and Universities	0.7
PUZ3	Hospitals	0.7
PUZ7	Museums/Mixed Use Zones	0.6
RDZ1	Major roads and freeways.	0.7
RLZ	Predominantly residential use in rural environment.	0.2
TZ	Small township with little zoning structure	0.55

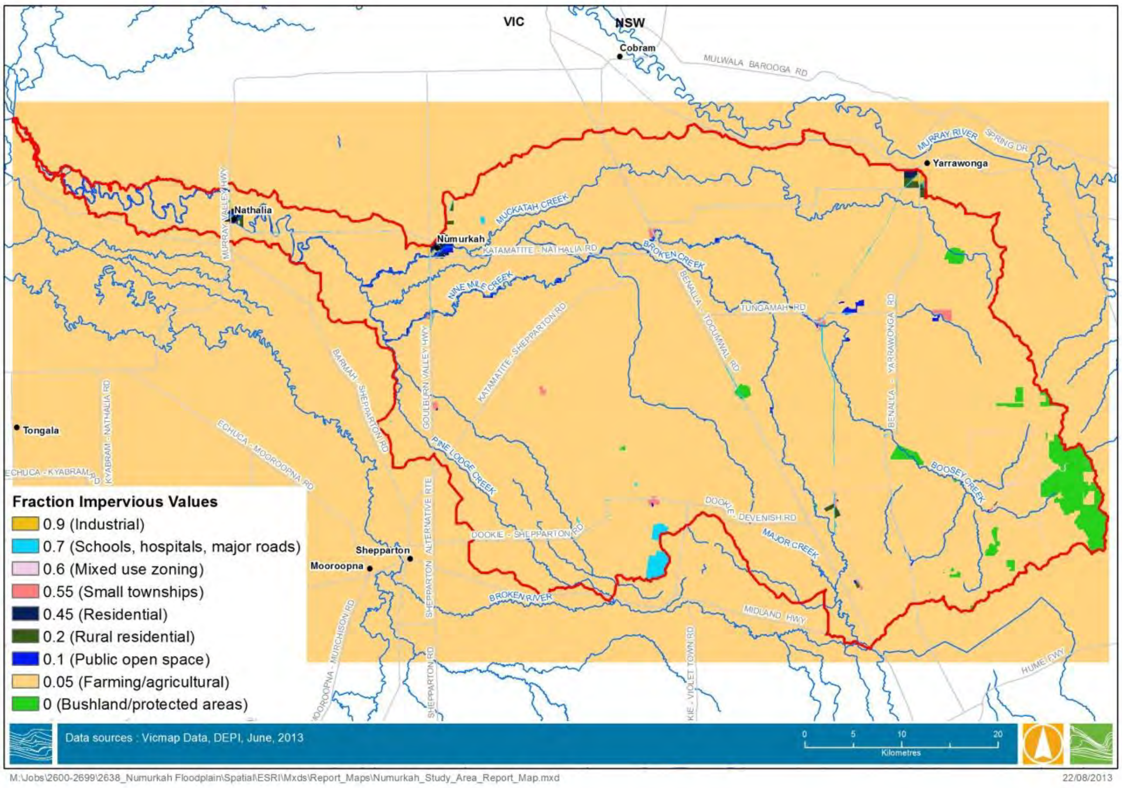


Figure 5-4 Fraction Impervious Map

[2] Melbourne Water, 2010 – Music Guidelines, Recommended input parameters and modelling approaches for MUSIC users

6. RORB MODEL CALIBRATION

6.1 Overview

The RORB model was calibrated to the March 2012 and October 1993 flood events. Calibration was based on comparing modelled hydrographs to recorded information at the 'Boosey Creek at Tungamah' and 'Broken Creek at Katamatite' streamflow gauges. Gauge records of flood levels at Nathalia and Walsh's Bridge were also used to verify timings. The 'Boosey Creek at Tungamah' gauge is located approximately 42 km upstream of Numurkah and 21 km upstream of the confluence with Broken Creek. The 'Broken Creek at Katamatite' gauge is located approximately 25 km upstream of Numurkah and 2 km upstream of the confluence with Boosey Creek.

The focus of the RORB model calibration was the determination of RORB parameters: kc, initial loss and continuing loss values for the entire catchment.

6.2 RORB Model calibration event data

Observed stream flow data

Streamflow data was required for the hydrological analysis and was sourced from DELWP. The two active streamflow gauges 'Boosey Creek at Tungamah' and 'Broken Creek Katamatite' were the primary focus of the RORB model calibration.

Additional gauges are located at Walsh's Bridge at Nathalia and Broken Creek at Nathalia. There is less information available from those gauges and so timings of peaks were used to assist with the calibration rather than achieving a full fit of hydrographs.

The data record at both Tungamah and Katamatite gauges provides good quality instantaneous data for both the March 2012 and October 1993 events as shown in Figure 6-1 and Figure 6-2.

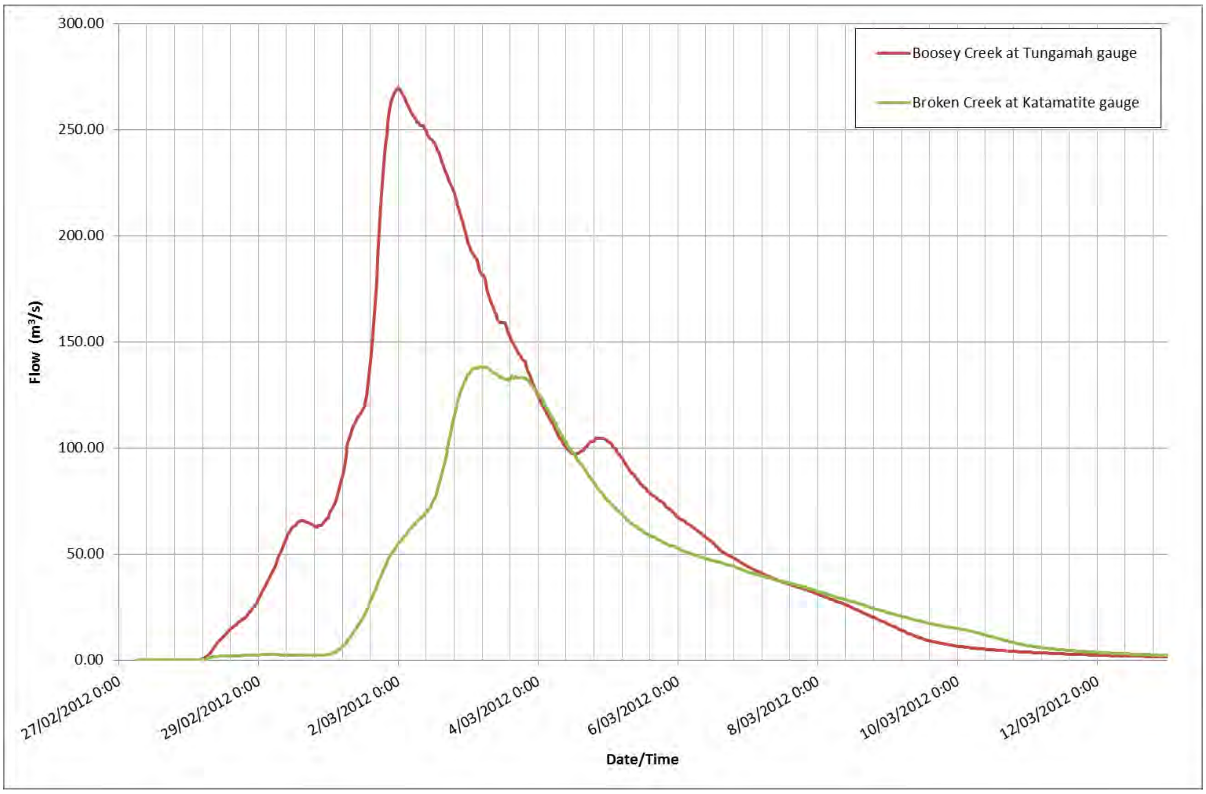


Figure 6-1 Gauge records for March 2012 event

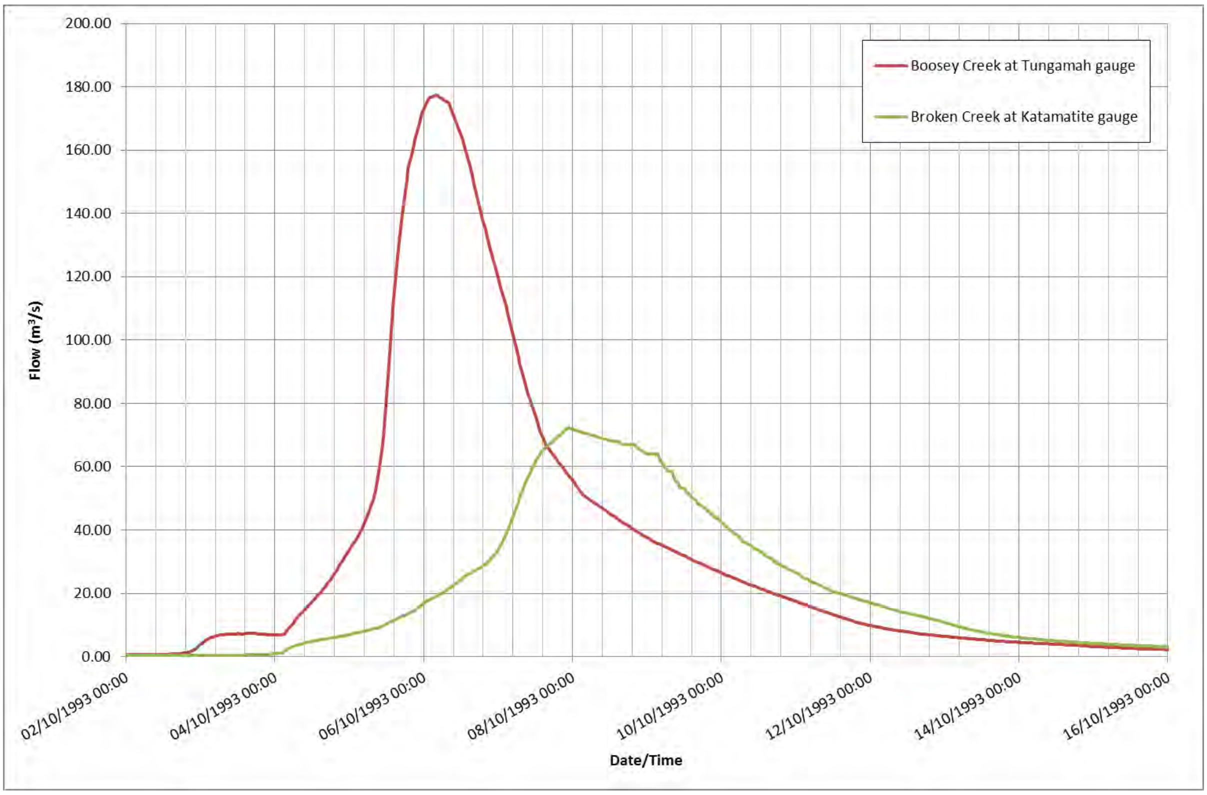


Figure 6-2 Gauge records for October 1993 event

Observed rainfall data

Both pluviograph and daily rainfall records were required for the hydrological analysis. Pluviographs record rainfall data at short time increments, indicating the temporal distribution of rainfall, while the more common daily rainfall data provides the spatial variation over the catchment. Pluviograph records (half hourly or hourly rainfall data) were available at Cobram, Wangaratta, Dookie and Tatura, whereas daily rainfall records were obtained from a number of stations located in and around the catchment.

RORB can treat a storm event either as a single storm or as multiple bursts within the storm. Using separate bursts allows the loss parameters to vary across each burst. For both the March 2012 and October 1993 events, a multi burst approach was adopted. The following points summarise the rationale behind adopting a multi burst approach:

- For the March 2012 event full pluviograph records were only available at the Tatura and Wangaratta Aero stations. The event ran over 5 days, with daily rainfall totals across the catchment varying over the event. Both the Tatura and Wangaratta pluviographs Figure 6-3 and Figure 6-4 show three separate rainfall bursts within the 2012 flood event. The first and second bursts are separated by a period of approximately 36 hours of no rainfall. The second and third bursts are separated by approximately 48 hours with the third burst being the smaller of the three. All three bursts were included in the RORB modelling as a three burst event.
- For the October 1993 event the full pluviograph records were available at Tatura, Dookie and Wangaratta (Ovens) stations. The event ran over 3 days, with daily rainfall totals across the catchment varying over the event. Both the Tatura and Dookie pluviographs Figure 6-5 and Figure 6-6 show two separate rainfall bursts during the 2012 flood event. The two bursts are separated by a 36 hour period of no rainfall. The second event was considerably larger than the first and consisted of several intense periods however was treated as a single burst in the RORB modelling. Both the first and second bursts were included in the RORB modelling as a two burst event; and
- The hydrographs recorded at Tungamah and Katamatite both show a multi-peaked event for the March 2012 event. Multi-peaked hydrographs are often easier to replicate using a multi burst approach.
- For the May 1974 event full pluviograph records were only available at the Dookie and Cobram stations. The event occurred over a 48 hour period however a small burst preceded the event approximately 4 days earlier. The 48 hour event was treated as a single burst event in the RORB modelling with the small preceding event taken into account when considering antecedent conditions.

The rainfall depth for each subarea was estimated using storm event rainfall isohyets. Six sets of rainfall isohyets were created, three for the triple burst event in March 2012, two for the double burst event in October 1993 and one for the May 1974 event.

The temporal rainfall distribution was determined using the rainfall pattern from the available pluviographs for each event. Figure 6-3 and Figure 6-4 display the pluviographs for the March 2012 event at Tatura and Wangaratta. Figure 6-5 and Figure 6-6 display the pluviographs for the October 1993 event at Tatura and Dookie. Figure 6-7 and Figure 6-8 display the pluviographs for the May 1974 event at Dookie and Cobram. Sub-areas across the catchment utilise a temporal pattern from one of these gauges depending on their proximity to each of them.

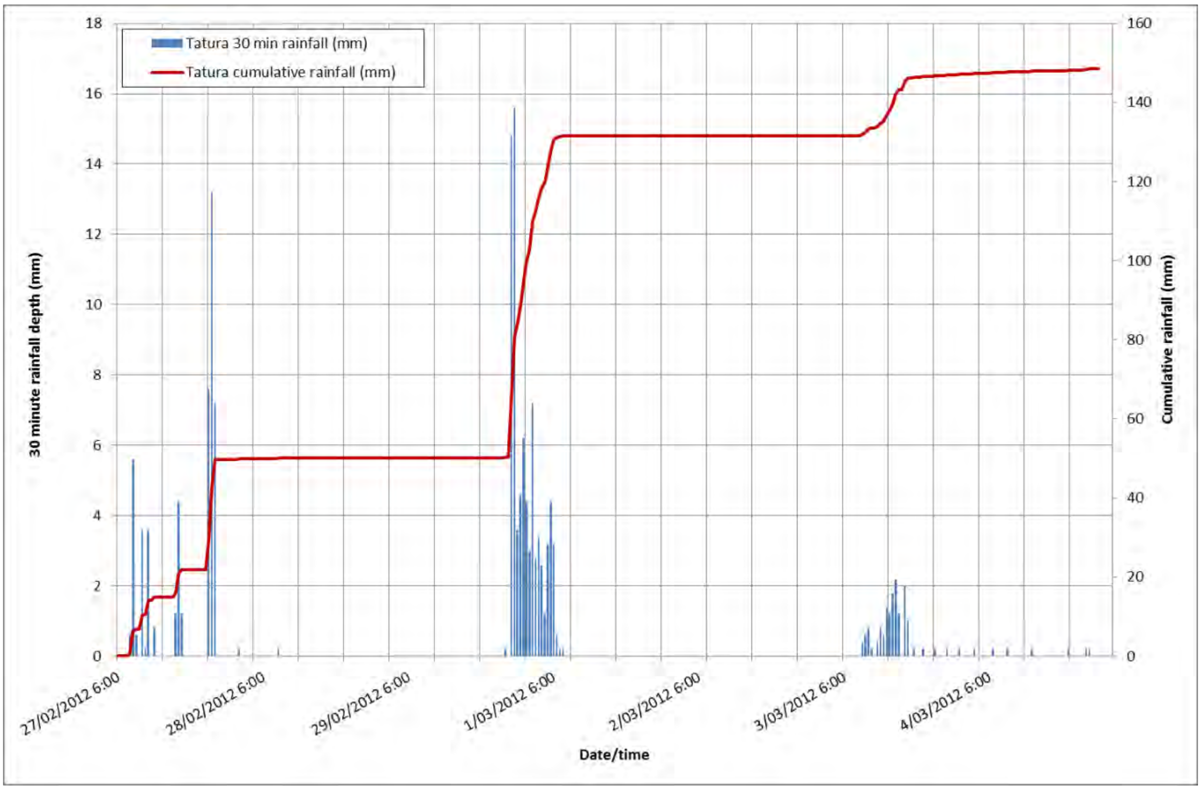


Figure 6-3 Tatura (81049) 30 minute and cumulative rainfall record for March 2012 event

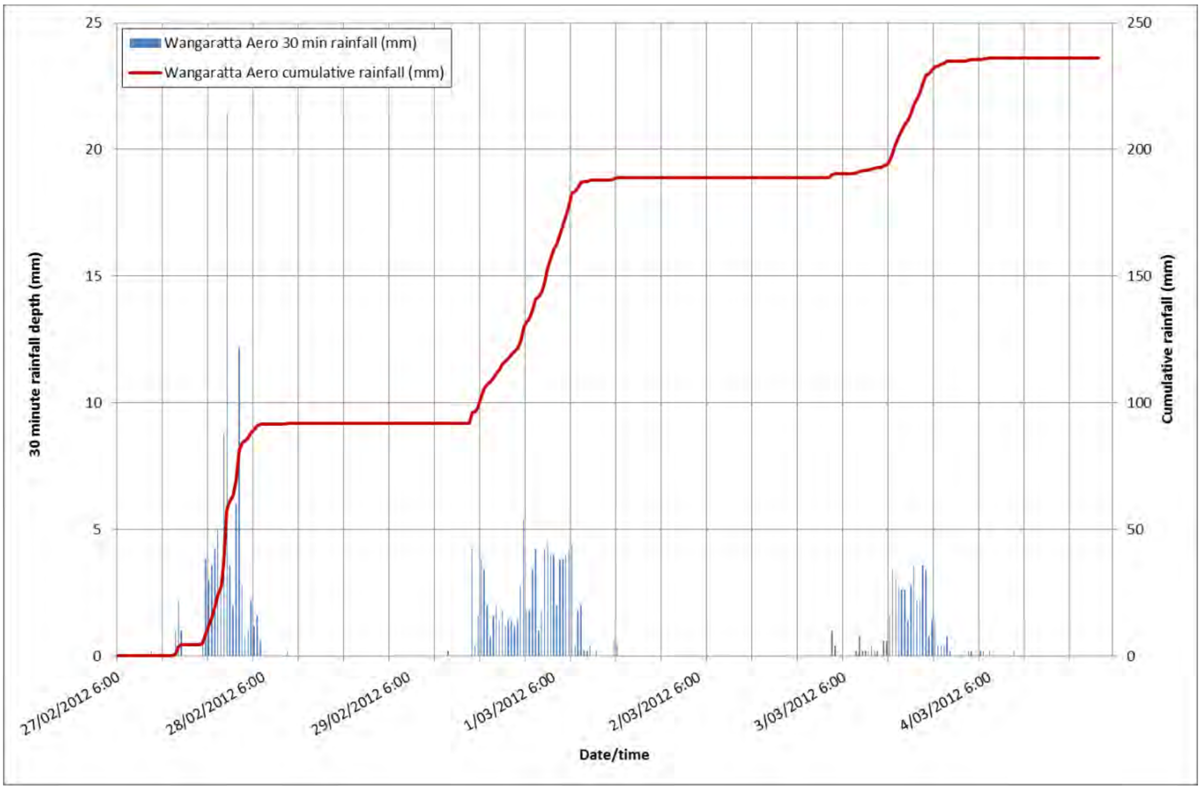


Figure 6-4 Wangaratta Aero (82138) 30 minute and cumulative rainfall record for March 2012 event

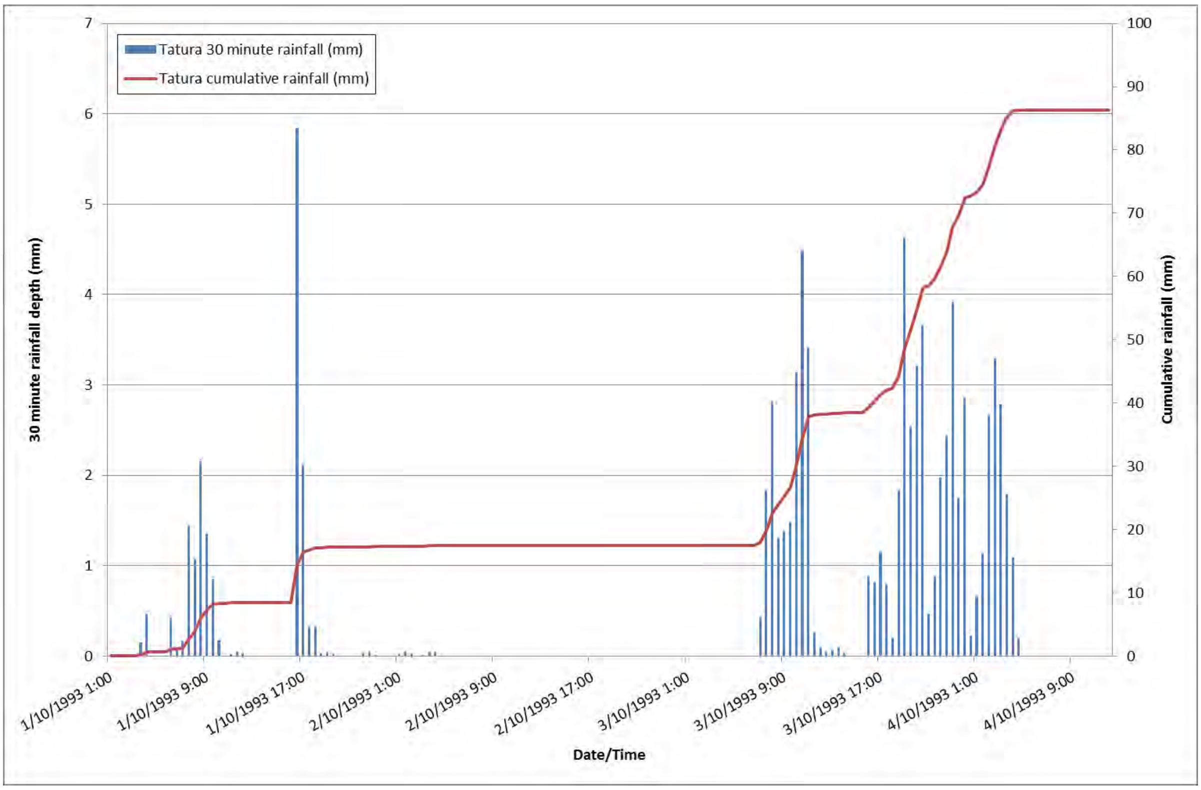


Figure 6-5 Tatura (81049) 30 minute and cumulative rainfall record for the October 1993 event

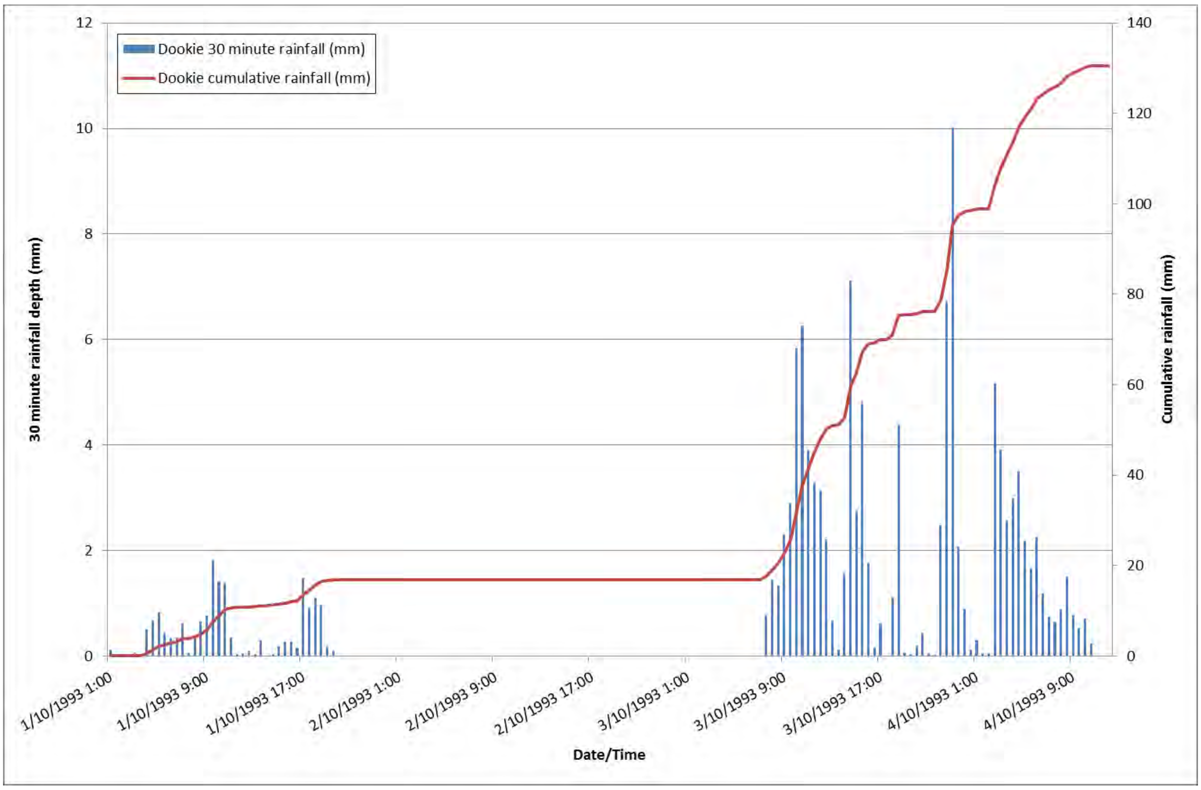


Figure 6-6 Dookie (81013) 30 minute and cumulative rainfall record for the October 1993 event

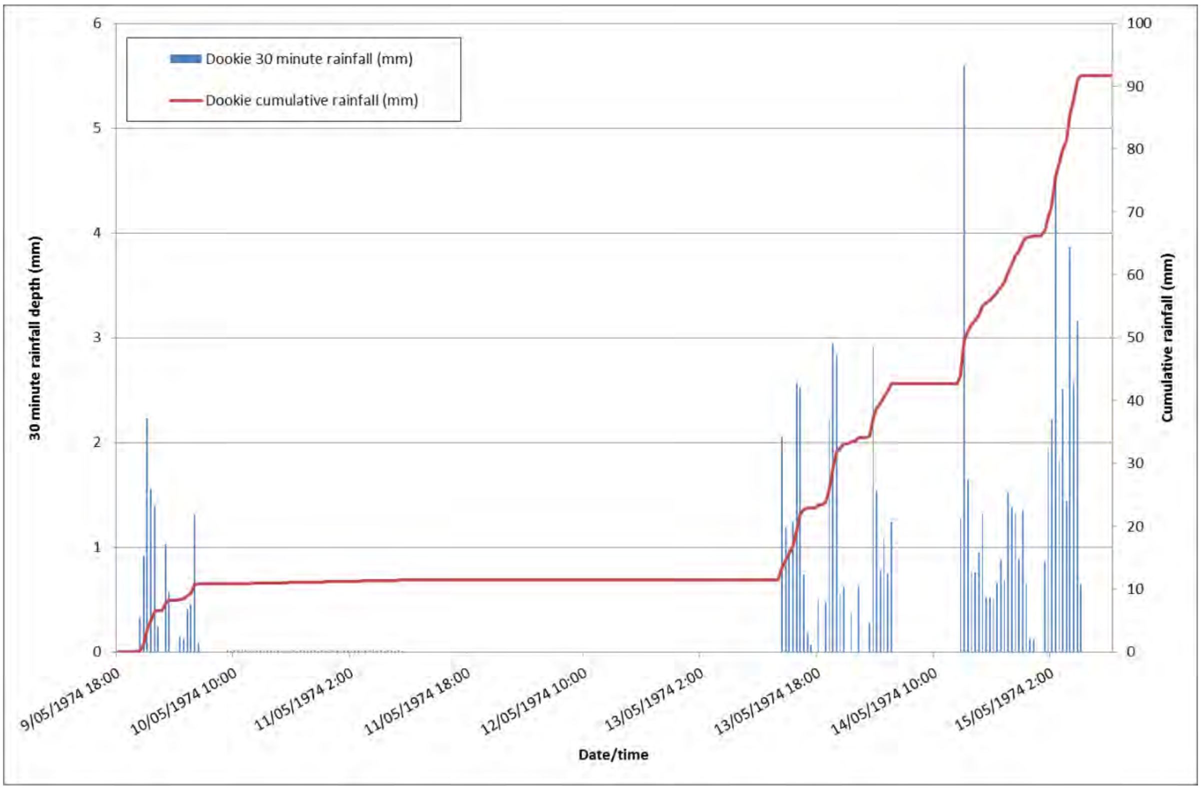


Figure 6-7 Dookie (81013) 30 minute and cumulative rainfall record for the May 1974 event

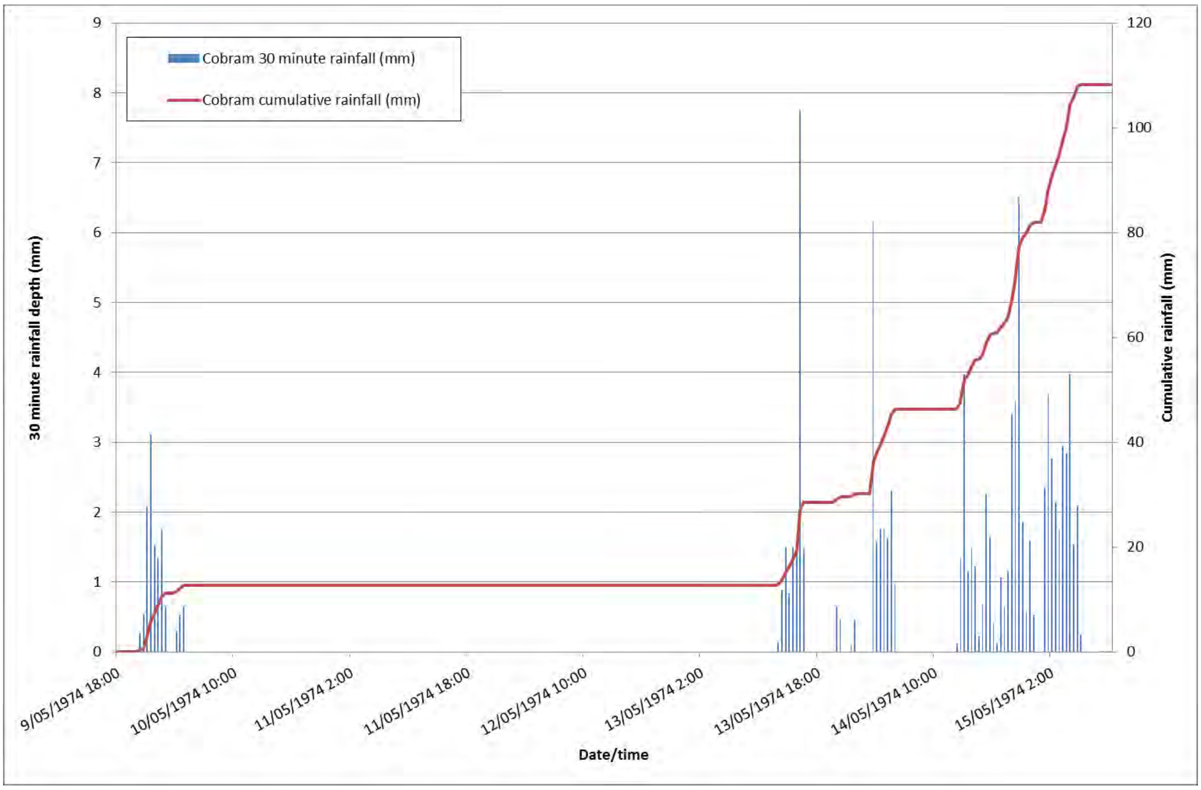


Figure 6-8 Cobram (80109) 30 minute and cumulative rainfall record for the May 1974 event

6.2.1 RORB Model Calibration Parameters

By calibrating the RORB model to historic events, model parameters for the catchment are determined, which then aids the selection of design parameters. The process involves comparison of modelled flood hydrographs with the observed flood hydrographs at the selected stream flow gauges and adjusting the value of kc to reproduce both the peak and volume. RORB also requires calibration of the initial loss and continuing loss for these events. The initial loss / continuing loss model was found to provide a better fit of observed and modelled flood hydrographs and was adopted for this study. The calibration involved matching the modelled hydrograph to the observed hydrographs at the ‘Boosey Creek at Tungamah’ and ‘Broken Creek at Katamatite’ streamflow gauges by adjusting the available kc and loss parameters.

The calibration approach adopted for this study was as follows:

- Set m = 0.80. This value is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987).
- The initial loss parameter (IL) was determined by finding a reasonable match between the modelled and observed rising limbs of the flood hydrograph.
- A continuing loss (CL) was selected to achieve a reasonable fit between the modelled and observed hydrograph volumes.
- The RORB kc parameter was initially calculated within RORB using a catchment area relationship (equation 2-5 in version 5 of RORB User Manual). This kc value was then varied to achieve a reasonable fit of the peak flow and general hydrograph shape.

Details of the selected calibration and verification events are provided in Table 6-1 below. The average catchment rainfall show in Table 6-1 was determined by creating a Triangular Irregular Network (TIN) of rainfall depths from the daily rainfall data. A mean depth for the catchment area was then extracted from the TIN.

Table 6-1 RORB model calibration event summary

Event	Event Start & Finish Date	Average Catchment Rainfall
March 2012	27/02/2012 8:00am to 03/03/2010 11:00pm	250mm (over a 5 day period)
October 1993	1/10/1993 10:30am to 4/10/1993 10:30am	95 mm (over 3 day period)
May 1974	9/5/1974 8:00pm to 15/5/1993 5:30pm	89mm (over a 6 day period however 90% occurred in the last 48 hours)

Table 6-2 RORB model calibration event peak flows

Event	Recorded Peak Flow at Boosey Creek @ Tungamah Gauge (m^3/s)	Recorded Peak Flow at Broken Creek @ Katamatite Gauge (m^3/s)
March 2012	269.6	138.1
October 1993	176.8	72.3
May 1974	231.5 (estimated)	58.6 (estimated)

The RORB model parameters and the approach taken to determine their values is described below:

kc value

A range of prediction equations for kc are available, some of which are built into RORB. These prediction equations were used to determine an initial kc value at the commencement of calibration. These equations use different inputs such as catchment area and D_{av} (the average flow distance in the channel network of sub area inflows), and have been developed using different data sets. The RORB model kc value was then adjusted to match the modelled hydrograph to the observed hydrograph at the 'Boosey Creek at Tungamah' and 'Broken Creek at Katamatite' streamflow gauges.

It was decided to use four interstation areas for the RORB model. A review of the topography indicated that the lower half of the catchment which includes Numurkah township and further downstream is significantly flatter than the upper half of the catchment which is demonstrated in the very slow travel times for floods to travel from the Tungamah and Katamatite gauges to Numurkah and then to Nathalia downstream. Boosey Creek, Muckatah Depression and the upper Broken Creek catchment also have different characteristics from each other and for this reason separate interstations were placed at the Broken and Boosey Creek gauge locations as well as the outlet of Muckatah Depression. As there is no gauge in the Muckatah Depression catchment the same parameters were used as the Broken Creek catchment as they have similar catchment characteristics in terms of size and topography. Routing parameters were varied upstream and downstream of the interstations resulting in three different kc values for the four different interstation areas.

Use of interstation areas is generally avoided unless there are particular circumstances that require it and there is available gauge data to allow for a detailed calibration. The observed timing of flows at the Walsh's Bridge and Nathalia gauges were used to guide the choice of kc for the lower half of the catchment. The Muckatah hydraulic model, as discussed in Section 6.4, was used to verify the flows in Muckatah Depression. The Muckatah flows were then scaled as described in Section 7.

Table 6-3 Methods of kc value calculation

Method	Equation	Boosey Creek	Broken Creek (upper)	Broken Creek (lower)
Default RORB	$kc = 2.2*A^{0.5}$	63.3	36.4	97.1
Vic MAR>800 mm - Eq 3.21 ARR (BkV)	$kc=2.57*A^{0.45}$	38.7	18.8	67.3
Victoria data (Pearse et al, 2002)	$kc=1.25*D_{av}$	46.0	63.2	170.7
Aust wide Dyer (1994) (Pearse et al 2002)	$kc=1.14*D_{av}$	41.9	57.7	155.7
Aust wide Yu (1989) (Pearse et al 2002)	$kc=0.96*D_{av}$	35.3	48.6	131.1
Catchment area		829 km^2	274 km^2	1,947 km^2
Average travel distance (D_{av})		37 km	51 km	137 km

m Value

m is a measure of a catchment's non-linearity. The value is rarely set as greater than 1 or less than 0.6 and a value of 0.8 is recommended in the RORB manual as an initial starting value. During the calibration process there was no justification to vary this value and it remained at 0.8.

There are methods for determining an appropriate value of m and one such method is Weeks (1980) which uses multiple calibration events to select kc and m. However, given the extrapolation of selected parameters to larger events and the goodness of fit obtained using the recommended value of 0.80, there appears no significant reason to vary it for the Broken Creek catchment.

This value is considered an acceptable value for the degree of non-linearity of catchment response and is consistent with other flood studies in the region (Australian Rainfall and Runoff, 1987).

Temporal patterns

Calibration temporal patterns used in the RORB model were extracted from the nearest available pluviographs which record instantaneous rainfall data. The pluviograph stations used were Tatura, Cobram, Dookie and Wangaratta Aero. In each calibration event only two or three acceptable pluviograph records were available. Figure 6-9, Figure 6-10 and Figure 6-11 below show the observed temporal patterns at the relevant stations for the March 2012, October 1993 and May 1974 events. The temporal patterns were applied to subareas according to locality with the temporal pattern from the nearest weather station applied to each individual subarea.

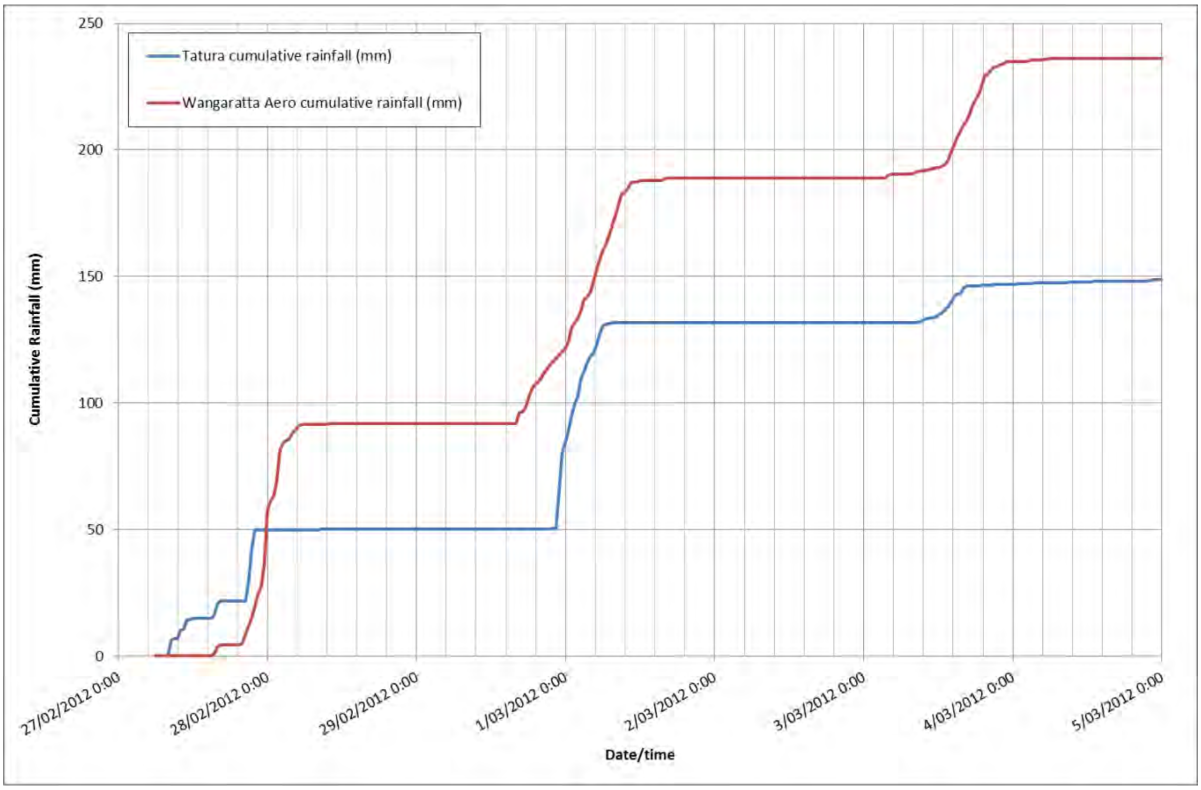


Figure 6-9 Observed temporal patterns at Tatura (81049) and Wangaratta Aero (81238) for the March 2012 event

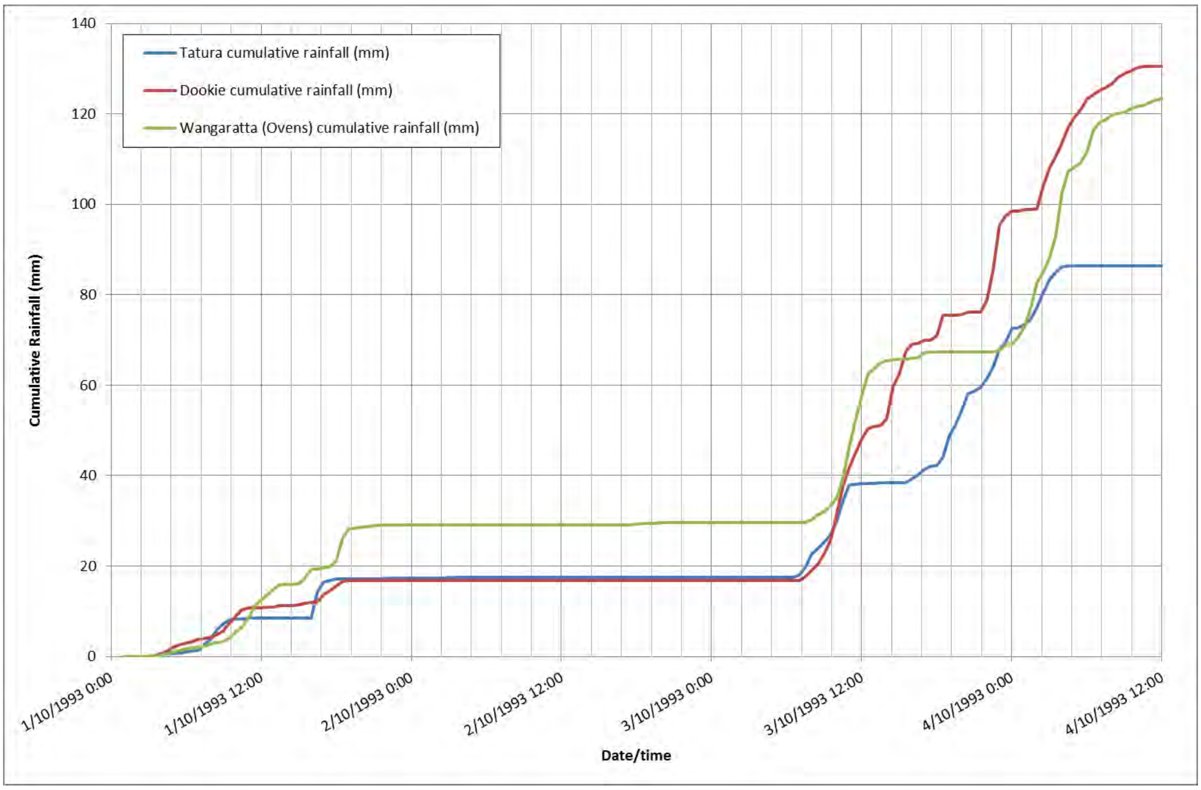


Figure 6-10 **Observed temporal patterns at Tatura (81049), Dookie (81013) and Wangaratta (Ovens) for the October 1993 event**

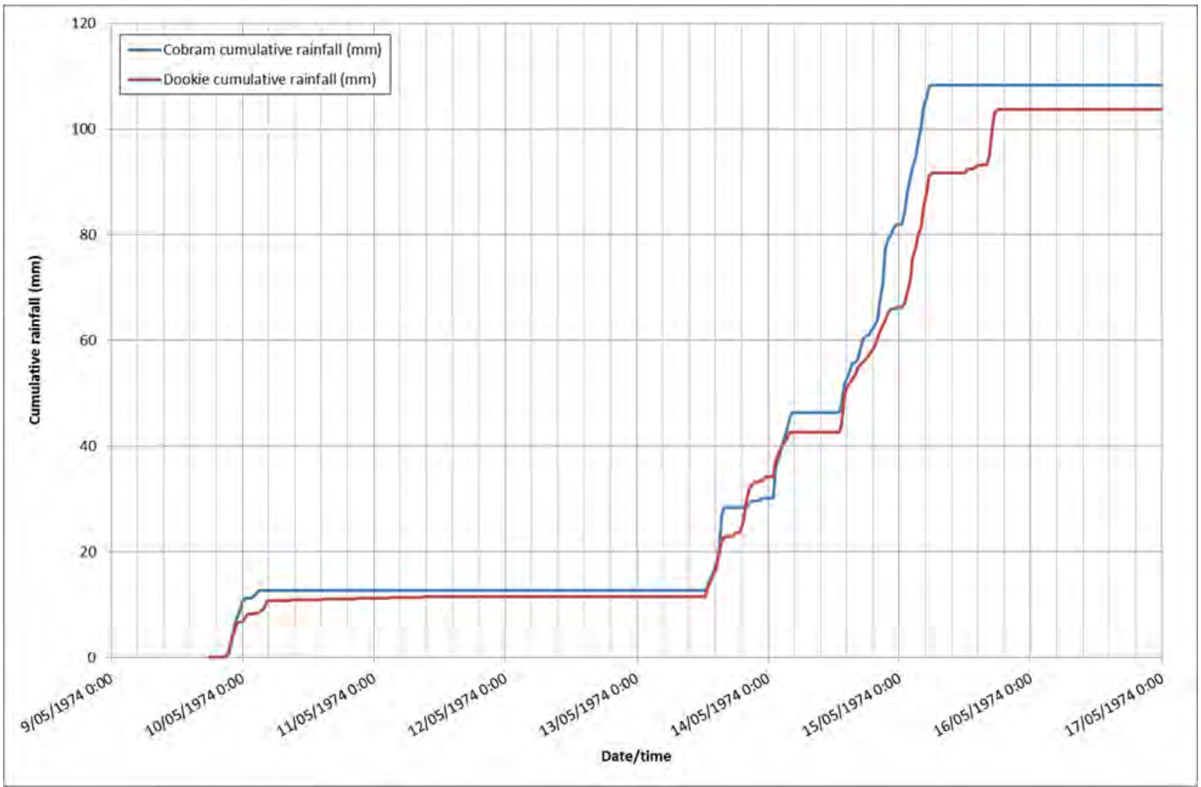


Figure 6-11 **Observed temporal pattern at Cobram (80109) and Dookie (81013) for the May 1974 event**

Spatial Patterns

Spatial patterns for calibration were based on the spatial distribution of rainfall observed during each of the events. The gauges used in determining the spatial patterns are discussed in Section 2.2 and shown in Figure 2-2. Each gauge's rainfall total over the duration of the event was used to create a set of rainfall isohyets for the event, creating a spatial distribution of rainfall covering the Broken Creek catchment. The rainfall depth for each subarea can then be estimated from the isohyets. Six rainfall isohyets were created, one for the May 1974 event, two for the double bursts in October 1993, three for the triple bursts in March 2012.

Losses

An initial and continuing loss model was adopted for the Broken Creek catchment as it is predominantly agricultural land with limited built up areas. Losses can vary widely from catchment to catchment and between events in the same catchment dependent on antecedent conditions.

6.3 RORB Model Flood Event Calibration

The calibration results are summarised in Table 6-4 to Table 6-7. Figure 6-12 and Figure 6-13 display the modelled and observed flood hydrographs for the calibration events at the two gauges.

Table 6-4 RORB model calibration parameters – March 2012 event

Interstation Area	Kc	Burst 1		Burst 2		Burst 3	
		IL	CL	IL	CL	IL	CL
Boosey Creek	120	55	5.5	0	1.75	0	2.75
Broken Creek (upper)	190	55	5.5	0	2.0	0	2.75
Broken Creek (lower)	600	55	5.5	0	2.0	0	2.75

Table 6-5 RORB model calibration peak flows and volumes – March 2012 event

March 2012 event	Boosey Creek at Tungamah		Broken Creek at Katamatite	
	Observed	Calculated	Observed	Calculated
Peak Flow (m^3/s)	269.6	261.3	138.1	118.5
Volume (m^3)	8.14×10^7	8.32×10^7	4.81×10^7	5.39×10^7

Table 6-6 RORB model calibration parameters – October 1993 event

Interstation Area	Kc	Burst 1		Burst 2	
		IL	CL	IL	CL
Boosey Creek	75	20	0.25	0	0.25
Broken Creek (upper)	175	20	2.75	0	2.75
Broken Creek (lower)	600	20	2.75	0	2.75

Table 6-7 RORB model calibration peak flows – October 1993 event

March 2012 event	Boosey Creek at Tungamah		Broken Creek at Katamatite	
	Observed	**Calculated**	**Observed**	**Calculated**
Peak Flow (m^3/s)	177.5	178.8	72.3	68.2
Volume (m^3)	$4.26x10^7$	$3.82x10^7$	$2.66x10^7$	$3.13x10^7$

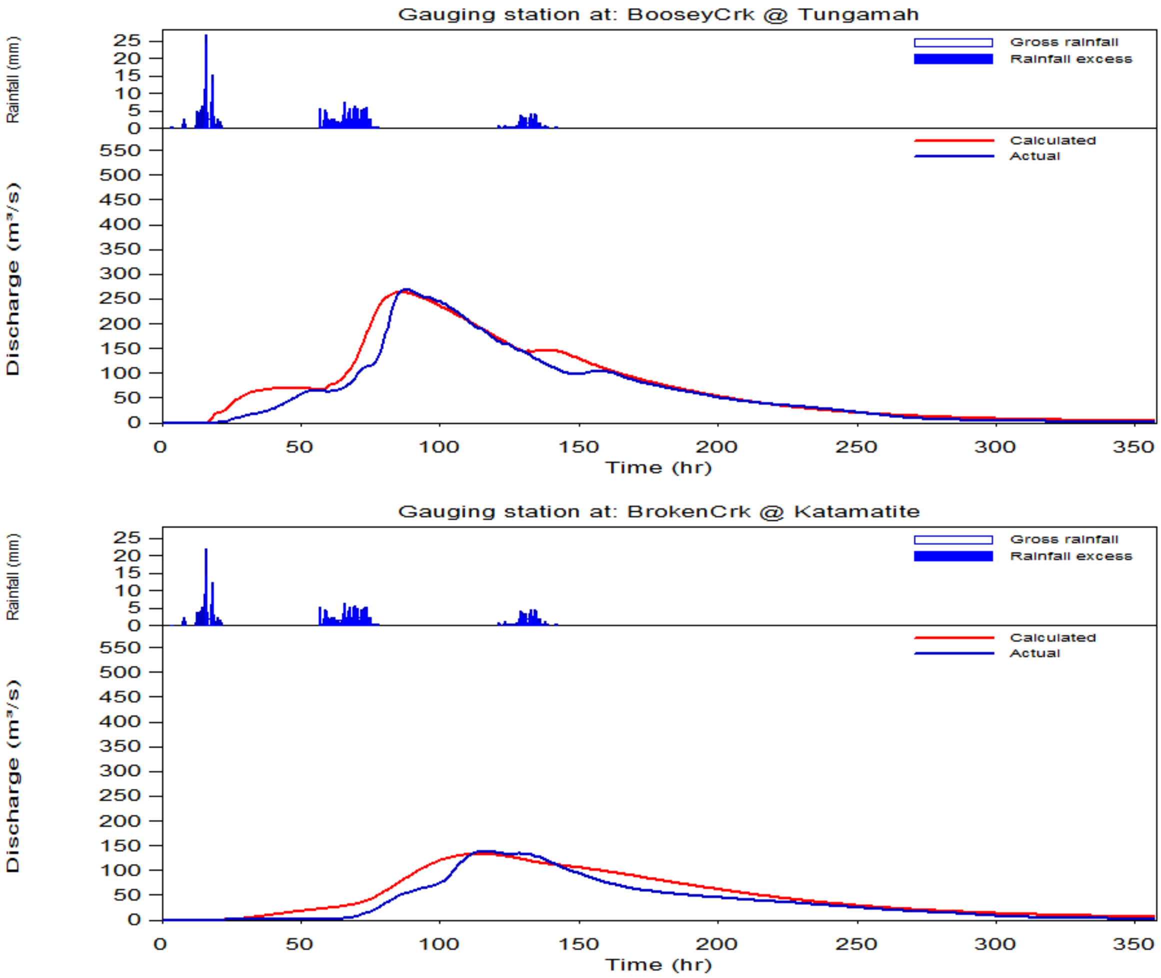


Figure 6-12 RORB calibration plots of March 2012 event

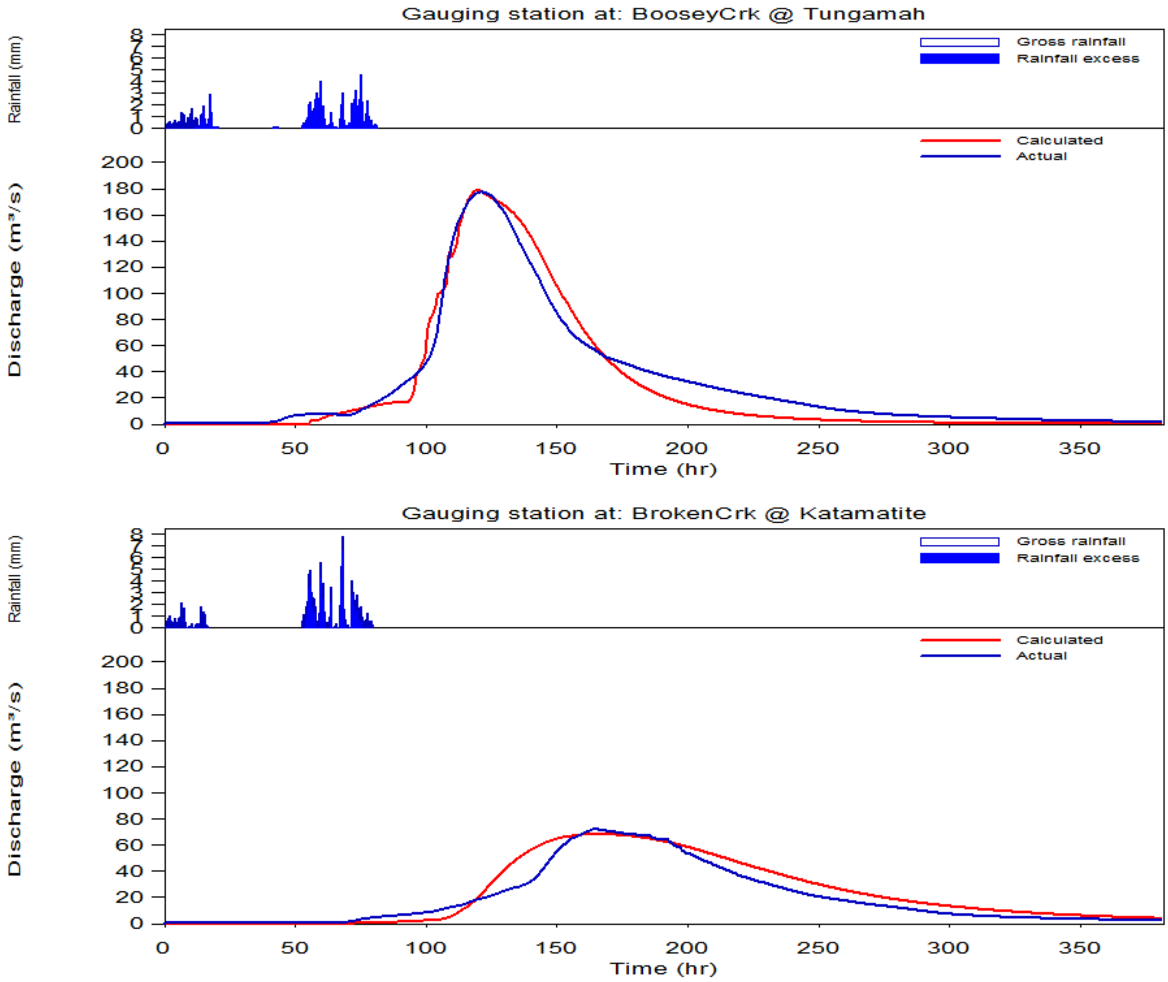


Figure 6-13 RORB calibration plots of October 1993 event (lagged at both gauges)

6.3.1 March 2012 Flood Event Calibration

For the March 2012 event, the modelled hydrographs at both gauges reproduced the peak flow, volume and general hydrograph shape reasonably well. At both gauges it can be seen that the modelled hydrograph rises and peaks slightly earlier than the gauge record however the falling limb has a good fit and the peak flow and volume is reproduced well.

It can be seen in Table 6-4 that high initial and continuing losses and high kc values were required to achieve a good calibration. It is believed that this is a result of the very flat topography and the presence of irrigation channels through the catchment which creates storage and slows flood routing significantly. The average gradient through the Broken Creek catchment is approximately 1 in 10,000 which partially explains the very slow passage of flood flows through the catchment and the necessity for high kc values, particularly downstream of the confluence of Major and Broken Creeks.

6.3.2 October 1993 Flood Event Calibration

For the October 1993 event, the modelled hydrographs at both gauges reproduced the peak flow, volume and general hydrograph shape very well however the timing was not able to be reproduced at both gauges. Despite significant testing of parameters it was found that the modelled peak flow was always significantly earlier than the gauged hydrograph. It is likely that this issue relates to the catchment characteristics described earlier with a very flat and heavily modified catchment. It could also be due to insufficient temporal data for the event. Three pluviograph records where used to produce the model temporal patterns located at Wangaratta, Dookie and Tatura. Of those only Dookie lies within the catchment and so it is possible that the timing of the event has not been accurately represented due to the lack of available data.

The RORB manual also mentions that RORB can sometimes have difficulty reproducing accurate timing in catchments and in some cases "the model produces a calculated hydrograph of similar shape to the actual one but preceding or lagging behind it (usually the former)"[3]. In those situations it recommends a translation be used to shift the hydrograph to achieve a better fit. For this reason it was deemed appropriate to translate the hydrograph to achieve a better fit for input into the hydraulic model and both hydrographs were lagged by approximately 40 hours at the reaches immediately upstream of the gauge locations. The hydrographs shown in Figure 6-13 are the result after the translation has been applied to the catchment file.

Nonetheless the modelled peak flow and volume were reproduced very well and it was considered that, given the purpose is for flood mapping in Numurkah, it was more important to focus on volume and peak flow. The resulting lagged hydrographs are an excellent representation of the 1993 gauged hydrographs with very similar volumes, peak flows and hydrograph shapes.

6.3.3 Inflow Hydrographs at Numurkah

Hydrographs and peak flows were extracted from the calibrated models at various points of interest around the catchment. This includes locations where inflows will be required for the hydraulic model on Muckatah, Broken and Majors Creeks, the flows for which are shown in Table 6-8. Hydrographs from the March 2012 and October 1993 events are shown in Figure 6-14 and Figure 6-15.

Table 6-8 Modelled peak flows at points of interest within the study area

Location	March 2012 event		October 1993 event	
	Modelled Peak Flow (m^3/s)	Modelled Peak Time	Modelled Peak Flow (m^3/s)	Modelled Peak Time
Boosey Creek at Tungamah gauge	**261.3**	3/03/2012 12:00am	**178.7**	6/10/1993 7:30
Broken Creek at Katamatite gauge	**118.5**	4/03/2012 20:30	**68.18**	8/10/1993 0:30
Broken Creek hydraulic model inflow point	**253.1**	4/03/2012 13:30	**145.6**	9/10/1993 2:30
Major Creek hydraulic model inflow point	**103.5**	3/03/2012 18:30	**17.05**	6/10/1993 22:30
Muckatah Depression hydraulic model inflow point	**128.7**	4/03/2012 16:30	**15.46**	6/10/1993 3:30
Numurkah township	**403.5**	5/03/2012 2:30	**171.9**	10/10/1993 4:30

[3] E.M. Laurenson et al, *RORB Version 6 User Manual*, Monash University, Melbourne, 2010, p, 26

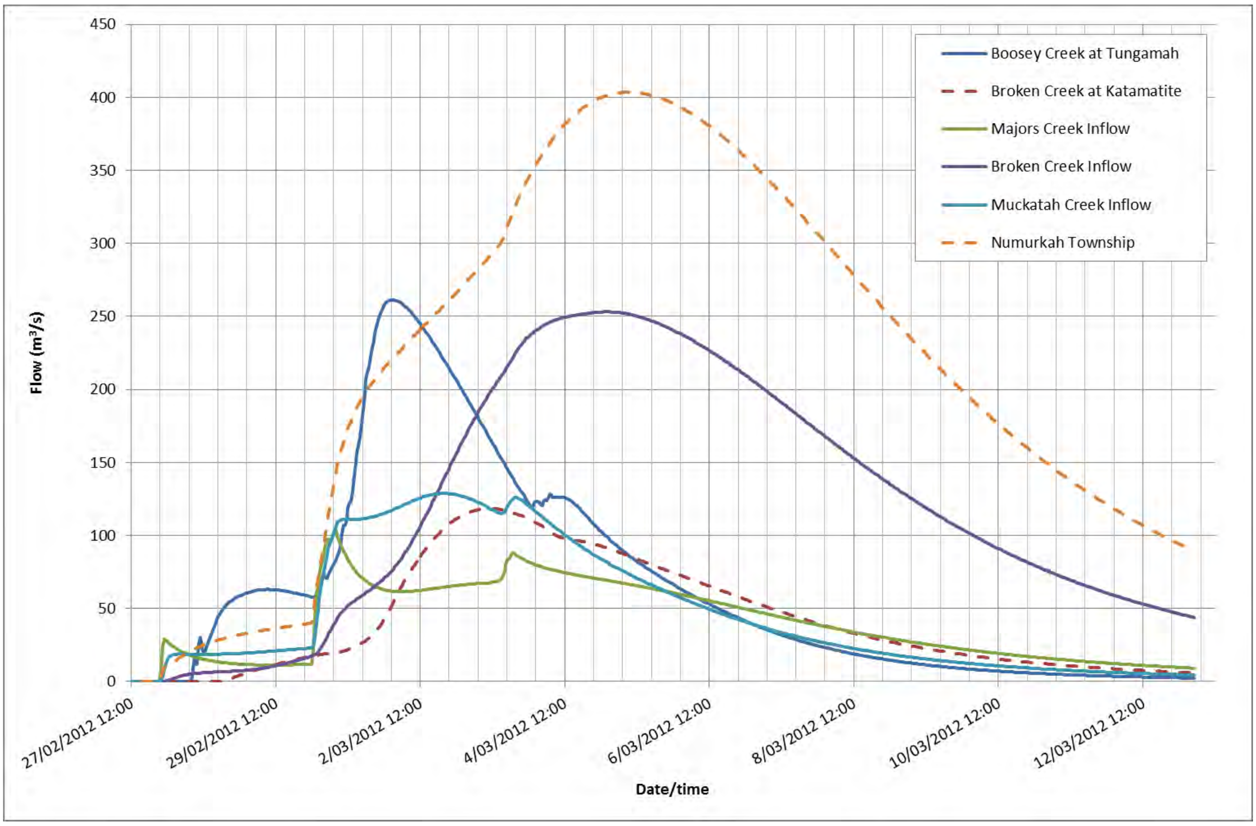


Figure 6-14 March 2012 event modelled flows

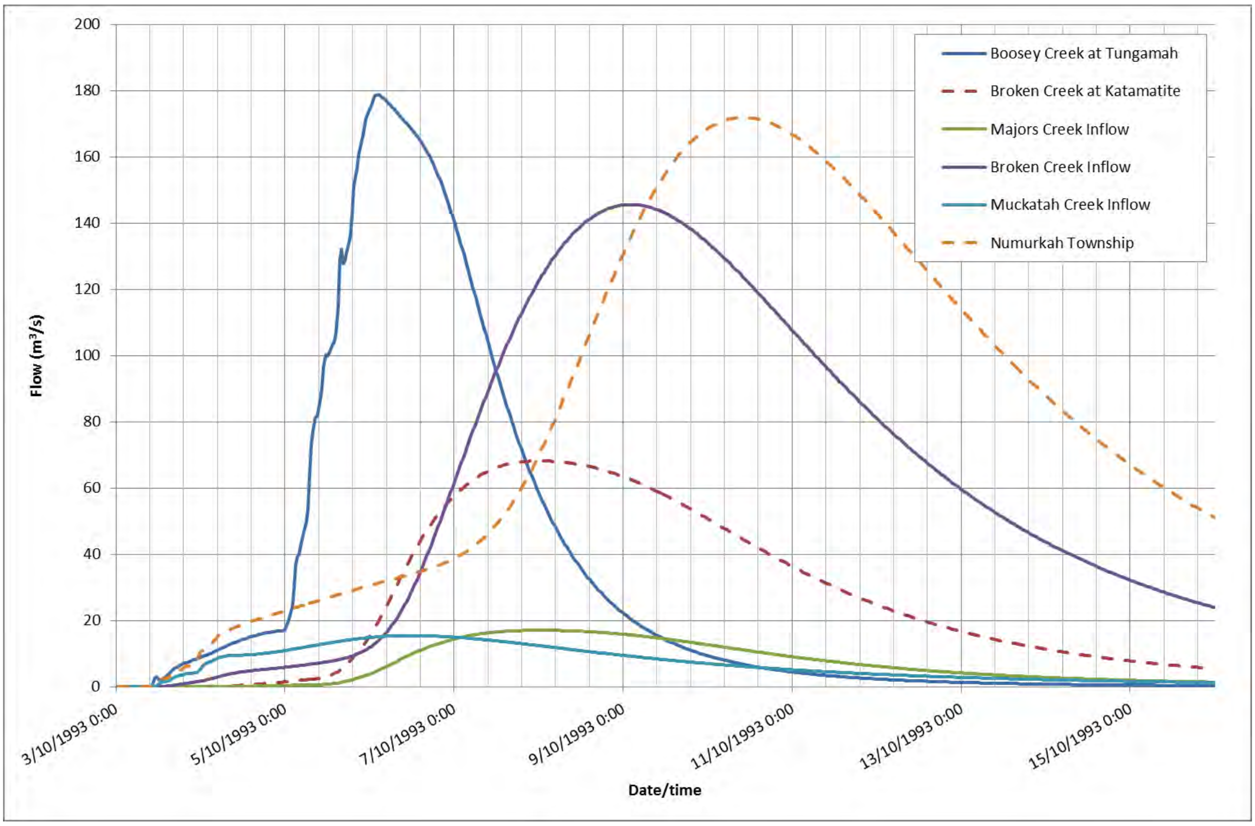


Figure 6-15 October 1993 event modelled flows

6.4 May 1974 Verification Event

The May 1974 event was used as a verification event following the calibration of the 2012 and 1993 events. The May 1974 event is considered one of the largest flood events in Numurkah's history and anecdotally was comparable to the March 2012 event. Data records at that time are limited and there is considerably less gauge data available than the 1993 and 2012 events. While full hydrographs were not recorded during the 1974 event, estimated peak flows are available at the Tungamah and Katamatite Gauges. Peak flows were used as the basis for the verification although the reliability of the 1974 estimates are unknown so the results must be treated with some caution. The results are shown below in Table 6-9 and Table 6-10 below.

Table 6-9 RORB model verification parameters – May 1974 event

Interstation Area	kc	Burst 1	
		IL	CL
Boosey Creek	75	0	0
Broken Creek (upper)	195	50	5.5
Broken Creek (lower)	600	50	5.5

Table 6-10 RORB model calibration peak flows and volumes – May 1974 event

March 2012 event	Boosey Creek at Tungamah		Broken Creek at Katamatite	
	Observed	Calculated	Observed	Calculated
Peak Flow (m^3/s)	231.5	201.3	58.6	63.5

It can be seen that the RORB model had difficulty in reproducing the peak flows at both locations, particularly at the Tungamah gauge. At the Tungamah gauge the model underestimated the peak flow even though no initial and continuing losses were used in that interstation area. At the Katamatite gauge the RORB model overestimated the flows despite relatively high losses being used in that interstation area. Overall it can be seen that the RORB model achieved a relatively poor representation of the 1974 event. The difficulties in representing the 1974 event further indicate that RORB has difficulty in handling the flat topography of the Broken Creek catchment and the associated catchment behaviour.

7. MUCKATAH DEPRESSION FLOW VERIFICATION

Initial perceptions of the RORB model flows for the Muckatah Depression were that they were too high. This was based on a comparison against previous estimates of flows from the Muckatah Depression from the SMEC 2005 RAFTS modelling.

To assist in verifying flows in the Muckatah Depression a 2D hydraulic model was constructed of the lower half of the Muckatah Depression catchment. The model schematisation, parameters and results are described below.

7.1.1 Muckatah Depression Hydraulic Model

Topography

The model topography was limited by the quality of the available datasets. The DEM used for the hydraulic model was a merged DEM of the high quality 1 m resolution LiDAR and low quality 20 m resolution VicMap dataset. The 1 m resolution LiDAR covered the south-western third of the model however the remainder of the model used the 20 m resolution dataset.

A further problem with the 20 m resolution dataset is that it did not contain any irrigation channels which are known to have a significant impact on flow paths around Numurkah. For this reason the larger irrigation channels were “stamped” into the topography to ensure they were represented. Aerial flood imagery from the 2012 event was used to assess which channels were important to represent in the Muckatah hydraulic model. The main channel to be included in the model was a 15 km section of the No. 4 Main Channel as shown in Figure 7-2. Aerial flood imagery confirms that this is the main channel which influences flow paths and flood routing in the lower sections of the Muckatah Depression.

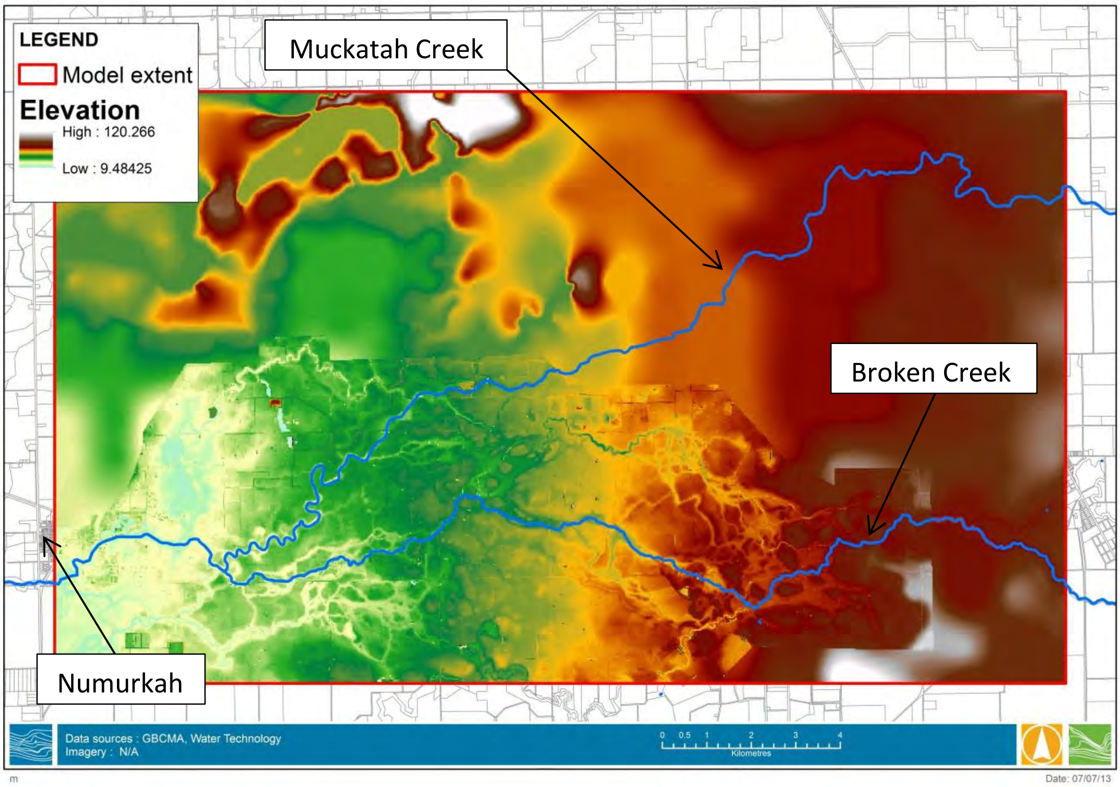


Figure 7-1 Muckatah Depression Hydraulic Model DEM and Extent

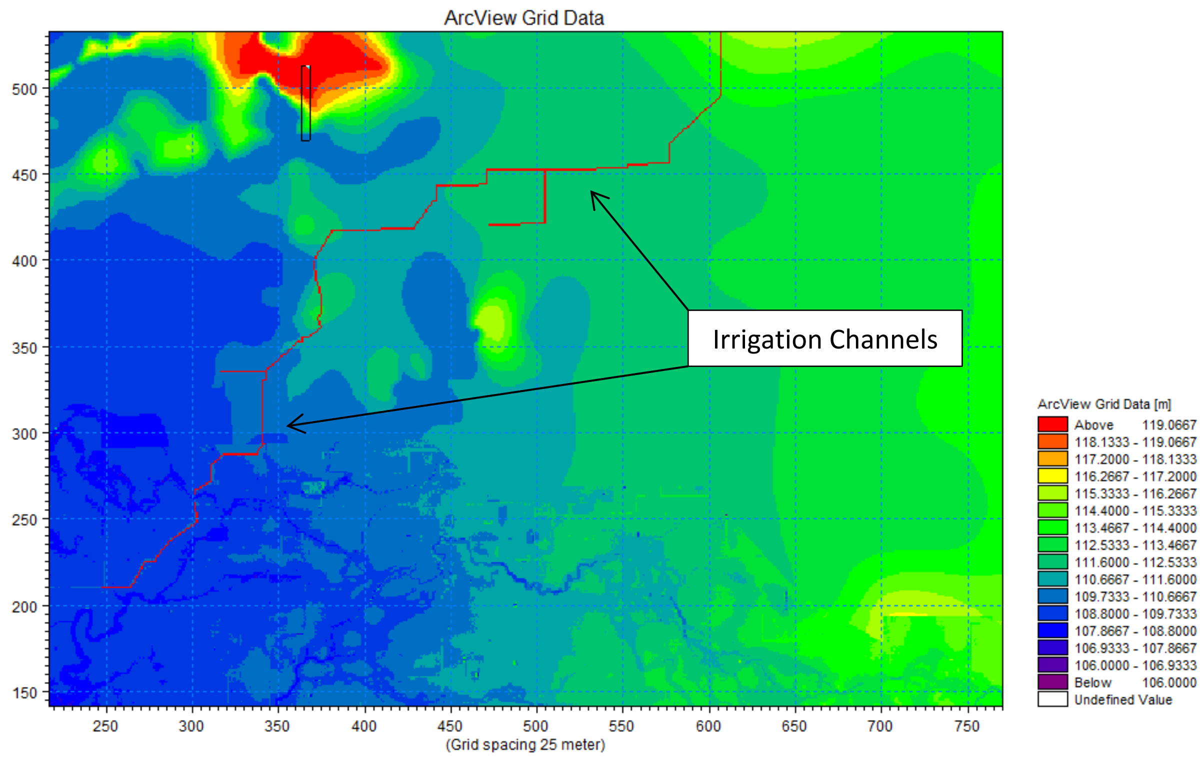


Figure 7-2 Model topography with inserted irrigation channels visible

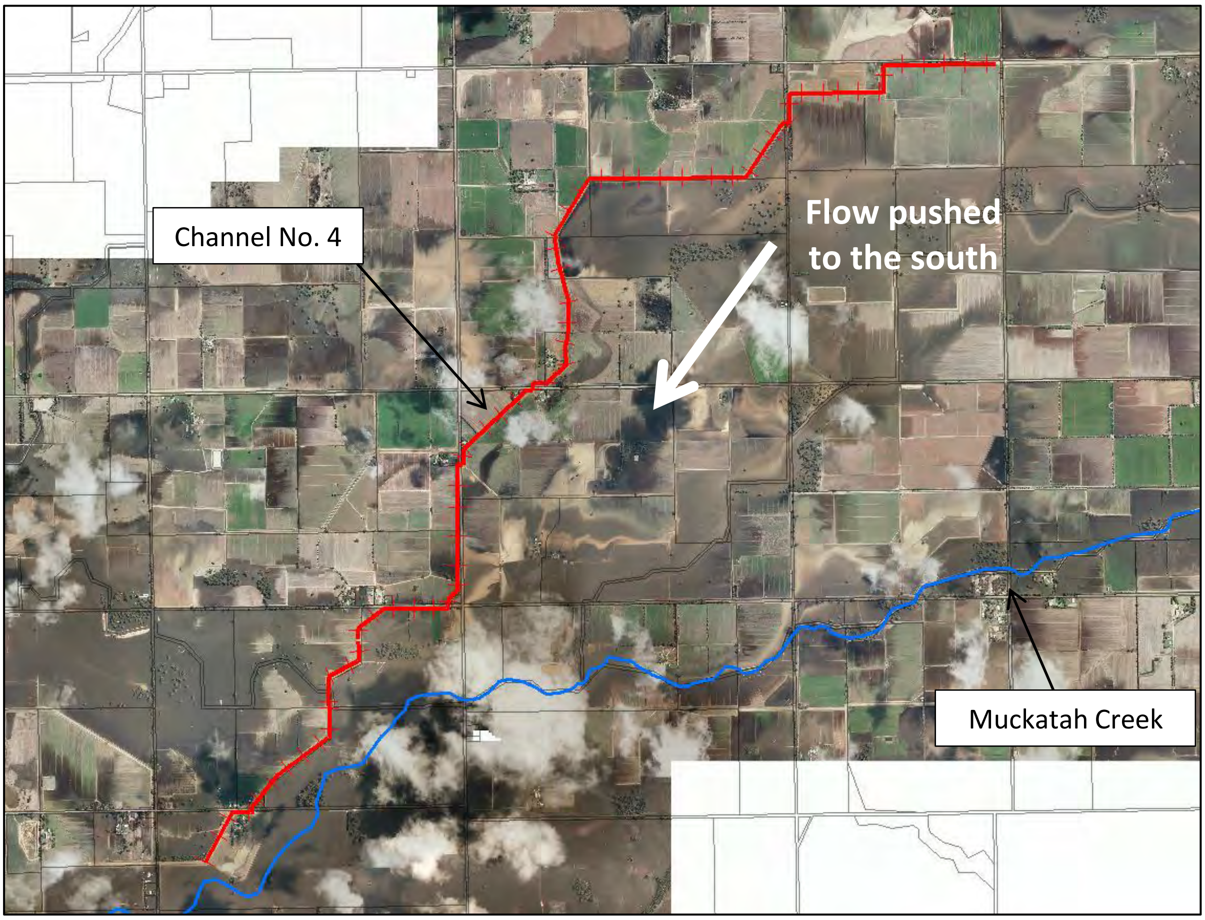


Figure 7-3 Aerial Imagery of Muckatah Depression with impact of Channel No. 4 on flow paths evident

Parameters

The parameters of the Muckatah Depression 2D hydraulic model are described below:

- A uniform Manning's roughness of 0.035 was used across the model extent.
- An inflow flux boundary was used for the Muckatah Creek at the upstream end of the model. Flows were extracted at that location from the RORB model for the March 2012 event.
- A water level boundary was used at the downstream end of the model in Broken Creek.

Results

The model was run for the March 2012 event and results verified using a combination of aerial flood imagery and flood level survey. A comparison of the flood level survey to the modelled water surface elevation showed that at most locations modelled levels were within 200 mm of survey levels. Given the coarseness of the model and poor topographical data for parts of the model this was deemed by Water Technology to be a good result.

The results were compared with a GIS file of historic high water levels along the Muckatah Depression. The levels in that file were all recorded in the 2012 event. There are 29 points located within the Muckatah hydraulic model extent. The comparison showed:

- At 21 locations modelled levels are within 200 mm of the recorded historic level.
- At 13 locations modelled levels are within 100 mm of the recorded historic level.

It should be noted that a significant portion of the Muckatah model topography is based on a lower quality 20 m resolution DEM and so there are likely to be inaccuracies and discrepancies in levels in those areas.

A summary of the Muckatah Depression flows extracted from RORB are provided below. Two Muckatah inflow locations were required for the hydraulic model. A main inflow boundary was extracted for the primary Muckatah Depression flow path with a second inflow further to the west where a number of sub-catchments are located and contribute to flows in Muckatah Depression at its downstream end. The location of the inflow boundaries was shown earlier in Figure 3-1.

Table 7-1 Muckatah Depression modelled inflows

Event	Muckatah Depression Primary Inflow (m^3/s)	Muckatah Depression Secondary Inflow (m^3/s)
March 2012	**129**	**28.0**
September 1993	**15.5**	**3.82**

7.1.2 Scaling of Muckatah Flows

Following discussions with stakeholders and preliminary testing of flows in the hydraulic model it was believed that the modelled flows given in Table 7-1 were too high. The lower half of the Muckatah Depression catchment is very flat and contains a large number of irrigation channels both of which are likely to slow the passage of water down the catchment significantly. A review of aerial flood photography identified several locations to the north-east of Numurkah in the vicinity of Loofs Road where flows appear to be significantly throttled as shown in Figure 7-4. It is likely that this throttling results in significantly less flow reaching the floodplain around Numurkah than estimated in the RORB modelling.

An analysis was done using LiDAR and aerial flood imagery to estimate the flows at the three locations where constrictions in flow were observed to occur. Flows were estimated using a Manning's calculation. The calculation was based on cross-sections extracted at the flow locations in Figure 7-4, slopes of the water surfaces based on aerial imagery and LiDAR and roughness values. A summary of this analysis and the resulting flows is shown in Table 7-2.

Table 7-2 Manning's Calculation Parameters and Resultant Flows

Location	Water Surface Slope (%)	Peak Water Surface Elevation (m AHD)	Roughness (n)	Peak Flow (m^3/s)
Location 1	0.25	110.35	0.0325	21.2
Location 2	0.18	110.18	0.0325	7.2
Location 3	0.1945	110.61	0.0325	6.6
			Combined Flow:	**35.0**

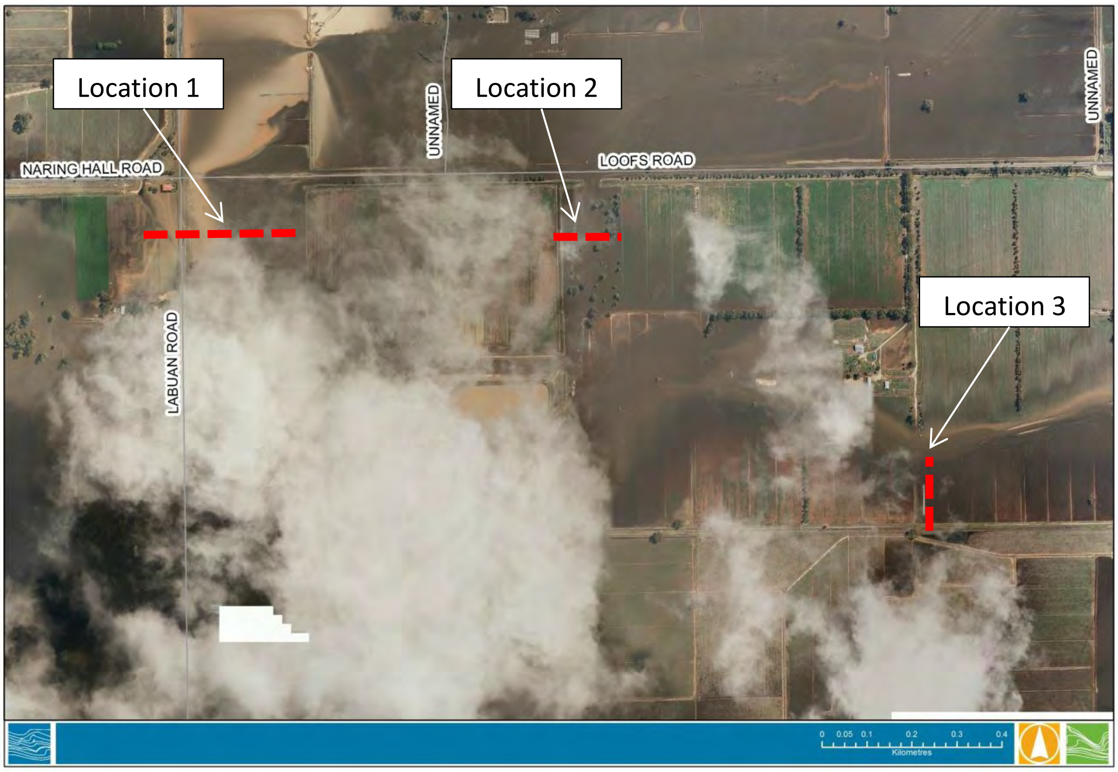


Figure 7-4 Location of constrictions in Muckatah Depression flows to the north-east of Numurkah

The combined flow in Muckatah Depression calculated using the Manning's Equation was 35 m^3/s, which is significantly lower than the 129 m^3/s RORB flow at the same location. The hydrograph for the 2012 flood event was scaled based on the above ratio. Preliminary testing of the hydraulic modelling for the 2012 event using the scaled flow suggested that the flows were reasonable and provided a better representation of flows from The Muckatah Depression than the RORB or Muckatah hydraulic model flows. A very good calibration in the primary Numurkah floodplain model for the March 2012 event was achieved using the revised flow.

Following submission of the draft hydrology report the feedback from the Reference Group and an independent review was that the flow may be too low and it was requested that additional sensitivity testing be undertaken. An additional scenario using an inflow of 69.4 m^3/s (6000 ML/d) was tested and resulted in a slightly improved calibration. A summary of the improved calibration is shown in

Table 7-3. Based on the additional testing an inflow of 69.4 m^3/s for the Muckatah catchment was adopted for the March 2012 event.

Table 7-3 Calibration summary for March 2012 event

Calibration	Original March 2012 Calibration	Revised March 2012 Calibration
Survey points within 100mm of model	73%	75%
Survey points within 200mm of model	97%	97%
Survey points within 300mm of model	100%	100%

It was deemed that scaling the Muckatah flows was not necessary for the October 1993 as the flow were considerably smaller. There is likely to be considerably less constriction to flow compared with the March 2012 event which had a particularly high level of rainfall and flows in the Muckatah Depression catchment compared with other events.

8. FLOOD FREQUENCY ANALYSIS

8.1 Flood Frequency Analysis – Peak Flows

A flood frequency analysis (FFA) allows the estimation of design peak flows based on a statistical analysis on an annual series of peak flood flows. FFA was undertaken for the two relevant gauges; Boosey Creek at Tungamah and Broken Creek at Katamatite. The aim of the FFA was to produce an estimate of a range of design flow events at those locations. An annual flood series was extracted from the available 30 years of instantaneous streamflow data, from 1982 to 2012 as show in Figure 8-1 and Figure 8-2. Flow estimates were made for the large flood event that occurred in 1974 and these were also recorded in the flow record.

Prior to 1974 it is known that a large flood event also occurred in 1917. Based on media and anecdotal reports it is believed that event was comparable in size to the 1974 event. The 1917 event was included in the analysis as an ungauged event with a flow threshold set to 231 m^3/s (20,000 ML/day) which is the peak flow of the 1974 event. The remaining ungauged years between 1917 and 1982 were treated as ungauged years below the 1917 threshold.

Design flows can be estimated from an annual series by fitting a distribution to the series of peak flows. Distributions were fitted to the annual peak flow series using FLIKE software, which uses a Bayesian approach to parameter fitting (recommended in the revised ARR) and allows the fitting of five different distribution types. The 'Log Pearson III' distribution provided the best fit to the recorded data at both gauges.

The resulting design peak flows are given in Table 8-1 while the 'Log Pearson III' analyses are shown in Figure 8-3 and Figure 8-4. Based on peak flows the March 2012 and October 1993 events are estimated as 1-2% and 2-5% AEP events respectively at both gauges.

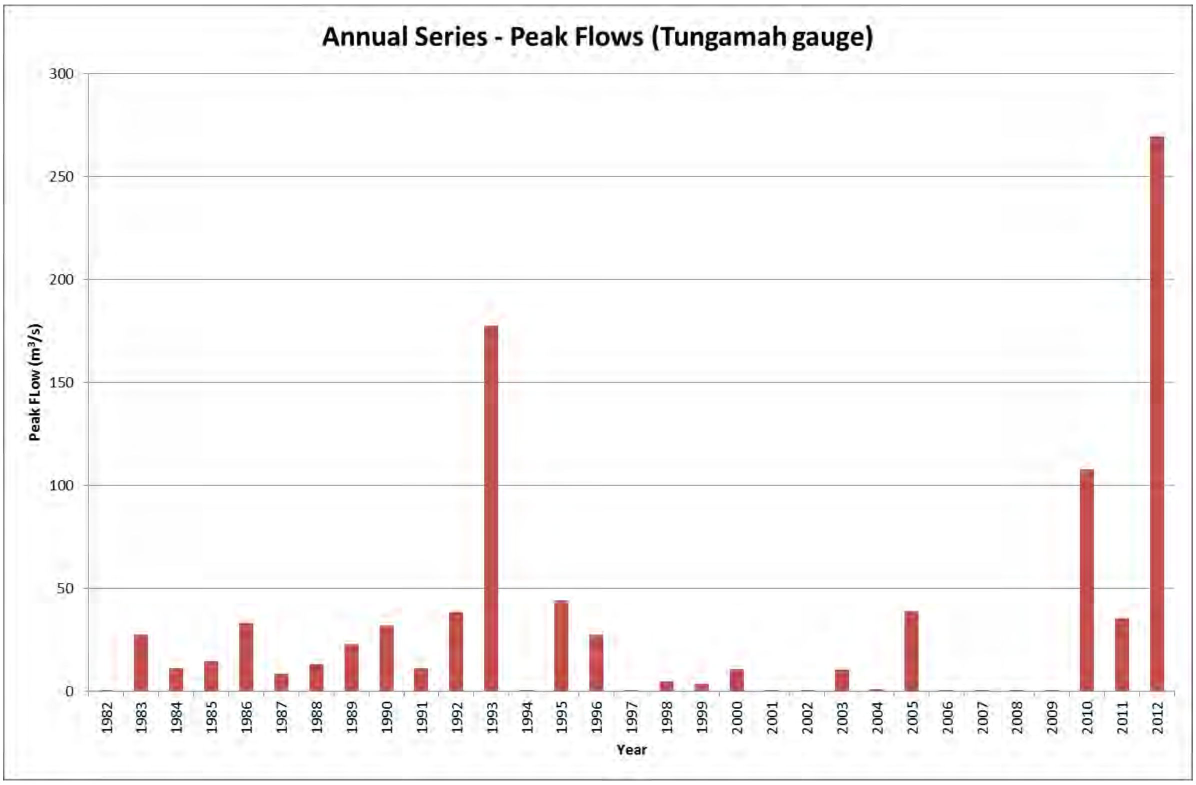


Figure 8-1 Annual series of peak flows at Boosey Creek at Tungamah gauge (404204)

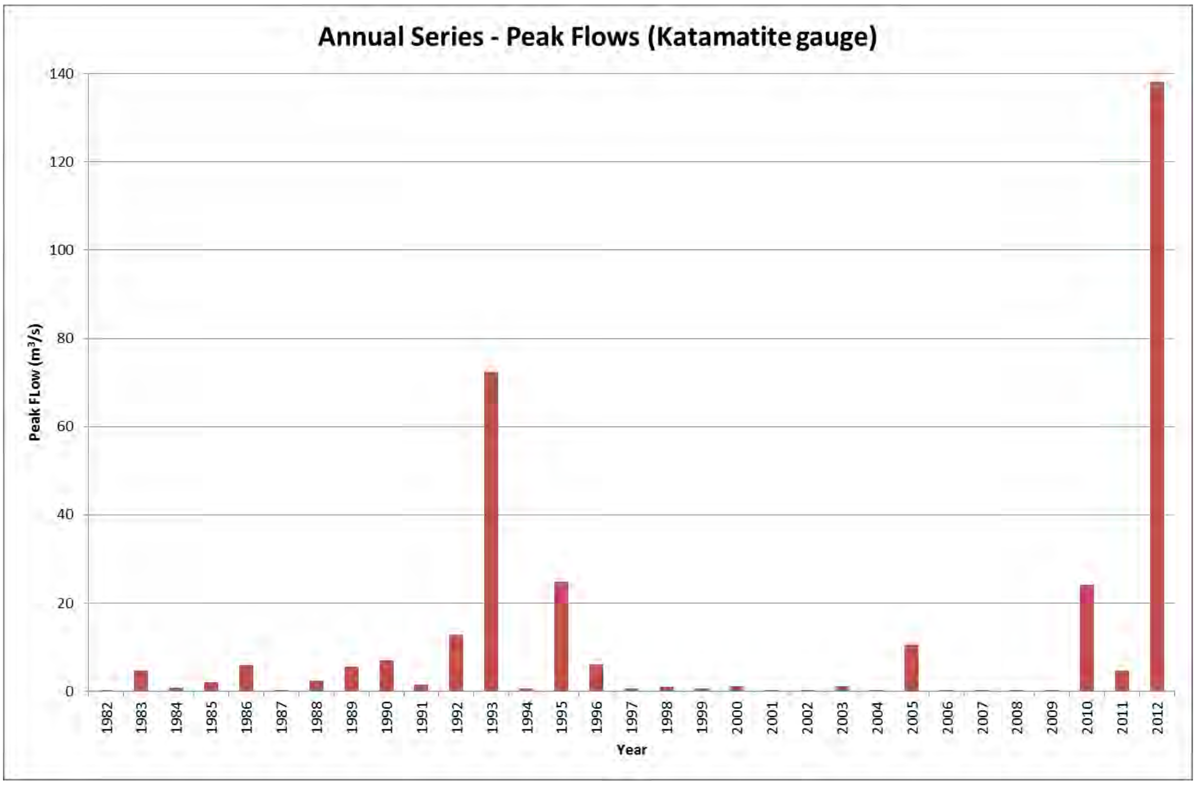


Figure 8-2 Annual series of peak flows at Boosey Creek at Katamatite gauge (404214)

Table 8-1 FFA design peak flood estimates (Log Pearson III)

AEP event (%)	ARI (years)	Peak Design flow (m^3/s)	
		Boosey Creek at Tungamah	Broken Creek at Katamatite
50	2	8.97	1.31
20	5	43.6	7.26
10	10	88.2	18.1
5	20	148	39.0
2	50	251	93.2
1	100	343	168
0.5	200	448	289
0.2	500	600	560

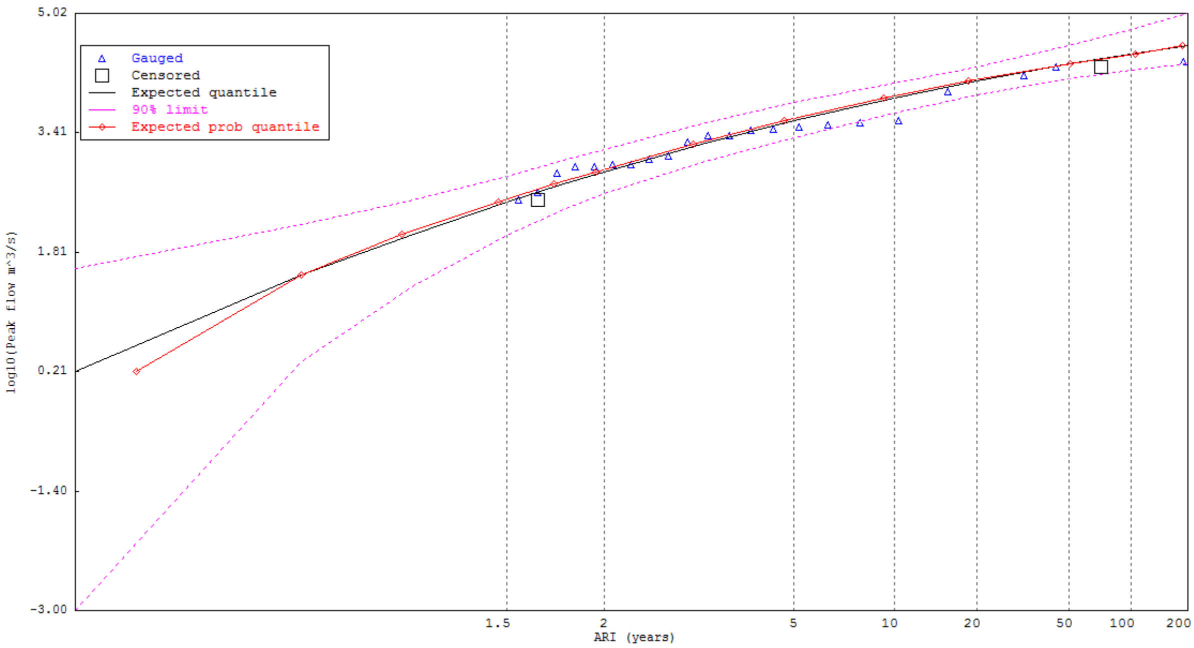


Figure 8-3 Flood Frequency Analysis (LP3) – Boosey Creek at Tungamah

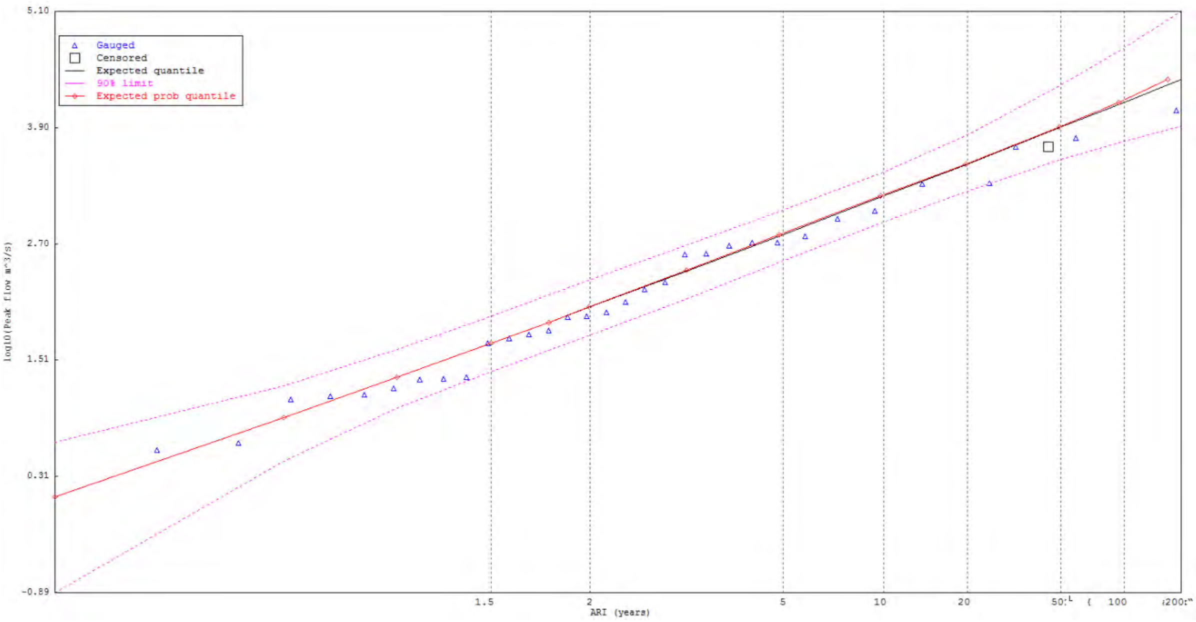


Figure 8-4 Flood Frequency Analysis (LP3) – Broken Creek at Katamatite

8.2 Flood Frequency Analysis – 7 Day Flood Volume

In order to estimate design flow hydrographs, a flood frequency analysis of flood volumes was also undertaken. A review of significant events in the flow record at Tungamah revealed that the average flood event duration was approximately 7 days. At the Tungamah gauge the maximum 7 day flood volume was calculated for each year (from the 30 years of available instantaneous data). The annual series of 7 day flood volumes is shown in Figure 8-5.

Distributions were fitted to the Tungamah annual flood volume series in FLIKE, and the Log Pearson III distribution was found to have the best fit as shown in Figure 8-6. Ten low flow years with maximum flood volume less than 1,295 ML were excluded from the analysis. The 1974 and 1917 events were included as threshold events with 7 day volumes greater than the 1993 event as their volumes are not known. The resulting design flood volumes are given in Table 8-2. Based on 7 day flood volumes the March 2012 and October 1993 events are estimated as 1% and 2-5% events respectively at the Tungamah gauge.

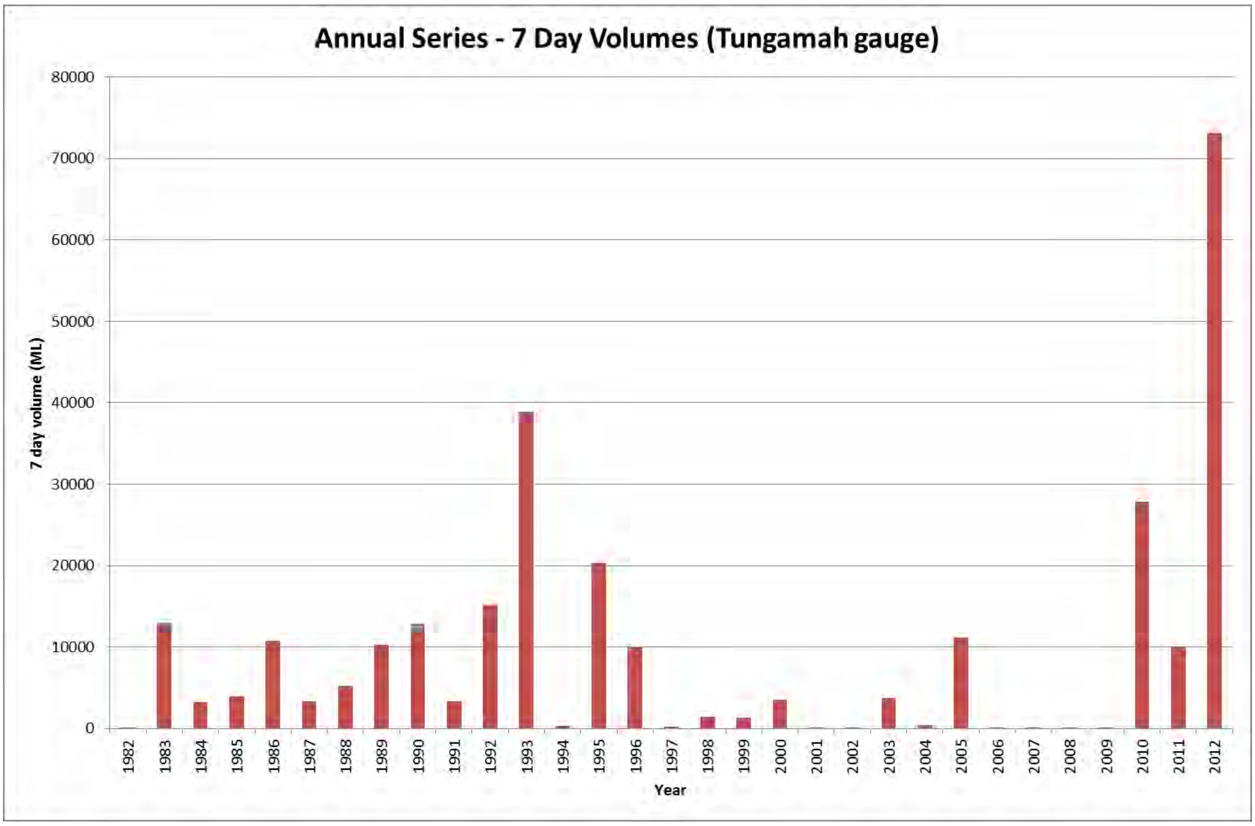


Figure 8-5 Annual series of 7 day volumes at Boosey Creek at Tungamah gauge (404204)

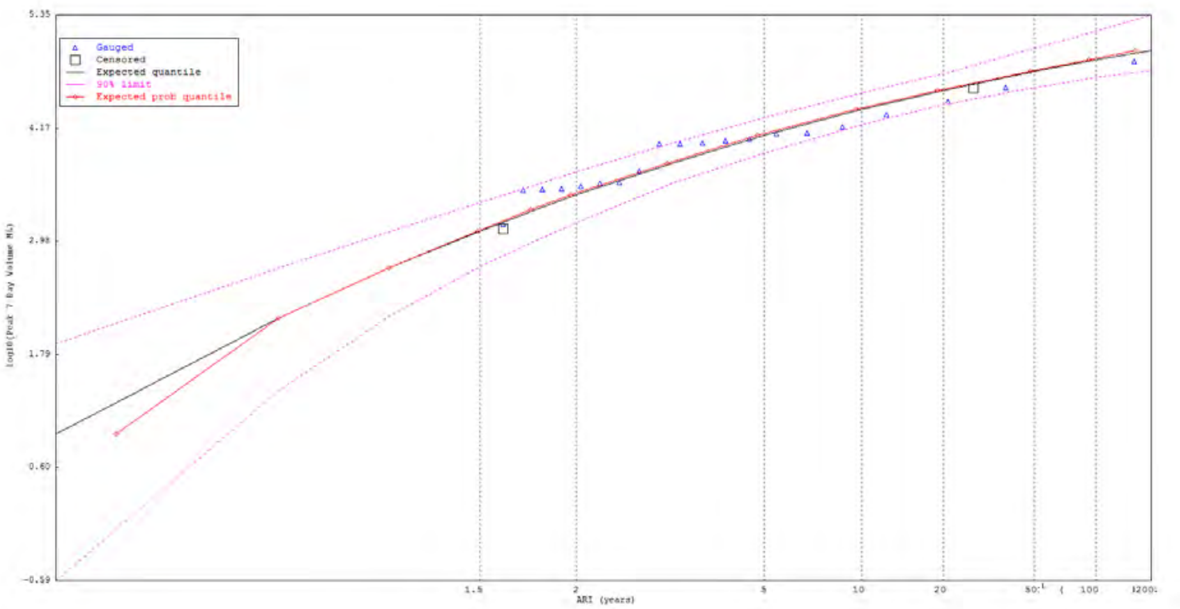


Figure 8-6 **Log Pearson III distribution fitted to 7 day volume annual series at Tungamah**

Table 8-2 **Tungamah design flood 7 day volume estimates from Log Pearson III distribution fitted to annual series with 10 low flow years excluded**

Annual Exceedance Probability (AEP)	Log Pearson III (ML)
20%	12,300
10%	23,000
5%	36,500
2%	57,900
1%	77,000
0.5%	95,400
0.2%	122,200

A review of significant events in the flow record at Katamatite revealed that the average flood event duration was approximately 10 days, somewhat longer than at the Tungamah gauge. This is a result of the larger catchment area upstream of Katamatite and the influence of breakout flows from the Broken River at Casey's Weir. The maximum 10 day flood volume was calculated at Katamatite for each year (from the 30 years of available instantaneous data). The annual series of 10 day flood volumes is shown in Figure 8-7.

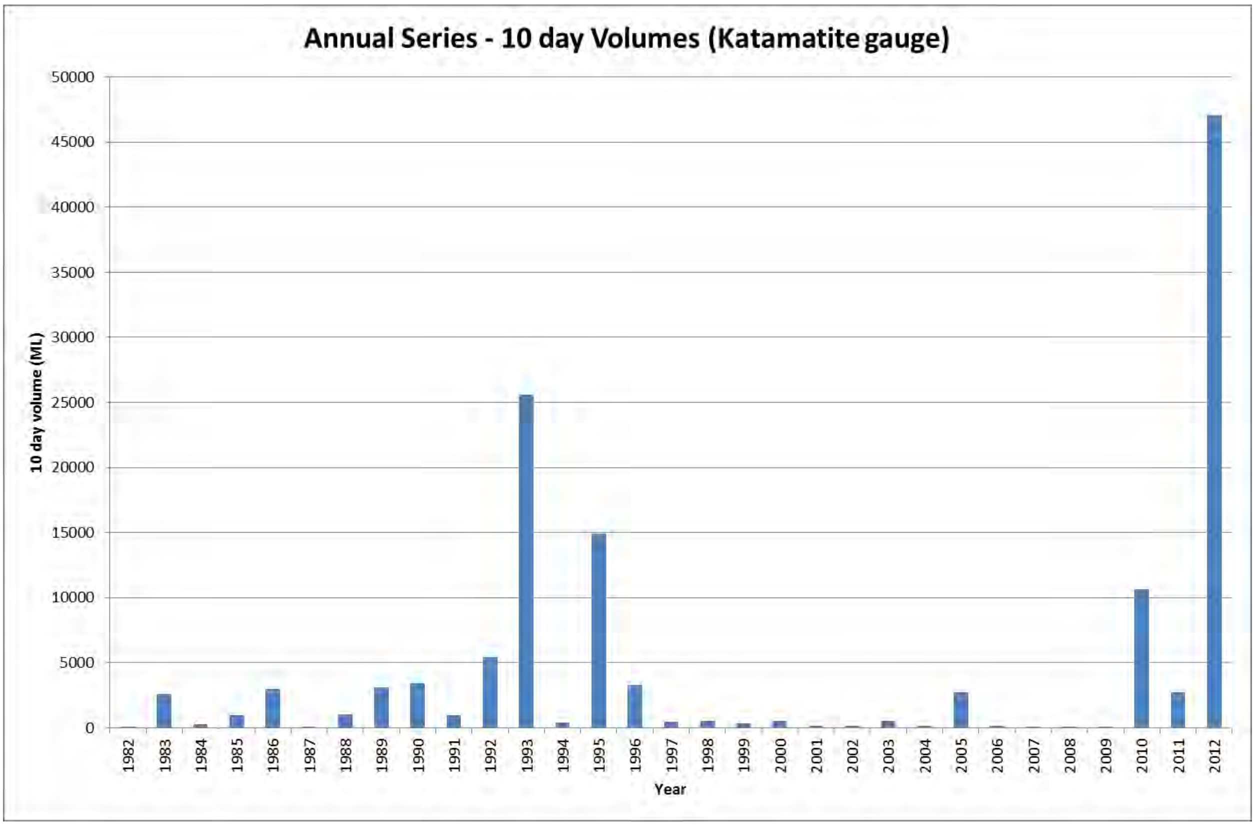


Figure 8-7 Annual series of 10 day volumes at Broken Creek at Katamatite gauge (404214)

Distributions were fitted to the Katamatite annual flood volume series in FLIKE, and the Log Pearson III distribution was found to have the best fit as shown in Figure 8-8 . Eight low flow years with maximum flood volumes less than 175 ML were excluded from the analysis. The 1974 and 1917 events were included as threshold events with 10 day volumes greater than the 1993 event as their volumes are not known. The resulting design flood volumes are given in Table 8-3. Based on 10 day flood volumes the March 2012 and October 1993 events are estimated as 1-2% and 2-5% events respectively at the Katamatite gauge.

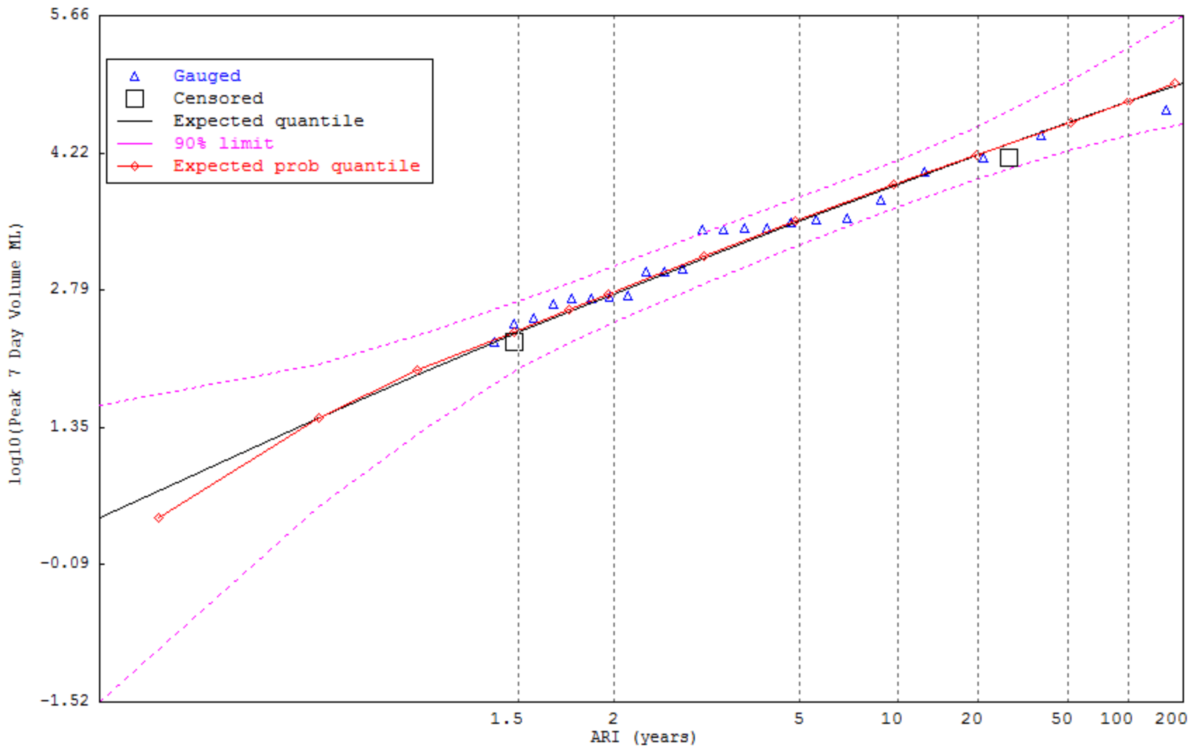


Figure 8-8 **Log Pearson III distribution fitted to 10 day volume annual series at Katamatite**

Table 8-3 **Katamatite design flood 10 day volume estimates from Log Pearson III distribution fitted to annual series**

Annual Exceedance Probability (AEP)	Log Pearson III (ML)
20%	3,300
10%	8,000
5%	16,200
2%	35,100
1%	58,200
0.5%	91,500
0.2%	156,700

8.3 Flood Frequency Analysis - Discussion

Flood frequency analyses were completed based on flood volume and peak flows at both the Tungamah and Katamatite gauges. The results indicate that the March 2012 and October 1993 events are generally estimated as 1-2% and 2-5% AEP events respectively.

The March 2012 event occurred over a one week period with more rainfall occurring in the Boosey Creek catchment then the upper Broken Creek catchment. This is reflected in the flood frequency results with the event being shown to be more significant at the Tungamah gauge than at the Katamatite Gauge. The results also indicate that the 10 day flood volume was statistically rarer than the event’s peak flow which is to be expected given the extended, multi-burst nature of the event.

The October 1993 event was a result of more rainfall in the upper Broken Creek catchment then the Boosey Creek catchment and flows in Broken Creek were also fed by a significant breakout from the Broken River. The flood frequency results are consistent with this and indicate that the event was a rarer event at the Tungamah gauge than at the Katamatite Gauge.

The flood frequency analysis has provided design peak flows and flood volumes which can be used to generate design hydrographs as described in the following section.

9. DESIGN EVENT MODELLING

9.1 Overview

As previously discussed the complexity of the hydrology in the Broken Creek catchment led to an approach that utilised a combination of flood frequency analysis, hydraulic modelling and RORB modelling to determine design hydrographs for the hydraulic model. Due to concerns around inaccuracies in the IFD rainfall depths in the upper Broken Creek catchment it was deemed that flood frequency analysis was a more robust method to determine design hydrographs in Broken Creek than using the RORB model. The inflows from Broken Creek into the study area are considerably larger than the flows from Muckatah Depression and Majors Creek. It was deemed acceptable to use design hydrographs from the RORB model for the ungagged Muckatah and Majors Creeks, particularly given their smaller influence on flows in Numurkah.

The two methods used to produce design hydrographs for the purposes of hydraulic modelling are summarised below:

- Flood Frequency Analysis (FFA) was used to determine design hydrographs for the Broken Creek inflow point as described in Section 9.2 below. Due to concerns around the accuracy of the IFD rainfall it was deemed that using flood frequency analysis was a more appropriate method for estimating design flows in Broken Creek particularly given the good gauge records that are available.
- RORB modelling was used to produce design hydrographs for the ungauged Muckatah and Major Creeks as described in Section 579.3 below (The March 2012 event was scaled back to the flow as calculated by the Manning's Equation estimate).

For this study design hydrographs were determined for the 5, 10, 20, 50, 100 and 200 year ARI events.

9.2 Broken Creek Design Flow hydrographs

As discussed above it was deemed more appropriate to generate design hydrographs in Broken Creek from the flood frequency analysis rather than using the RORB model. The process used to generate design hydrographs at the hydraulic model boundary based on flood frequency analysis is described below.

9.2.1 Broken Creek design hydrographs

Model hydrographs were selected from the gauge records at both the Tungamah and Katamatite gauges and scaled by peak flow and volume to give the design flow hydrographs at the gauge locations. To determine an appropriate model hydrograph the gauge record was inspected at both gauging sites to identify hydrographs which could be appropriate for scaling – hydrographs that start and end at low flow values, have a single peak, and are regular in shape. Six of the largest events on record were identified that could be used to scale the design flows; September 1992, October 1993, July 1995, December 2010, February 2011 and March 2012. The ratio of volume to peak flow was calculated for the design events and was compared to the ratio for gauged hydrographs. The selected gauged hydrographs at Tungamah had a ratio that ranged from 2.78-8.15 () while the ratio for the design flows ranged from 2.47-3.74. At Katamatite the selected gauged hydrographs had a ratio that ranged from 1.85-7.00 () while the ratio for the design flows ranged from 3.67-5.26.

Table 9-1 Historical event hydrograph characteristics – Tungamah Gauge

Event	Peak Flow (ML/d)	Volume (ML)	Volume/ Peak Flow Ratio
March 2012	23,300	81,500	3.49
October 1993	15,300	42,900	2.78
July 1995	3,800	31,000	8.15
Sept 1993	3,100	14,200	4.48
Dec 2010	9,300	33,100	3.56
Feb 2011	3,100	16,500	5.32
		Mean	4.63

Table 9-2 Historical event hydrograph characteristics – Katamatite Gauge

Historic Event	Peak Flow (ML/d)	Volume (ML)	Volume/ Peak Flow Ratio
March 2012	11,900	50,400	4.23
October 1993	6,200	27,100	4.37
July 1995	2,100	17,600	8.38
Sept 1992	6,300	11,600	1.85
Dec 2010	2,100	11,300	5.38
Feb 2011	400	2,800	7.00
		Mean	5.20

The 1993 hydrographs were selected at both locations for the representative design hydrograph shape for scaling as they had a single peak, were regular in shape and had a volume to peak flow ratio that was within the range of the design estimates from flood frequency analysis. The hydrographs were scaled to each design peak flow and volume, first by a linear scaling of the flow magnitudes to match the design peak flow, then by a linear scaling of the time step.

Table 9-3 Volume/peak flow ratio for design flow hydrographs at Tungamah

AEP event (%)	ARI (years)	Peak Design Flow (ML/d)	7 Day Design Volume (ML)	Volume/Peak Flow Ratio	Model Hydrograph
20	5	3,769	12,300	3.74	1993
10	10	7,617	23,000	3.02	1993
5	20	12,823	36,500	2.85	1993
2	50	21,665	57,900	2.67	1993
1	100	29,687	77,000	2.59	1993
0.5	200	38,700	95,400	2.47	1993
0.2	500	51,876	122,200	2.36	1993

Table 9-4 Volume/peak flow ratio for design flow hydrographs at Katamatite

AEP event (%)	ARI (yrs)	Peak Design flow (ML/d)	10 Day Design volume (ML)	Volume/Peak Flow Ratio	Model Hydrograph
20	5	627	3,300	5.26	1993
10	10	1,566	8,000	5.10	1993
5	20	3,366	16,200	4.81	1993
2	50	8,052	35,100	4.36	1993
1	100	14,496	58,200	4.01	1993
0.5	200	24,940	91,500	3.67	1993
0.2	500	48,420	156,700	3.24	1993

While the flood frequency analysis allowed hydrographs to be determined at the gauge locations, for the purposes of hydraulic modelling hydrographs are required at the upstream model boundary which is located approximately 1 km downstream of the confluence of Boosey Creek and Broken Creek. To determine hydrographs at that location, flows and volumes at the gauges were required to be routed first to the confluence and then to the model boundary. The calibrated historic events and a number of sample design events were analysed in RORB to determine relationships between flows at the gauge locations, confluence and hydraulic model boundary. The following relationships were determined:

- The routing time for the flood peak to travel along Boosey Creek from the Tungamah gauge to the Boosey Creek outlet, a distance of 25 km, is approximately 74 hours. Along that reach peak flows are reduced by approximately 55% while total flood volumes increase by approximately 20%.
- The routing time for the flood peak to travel along Broken Creek from the Katamatite gauge to the Boosey Creek outlet, a distance of 2.5 km, is approximately 7-8 hours. Along that reach peak flows and flood volumes remain steady.
- In both the 1993 and 2012 events the flood peak from the upper Broken Creek catchment reached the confluence before the peak from the Boosey Creek catchment. This is likely to vary considerably depending on the nature of the event, antecedent conditions and breakouts from the Broken River. For the purposes of design modelling it is assumed that the upper Broken Creek catchment peaks 20 hours prior to the Boosey Creek catchment with the resultant peak flow being approximately 10% less than the direct sum of the peak flows from each catchment. This is consistent with the 1993 event which for the purposes of design modelling is considered a "typical" event.
- The routing time for the flood peak to travel along Broken Creek from the confluence to the model boundary, a distance of 1 km, is approximately 2-3 hours. Along that reach peak flows and flood volumes remain steady.

The above relationships were used to transpose design flood volumes and peaks from the upstream gauges to the confluence of Broken and Boosey Creeks as shown in Table 9-5. These flows and volumes are considered to be appropriate for use at the hydraulic model boundary a short distance downstream. The adopted values are shown in Table 9-6 and Table 9-7.

Table 9-5 Routed peak flows and volumes in Boosey Creek, Tungamah to Broken Creek

AEP event (%)	ARI (years)	Tungamah Peak flow (m^3/s)	Broken Crk Confluence Peak Flow (m^3/s)	Tungamah Design volume (ML)	Broken Crk Confluence Design volume (ML)
20	5	43.6	19.7	12,300	14,800
10	10	88.2	39.4	23,000	27,600
5	20	148	66.8	36,500	43,800
2	50	251	113	57,900	69,500
1	100	344	155	77,000	92,400
0.5	200	448	201	95,400	114,500
0.2	500	600	270	122,000	146,600

Table 9-6 Adopted Design Flood Volumes at Broken Creek Hydraulic Model Boundary

AEP event (%)	ARI (years)	Boosey Creek Volume (ML)	Upper Broken Creek Volume (ML)	Adopted Design Volume (ML)
20	5	14,800	3,300	18,100
10	10	27,600	8,000	35,600
5	20	43,800	16,200	60,000
2	50	69,500	35,100	104,600
1	100	92,400	58,200	150,600
0.5	200	114,500	91,500	206,000
0.2	500	146,640	156,700	303,340

Table 9-7 Adopted Design Peak Flows at Broken Creek Hydraulic Model Boundary

AEP event (%)	ARI (yrs)	Boosey Creek Peak Flow (m^3/s)	Upper Broken Creek Peak Flow (m^3/s)	Combined Peak Flow (m^3/s)	Adopted (adjusted) Design Peak Flow (m^3/s)
20	5	19.7	7.3	26.9	26.0
10	10	39.4	18.1	57.5	55.6
5	20	66.8	39.0	106	102
2	50	113	93.2	206	199
1	100	155	168	322	312
0.5	200	201	289	490	474
0.2	500	270	560	831	803

The final step to produce the design hydrographs at the hydraulic model boundary location was to scale the 1993 RORB model hydrograph at the same location to each of the design transposed peak flow and volume estimates. First linear scaling of the flow magnitudes was undertaken to match the design peak flow, then linear scaling of the time step was undertaken to match the volume. The resulting design hydrographs are shown in Figure 9-1.

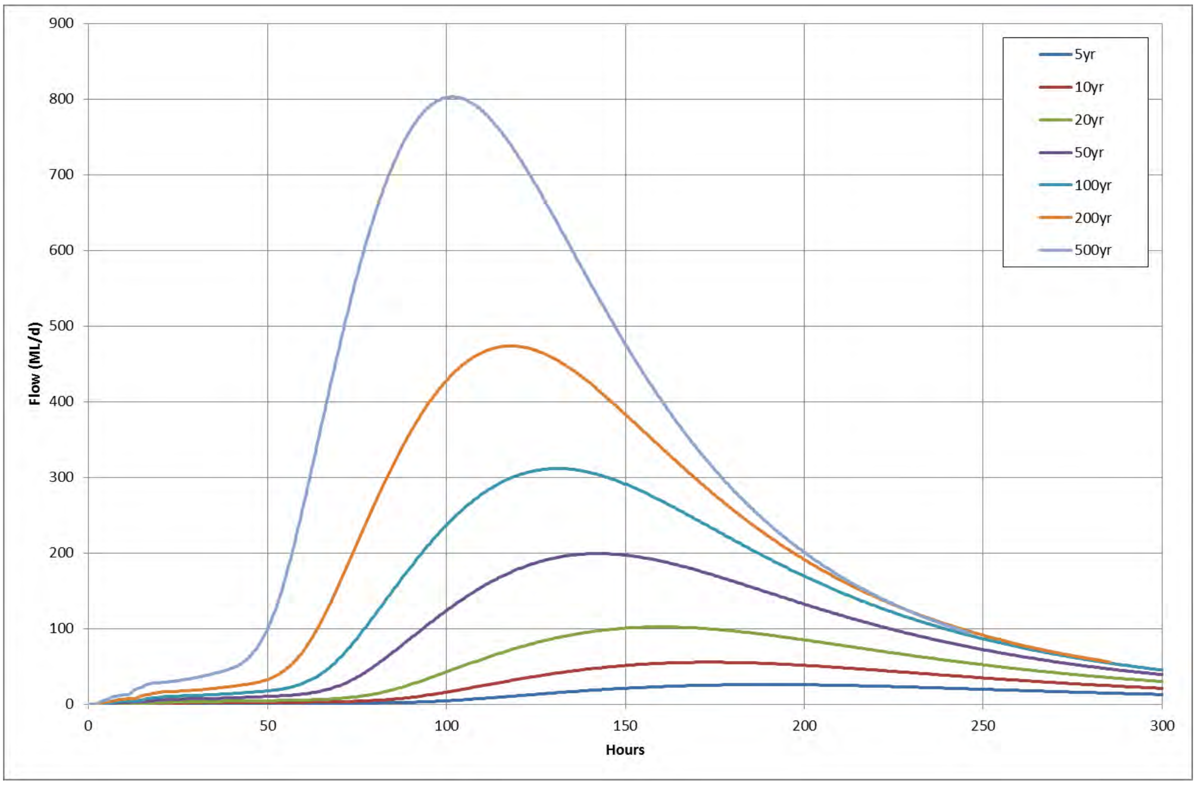


Figure 9-1 Design hydrographs at the Broken Creek hydraulic model boundary

9.3 RORB Design Modelling for Muckatah Depression and Majors Creek

9.3.1 Overview

The RORB model was used to generate design hydrographs in Muckatah and Majors Creek. Both watercourses are ungauged and so generating design hydrographs from flood frequency analysis was not an option.

9.3.2 Design Rainfall

Design rainfall depths

Design rainfall depths were determined using the IFD methodology outlined in AR&R Volume 2, 1987. IFD parameters were generated from the Bureau of Meteorology's online IFD tool. Table 9.8 below shows values extracted from the BOM online IFD extraction tool at the centroid of the Broken Creek catchment upstream of Numurkah.

Table 9-8 Catchment IFD Parameters

Location	$2I_1$ (mm/hr)	$2I_{12}$ (mm/hr)	$2I_{72}$ (mm/hr)	$50I_1$ (mm/hr)	$50I_{12}$ (mm/hr)	$50I_{72}$ (mm/hr)	G	F2	F50	Zone
Broken Creek catchment	18.92	3.51	0.9	39.14	6.70	1.76	0.16	4.32	15.15	2

Catchment centroid location: -36.223763,145.827452, catchment area = 2,038 km^2

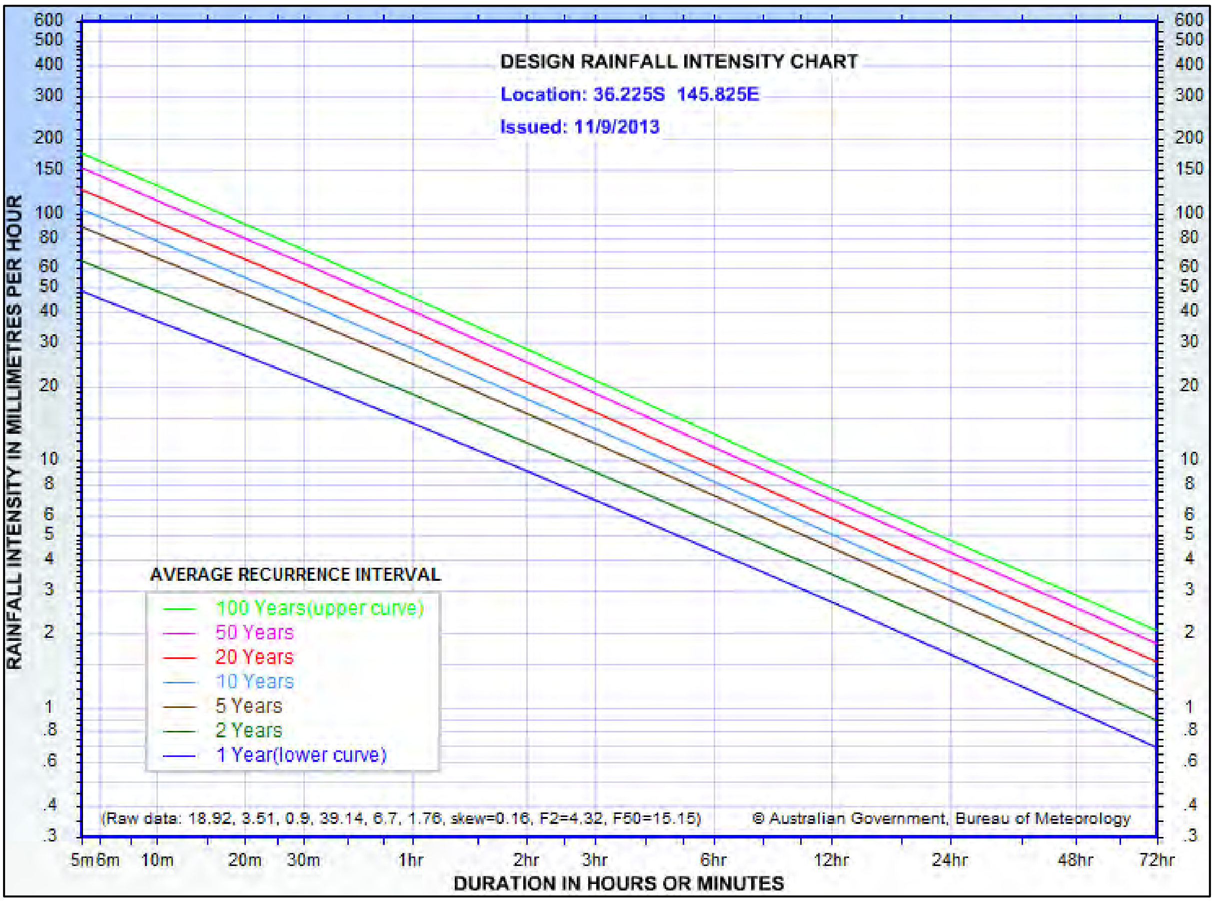


Figure 9-2 IFD chart for Broken Creek catchment upstream of Numurkah

Design temporal pattern

Design temporal patterns were taken from AR&R (1987) and the Generalised South East Australian Method (GSAM). The 72 hour duration was observed to be the critical duration event and so GSAM patterns were used.

The Broken Creek catchment is located within Zone 2 of the temporal pattern map as defined in AR&R (1987).

Design spatial pattern

A uniform spatial rainfall pattern was adopted for the generation of design flood hydrographs for events up to and including the 1% AEP event. GSAM spatial patterns were used for events beyond the 1% AEP event.

Areal reduction factor

Areal reduction factors convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. Siriwardena and Weinmann (1996) [4] reduction factors were applied.

Table 9-9 Summary of Design Inputs

Design Consideration	AEP	
	Large (up to 1% AEP)	Rare (beyond 1% AEP)
Point rainfall depths	IFD information	
Areal reduction factors	Siriwardena and Weinmann (1996)	
Temporal patterns	Long duration: unsmoothed GSAM	
Spatial patterns	Uniform	GSAM

9.3.3 Design Model Parameters

For the purposes of determining flows in the Muckatah Depression and Major Creek design model parameters (k_c and losses) were adopted from the 1993 calibration event. The 1993 event is considered a typical event and in the mid-range of AEP events. Adopting model parameters from a historic calibration event for design purposes is not the usual approach, as a historic event may have particular antecedent conditions that greatly influence the choice of parameters. However given that the Broken Creek catchment is not an ordinary catchment due to its flatness, and that the model parameters adopted for calibration were outside the normal design parameters, it would not be appropriate to adopted standard design parameters from 'normal' catchments.

Routing parameters

Various regional k_c estimation equations were initially trialled for the calibration process and the adopted values were found to provide a good fit of the observed and modelled hydrographs. There was some variation in the k_c values between the 1993 and 2012 events. It was deemed acceptable to use the 1993 event parameters for use in design modelling as the 1993 event was considered a typical, mid-range event. The adopted design parameters are shown below in Table 9-10.

Table 9-10 Adopted RORB design model parameters

Interstation Area	Kc	m
Boosey Creek	75	0.8
Broken Creek (upper)	175	0.8
Muckatah Depression	175	0.8
Majors Creek	175	0.8
Broken Creek (lower)	600	0.8

[4] Siriwardena and Weinmann, 1996 - Derivation of Areal Reduction Factors For Design Rainfalls (18 - 120 hours) in Victoria

Design losses

It was intended that design losses would be adopted through validation of design flows against flood frequency analysis however it was found that the design peak flows could not be matched to the flood frequency analysis peak flows despite a range of losses being tested. It is suspected that the reason for this is that the IFD rainfall depths are not accurate and underestimate rainfall in the upper Broken Creek catchment. Loss parameters were therefore adopted from the 1993 calibration event modelling and these were applied across all AEP events. As discussed previously the 1993 event was a mid-range event and the RORB model was able to represent the peak flow and volumes very well in that event. The adopted loss values are shown in Table 9-11. The loss values are consistent with regional values described in AR&R (1987).

Table 9-11 Adopted design losses

IL (mm)	CL (mm/hr)
20	2.75

9.3.4 Majors Creek and Muckatah Depression design hydrographs

Design hydrographs were extracted from the RORB model at the lower end of Majors Creek and Muckatah Depression for input into the hydraulic model. Both creeks are ungauged so using flood frequency analysis was not an option. The 72 hour duration event was used as it was found to be the critical event in Muckatah, Broken and Majors Creeks. As previously discussed kc and losses utilised in the 1993 event calibration were adopted and are shown in Table 9-9 and Table 9-11. The initial loss and continuing loss values are consistent with regional ranges as described in Australian Rainfall & Runoff (1988).

Additional work was completed in order to determine appropriate design flows for the Muckatah inflow. Initial feedback was that the design flows extracted directly from RORB were too low. An Intensity Frequency Duration (IFD) analysis was completed for the March 2012 rainfall event at the rainfall stations closest to the upper Muckatah Depression catchment. An IFD analysis allows an estimate of the frequency/severity of a historic rainfall event to be determined based on a comparison against design rainfall. The results of the analysis are shown in Table 9-12 and it can be seen that the IFD analysis indicates that the March 2012 rainfall event in that area was in the region of a 0.2% AEP (or 1 in 500 year) event or greater. It is likely that the rainfall event over the rest of the Boosey and Broken Creek catchments was lesser than that experienced in the upper Muckatah Depression catchment area, with a particularly intense storm falling on the upper Muckatah catchment in the March 2012 event.

Table 9-12 Summary of IFD Analysis for March 2012 event

Gauge Location	28th Feb – 1st March 3 day Rainfall (mm)	Likelihood of event (approx.)
Yarrawonga (81124)	187	0.2% AEP (1 in 500 year ARI)
Tungamah (81051)	228	>0.2% AEP (1 in 500 year ARI)

Based on the IFD analysis and feedback that the RORB design estimates were potentially too low it was proposed that the March 2012 event flow of 69.4 m^3/s (6,000 ML/d) be adopted as the 0.2% AEP design flow. This makes the assumption that the estimate of 69.4 m^3/s is representative of the actual March 2012 flow (supported by the hydraulic modelling results), and the assumption that the likelihood of the rainfall is the same as the likelihood of the runoff (AEP neutrality). The RORB 0.2% design hydrograph could be scaled to match the 69.4 m^3/s peak. It is proposed that the RORB hydrographs for the remaining design events also be scaled up using the same multiplication factor that was determined for the 0.2% event. The resulting peak flows are presented in Table 2-4 below.

Table 9-13 Scaled Muckatah Depression Inflows

AEP	Original Muckatah Depression Primary Peak Inflow (m^3/s)	Scaled Muckatah Depression Primary Peak Inflow (m^3/s)	Original Muckatah Depression Secondary Peak Inflow (m^3/s)	Scaled Muckatah Depression Secondary Peak Inflow (m^3/s)
20%	1.35	2.38	0.52	0.91
10%	4.33	7.62	1.52	2.67
5%	9.17	16.1	3.07	5.40
2%	18.8	33.0	6.08	10.7
1%	25.1	44.2	7.95	14.0
0.5%	30.9	54.4	9.60	16.9
0.2%	39.5	69.4	11.9	21.0

The resulting adopted peak flow for Majors Creek and the Muckatah Depression are shown in Table 9-14 while design hydrographs are provided in Figure 9-3 and Figure 9-4. It can be seen that the hydrographs have a fairly sharp rise at the beginning of the hydrograph which is a result of some large sub-catchments in the RORB model located immediately upstream of the flow extraction point. Despite the sharp initial rise, the volume of flood water in the hydrograph is correct. The subsequent routing of the flows through the hydraulic model ensures the "peaky" hydrograph behaviour does not have any undue impacts on results in the area of interest around Numurkah.

Table 9-14 Adopted Design Peak Flows for Majors Creek and Muckatah Depression

AEP	Majors Creek Adopted Peak Inflow (m^3/s)	Muckatah Depression Primary Inflow (m^3/s)	Muckatah Depression Secondary Inflow (m^3/s)
20%	1.19	2.38	0.91
10%	3.86	7.62	2.67
5%	8.04	16.1	5.40
2%	16.1	33.0	10.7
1%	21.3	44.2	14.0
0.5%	25.8	54.4	16.9
0.2%	32.1	69.4	21.0

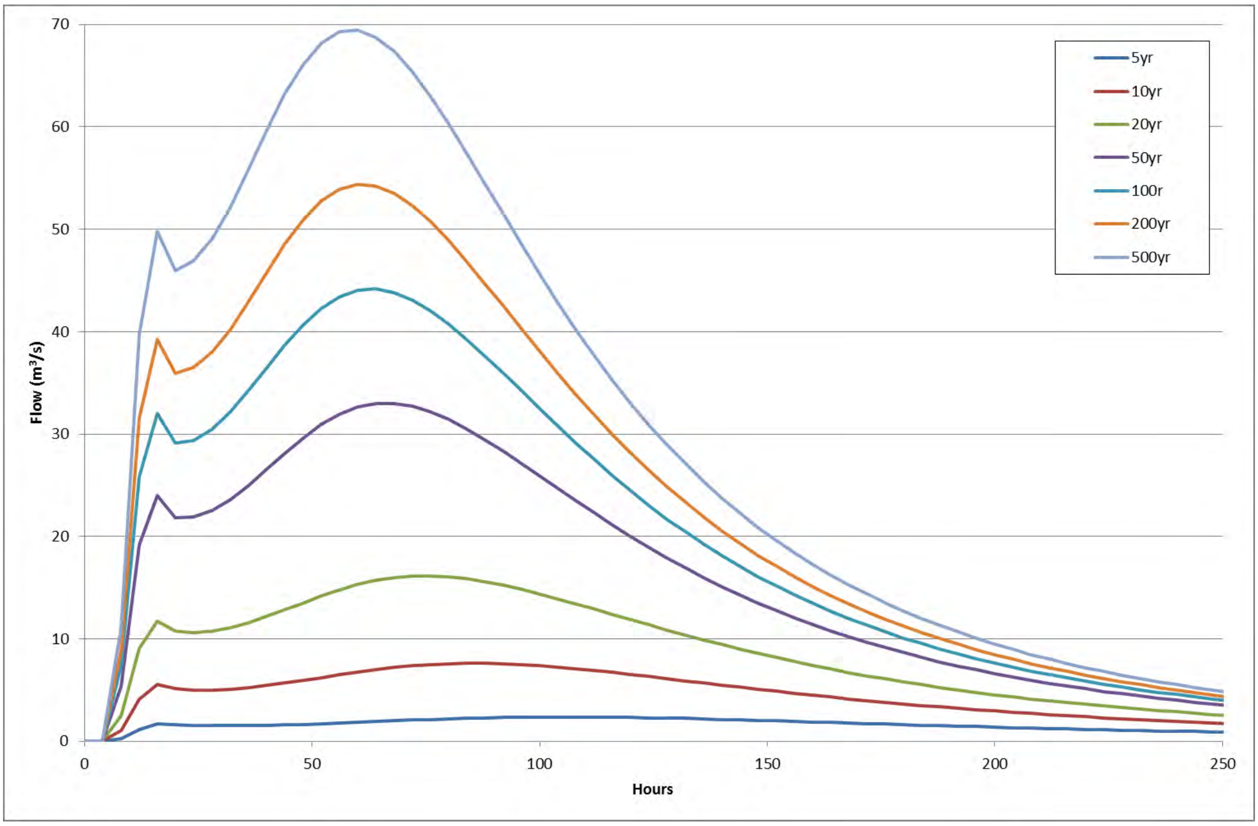


Figure 9-3 Muckatah Depression Design Hydrographs

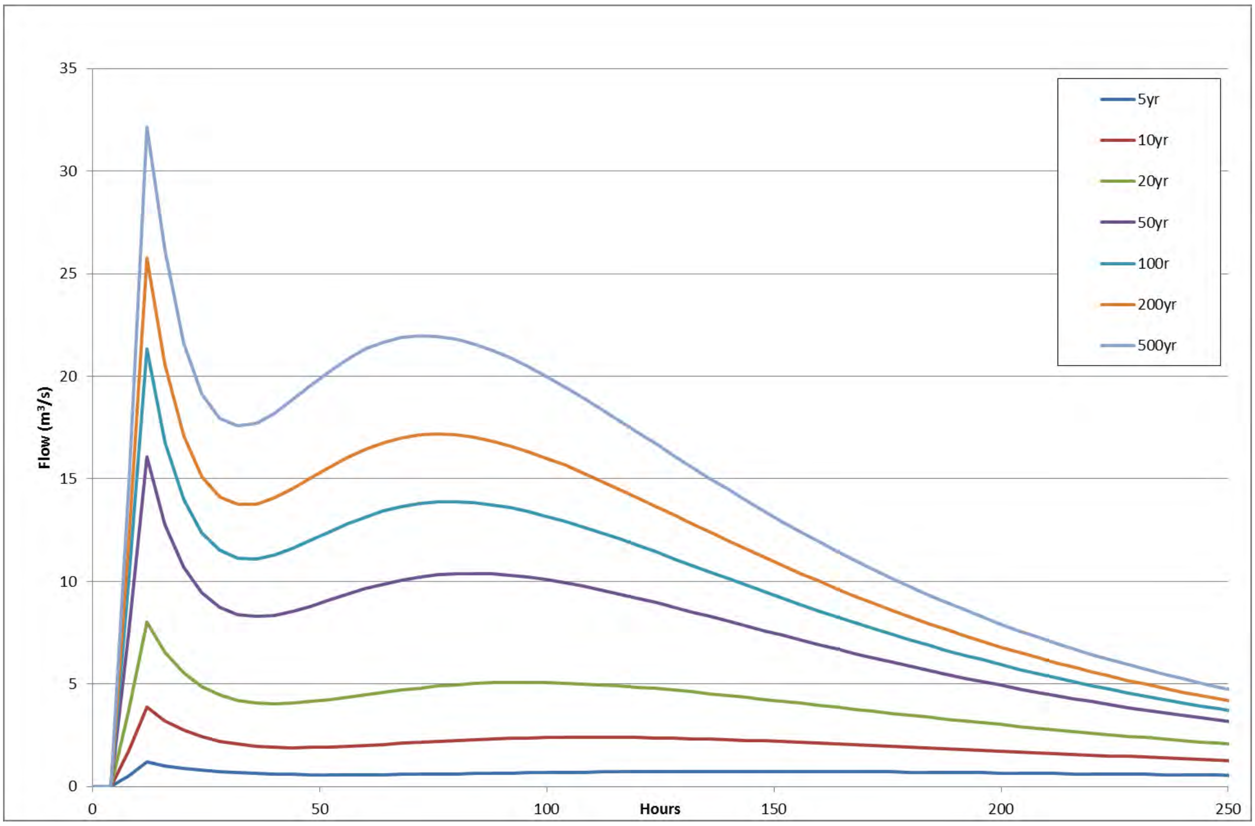


Figure 9-4 Majors Creek Design Hydrographs

9.4 Comparison with Rational and Regional Methods

Both rational and regional methods were used in an attempt to verify design flows with the results shown in Table 9-15. The rational method is generally used for estimating peak flows from small catchments, and is not designed to be used for large rural catchments such as the Broken Creek catchment above Numurkah. Design flows were also verified against regional methods described in Hydrological Recipes – Estimation Techniques in Australian Hydrology (Grayson et al, 1996). This method utilises a regional equation for the 100 year ARI event in rural catchments. The equation is shown below:

$$Q_{100} = 4.67 \times (Area^{0.763})$$

It can be seen from Table 9-15 that at all locations the rational and regional flow methods have overestimated the design flows considerably.

It can be concluded that the rational and regional methods for estimating peak flows are not applicable for use in the Broken Catchment due to the unique characteristics of the catchment which include very slow travel times as a result of the flat and heavily-modified topography.

Table 9-15 Comparison between Design Flows and Rational Method Calculations

Location	Area (km^2)	Rational Method 100yr flow (m^3/s)	Regional Method 100yr flow (m^3/s)	Design 100yr flow (m^3/s)
Boosey Creek at Tungamah	829.7	509	788	344
Broken Creek Hydraulic Model Inflow point	1234	683	1067	312
Muckatah Depression	509.5	355	543	25.1
Majors Creek	218.2	317	284	21.3

10. HYDROLOGY SUMMARY

Design flows were generated for the study area using a combination of flood frequency analysis and RORB modelling. Table 10-1 provides a summary of the peak flows determined at the hydraulic model inflow boundaries including the method used to determine the flows.

Flood frequency analyses were completed for the Boosey Creek at Tungamah and Broken Creek at Katamatite gauges which allowed design peak flows and flood volumes to be determined. Flows were translated to the location of the Broken Creek hydraulic model boundary. Design hydrographs were then generated using the 1993 event hydrographs as "model" hydrographs.

A RORB hydrological model was constructed to generate design flows for the study. The RORB model developed for the catchment was calibrated to the October 1993 and March 2012 flow hydrographs at the two gauges located at Tungamah and Katamatite. The RORB model was able to reproduce the peak flows and volumes of the calibration events quite well however had difficulty in replicating the timing of the 1993 event. Due to concerns around the accuracy of IFD rainfall in the upper Broken Creek catchment it was deemed that flood frequency analysis was a more appropriate method to produce design hydrographs in Broken Creek.

The RORB model was used to generate design flows in the ungauged Muckatah Depression and Majors Creek for the 5, 10, 20, 50, 100 and 200 year ARI events. Design flows for Muckatah Depression were scaled up based on IFD analysis and using the March 2012 flow of 6000 ML/d as the 0.2% AEP inflow.

The design flows indicate that the March 2012 and October 1993 flood events were approximately 1-2% and 2-5% AEP events respectively at both the Broken Creek at Katamatite and Boosey Creek at Tungamah gauges.

Table 10-1 Summary of Design peak flows - Broken and Majors Creeks

	Broken Creek Hydraulic Model Inflow Point (see Table 9-7)			Majors Creek Inflow (see Table 9-14)		
AEP	Peak flow (m^3/s)	Critical Duration (hrs)	Source of Design Flow	Peak flow (m^3/s)	Critical Duration (hrs)	Source of Design Flow
20%	26.0	72	Transposed FFA	1.19	72	RORB
10%	55.6	72	Transposed FFA	3.86	72	RORB
5%	102.2	72	Transposed FFA	8.04	72	RORB
2%	199.2	72	Transposed FFA	16.1	72	RORB
1%	311.6	72	Transposed FFA	21.3	72	RORB
0.5%	473.7	72	Transposed FFA	25.8	72	RORB
0.2%	802.8	72	Transposed FFA	32.1	72	RORB

Table 10-2 Summary of Design Peak Flows – Muckatah Depression

AEP	Muckatah Depression Primary Inflow (see Table 9-14)			Muckatah Depression Secondary Inflow (see Table 9-14)		
	Peak flow (m^3/s)	Critical Duration (hrs)	Source of Design Flow	Peak flow (m^3/s)	Critical Duration (hrs)	Source of Design Flow
20%	2.38	72	Scaled RORB	0.91	72	Scaled RORB
10%	7.62	72	Scaled RORB	2.67	72	Scaled RORB
5%	16.1	72	Scaled RORB	5.40	72	Scaled RORB
2%	33.0	72	Scaled RORB	10.7	72	Scaled RORB
1%	44.2	72	Scaled RORB	14.0	72	Scaled RORB
0.5%	54.4	72	Scaled RORB	16.9	72	Scaled RORB
0.2%	69.4	72	Scaled RORB	21.0	72	Scaled RORB

11. HYDRAULIC ANALYSIS

11.1 Overview

A detailed combined 1D-2D hydraulic modelling approach was adopted for this study. The hydraulic modelling approach consisted of the following components:

- One dimensional (1D) hydraulic model of key hydraulic structures; and
- Two dimensional (2D) hydraulic model of the Broken Creek channel and broader floodplain.

The hydraulic modelling software MIKE FLOOD developed by the Danish Hydraulic Institute (DHI) was used for this study. MIKE FLOOD is a state-of-the-art tool for floodplain modelling that combines the dynamic coupling of the 1D MIKE 11 river model and 2D MIKE 21 model systems. Through coupling of these two systems it is possible to accurately represent river and floodplain processes.

The primary input to the hydraulic model was the available topographic data. The representation of significant topographic features including the form of the waterway and floodplain underpins a robust hydraulic model.

The hydraulic model was calibrated against observed flood levels and extents in the March 2012 and October 1993 flood events. The model calibration enabled the assessment of the hydraulic model's ability to reproduce observed flood behaviour. For calibration purposes, the condition of the waterways and floodplain was slightly altered from current conditions in order to best represent the condition at the time of the March 2012, and October 1993 events respectively.

11.2 Hydraulic Model Development and Parameters

11.2.1 Model Schematisation

The hydraulic model was constructed using a linked 1D-2D modelling approach. The 1D hydraulic model was used to represent the main bridges and culverts in the townships while the 2D model was used to model the waterways and broader floodplain.

The 1D and 2D components were linked using a number of standard links at the upstream and downstream ends of the 1D bridges and culverts. Water entered the model through four 2D inflow boundaries, representing inflows from Broken, Majors and Muckatah Depression as well as a secondary inflow from a Muckatah Depression breakout flow to the north. Water flowed out of the 2D model using a 2D water level boundary in Broken Creek and a second water level boundary for a minor tributary to the south-east of Numurkah.

Further detail regarding the model schematisation can be found in the relevant sections below.

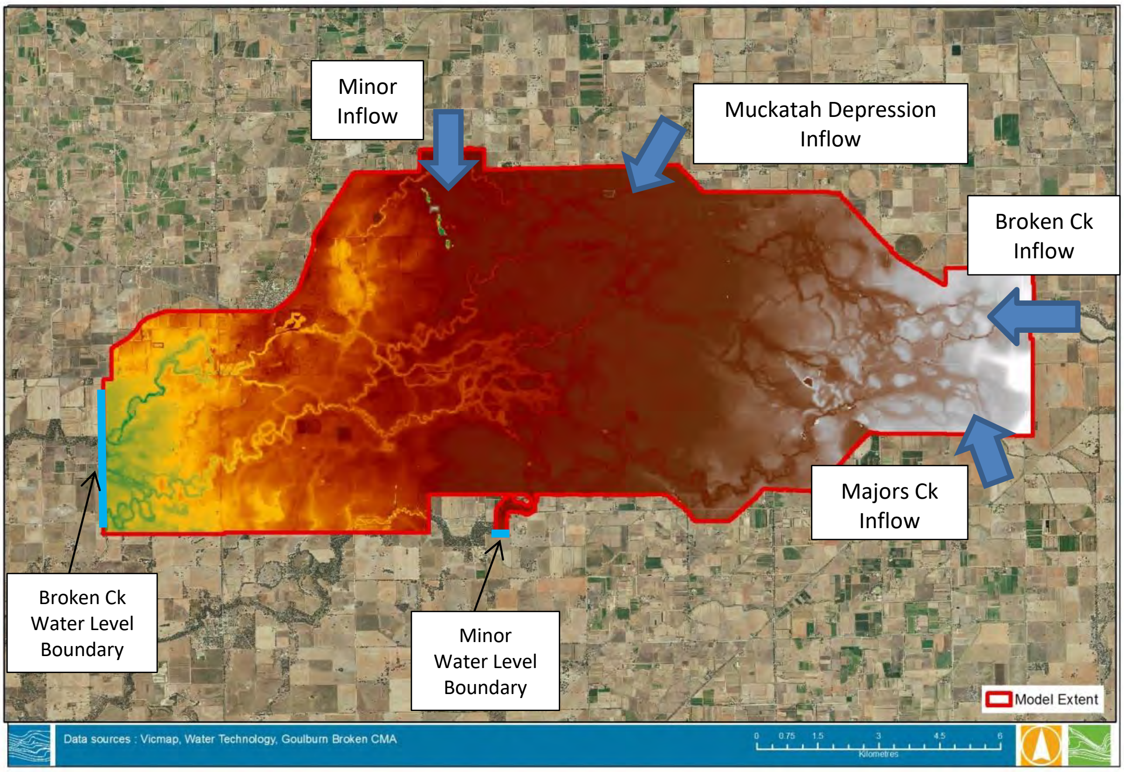


Figure 11-1 Hydraulic Model extent and boundary locations

11.2.2 Topography

The hydraulic model included the area from the intersection of the Katamatite-Nathalia (C361) and the Katamatite-Shepparton (C363) Roads in the east to 3 km west of the Goulburn Valley Highway. The northern boundary is located close to Allerts Road/Mills Road, while the southern boundary is located just south of Purdies Road/Drumanure Road. The model extent covers an area of 219 km^2. The terrain is relatively flat with ground elevations within the modelled area ranging from 104 m to 118m AHD. Across the floodplain there are a number of drainage channels, levee banks and roadways which influence flood behaviour.

In order to best represent the model area, while allowing for reasonable run times, the 2D model topography was based on a 20 m grid resolution. As some important features may not be captured by a 20 m grid, a number of significant levees, roads and drainage channels were "stamped" onto the topography using the values extracted from detailed LiDAR. Features incorporated included:

- The embankment between the railway line and the Goulburn Valley Highway in Numurkah township;
- Numerous roads throughout the floodplain;
- Kinnaird's Road irrigation infrastructure;
- The driveway on Irrigation Road off Goulburn Valley Highway,
- Levee crest along the southern shore of Lake Numurkah; and
- The crest of the railway line, Goulburn Valley Highway and Walsh's Bridge Road.

Due to the long time span between the historic flood event and different ways in which the flood events were managed it was necessary to consider the topography at the time of the two calibration events. This was due to the different flood mitigation measures that were undertaken during the flood events which impacted on flow paths and flood levels.

Three hydraulic model topographies were developed to reflect the different flood mitigation measures as follows:

- 1993: The topography included Lake Numurkah and permanent levee works along the southern boundary of Lake Numurkah as these occurred prior to 1993. This topography was used in the model calibration for the October 1993 event.
- 2012: The topography included temporary mitigation measures undertaken during the 2012 event. These included temporary levees across Pine Street and Wattle Drive and a levee near the south-eastern shore of Lake Numurkah.
- Design conditions: Similar to 2012 topography with all temporary levees removed.

The 1 m resolution LiDAR used to sample the model topography is shown in Figure 11-2.

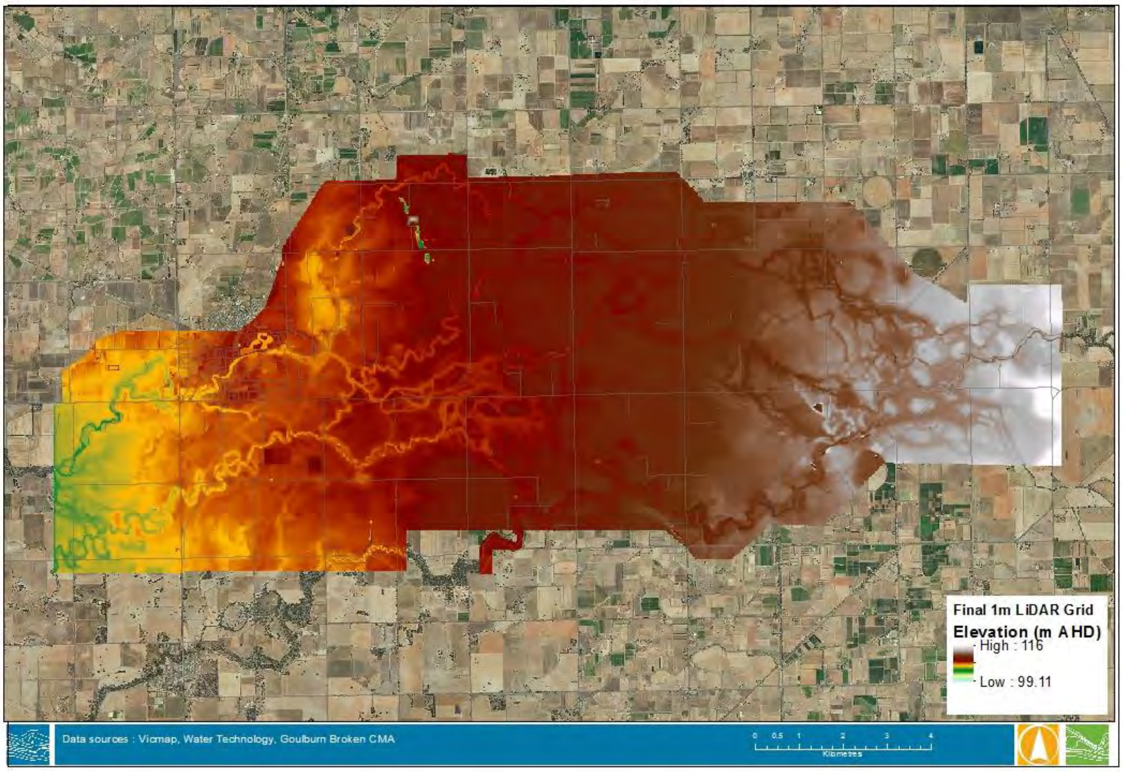


Figure 11-2 LiDAR (1 m resolution) used to sample model topography

11.2.3 1D Model Component

1D Network and Structures

The 1D MIKE11 model included the main bridges and culverts in and around Numurkah which have a significant impact on the floodplain hydraulics. The 1D model network included the following structures:

- Bridges
  - Station Street
  - Goulburn Valley Highway
  - Railway Bridge
  - 51663 - Follets Bridge
  - 45761 - Melville Road Bridge
  - Sloleys Bridge
- Culverts:
  - 47451 (Kelly's Road)
  - 46567 (Labuan Rd)
  - 46137 (Lukies Road - east)
  - 46138 (Lukies Road – west)

These structures were modelled using very short 1D branches extending out either end of the structure, and linked into the 2D model using standard links. All structures were modelled as 1D culvert and 2D weir structures to simulate flow under the road and flow over the road during large events. Standard default 1D MIKE11 structure parameters were utilised for these structures, including a roughness of 0.013 for concrete lined culverts and appropriate roughness values for bridges on waterways based on photos and site visits.

11.2.4 2D Model Component

2D Grid Size and Topography

The 2D MIKE21 model was linked to the 1D model using standard links at the upstream and downstream end of each 1D structure. A 2D model grid was sampled from the 1 m resolution LiDAR supplied. A 20 m model grid resolution was adopted, achieving good representation of the 2D topography but allowing for reasonable model run times given the very large area of floodplain included in the model domain.

The 2D topography was manually refined to ensure connectivity of key waterways, and accurate representation of roads, channel banks and levees throughout the floodplain. The levels from the detailed 1 m resolution LiDAR was stamped onto the 20 m model grid to ensure the correct elevation of these critical floodplain features was accurately resolved within the model.

Channel and Floodplain Roughness

The variation in hydraulic roughness within the study area was schematised as a hydraulic roughness grid, representing various hydraulic roughness values (e.g. roads, floodplain, channels, vegetation, buildings and land). The hydraulic roughness grid (Figure 11-3) was based on planning layers and aerial imagery and adjusted as necessary based on observations during site visits. Table 11-1 outlines the roughness parameters used for each land use type. The selection of roughness values were based on literature, experienced engineering judgement and the calibration process.

Table 11-1 Preliminary 2D hydraulic model roughness parameters

Floodplain Element	Manning's 'n' value
Road/road reserves/car parks	0.02
Waterways	0.04
Grassed agricultural areas/golf course/ recreational areas	0.04
Dense vegetation	0.07
Township	0.1

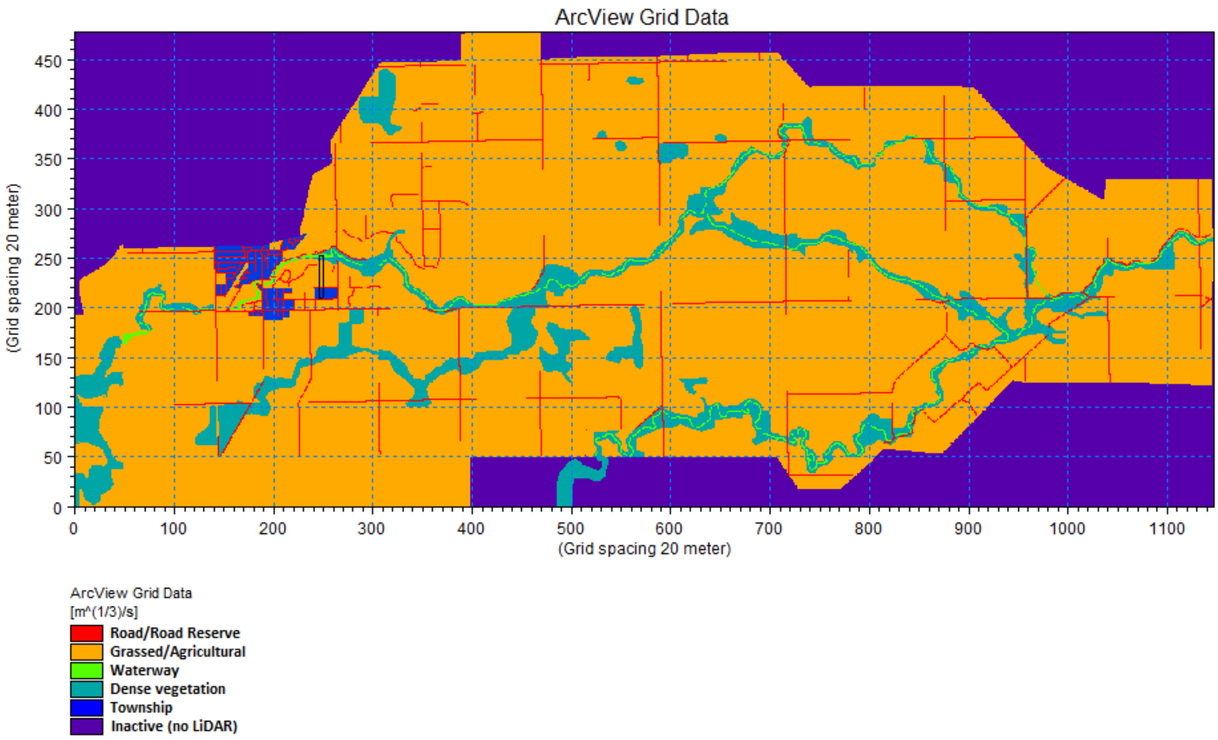


Figure 11-3 MIKE21 2D hydraulic model roughness grid

11.2.5 1D-2D Model Linking

Within MIKE FLOOD there are two main types of linking methods:

- Standard Links – linking a 1D branch to the 2D grid at the end of a branch
- Lateral Links – linking a 1D branch to the 2D grid along a reach of the branch

The connection between the main bridges and culverts (modelled in 1D) and the 2D grid was set up using standard links at each end of the 1D branch. Lateral links were not utilised in the model as all waterways were modelled in 2D.

11.2.6 Boundary Conditions

Inflow Boundaries

The model inflow boundary conditions were set at the following locations:

- Broken Creek immediately downstream of confluence of the Boosey and Broken Creeks
- Major Creek immediately upstream of the confluence with Broken Creek
- Muckatah Depression (north-east of Numurkah)
- Secondary minor Muckatah Depression inflow (north of Numurkah)

Flood flow conditions were established from hydrological modelling described in Sections 3 to 10. These included flow estimates for the October 1993 and March 2012 flood events (for calibration purposes), and design flood hydrographs for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP design events.

Outflow Boundaries

Water flowed out of the 2D model using a 2D water level boundary in Broken Creek and a second water level boundary for a minor tributary to the south-east of Numurkah. The boundaries are located a sufficient distance from areas of interest for the boundaries not to have an impact on water levels in those areas.

11.3 Hydraulic Model Calibration

11.3.1 Overview

This section details the calibration of the model to observed flood data. The model was calibrated to two large historic flood events which occurred in March 2012 (the largest on record), and October 1993. The calibration flood events were chosen as they are both large events with a significant amount of calibration data available. Surveyed flood marks (provided by the Goulburn Broken CMA), general observations from local members of the Reference Group, and aerial flood imagery were used in the calibration.

The calibration of the model centred on the determination of Manning's n values for the river and floodplain and the incorporation of key hydraulic structures to achieve a reasonable agreement between observed and modelled flood levels. Key topographic features affecting hydraulic behaviour on the floodplain were also identified during the calibration process.

Additionally, structures such as bridges and culverts that exert a significant influence on flow behaviour were identified during the calibration process and they were incorporated within the model scheme as 1D structures.

It should be noted that while flood mark survey is available for the calibration events there is inherent inaccuracies in the collection of flood levels post flood. The levels are primarily based on flood debris marks which may be significantly higher or lower than the true water level peak due to a number of reasons such as debris piling up on the upstream side of an obstruction or debris collecting on the recession of a flood.

A certain degree of judgement is required in the collection of this data and inaccuracies in the data at some locations are likely. The flood survey for the 1993 event was observed to be of significantly lower quality than that for the 2012 event with much fewer available and several inconsistences observed in neighbouring levels.

11.3.2 March 2012 Calibration and Flood Behaviour

Flood survey was commissioned by Goulburn Broken CMA following the March 2012 flood event and approximately 220 survey points of peak flood levels were captured. Of those points 119 were deemed as valid for use with the remainder being either outside the model area or displaying clear inconsistencies with adjacent points. Aerial flood imagery and feedback from the local Reference Group members were also used in the calibration process.

Calibration plots for the March 2012 flood event are shown in Figure 11-4 and Figure 11-5 below.

Of the 119 valid survey flood marks located within the study area:

- 74% were within +/- 100 mm of the modelled flood level
- 97% were within +/- 200 mm of the modelled flood level
- 100% were within +/- 300 mm of the modelled flood level

The results above demonstrate an excellent calibration of the March 2012 event and show the hydraulic model has been able to produce a very good representation of the event. The modelled flood extents also correlate very well with observations, community feedback and aerial flood imagery.

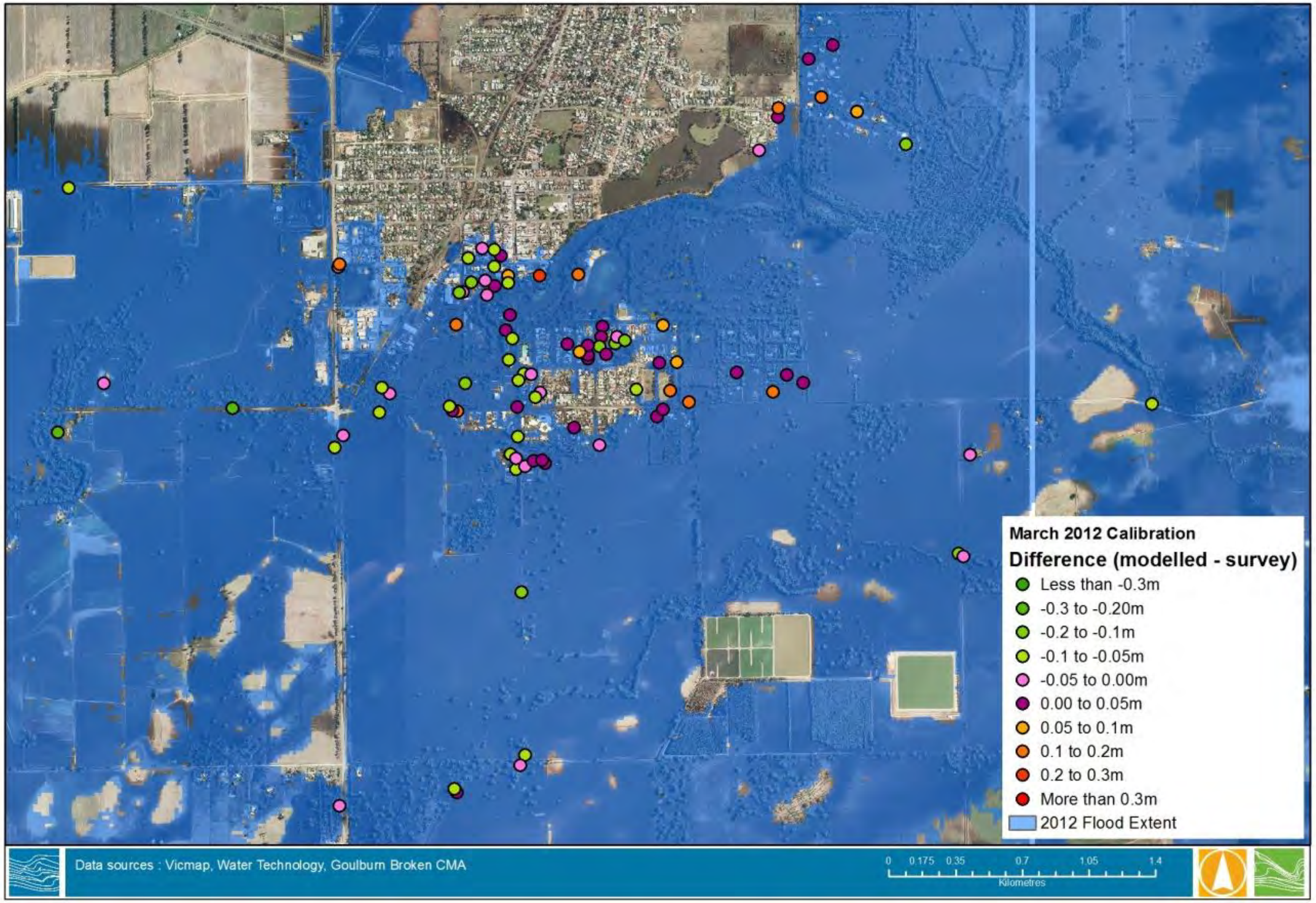


Figure 11-4 March 2012 event calibration plot of Numurkah and floodplain

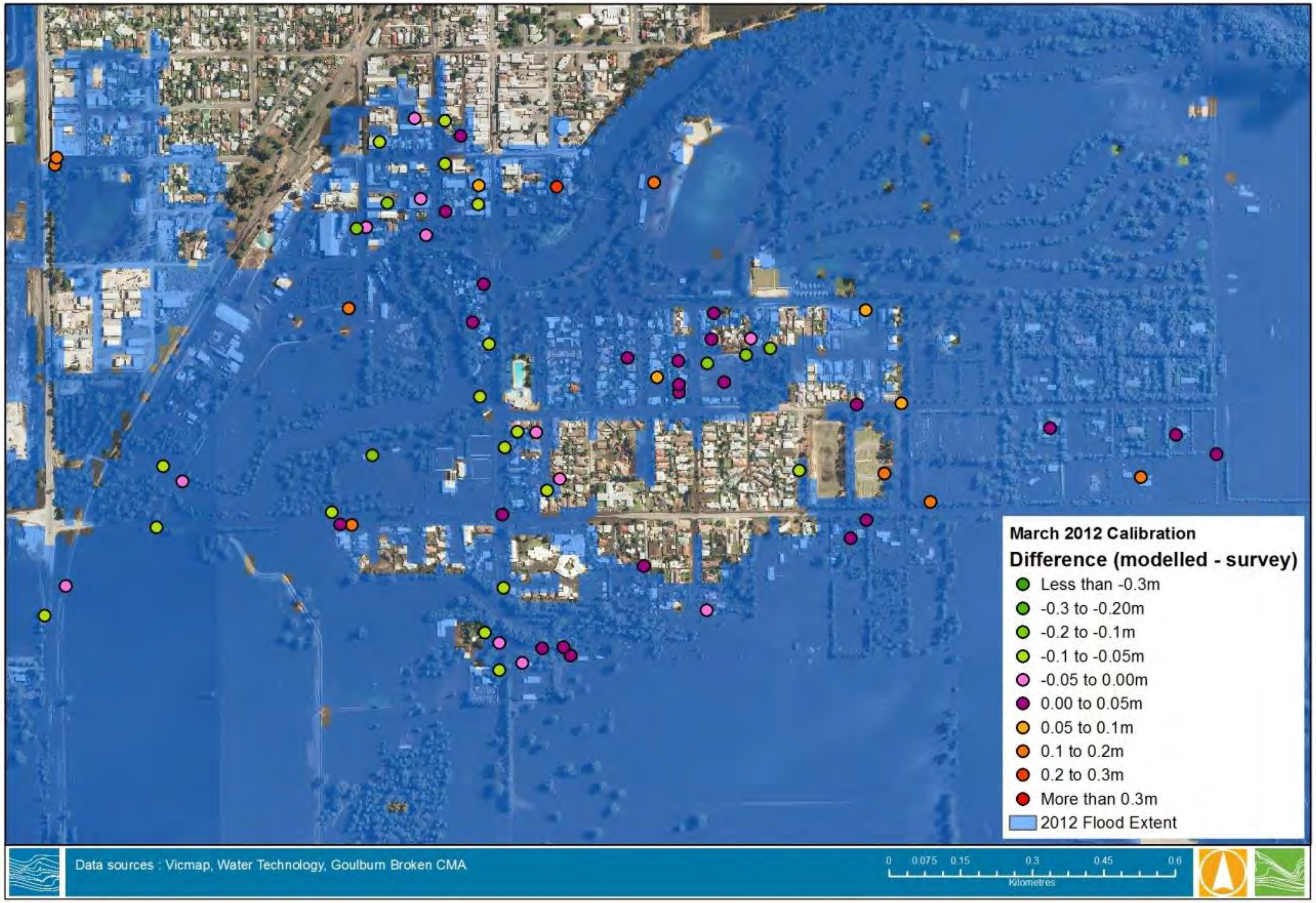


Figure 11-5 March 2012 event calibration plot of Numurkah township

Flood Behaviour

The following points summarise the flood behaviour observed from the modelling of the March 2012 event:

- The low-lying areas to the east of Numurkah around Kinnaird Wetland and Brookes Court filled quickly and early in the event.
- Breakouts from Broken Creek occurred upstream of Numurkah early in the event leading to inundation of the hospital depression and floodplain to the south of Numurkah
- The irrigation channel banks adjacent to Kinnaird's Rd and the temporary levees placed on Pine Street provided significant protection to the eastern parts of Numurkah. Temporary levees placed near the Lake Country Club and south-eastern shore of Lake Numurkah also provided significant protection to properties in that area.
- Extensive inundation through southern Numurkah resulted in inundation of approximately 60 properties below floor including the Numurkah Hospital.
- Significant inundation of properties around Brooke Court in the east of Numurkah occurred, however only one property flooded above floor due to raised building pads.
- Breakouts from the northern bank of Broken Creek in the vicinity of Melville Street inundated a number of commercial properties in that area including the El Toro Motel. Note that local accounts described stormwater backing up and surcharging prior to overland flows breaking out from the creek.

The peak flow from the March 2012 event at a number of key hydraulic structures and flow paths around the town is provided below in Table 11-2 and Table 11-3. Figure 11-6 displays a map of the main flow paths with peak flows marked for the March 2012 event.

Table 11-2 Peak flows through hydraulic structures during March 2012 event

Structure	March 2012 Peak Flow (m^3/s)
Highway bridge	75
Railway bridge	75
Station St bridge	19
Melville St bridge	26

Note: flows in above table are only flows under the culverts/bridge deck, not over the roadway/railway deck.

Table 11-3 Approximate peak flows in the main flow paths around Numurkah

Location	March 2012 Peak Flow (m^3/s)
Broken Creek though central township	87
Flow south of township including hospital depression	230
Minor flow paths further to south	58

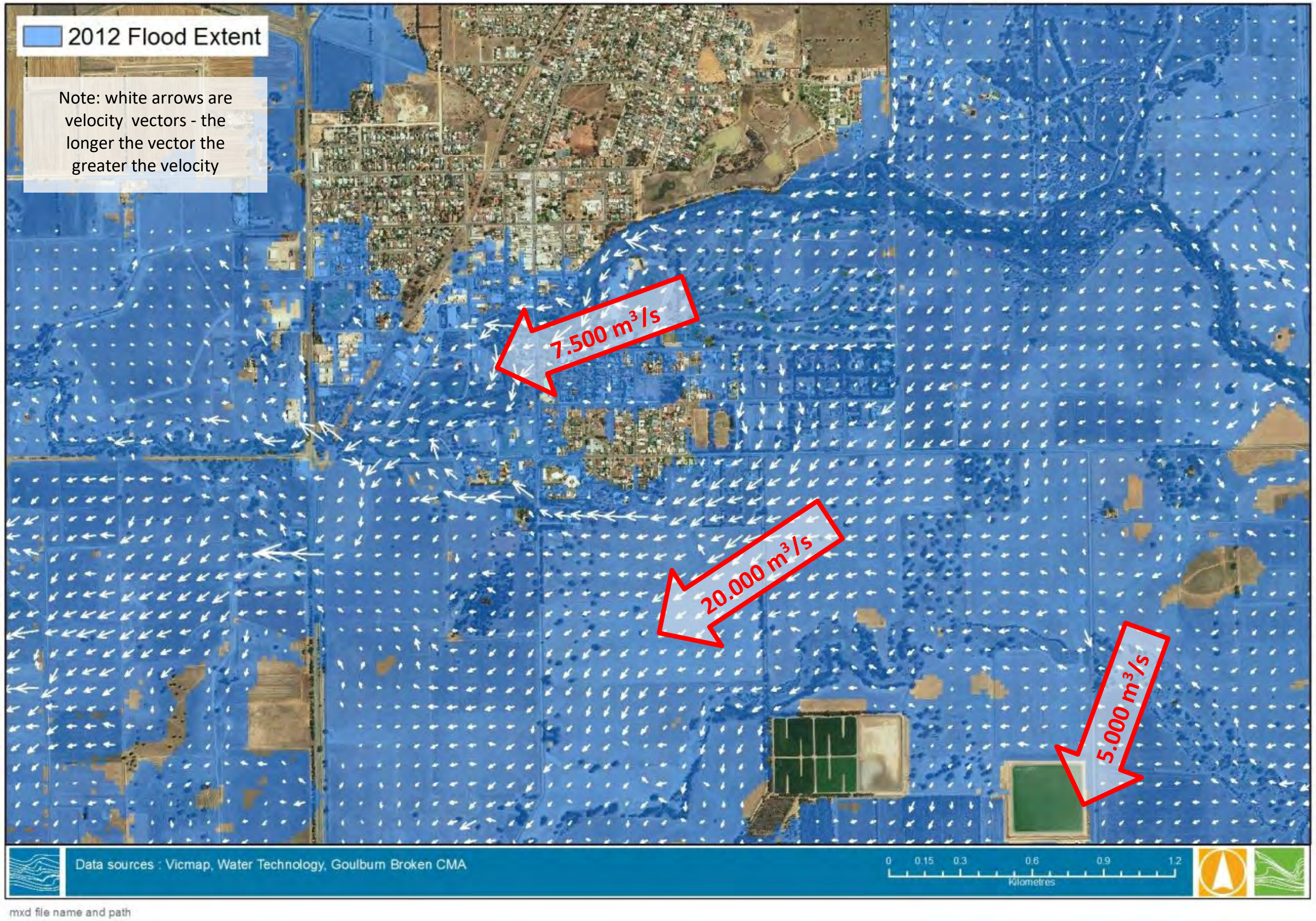


Figure 11-6 Velocity vectors and main flow paths during the March 2012 event

11.3.3 October 1993 Calibration and Flood Behaviour

Surveyed flood marks were also collected after the October 1993 flood event, however the points collected were fewer and of seemingly less accuracy than the survey for the March 2012 event.

Of the 50 valid survey flood marks located within the study area:

- 36% were within +/- 100 mm of the modelled flood level
- 82% were within +/- 200 mm of the modelled flood level
- 94% were within +/- 300mm of the modelled flood level

Figure 11-7 and Figure 11-8 below show the modelled flood extent and the comparison between modelled and surveyed flood levels from the October 1993 event.

Flood Behaviour

The following points summarise the flood behaviour observed in the modelling during the October 1993 event:

- Engagement of the floodplain and hospital depression to the south of Numurkah township but to a much smaller extent than the March 2012 event.
- Inundation of approximately 25 properties (below floor) predominately south of the Broken Creek channel, in the region of Melville Street and Tunnock Road. Several commercial properties inundated north of Melville Street Bridge (below floor).
- Water backing up behind the Goulburn Valley Highway and railway but no overtopping of either.
- Irrigation channel banks to the east of Numurkah adjacent to Kinnaird's Road holding water back and protecting a number of properties in that area.
- Water overtopping and flowing into Lake Numurkah. Temporary levees were not used in that area so additional inundation occurred in that area compared with the 2012 event.
- Flood extents are significantly smaller and water levels lower than March 2012 with the difference in peak flood levels varying from 100-500 mm depending on location. The modelling has indicated in the vicinity of the Melville street bridge March 2012 flood levels were up to 400 mm higher than the 1993 event while through the hospital depression levels were approximately 200-250 mm higher in the March 2012 event. These modelled differences correlate well with the available flood survey.
- In the floodplains to the south and upstream to the east of Numurkah differences in peak flood level also vary but are generally in the range of 150mm to 250mm higher in the March 2012 event compared with the October 1993 event.

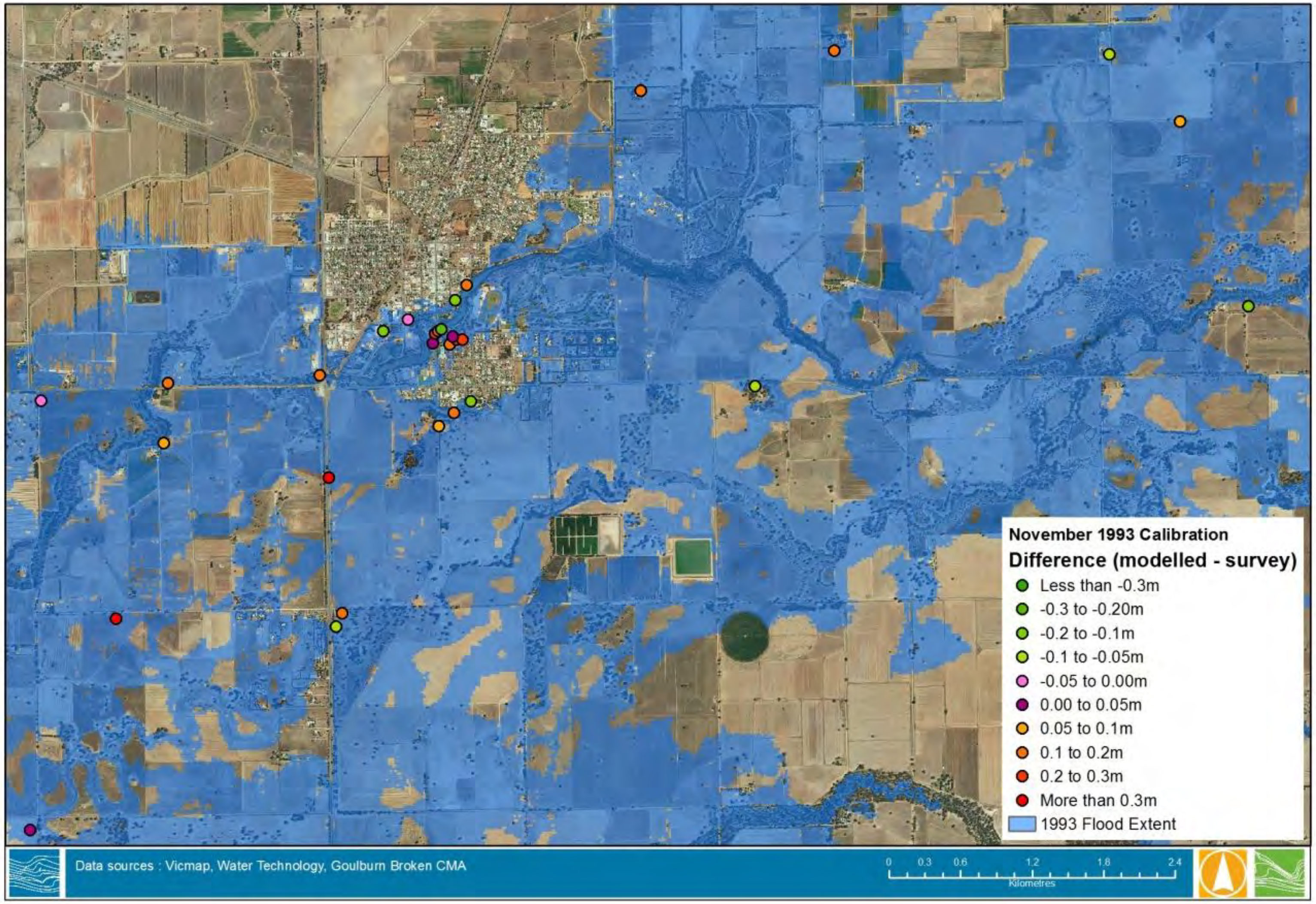


Figure 11-7 October 1993 event calibration plot of Numurkah and floodplain

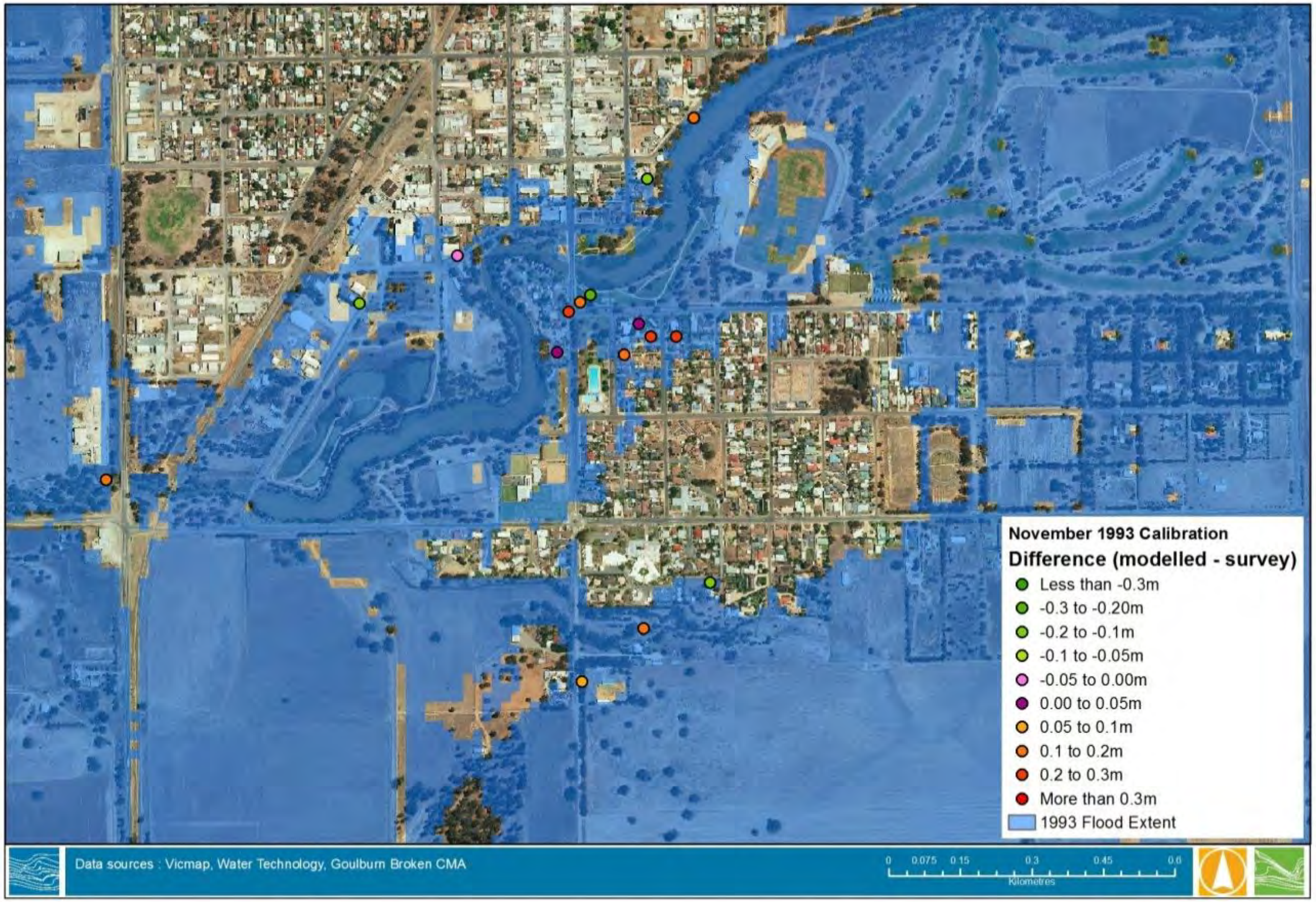


Figure 11-8 October 1993 event calibration plot of Numurkah township

11.3.4 Hydraulic Model Calibration Summary

The hydraulic models have provided a very good representation of the March 2012 and October 1993 flood events which impacted Numurkah. The calibration of the March 2012 event is considered excellent while the October 1993 calibration was not as close but still considered a very good calibration. The modelling demonstrates that the events were quite different in nature which correlates with local observations that the March 2012 was a much larger and more damaging event.

The 2012 event inundated approximately 93 residential buildings[5] across the township while the 1993 event was less damaging and resulted in inundation of approximately 25 buildings (below floor level) located mainly in the southern part of the township

Modelling has identified that the peak flow in Broken Creek through the central township in March 2012 was approximately 87 m^3/s with an additional 231 m^3/s passing to the south of township through the hospital depression and further south. This compared to a peak flow of 45 m^3/s through the central township in October 1993 and 104 m^3/s to the south of the township.

The difference in flows resulted in the 2012 peak flood levels being significant higher than the 1993 event with the modelled differences varying from 100-500 mm depending on location. The modelling has indicated in the vicinity of the Melville street bridge March 2012 flood levels were up to 400 mm higher than the 1993 event while through the hospital depression levels were approximately 200-250 mm higher in the March 2012 event. These modelled differences correlate well with the available flood survey. Both events engaged the floodplain to the south of Numurkah which includes the low lying area immediately south of the township known as the hospital depression. Significantly larger areas of the floodplain were engaged in the 2012 event.

In both events the railway line and highway provided significant obstructions with water banking up behind the railway on the upstream side. The March 2012 flood event resulted in water overtopping the railway and highway at multiple locations with a significant washout occurring adjacent to Broken Creek.

A long-section plot of flood levels along Broken Creek during the March 2012 and October 1993 events, is shown in Figure 11-9. This indicates four key constriction points where water was held up; a narrowing of the waterway adjacent to the golf course, Melville Street bridge and the railway and highway bridges. It demonstrates that these structures have significant impacts on flood behaviour in Numurkah.

[5] *Report of the 2012 North East Victoria Flood Review*, Offices of the Emergency Services Commissioner, prepared by Molino Stewart, 2 October 2012, viewed 11 December, 2013, http://www.oesc.vic.gov.au/resources/5b778d54-07cc-4f50-8941-761eadbd4e19/report_2012_north_east_victoria_flood_review.pdf

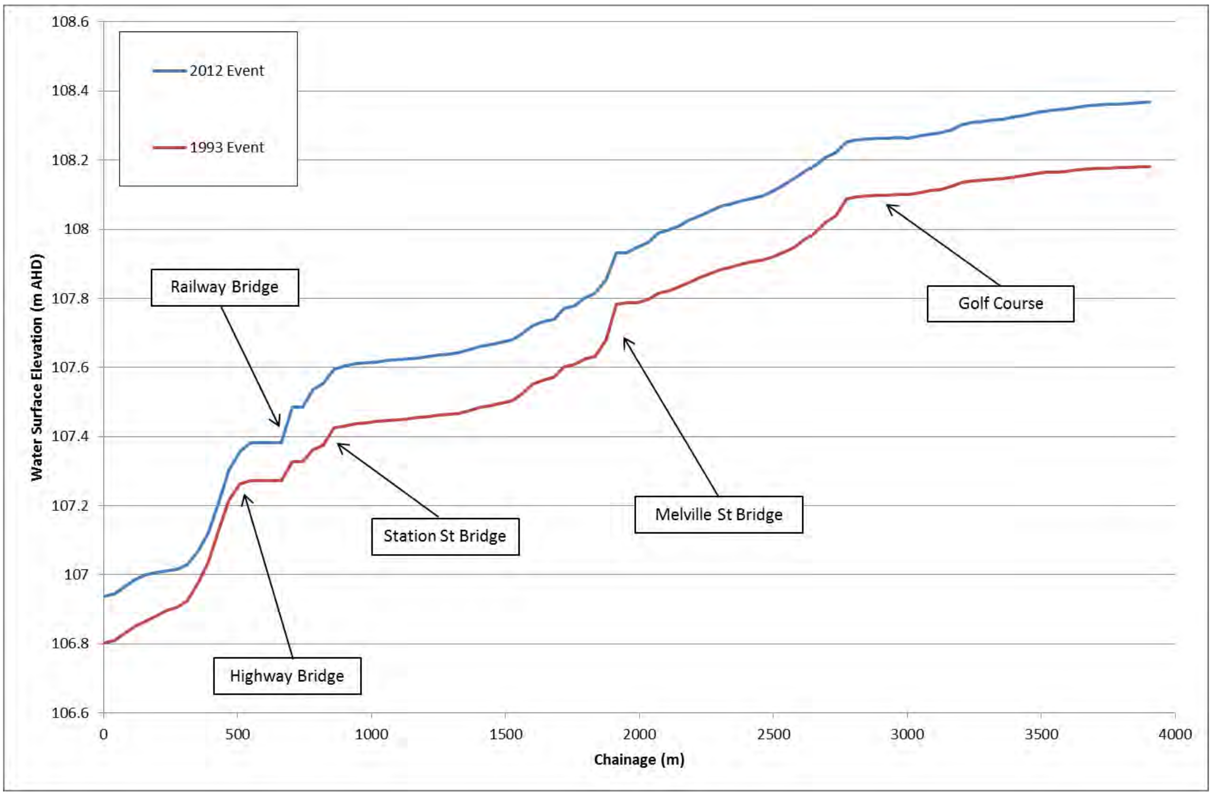


Figure 11-9 Long section of flood levels in 2012 and 1993 events

The modelling also confirmed that irrigation channel banks had a significant role in protecting properties from inundation in both events. In particular the irrigation channel to the east of the township adjacent to Kinnaird's Road has an important role in holding back flood water and protecting much of the eastern township from inundation in large events. Temporary levees also played an important role particularly in the March 2012 event.

In summary, the hydraulic model results for the March 2012 and October 1993 floods replicated the observed flood behaviour through the town quite accurately; this was confirmed by post flood level survey from debris marks, aerial images and positive community feedback. The model is considered appropriate for use for design event modelling and mitigation options investigation.

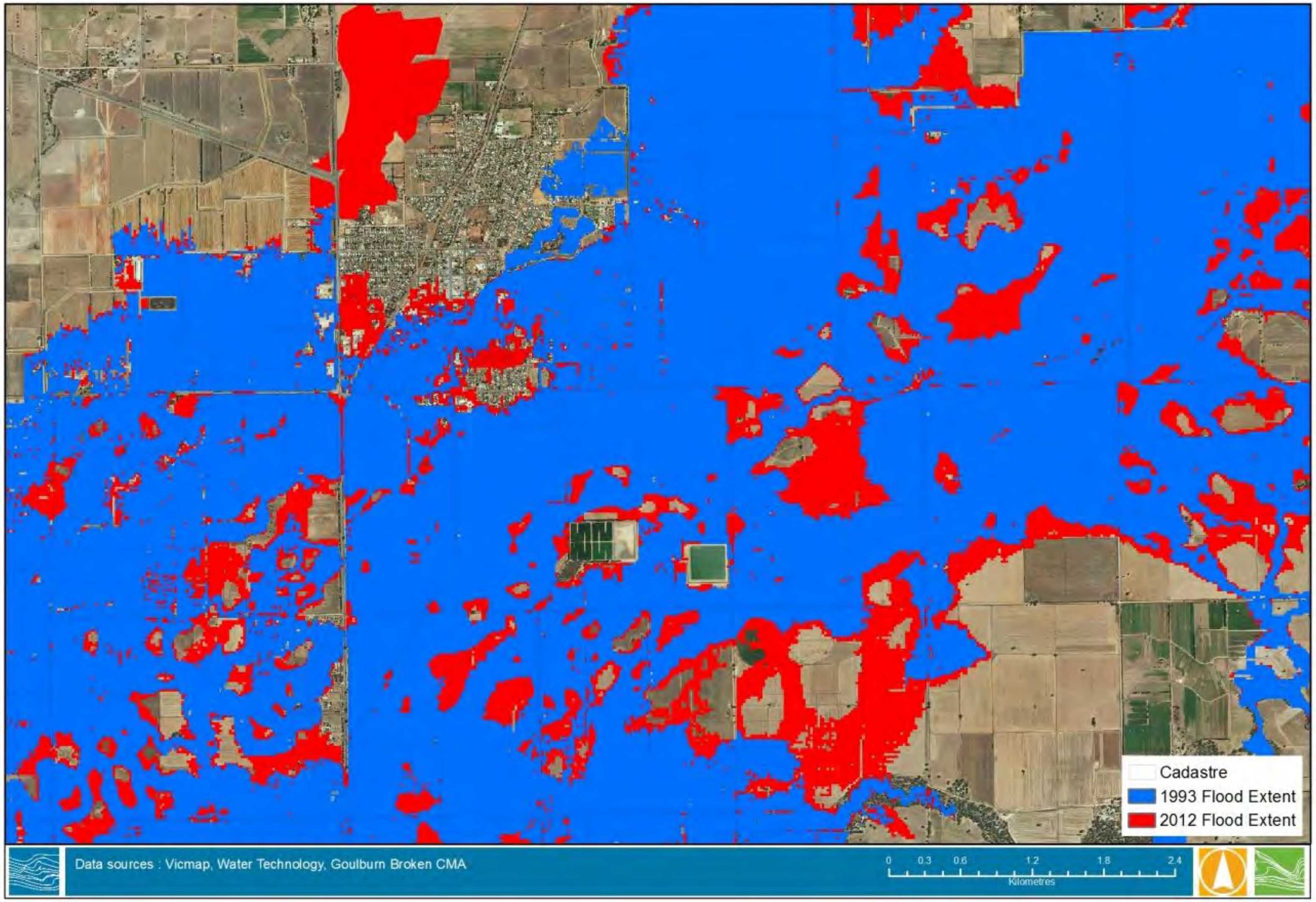


Figure 11-10 Comparison of March 2012 and October 1993 modelled flood extents

11.4 Design Flood Modelling

The hydraulic model used for calibration and as described earlier in this report was also used to run the 20%, 10%, 5%, 2%, 1% and 0.5% AEP design events. A suite of flood maps was developed for the range of flood magnitudes and have been provided in PDF format as digital deliverables for the study. The 1% AEP flood extent was very similar to the March 2012 flood extent apart from areas protected by temporary levees in the 2012 event. All temporary levees were removed for design conditions.

The design flood mapping deliverables consist of hardcopy plans, along with digital PDF maps showing flood extents, depth, velocity and hazard. Maps also include VFD and flood planning maps. Currently 1% AEP draft flood maps are available and have been provided with this report for review. Figure 11-11 shows the draft 1% AEP design flood map of central Numurkah while Figure 11-12 shows the broader floodplain. Figure 11-13 shows the range of design flood extents overlayed on the one map for comparison.

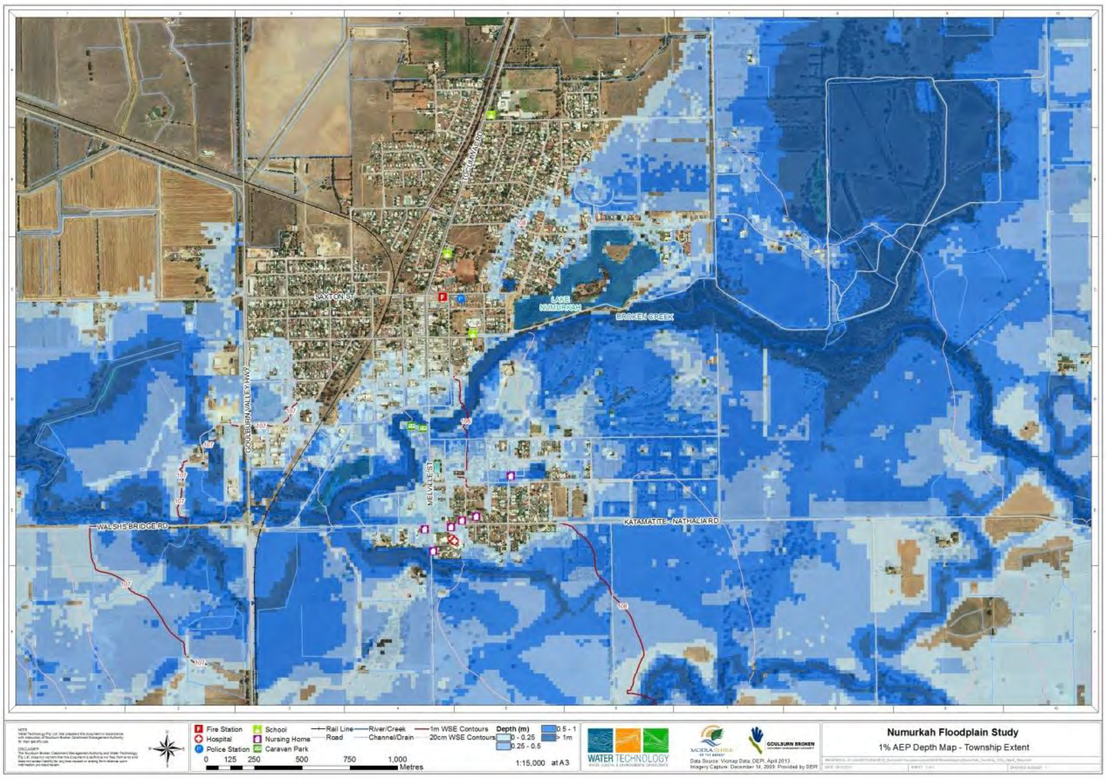


Figure 11-11 Draft 1% AEP depth map of Numurkah township

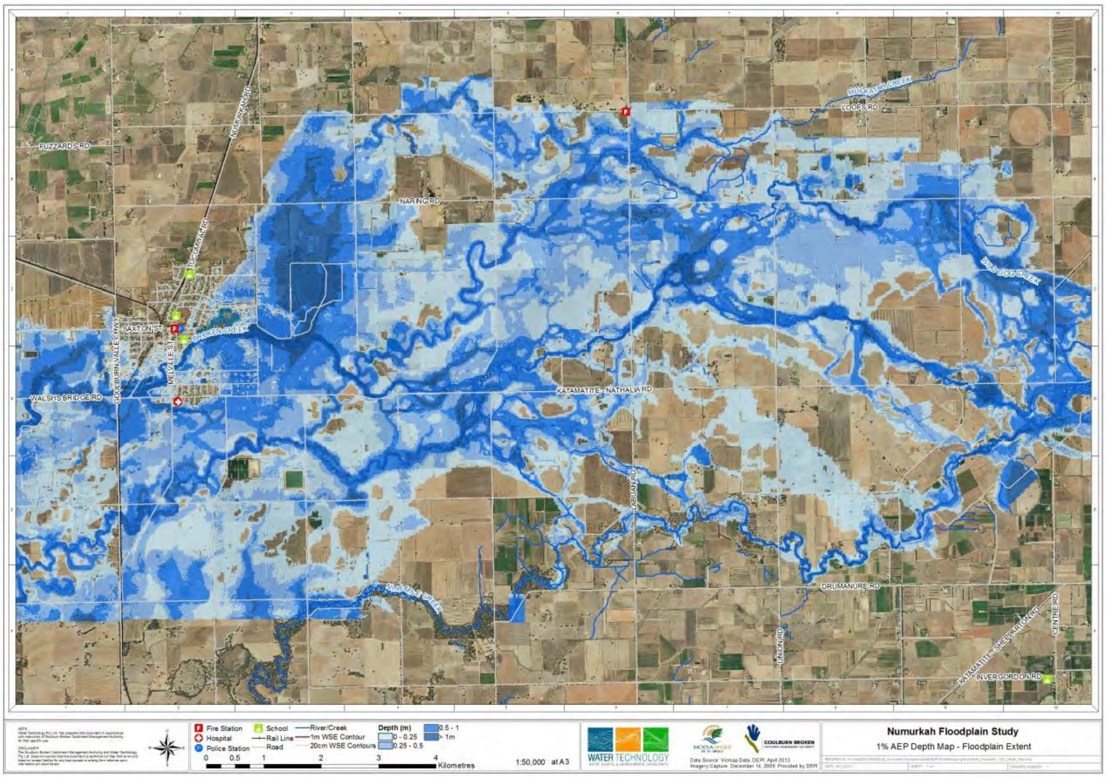


Figure 11-12 Draft 1% AEP depth map of Numurkah floodplain

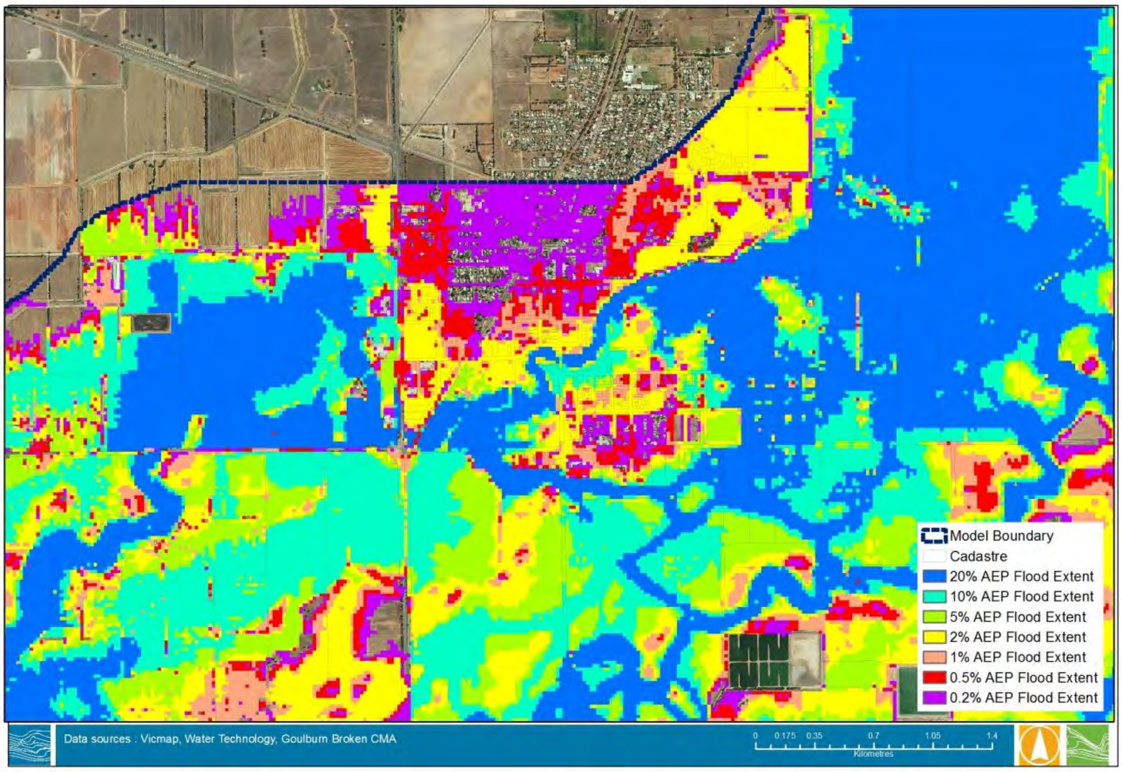


Figure 11-13 Comparison of design flood extents around Numurkah township

11.5 Design Flood Behaviour

A review of the model results over the range of design events allows flood behaviour to be better understood. It can be seen that breakouts occur from Broken Creek in relatively small events with even the 20% AEP event breaking out across the floodplain to the south of Numurkah. Properties are inundated from the 20% event and above with inundation initially occurring in the southern part of the township. As the flow in the river increases the water levels rise and the extent of inundation widens significantly. It can also be seen that the irrigation infrastructure adjacent to Kinnaird's Road has a significant role in holding back water and protecting parts of Numurkah from inundation.

What is also obvious is that in the design events where the temporary levee mitigation was not included, the flood extents are much wider spread in some areas, which were protected by those measures in the March 2012 flood event.

The following comments summarise the key flood characteristics in Numurkah for each design event.

20% AEP Event

- Flooding generally well-contained in Broken Creek in central Numurkah.
- Breakouts upstream of Numurkah resulting in inundation of parts of the golf course and some flow through the hospital depression.
- Some low-lying areas in the floodplain to south of Numurkah inundated.
- Inundation of approximately 12 properties at eastern end of Madeleine and Tunnock Streets in south-eastern Numurkah with depths up to 300 mm.
- Breakout near Station St inundating wetland area and one commercial property on Station St.
- Inundation of Kinnaird Wetlands and low-lying areas around Brooke Court to the east of Numurkah. Partial inundation of approximately 15 properties on Brooke Court/Kinnaird's Road (all below floor flooding).
- Overtopping of Katamatite-Nathalia Road occurs as a result of flows from the hospital depression.
- Some low-lying areas in the floodplain to south of Numurkah inundated.
- Inundation of a number of paddocks downstream of the highway and railway bridges.
- Properties inundated above floor level: 2
- Properties inundated below floor level: 77

10% AEP Event

- Breakouts begin to occur from Broken Creek in central Numurkah inundating 15 properties near the corner of Melville Street and Tunnock Road. Inundation of Numurkah Caravan Park.
- Additional properties inundated in south-east of Numurkah including several properties on Numurkah- Katamatite Road (below floor flooding).
- Water starts backing up behind the railway line resulting in water flowing south across Katamatite-Nathalia Road and engaging the secondary railway and highway culverts located 400m further south.
- Increased engagement of the floodplain to the south of Numurkah.
- Flood levels approximately 200 mm higher than the 20% AEP event in Central Numurkah.
- Properties inundated above floor level: 5
- Properties inundated below floor level: 139

5% AEP Event

- All properties on Brooke Court inundated (all below floor).
- Additional properties inundated in southern Numurkah including several on Newby and Thornton Streets.
- Additional commercial properties inundated on Station Street with water backing up behind the railway line in that area.
- Significantly more inundation of floodplain to the south of Numurkah.
- Walsh's Bridge Road begins to overtop to west of Sloleys Bridge.
- Flood levels approximately 140 mm higher than the 10% AEP event in Central Numurkah.
- Properties inundated above floor level: 5
- Properties inundated below floor level: 189

2% AEP Event

- Significantly more breakouts from the north bank of Broken Creek leading to overtopping into Lake Numurkah and inundation of approximately 10 commercial properties in central Numurkah. Raised levels in Lake Numurkah lead to inundation of 7-8 properties on Reynolds Drive.
- Additional 25 properties flooded in southern Numurkah.
- Water begins flowing along Pine Street over the irrigation channel adjacent to Kinnaird's Road resulting in inundation of approximately 25 properties in eastern Numurkah in the vicinity of Maple Crescent.
- Significantly more flooding in southern Numurkah leading to inundation of additional 40 residential properties.
- Flooding to rear grounds of Lakeside Country Club. Hospital grounds begin to flood.
- Flood water flows north across Saxton Street West to the west side of Highway towards proposed industrial area.
- Widespread inundation across the floodplain to the south of the township. Highway and railway begin to overtop to south of Katamatite-Nathalia Rd intersection.
- Flood levels approximately 140 mm higher than the 5% AEP event in Central Numurkah.
- Properties inundated above floor level: 56
- Properties inundated below floor level: 509

1% AEP Event

- Inundation of additional 20 commercial properties in central Numurkah.
- More flooding in southern Numurkah leading to inundation of additional 25 residential properties.
- Additional 35 properties inundated in eastern Numurkah as a result of overtopping of Lake Numurkah and flows from Pine Street. Much of Lakeside Country Club inundated.
- Railway begins to overtop in central Numurkah near Orchard Street.
- The Goulburn Valley Highway is likely to be overtopped and impassable for more than 5 days week depending on the length of the rainfall events.
- Flood levels approximately 110 mm higher than the 2% AEP event in central Numurkah.
- Properties inundated above floor level: 125
- Properties inundated below floor level: 709

0.5% AEP Event

- Flood levels approximately 100 mm higher than the 1% AEP event in central Numurkah
- Significantly worse flooding through central and eastern township with approximately 60 additional properties inundated compared with the 1% AEP event.
- Additional 50 additional properties inundated in western Numurkah in the vicinity of Nelson Street, Saxton Street and Cullen Court as a result of water flowing back across the highway and the railway overtopping near Orchard Street
- Widespread inundation across the floodplain to the south and south-east of Numurkah.
- Properties inundated above floor level: 297
- Properties inundated below floor level: 790

0.2% AEP Event

- Widespread inundation across the floodplain and through the township. 90% of central Numurkah inundated with flood depths of 200-250 mm through the central business area on Melville Street.
- Flood levels approximately 180 mm higher than the 0.5% AEP event in Central Numurkah.
- Properties inundated above floor level: 713
- Properties inundated below floor level: 850

11.6 Comparison of March 2012 and 1% AEP Flood Event

This section aims to compare the flood behaviour between the modelled March 2012 and 1% AEP events. The events are quite similar in many ways and the comparison below aims to quantify some of the similarities and differences between the two events.

11.6.1 Comparison of Flood Extents

The flood extents of the March 2012 and 1% AEP events are generally quite similar apart from the eastern area of the township which is shown as inundated in the 1% AEP event but was protected by temporary mitigation works in the March 2012 event. For the purposes of design conditions modelling the temporary works were not included. This is a conservative approach (assuming there could be some circumstance that reduces the effectiveness of the measures) and is typical practice in such studies.

Figure 11-14 below compares the flood extents across the township. It can be seen that the extents are very similar with the March 2012 event extending marginally further in some areas. Differences of 20 m or less are evident in nearly all locations.

In the eastern part of the township the 1% AEP extent extends considerably further than the March 2012 event as shown in Figure 11-15 as a result of the assumptions for design conditions discussed above.

There are two small pockets in the west of Numurkah where the March 2012 event extents further than the 1% AEP event by approximately 100m. This is generally shallow inundation (less than 100 mm) and is confined to roads and rural areas.

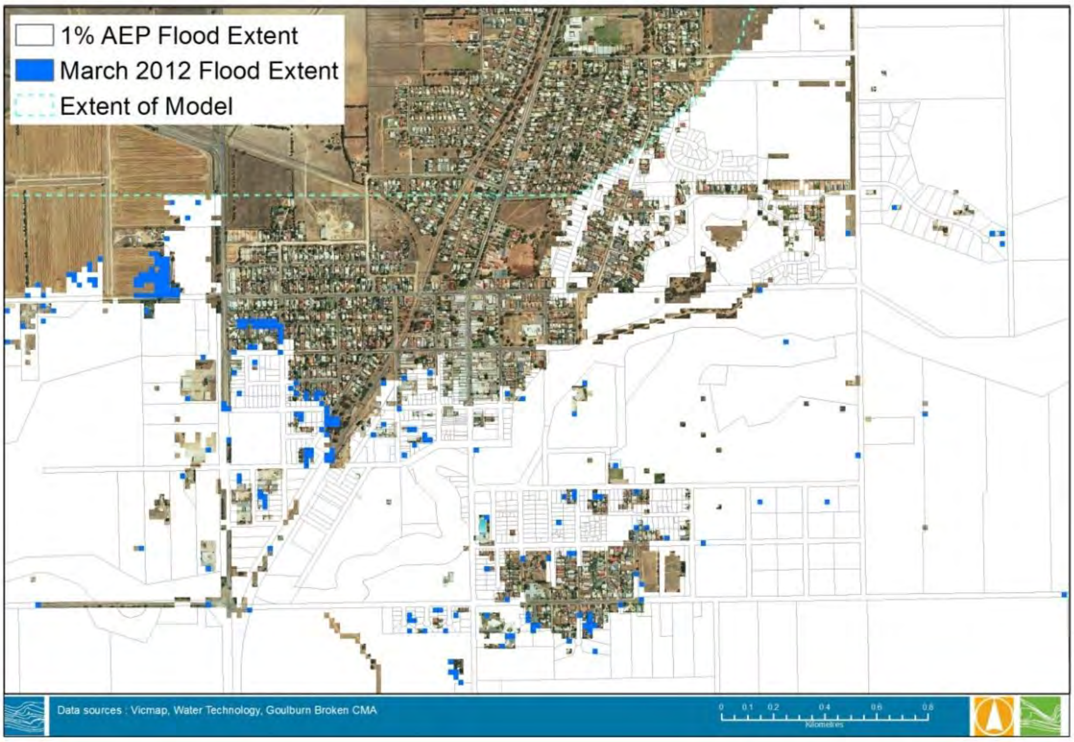


Figure 11-14 Comparison of flood extents across the township

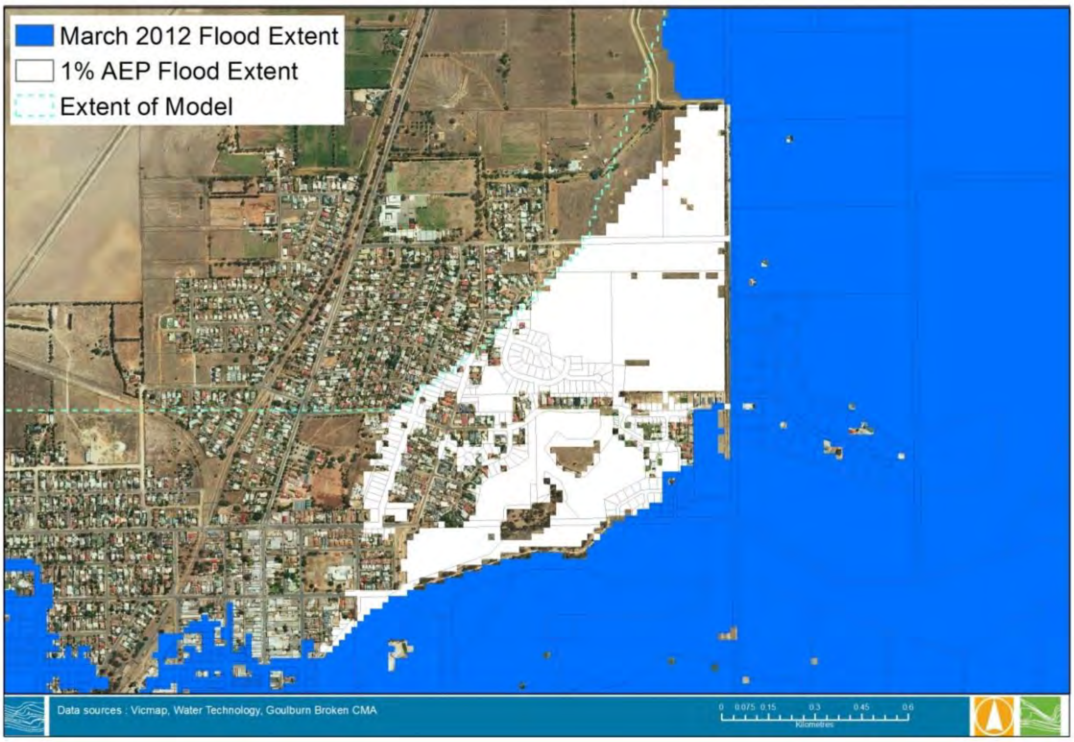


Figure 11-15 Comparison of flood extents in eastern Numurkah (Note: the order of flood extents has been swapped from previous map to highlight the differences in extents as a result of the temporary mitigation measures in March 2012)

11.6.2 Comparison of Peak Water Levels

Water levels between the March 2012 and 1% AEP events were compared at key locations around the township and are presented in Table 1 below with the point locations presented in Figure 11-16. It can be seen that the difference in flood levels at most locations is generally less than 20 mm, with the March 2012 levels being slightly higher than the 1% AEP levels in all areas. A further comparison of peak flood levels is provided in Section 11.6.5 using longitudinal profiles.

A slightly larger difference in water level of 40 mm occurs at Brooke Court in the east of Numurkah. It should be noted that all properties in the vicinity of Brooke Court have been built with appropriate design floor levels including freeboard and none were flooded above floor in the March 2012 event.

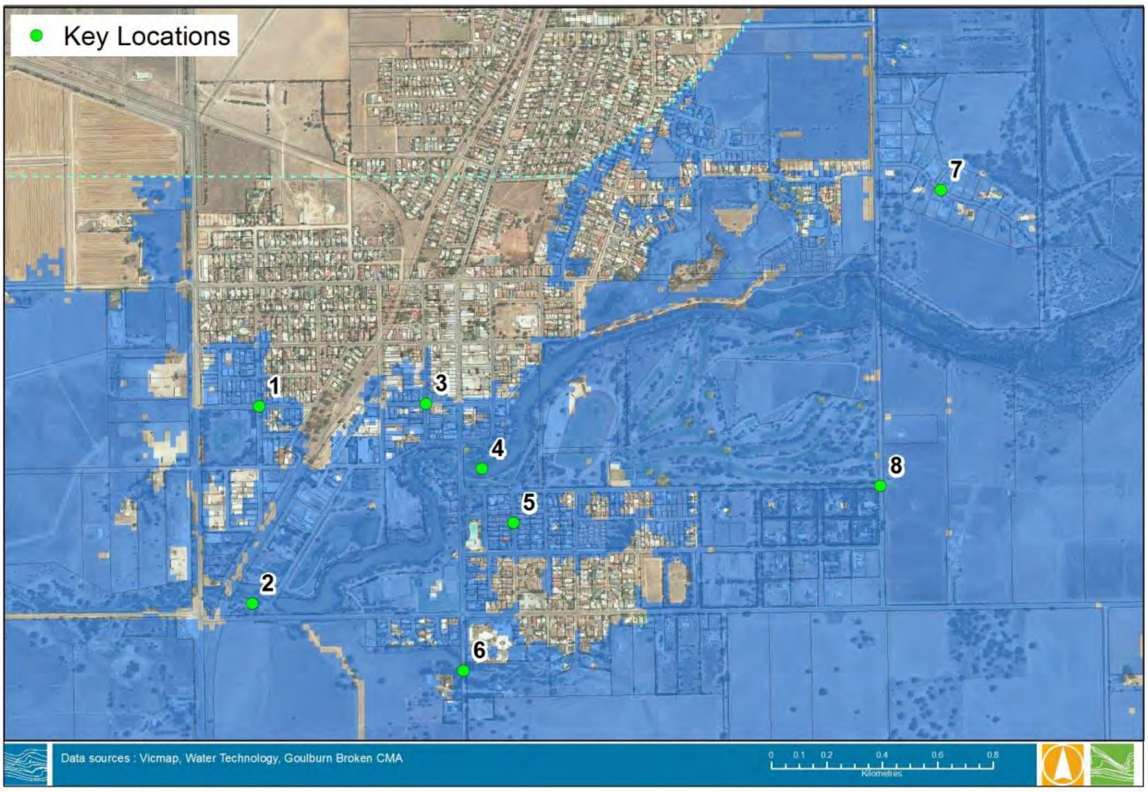


Figure 11-16 Key location where water levels were compared

Table 11-4 Comparison of water levels at key locations

Location No.	Location	March 2012 Peak Water Level (m, AHD)	1% AEP Peak Water Level (m, AHD)	Difference (m)
1	Western township (corner of Know and Nelson St)	107.02	106.99	-0.03
2	Broken Creek (immediately upstream of railway bridge)	107.58	107.55	-0.03
3	Central township (corner of Knox and Meiklejohn St)	107.84	107.82	-0.02

4	Broken Creek (immediately upstream of Melville St)	107.97	107.95	-0.02
5	Southern residential area (Thornton Street)	108.02	108.00	-0.02
6	Hospital Depression (Melville St)	107.79	107.77	-0.02
7	Brooke Court	108.42	108.38	-0.04
8	South-east township (corner of Kinnairds and Tunnock Road)	108.33	108.30	-0.03

11.6.3 Comparison of Peak Flow Velocities

The difference in flow velocities between the March 2012 and 1% AEP event is also very similar with negligible difference between the events in all locations as shown in Table 11-5. The differences in velocities range from 0.01 to 0.03 m/s. In terms of velocity, the floods would be indistinguishable to an observer on the ground.

Table 11-5 Comparison of water levels at key locations

Location No.	Location	March 2012 Peak Velocity (m/s)	1% AEP Peak Velocity (m/s)	Difference (m/s)
1	Western township (corner of Know and Nelson St)	0.07	0.05	-0.02
2	Broken Creek (immediately upstream of railway bridge)	0.48	0.46	-0.02
3	Central township (corner of Knox and Meiklejohn St)	0.10	0.07	-0.03
4	Broken Creek (immediately upstream of Melville St)	0.64	0.67	+0.03
5	Southern residential area (Thornton Street)	0.08	0.07	-0.01
6	Hospital Depression (Melville St)	0.90	0.87	-0.03
7	Brooke Court	0.32	0.30	-0.02
8	South-east township (corner of Kinnairds and Tunnock Road)	0.26	0.24	-0.02
			Mean difference across all locations:	**0.015 m/s**

11.6.4 Comparison of Properties Impacted

The number of properties impacted by each event was also compared and is presented in Table 11-6 and Figure 11-17 below. It is difficult to make a direct comparison due to the additional area inundated in the 1% AEP event as a result of assumptions around the temporary mitigation works which protected those areas in the March 2012 event. It was important that those temporary works were not included in design modelling, to give a true indication of flood behaviour under existing conditions, which in turn provides justification for funding similar works in the future.

If those buildings flooded above flood in the east of Numurkah in the 1% AEP are removed from the comparison, the March 2012 event has approximately 23 more properties flooded above floor than the 1% AEP event. This is a significant difference given the relatively small difference in water levels, and shows that a number of properties are flooded at very close to floor level in both the 1% AEP and March 2012 events. Despite those 23 properties experiencing peak water levels slightly below floor level in the 1% AEP event the damage cost is likely to be almost as significant.

Some additional observations are provided below:

- In the southern residential area 32 properties were flooded above floor in the March 2012 event compared with 26 in the 1% AEP event.
- In the central township 42 properties were flooded above floor in the March 2012 event compared with 33 in the 1% AEP event
- To the west of the railway line on the northern bank, 16 properties were flooded above floor in the March 2012 event compared with 10 in the 1% AEP event.

Table 11-6 Comparison of properties inundated

Event	Buildings Flooded Above Floor	Properties Flooded Below Floor	Total properties impacted
March 2012 Event	94	340	434
1% AEP Design Event	125*	790*	1087*

* Includes properties in the centre and east of Numurkah that are inundated in the 1% AEP event but were protected by temporary works in the March 2012 event

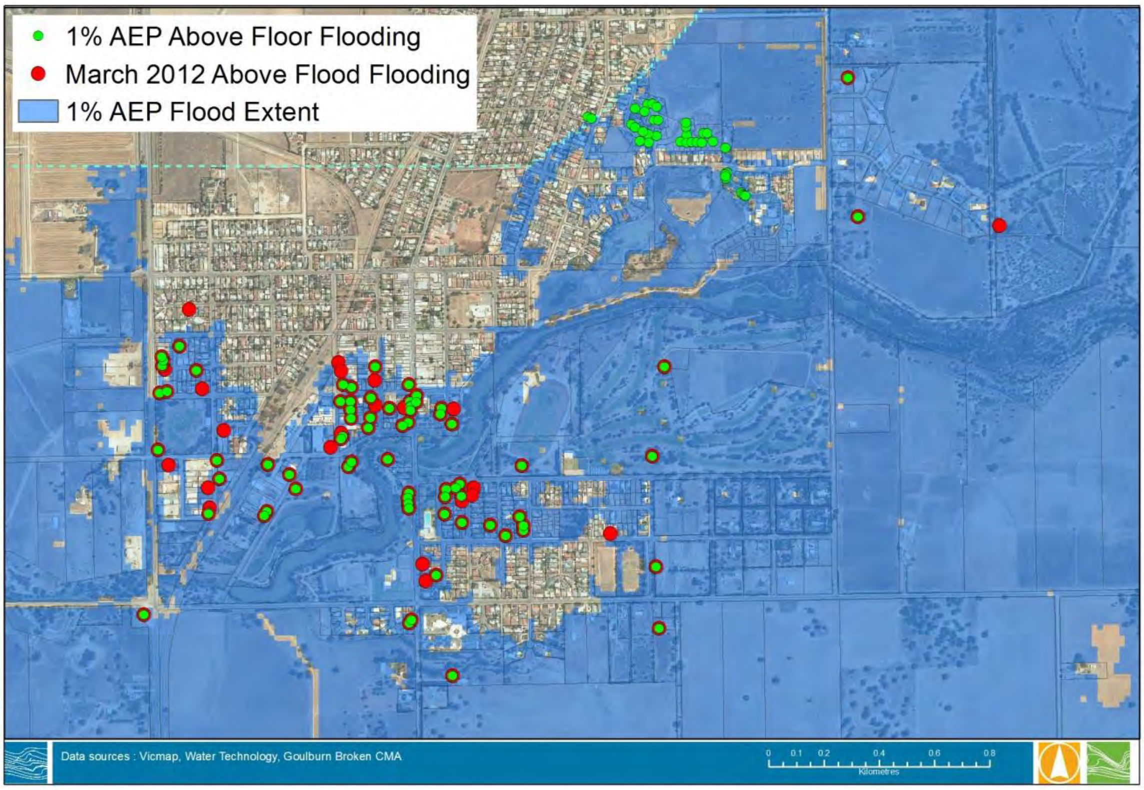


Figure 11-17 Comparison of buildings flooded above floor

In summary, the comparison of impacted properties shows that significant numbers of properties are flooded in the 1% AEP and March 2012 events both above and below floor. A higher number of properties are inundated in the 1% AEP event compared with March 2012 due to the additional areas inundated in the eastern section of Numurkah. In the areas impacted by both the March 2012 and 1% AEP events, approximately 23 more buildings are flooded above floor for March 2012 than for the 1% AEP event due to the slightly higher water levels.

11.6.5 Longitudinal Profiles

A longitudinal profile allows the differences in flood levels to be better visualised. Profiles are presented in Figure 11-19 along both Broken Creek and in Figure 11-20 along the Hospital depression. The locations of the profiles are shown in Figure 11-18.

It can be seen in the first profile (Figure 11-19), along the centre-line of Broken Creek, that peak water levels for the March 2012 event remain slightly above the 1% AEP along the entire reach. The difference varies from less than 10mm downstream of the Goulburn Valley Highway to approximately 40mm upstream of the golf course, in the vicinity of Kinnairds Road. In the central township the difference is 20-25 mm. It can be seen that the same control points exist in both profiles with the railway, Melville Street and the constriction around the football oval and golf course all having some impact on upstream water levels.

Similar differences can be seen in the second profile (Figure 11-20), which is located along Broken Creek and the Hospital Depression. The peak water levels in the March 2012 event remain slightly above the 1% AEP for the entire reach. The differences in the second profile vary from less than 10 mm downstream of the Goulburn Valley Highway to approximately 40 mm upstream at Kinnairds Road. In the central township the different is 20-25 mm. In terms of control points through the hospital depression there are none as significant as in the first profile however a slight head drop is observed across Melville Road adjacent to the hospital.

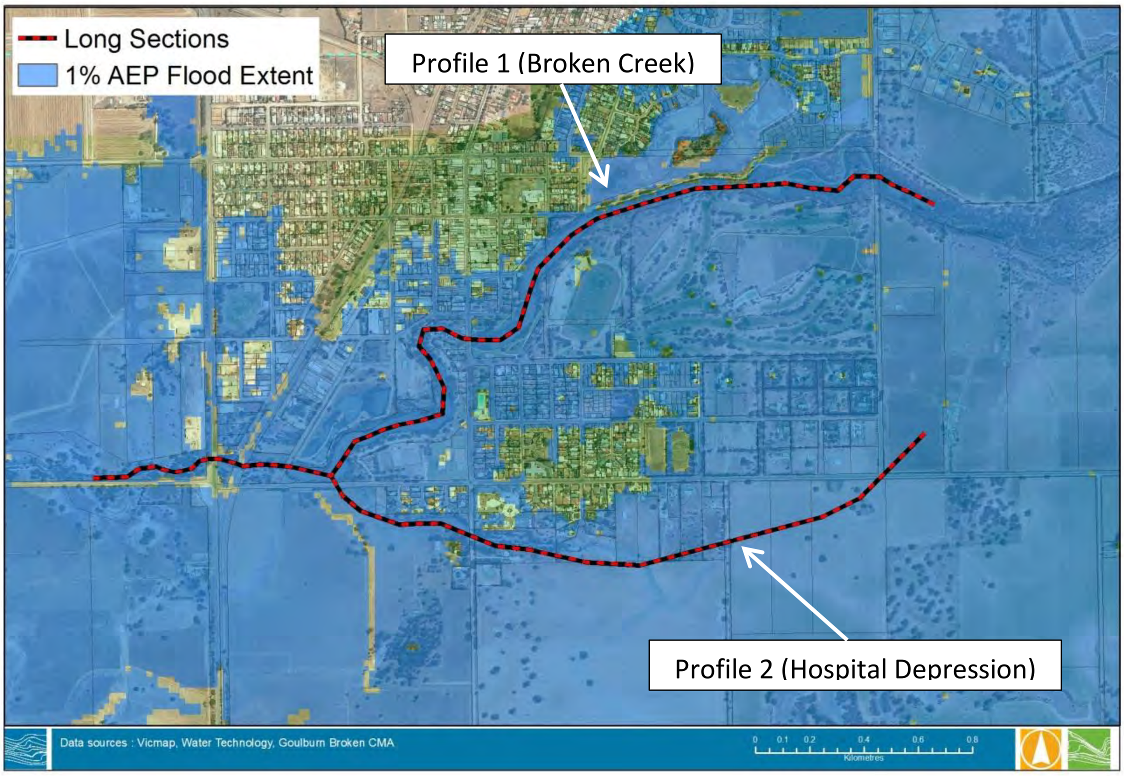


Figure 11-18 Location of longitudinal profiles

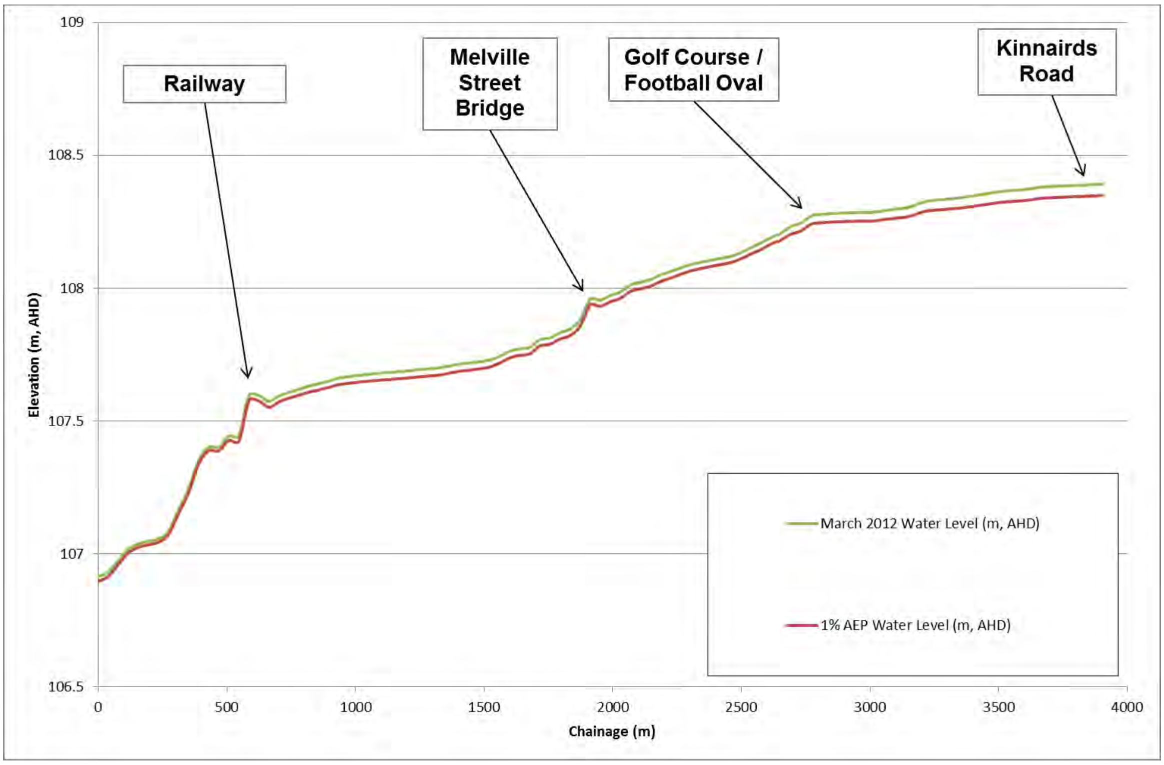


Figure 11-19 Longitudinal profile along Broken Creek

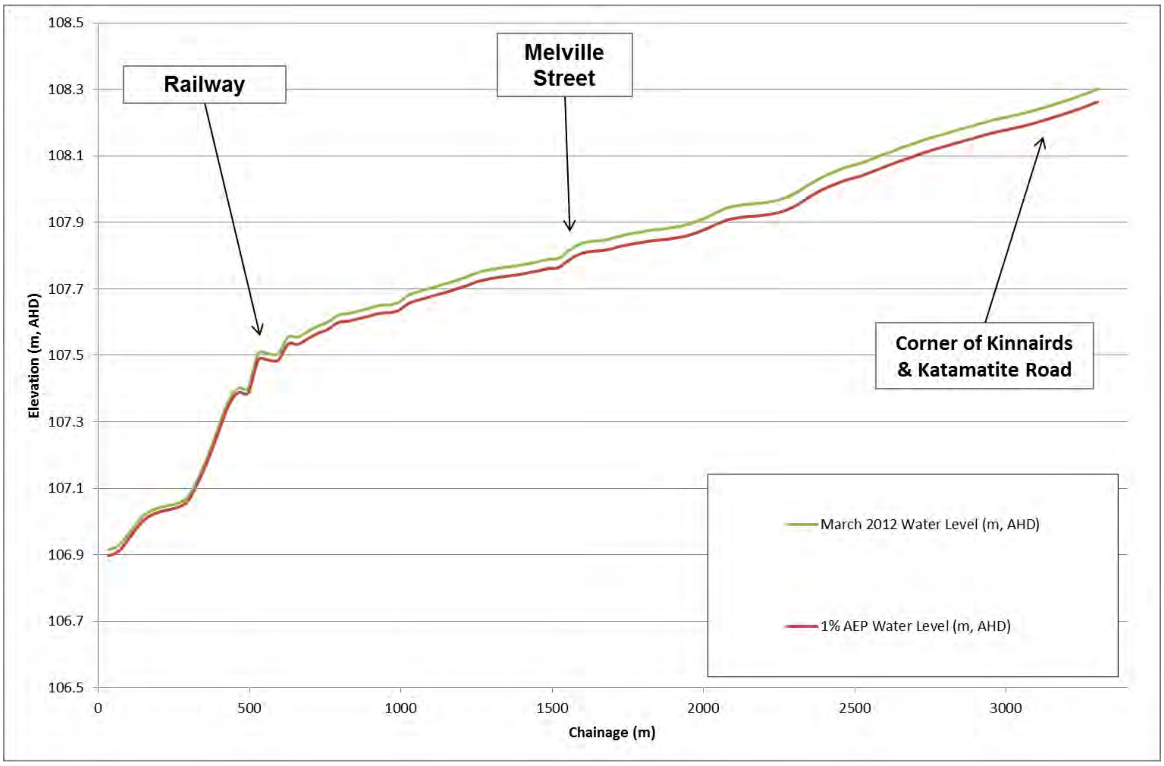


Figure 11-20 Longitudinal profile along the Hospital Depression and Broken Creek

11.6.6 Summary of Comparisons

This section demonstrated that the modelled flood behaviour of the March 2012 and 1% AEP event was generally quite similar with the 1% AEP being marginally lower in terms of peak flood levels and velocities and with a reduced flood extent. It has also demonstrated that a number of properties experience flood levels very close to floor level in the 1% AEP event, with an additional 26 buildings being flooded above floor in the March 2012 despite relatively small increases in flood levels. The total number of properties flooded in the 1% AEP is significantly greater than the March 2012 event due to the inclusion of areas of inundation in the 1% AEP extent that were protected by temporary works in the March 2012 event.

11.7 Numurkah Flow Distribution

Figure 11-21 below displays the breakup of flows through Numurkah in the 1% AEP event. It can be seen that there are three distinct flow paths which consist of Broken Creek through central Numurkah, a primary southern flow path (which includes the hospital depression) and a secondary southern flow path further to the south-east. The largest flow path is the primary southern flow path with a peak flow of approximately 18,000 ML/d in the 1% AEP event.

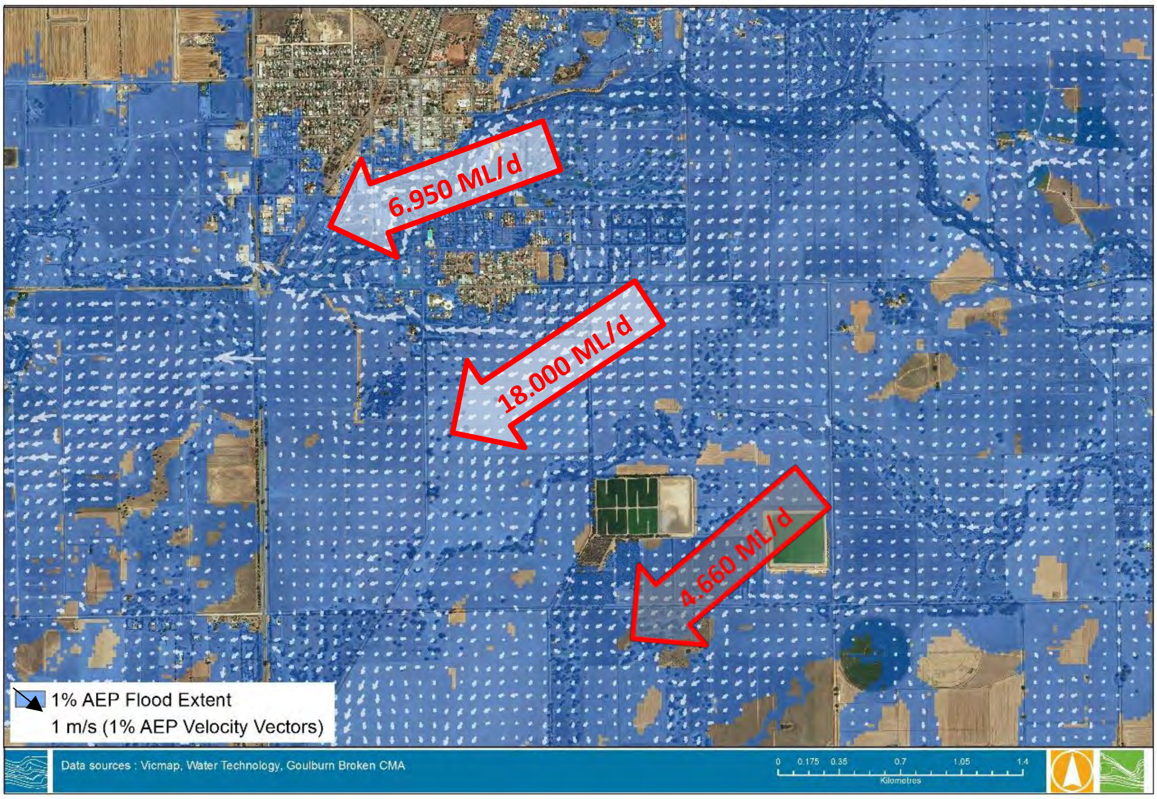


Figure 11-21 1% AEP peak flows at key flow paths across floodplain near Numurkah

11.8 Hydraulics Summary

To complete the hydraulic modelling phase of the Numurkah Floodplain Management Study a 1D/2D Mike FLOOD hydraulic model was constructed. The model was calibrated to the March 2012 and October 1993 historic events and a full range of design events were run using the flows determined in the hydrology phase of the project.

The hydraulic model was calibrated against observed flood levels and extents in the March 2012 and October 1993 flood events. The calibration of the March 2012 event was considered excellent while the October 1993 calibration was not as close but still considered a very good calibration. The modelling demonstrates that the events were quite different in nature which correlates with observations that the March 2012 was a much larger and more damaging event. Overall the hydraulic models provided a very good representation of the historic events which impacted Numurkah.

Flood mapping deliverables consisted of hardcopy plans, along with digital PDF maps showing flood extents, depth, velocity and hazard. The flood mapping provided significantly more detail than any previous mapping of the study area. The outputs will be used to better manage development within the study area, and also predict and manage flood conditions during times of emergency.

12. FLOOD MITIGATION OPTIONS

This section provides an overview of the mitigation options available to reduce the flood risk and flood damages in Numurkah. The options are divided into structural and non-structural mitigation options.

12.1 Structural Mitigation Options

12.1.1 Overview

This section provides an assessment of potential structural flood mitigation measures for the township of Numurkah. These are made up of community-suggested options as well as options suggested by the CRG, Council, CMA and Water Technology. All options were considered for detailed assessment, and a large number of options were tested in preliminary modelling to better understand their impact in reducing flood risk in Numurkah. Following this process, which included a number of meetings with the Reference Group and a period of community consultation, options which were feasible and effective in reducing flood risk were included in the final mitigation packages for detailed modelling.

12.1.2 Preliminary Modelling

A large number of individual options and combination of options were tested prior to the final packages of mitigation works being selected. Further detail regarding the various options tested and modelling results can be found in Appendix A. The range of options tested included:

- Formalising the levee along northern bank of Broken Creek (various alignments trialled).
- Southern levee protecting the southern residential areas (various alignments trialled).
- Eastern levee protecting Brooke Court and southern residential areas (various alignments trialled).
- Removal of disused irrigation channel banks to the south-west of Numurkah near the hospital depression.
- A range of culvert and bridge upgrades including extensive banks of culverts under the railway line and Goulburn Valley Highway.
- Floodway near the Train Park and Melville Street bridge (various alignments and geometries trialled).
- Earthworks to levee banks upstream of Numurkah near the Numurkah Go Kart Track.
- Removal and/or lowering of the railway line and Goulburn Valley Highway to natural surface level.
- Lowering of high ground in the vicinity of the Numurkah football club to reduce hydraulic constrictions in that area.

Based on the results of preliminary mitigation modelling and an extensive period of consultation with the CRG, and general community through a public meeting and one-on-one meetings, three final recommend packages of mitigation works were determined and are described below.

12.1.3 Extended Hydraulic Model

A number of preliminary mitigation runs demonstrated that the existing hydraulic model had insufficient coverage to fully assess the impact of some mitigation options upstream of Numurkah. As a result of the very low gradients in the topography and flood water levels through these areas, increases in water levels at Numurkah can extend for a significant distance upstream. It was deemed that additional model coverage was needed upstream of Numurkah, particularly to the north and north-east of Numurkah, to properly assess the impacts of potential mitigation works. To achieve this, additional laser survey (LiDAR) was funded and commissioned by DELWP and this new dataset allowed the hydraulic model to be extended. The extended model extent compared to the previous model extent is shown in Figure 12-1. The new model provides additional coverage not only to the north-east of Numurkah but also through the central township where previously the model was limited by LiDAR availability. The model was also been extended to the east to just upstream of the confluence of Broken and Boosey Creeks. The hydrographs were modified to account for the new Broken Creek location based on the previous hydrological analysis which considered the timing and attenuation between the confluence of Broken and Boosery Creeks and the previous inflow location.

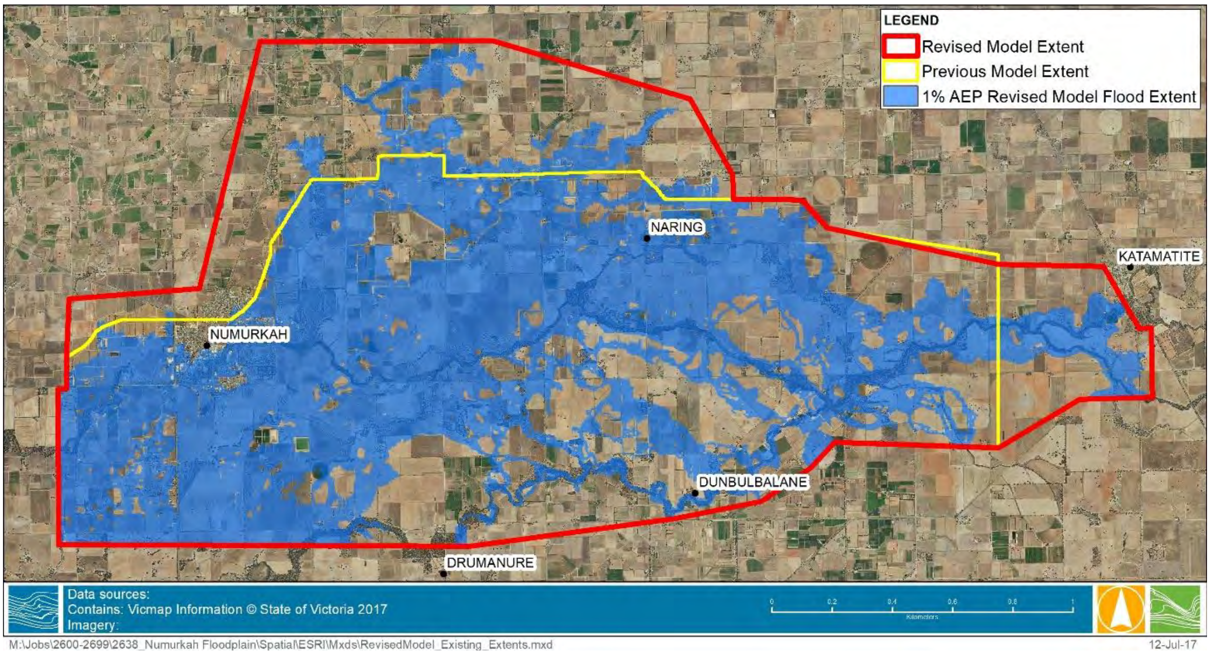


Figure 12-1 Comparison of revised model extent to existing model

Extended Model Validation

To validate the extended model results, the flood levels were compared against the original model which had undergone a significant calibration process to the October 1993 and March 2012 events.

A difference plot comparing the revised and previous model extents for the 1% AEP event is shown in Figure 12-2. It can be seen that a very close match occurs throughout central Numurkah with differences of less than 10 mm. Some significant differences in flood levels can be seen in the northern part of the township. This is a result of insufficient LiDAR coverage in the previous hydraulic model which artificially restricted the flow of flood water through this area. Based on the validation process described above the model was deemed appropriate for design and mitigation modelling.

Extended Model Scenarios

The extended model was used to test a number of mitigation works and packages. Based on discussions with the CRG and key agency stakeholders, three final mitigation packages were modelled for the full range of design events and are presented below.

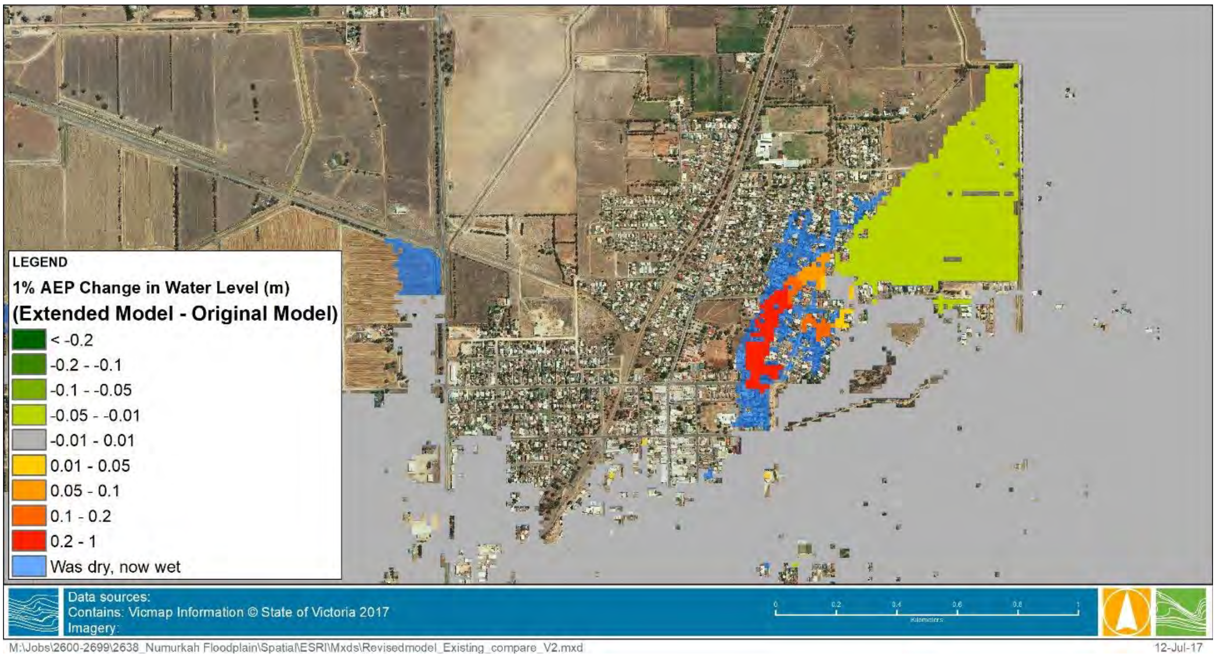


Figure 12-2 Difference plot comparing revised 1% AEP results to previous results

12.2 Final Mitigation Packages

Following extensive consultation with the CRG and key agency stakeholders, three final flood mitigation packages were developed which consist of three different levee arrangements for the town. These packages were modelled in the extended hydraulic model and the key components of the modelling and results are described below.

12.2.1 Final Mitigation Package A – Northern Levee and Southern Ring Levee (which protects the smaller southern residential areas, caravan park and football and golf clubrooms)

The key components of the final Mitigation Package A are shown in Figure 12-3 and Figure 12-4 and consist of:

- Construction of a northern levee extending from the Goulburn Valley Highway, along the northern bank of Broken Creek, across Melville Street near the central township and along the alignment of the existing irrigation channel banks adjacent to Kinnairds Road to the east of the township. The Brooke Court area is included within the levee. The northern levee would be constructed with 300 mm of freeboard above the 1% AEP water level. The irrigation channel banks to the east, which currently provide a level of protection in large events, would need to be replaced and/or upgraded to new design standards. The constructed levee would be 4.5 km in length and have an average height of 0.8 metres. Moira Shire Council would be the construction authority for the levee, which includes management of the operation and maintenance plan.
- A southern ring levee which encompassed the smaller lots in the southern residential area, the caravan park, the football clubrooms and football ground and approximately half of the golf course. The levee extends as far east as Corke Street. The ring levee was assumed to be predominantly an earthen levee with some sections of raised road along Tunnock Road, Corke Street and Katamatite Road.
- An earthen ring levee protecting several properties in the hospital depression.
- Broken Creek channel enlargement in the vicinity of the caravan park, Melville Street, skate park and football club to reduce the hydraulic constriction that occurs through that area.
- Floodways across the Katamatite-Nathalia Road at two locations - at the lower end of the Hospital Depression and at the upper end of the depression 400 metres to the east of the intersection with Kinnaird's Road. In order to ensure safe access to the southern residential areas during flood event, a culvert/bridge structure may replace the western floodway and this will be determined during detailed design. Safe access will be required to ensure the Numurkah District Health Service and Ambulance Station are accessible during flood events. The issue of access is discussed further in Section 12.2.5
- There are a total of nine locations where the northern and southern levees would cross minor roads or access tracks and a system of headwalls and drop boards, flood gates or raised trafficable crossings would be required at those points. Removal of earthen embankments to the east of Numurkah in the vicinity of the Go Kart Track.
- Installation of non-return valves on all major stormwater outlets into Broken Creek from the northern and southern sections of the township. This is to ensure flood water does not back up in large flood events resulting in flood water on the protected side of the levee.

This package of works has been costed and the total capital cost is estimated to be $16,935,000 (ex. GST) (inclusive of land acquisition, contingencies, admin and engineering). The cost excludes any local mitigation measures that might be required as a result of the increased water levels upstream and downstream of Numurkah.

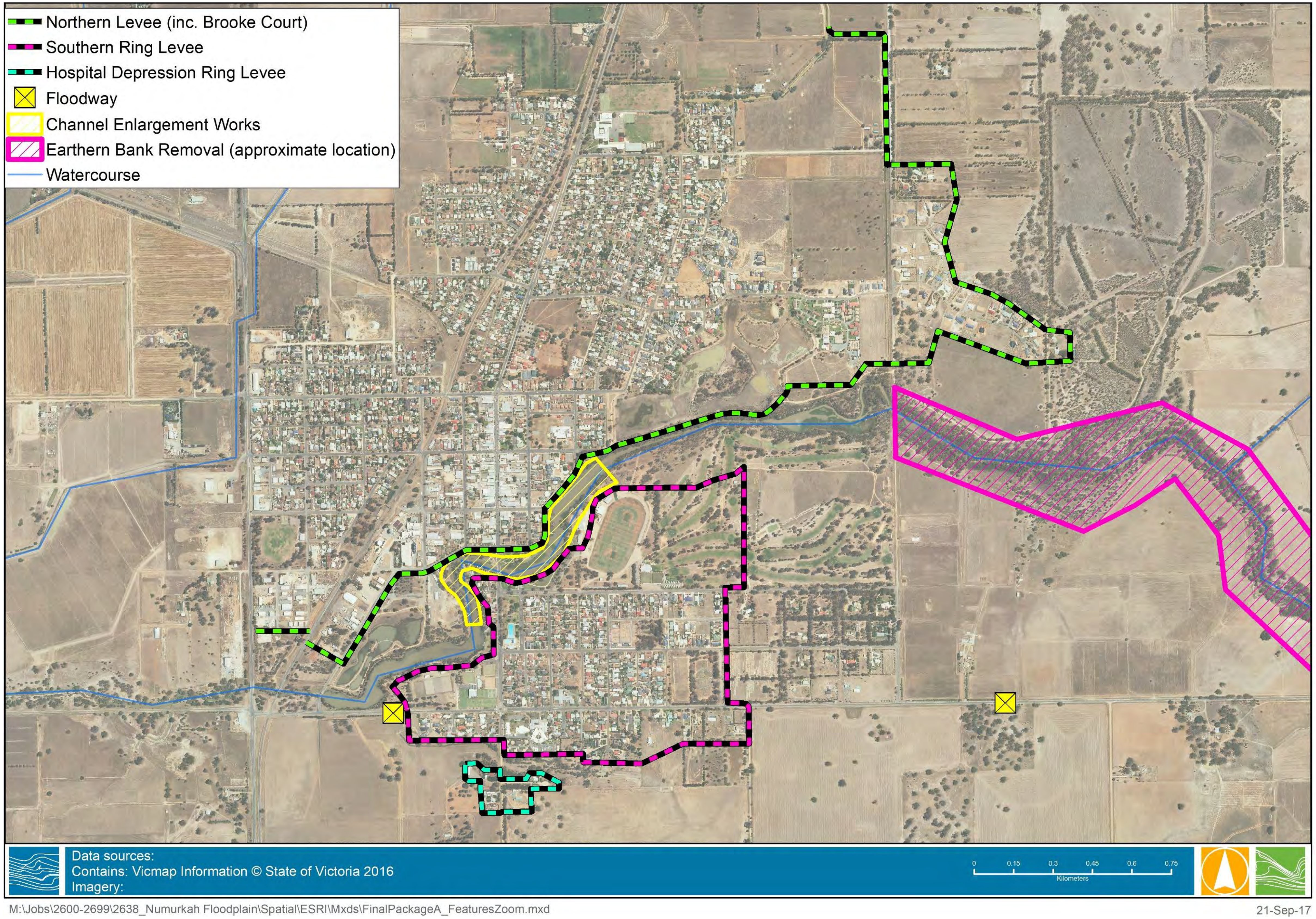


Figure 12-3 Final Mitigation Package A Options – town view

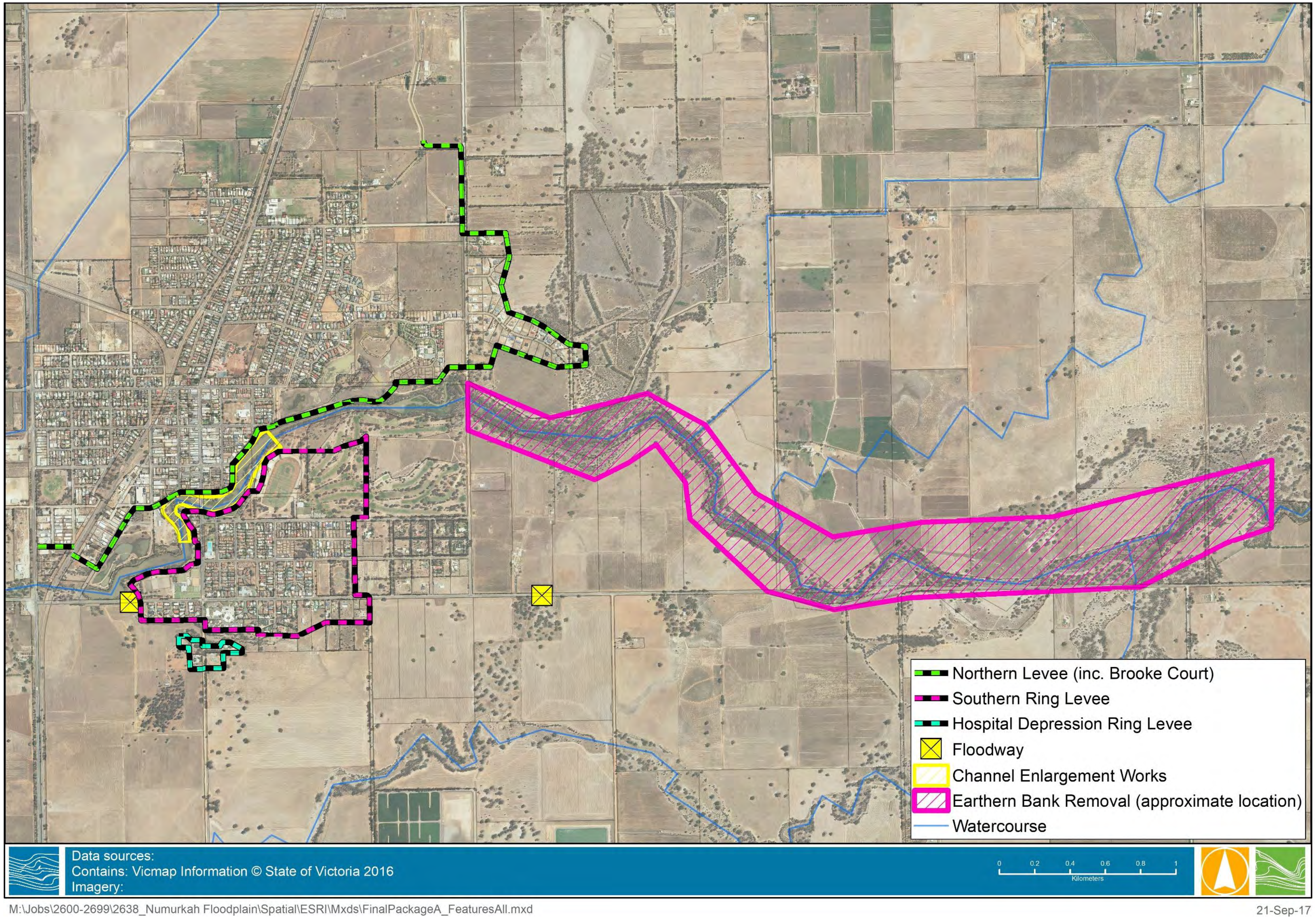


Figure 12-4 Final Mitigation Package A Options – floodplain view

Final Mitigation Package A Results

The scenario was modelled for full range of design events. The results for the 1% AEP event are shown below in Figure 12-5, Figure 12-6 and Figure 12-7. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all of the smaller southern residential lots and all properties in Numurkah township to the north of Broken Creek including those on and around Brooke Court.
- Water levels upstream of the levee systems are increased by generally 50 to 65 mm. These impacts extend for approximately 2.8 km to the east and 5.2 km to the north up into the Muckatah Depression. Water levels also increase across the floodplain to the south of Numurkah with increases of more than 10 mm likely to extend to Wunghnu.
- Increased water levels of up to 100 mm within Numurkah immediately to the east of the southern levee through the larger, southern residential lots. Most buildings through this area are built up, however there is one property at 2547 Katamatite-Nathalia Road which would flood above floor with this scenario but doesn't under existing conditions. Local measures would be required to mitigate the impact to this property. In addition, the Municipal Flood Emergency Plan (MFEP) will need to include specific actions for this property and others in this area impacted by inundation.
- Moderate increases in water levels of 10 to 50 mm between the north and south levees upstream of Melville Street including through the golf course.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 20 to 50 mm downstream of the Goulburn Valley Highway extending for approximately 2 km.
- 10 to 50 mm increase in flood levels downstream of the Goulburn Highway south of Sampsons Road.
- During a 1% AEP event, the package reduces the total number of properties inundated from 834 properties to 74 properties, with the number of properties flooded above floor reduced from 125 to 6.

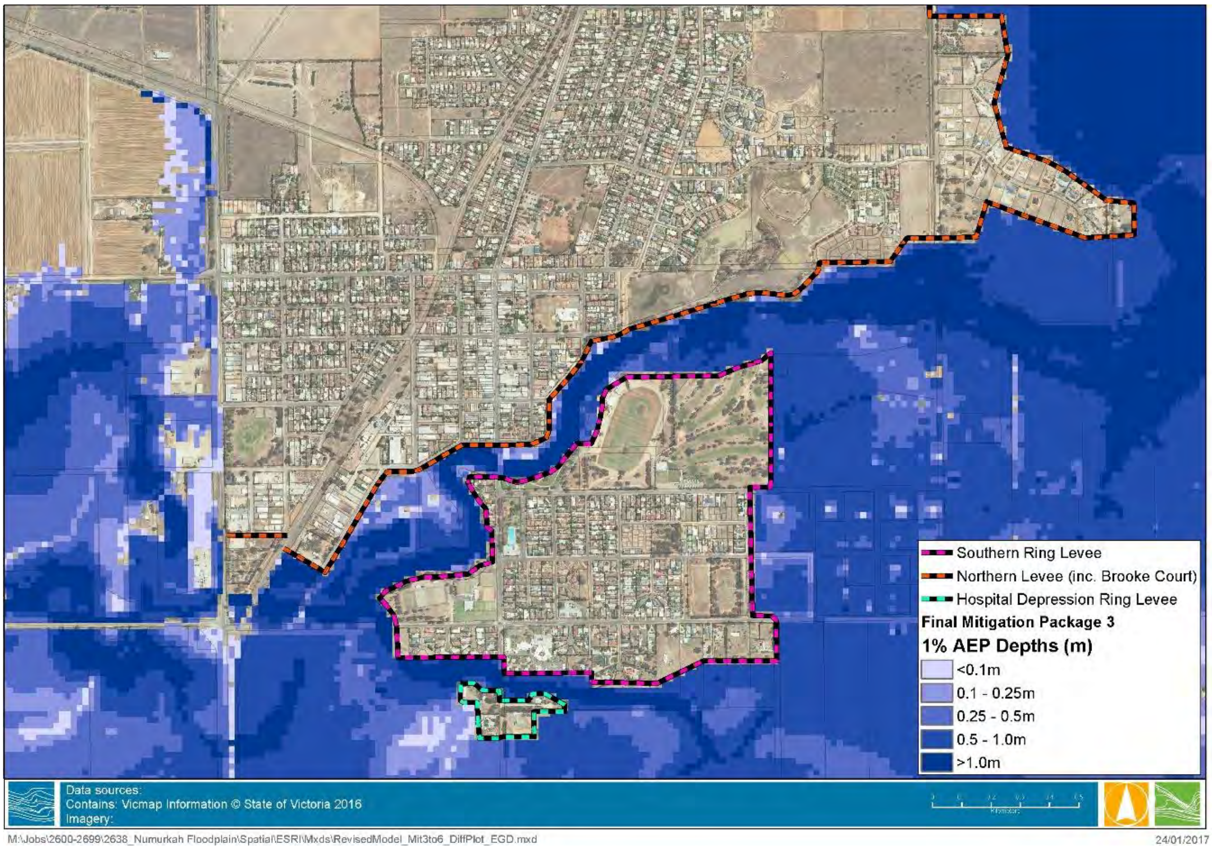


Figure 12-5 Final Mitigation Package A - 1% AEP depth results

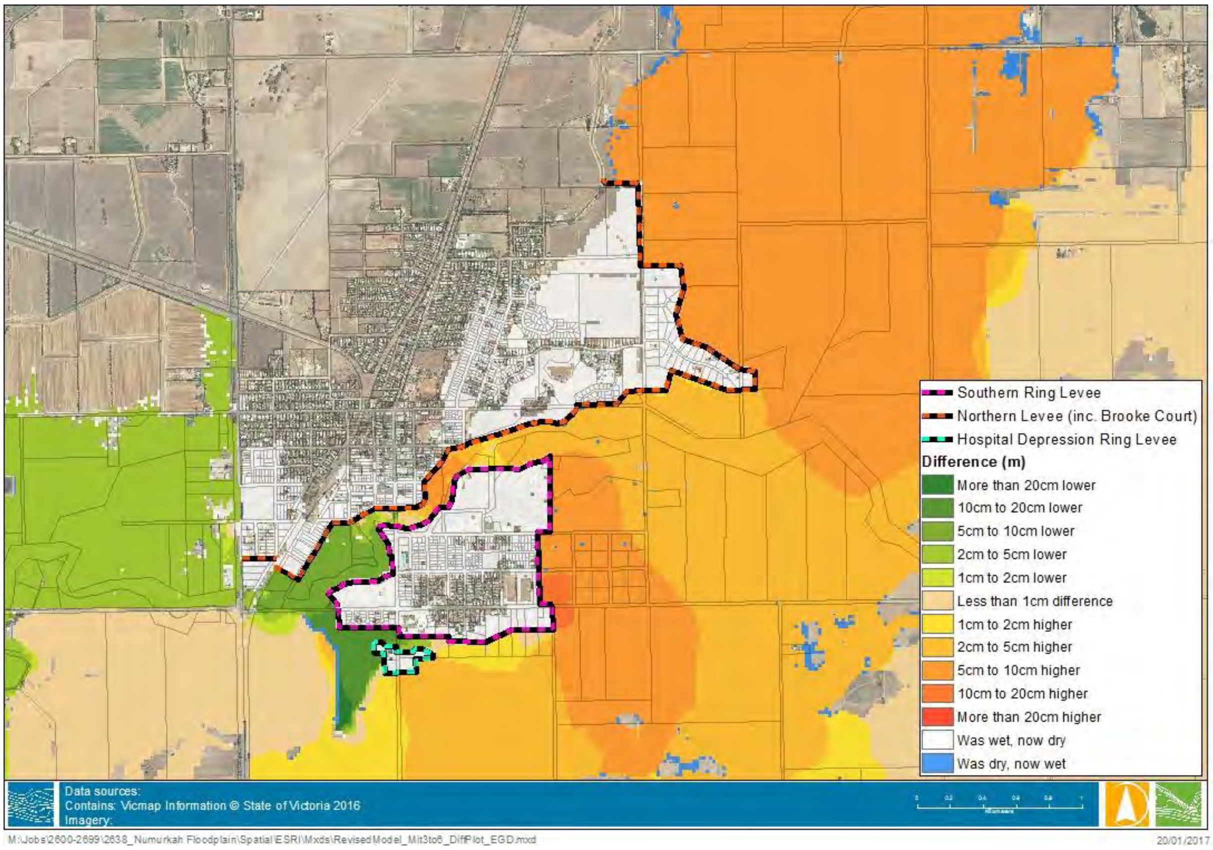


Figure 12-6 Final Mitigation Package A - 1% AEP Difference Plot – Zoom View

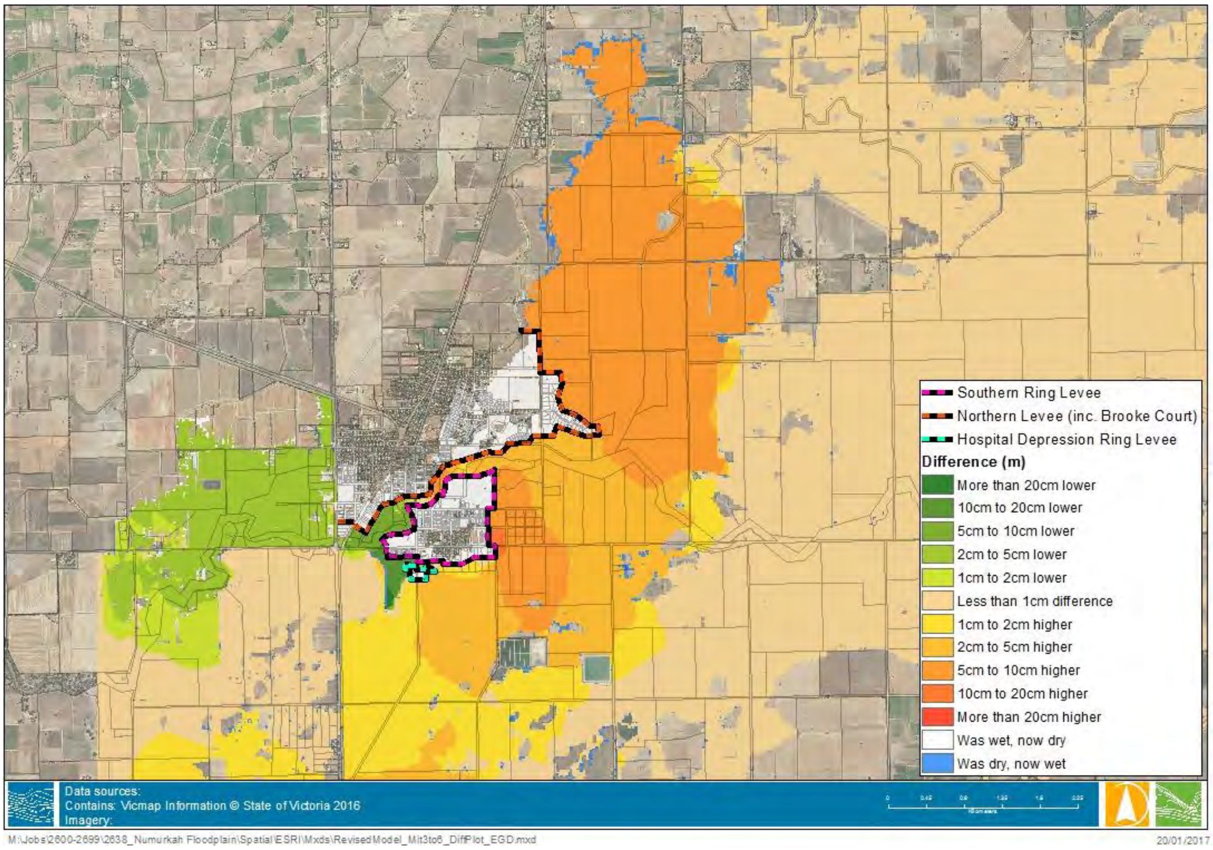


Figure 12-7 Final Mitigation Package A - 1% AEP Difference Plot

Final Mitigation Package A Summary

Overall it can be seen that the final Mitigation Package A protects a significant proportion of residential properties through Numurkah but with moderate impacts to the south, east and north-east of the levee systems which extend for more than 5 kilometres.

The increased water levels are marginally greater than final Mitigation Package B and extend for a greater distance across the floodplain. One additional property would become flooded above floor within Numurkah at 2547 Katamatite-Nathalia Road. Flooding would be made worse for several properties within Numurkah as well as properties in outlying areas. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying areas.

Detailed costings for this package are provided in Section 14 and Appendix B.

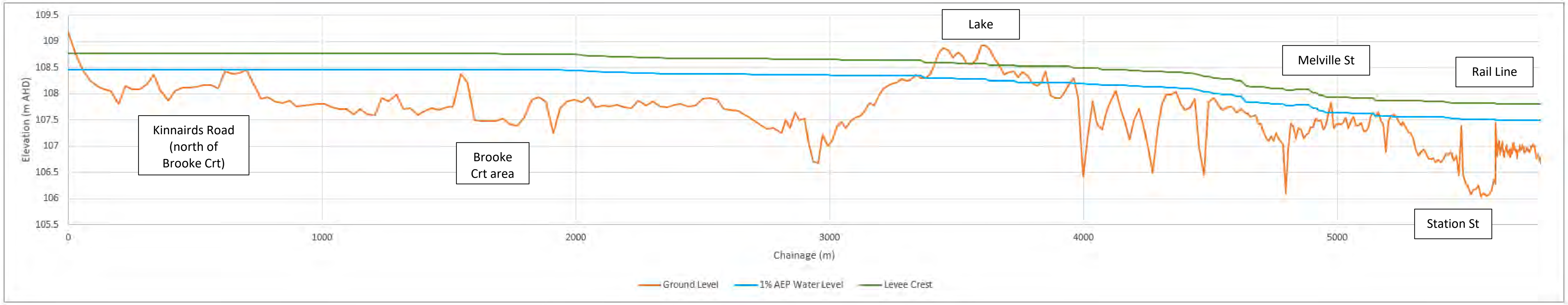


Figure 12-8 Long-section along northern levee alignment for Mitigation Package A

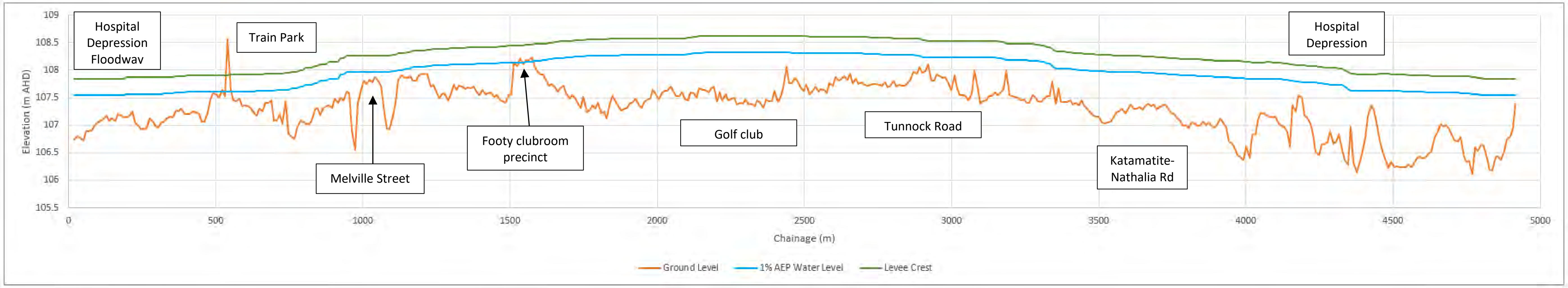


Figure 12-9 Long-section along southern levee alignment for Mitigation Package A

12.2.2 Final Mitigation Package B – Northern Levee and Southern Ring Levees (which protects the smaller southern lots) (Scenario 3)

Overview

The key components of the final Mitigation Package B are shown in Figure 12-10 and Figure 12-11 and consists of:

- The northern levee as per Final Mitigation Package A with Brooke Court included within the levee.
- A southern ring levee which encompasses all of the smaller residential lots in the southern residential area. The levee alignment generally follows existing roads and so it has been assumed that much of the levee would occur from the raising of roads. Other options such as temporary flood barriers placed along the roadways could also be considered. The larger residential lots to the east were excluded from the levee. Most of these houses are built up and did not flood above floor in the March 2012 event.
- Ring levee protecting several properties from 160-172 Melville Street and the caravan park residence. This ring levee will allow the flow of water to continue across Melville Street and through the train park and reduces the constriction that occurs at the Melville Street Bridge. An unoccupied house at 174 Melville Street was excluded from this ring levee in the modelling however it is understood the house has recently been demolished and a new dwelling may be constructed but raised above flood level. The inclusion or exclusion of this dwelling within the levee would need to be considered as part of the functional and detailed design phase.
- An earthen ring levee protecting several properties in the hospital depression.
- Ring levee or flood wall around the football club clubrooms
- Broken Creek channel enlargement in the vicinity of the caravan park, Melville Street, skate park and football club to reduce the hydraulic constriction that occurs through that section of Broken Creek.
- Floodways across the Katamatite-Nathalia Road at two locations - at the lower end of the Hospital Depression and at the upper end of the hospital depression 400 metres to the east of the intersection with Kinnairds Road. In order to ensure safe access to the southern residential areas during flood event, a culvert/bridge structure may replace the western floodway and this will be determined during detailed design. Safe access will be required to ensure the Numurkah District Health Service and Ambulance Station are accessible during flood events. The issue of access is discussed further in Section 12.2.5.
- There are a total of nine locations where the northern and southern levees would cross minor roads or access tracks and a system of headwalls and drop boards, flood gates or raised trafficable crossings would be required at those points.
- Removal of earthen embankments to the east of Numurkah in the vicinity of the Go Kart Track.
- Installation of non-return valves on all major stormwater outlets into Broken Creek from the northern and southern sections of the township. This is to ensure flood water does not back up in large flood events resulting in flood water on the protected side of the levee.

This package of works has been costed and the total capital cost is estimated to be $23,102,000 (ex. GST) (inclusive of land acquisition, contingencies, admin and engineering). The cost excludes any local mitigation measures that might be required as a result of increased water levels upstream and downstream.

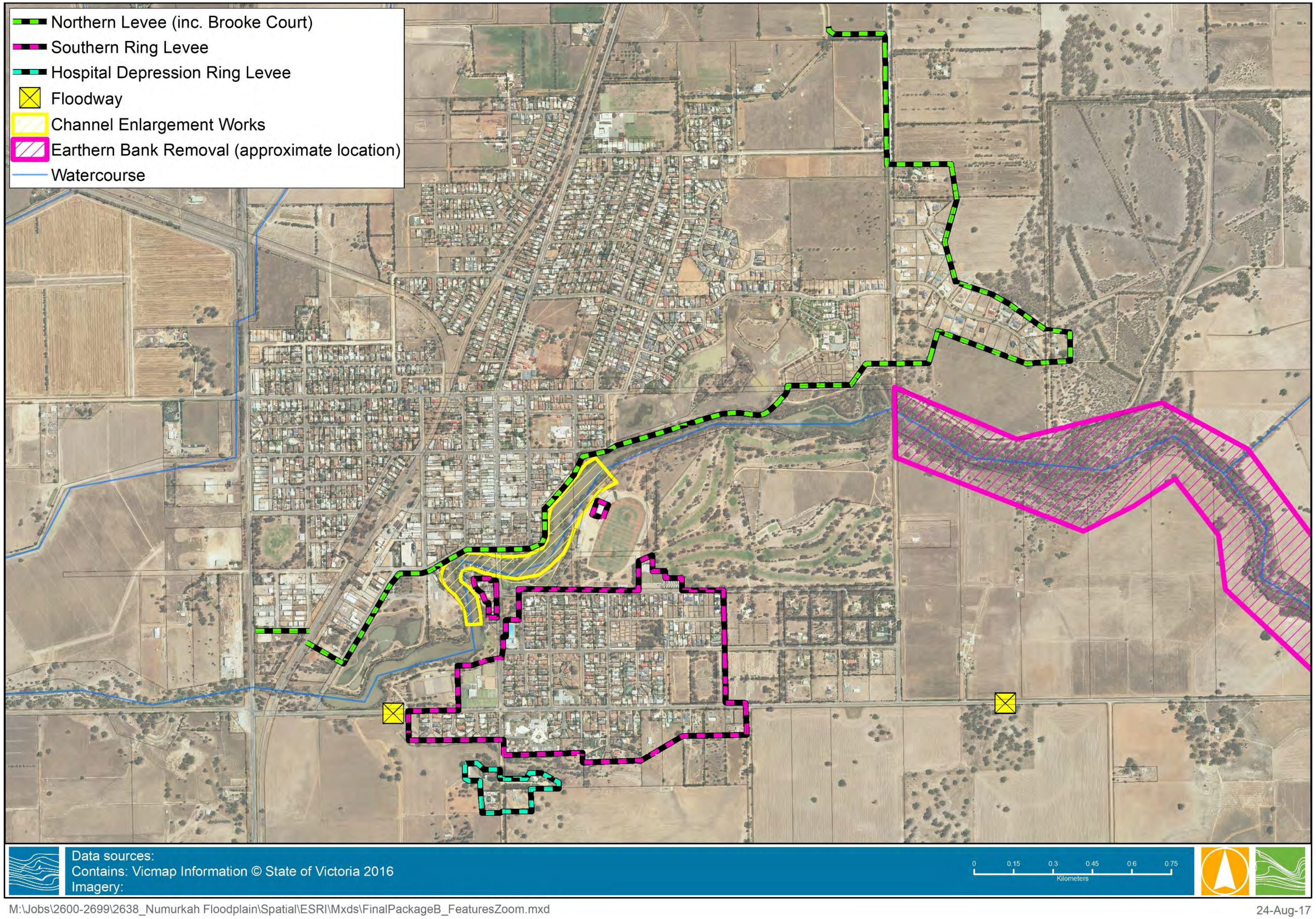


Figure 12-10 Final Mitigation Package B Options – town view

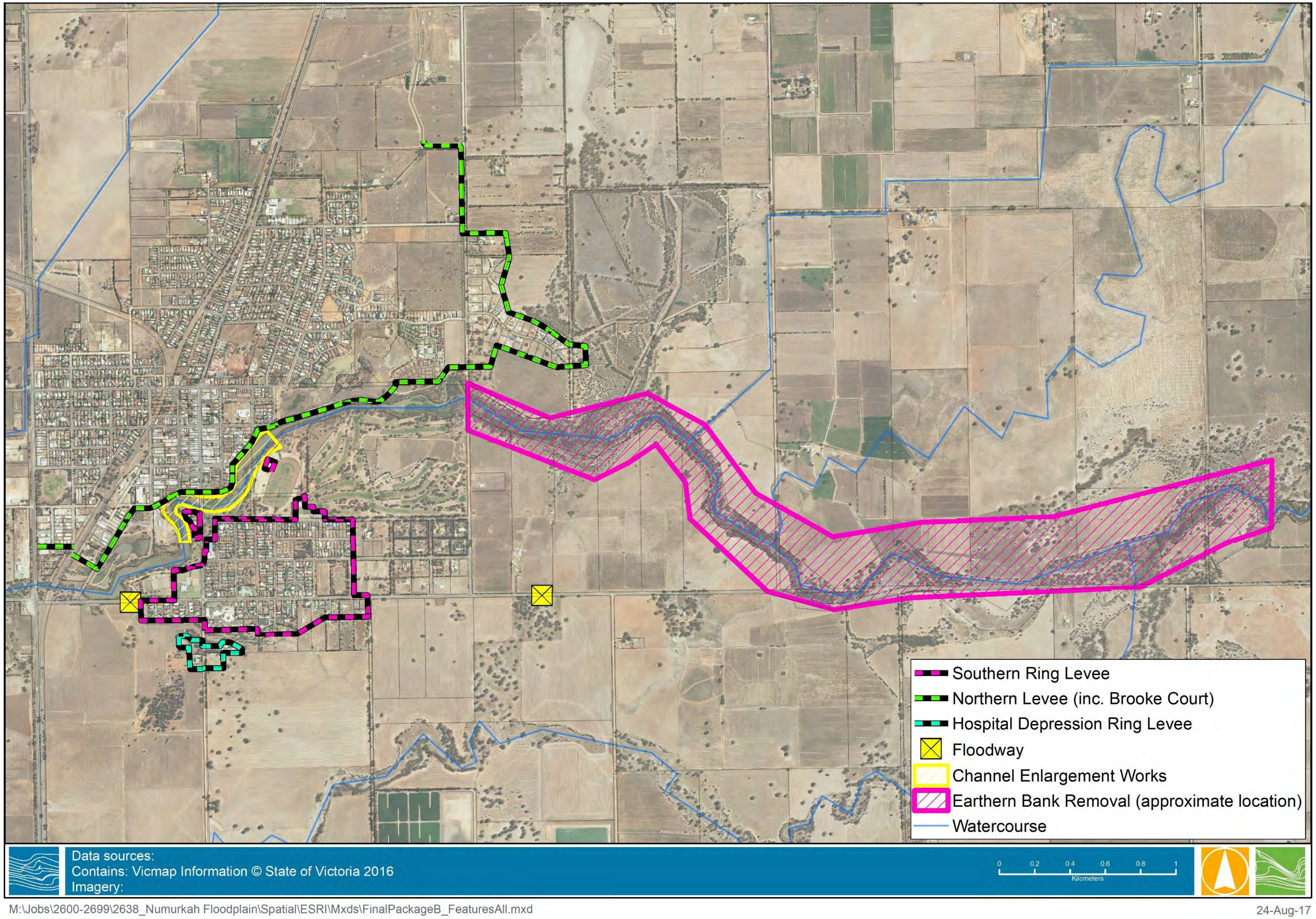


Figure 12-11 Final Mitigation Package **B Options – floodplain view**

Final Mitigation Package B Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 12-12 and Figure 12-13 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all of the smaller, southern residential lots and all properties in Numurkah township to the north of Broken Creek excluding those at Brooke Court. It is of note that whilst outside of the levee the larger southern residential properties have floor levels built up and there would be no above floor flooding at these properties under existing or Package B mitigated conditions. Nonetheless, the Municipal Flood Emergency Plan (MFEP) will need to include specific actions for properties in this area which are impacted by inundation.
- Water levels upstream of the levee systems are increased by generally 20-50 mm with the largest impacts to the north of the Brooke Court levee. These impacts extend for approximately 2.8 km to the east and 5.2 km to the north up into the Muckatah Depression. Water levels increase for approximately 1.3 km across the floodplain to the south of Numurkah. The impacts to the south are considerably less than Package A.
- Minor increases in water levels of 10-30 mm between the north and south levees upstream of Melville Street including through the golf course and football oval areas. The impacts through this area are less than Package A.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 20-30 mm downstream of the Goulburn Valley Highway extending for approximately 3.2 km.

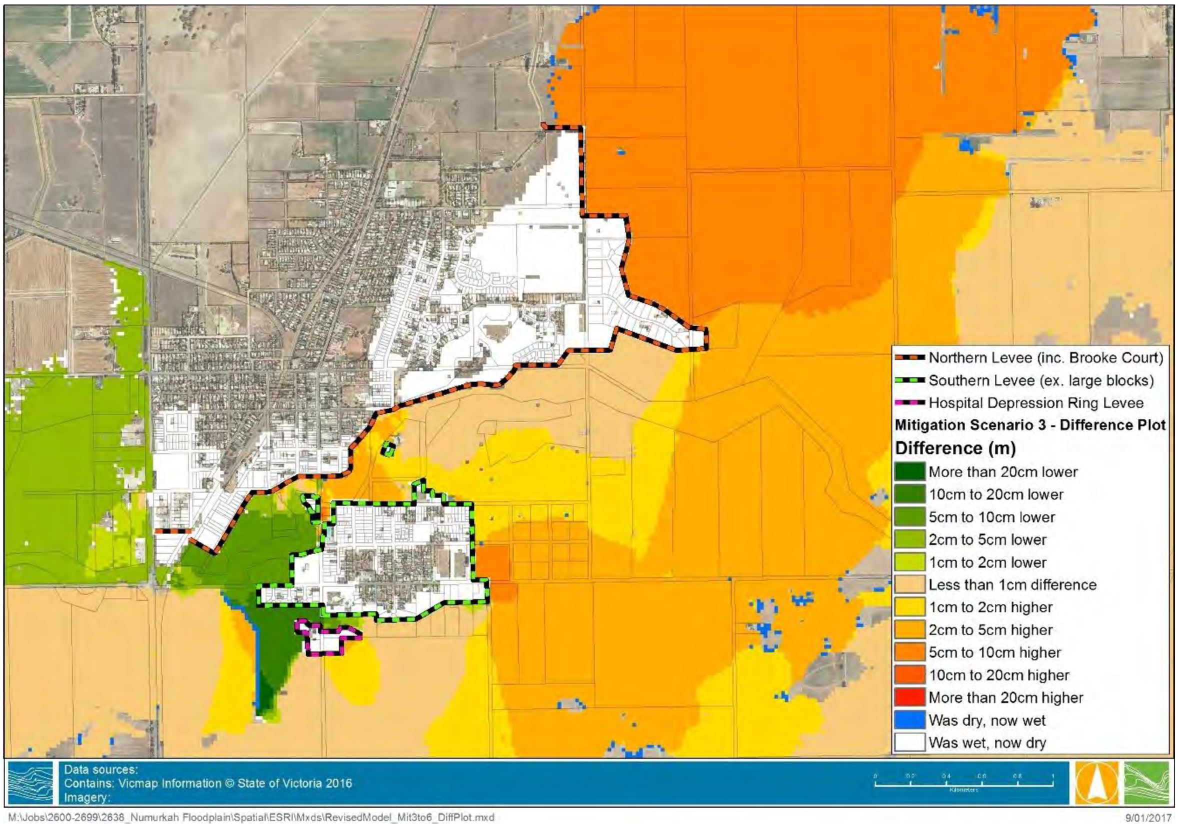


Figure 12-12 Final Mitigation Package B - 1% AEP Difference Plot – Zoom View

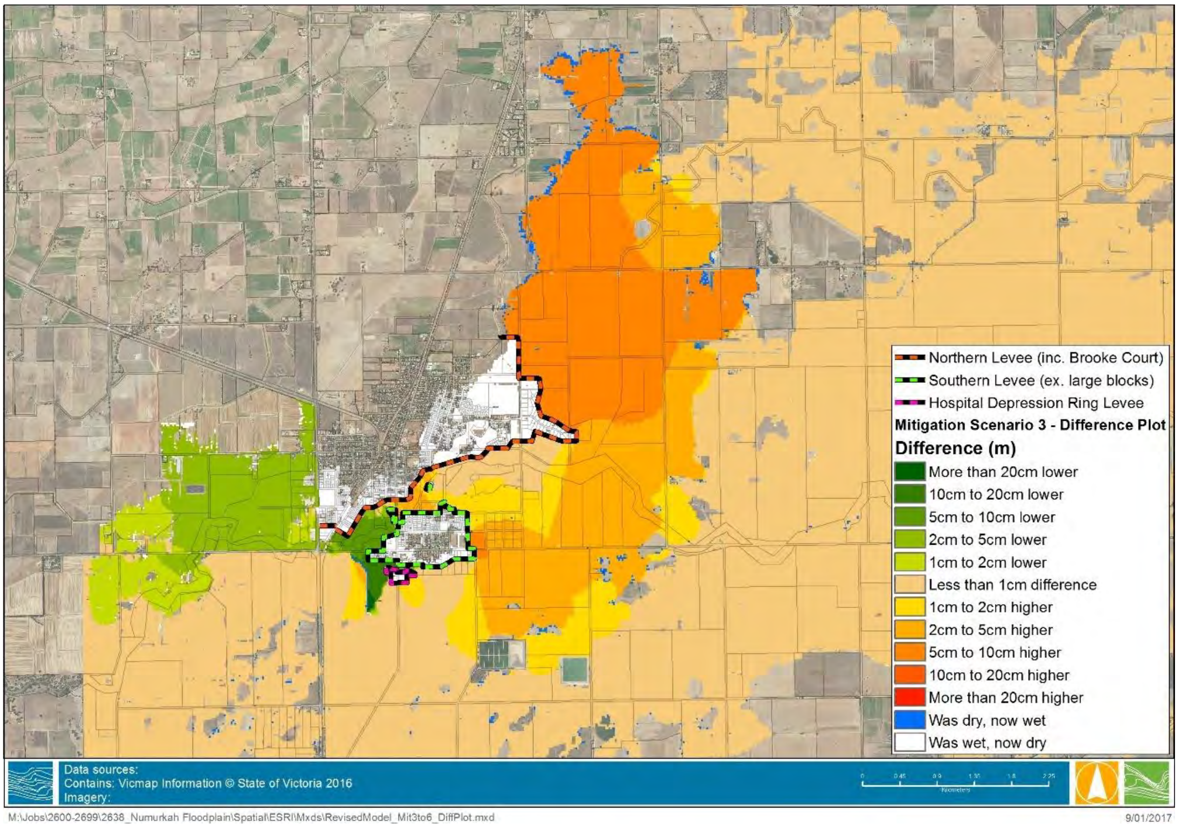


Figure 12-13 Final Mitigation Package B - 1% AEP Difference Plot – Floodplain View

Final Mitigation Package B Summary

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah with less impacts than Package A but more impacts than Package C. Upstream water levels are generally 30-50 mm higher to the east and north-east of Numurkah. The impacts do not extend as far across the floodplain to the south of Numurkah as Package A. Above floor flooding would not be made worse for properties within Numurkah however there are some properties in outlying rural areas that would be impacted. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

The impacts upstream of the township are significant and local mitigation options would need to be further investigated if this option was to be implemented. This would occur as part of a functional and detailed design phase.

Detailed costings for this package are provided in Section 14 and Appendix B.

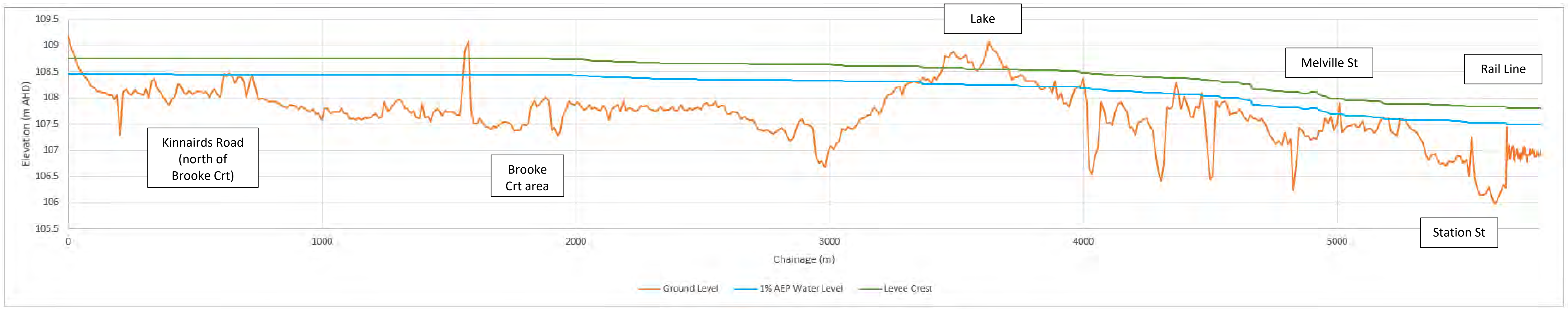


Figure 12-14 Long-section along northern levee alignment for Mitigation Package B

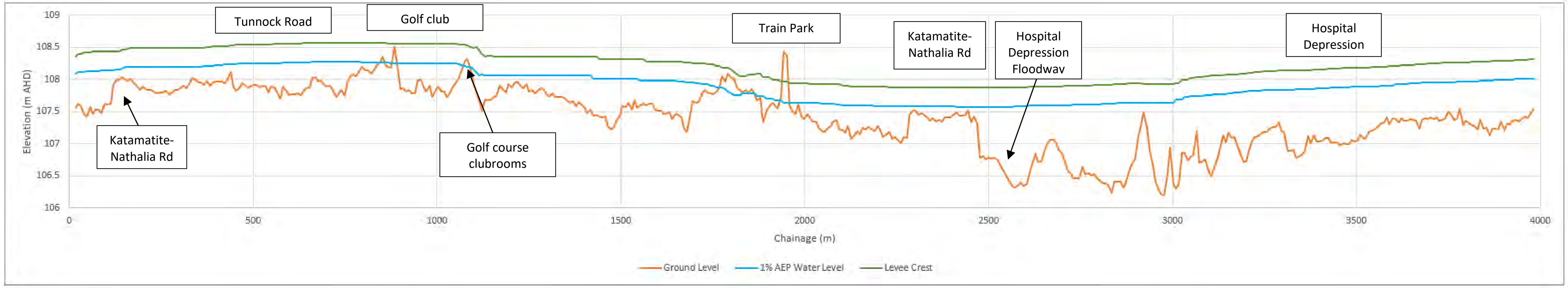


Figure 12-15 Long-section along southern levee alignment for Mitigation Package B

12.2.3 Final Mitigation Package C – Northern Levee and Southern Ring Levees (which protect all southern residential lots)

Overview

The key components of the final Mitigation Package C are shown in Figure 12-16 and Figure 12-17 and consists of:

- The northern levee as per Mitigation Package A with Brooke Court included within the levee.
- A southern ring levee which encompasses both the smaller and larger residential lots through the southern residential area. The levee alignment generally follows existing roads and so it has been assumed that much of the levee would occur from the raising of roads. Other options such as temporary flood barriers placed along the roadways could also be considered.
- Ring levee protecting several properties from 160-172 Melville Street and the caravan park residence. This ring levee will allow the flow of water to continue across Melville Street and through the train park and reduces the constriction that occurs at the Melville Street Bridge. The unoccupied house at 174 Melville Street has been excluded from this ring levee and it is assumed in this scenario that the property would be acquired and form part of the flow path across Melville Street.
- An earthen ring levee protecting several properties in the hospital depression.
- Ring levee or flood wall around the football club clubrooms
- Broken Creek channel enlargement in the vicinity of the caravan park, Melville Street, skate park and football club to reduce the hydraulic constriction that occurs through that section of Broken Creek.
- Floodways across the Katamatite-Nathalia Road at two locations - at the lower end of the Hospital Depression and at the upper end of the hospital depression 400 metres east of the intersection with Kinnairds Road. In order to ensure safe access to the southern residential areas during flood event, a culvert/bridge structure may replace the western floodway and this will be determined during detailed design. Safe access will be required to ensure the Numurkah District Health Service and Ambulance Station are accessible during flood events. The issue of access is discussed further in Section 12.2.5.
- There are a total of nine locations where the northern and southern levees would cross minor roads or access tracks and a system of headwalls and drop boards, flood gates or raised trafficable crossings would be required at those points.
- Removal of earthen embankments to the east of Numurkah in the vicinity of the Go Kart Track.
- Installation of non-return valves on all major stormwater outlets into Broken Creek from the northern section of the township. This is to ensure flood water does not back up in large flood events resulting in flood water on the protected side of the levee.

This package of works has been costed and the total capital cost is estimated to be $25,487,000 (ex. GST) (inclusive of land acquisition, contingencies, admin and engineering). The cost excludes any local mitigation measures that might be required as a result of increased water levels upstream and downstream.

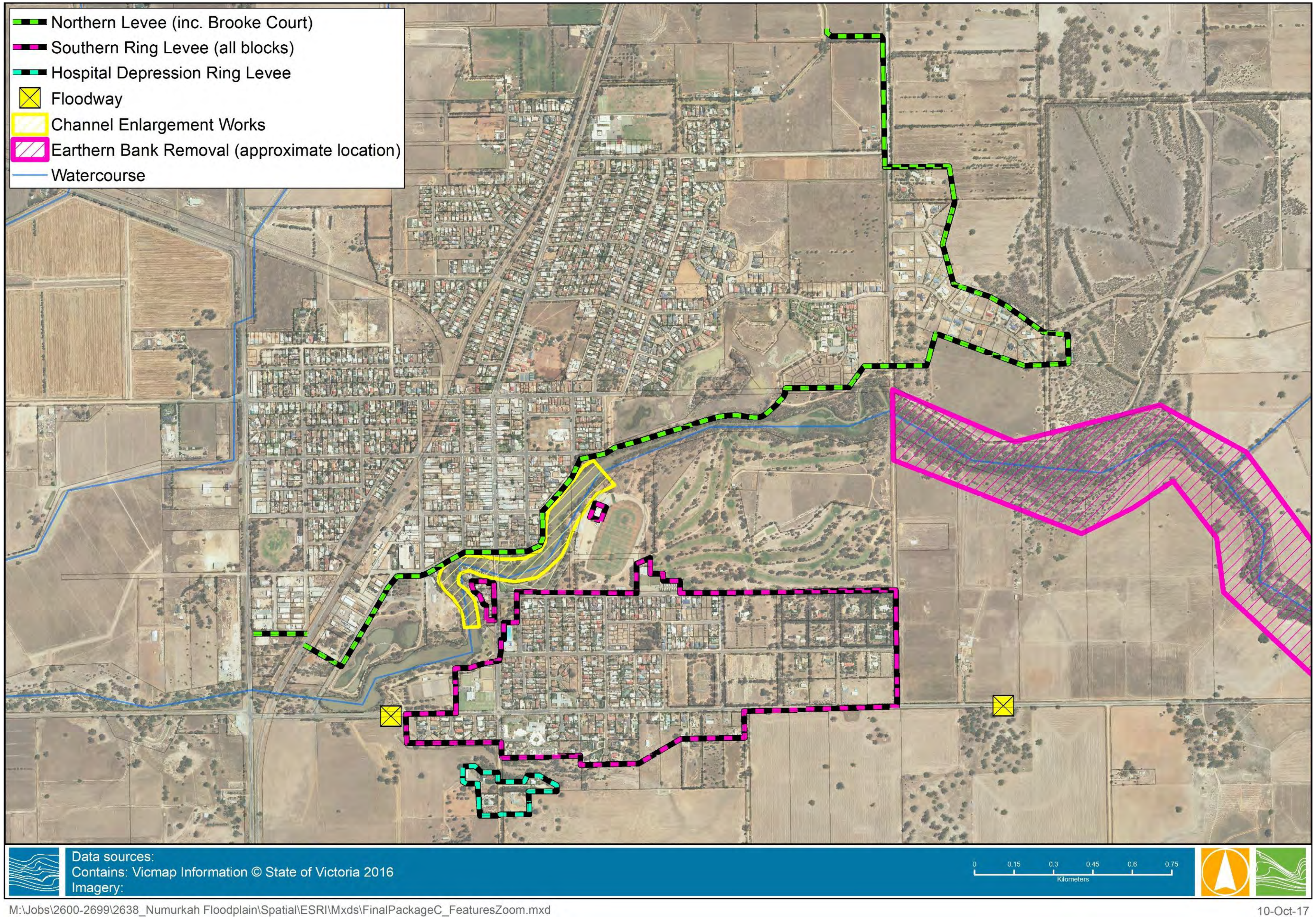


Figure 12-16 Final Mitigation Package C Options – town view

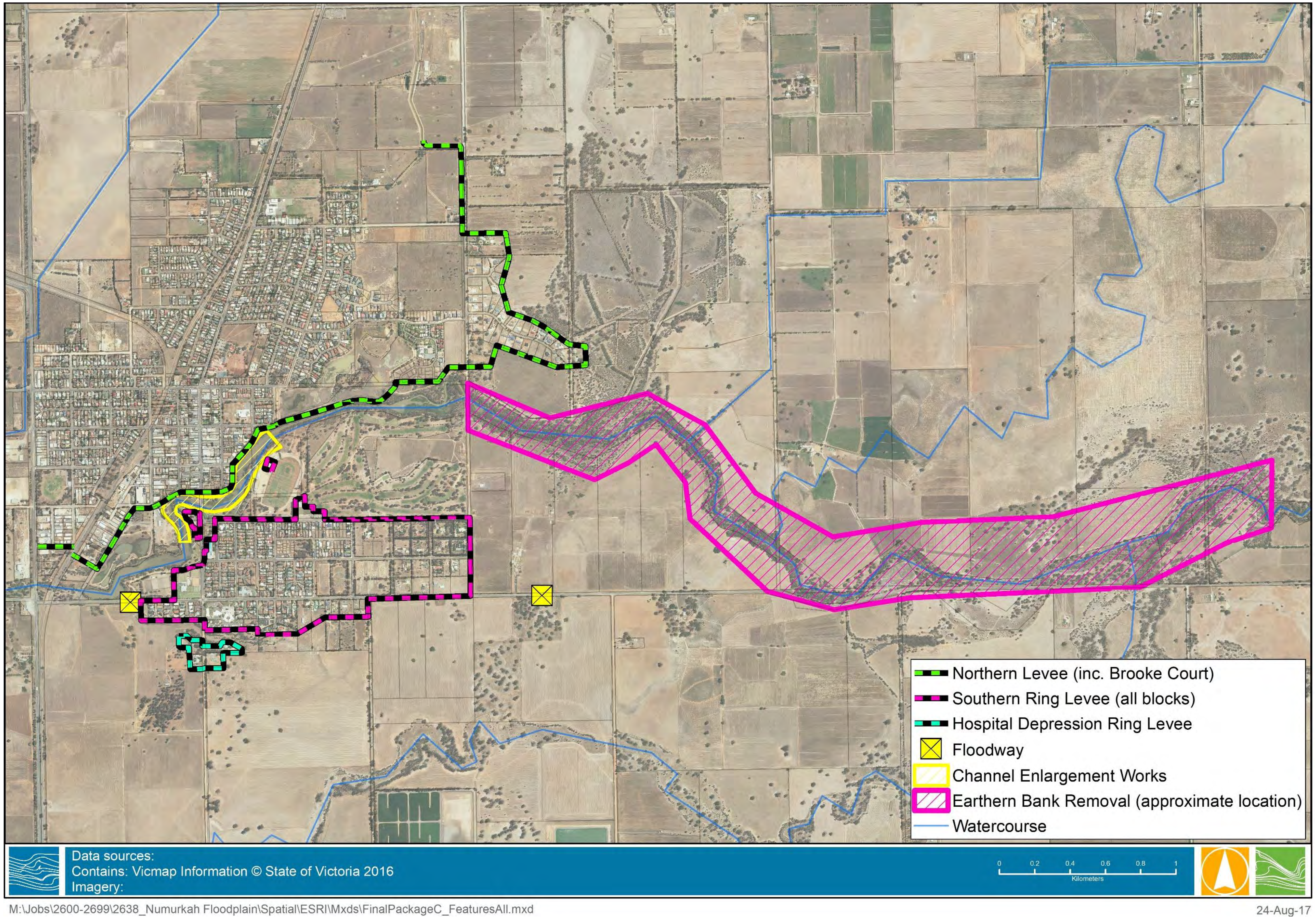


Figure 12-17 Final Mitigation Package C Options – floodplain view

Final Mitigation Package C Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 12-18 and Figure 12-19 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all southern residential lots (small and large) and all properties in Numurkah township to the north of Broken Creek including those at Brooke Court.
- Water levels upstream of the levee systems are increased by generally 80-100 mm. These impacts extend for approximately 2.8 km to the east and 5.8 km to the north up into the Muckatah Depression. Water levels also increase across the floodplain to the south of Numurkah with increases of more than 10 mm likely to extend to Wunghnu.
- Significant increases in water levels of 100-200 mm between the north and south levees upstream of Melville Street including through the golf course and football oval areas.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 10-20 mm downstream of the Goulburn Valley Highway extending for approximately 2 km.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah but with more impacts than Packages A and B. The increases in upstream water levels are significantly greater and extend further to the north and south of Numurkah than the other packages. Above floor flooding would not be made worse for properties within Numurkah however there are properties in outlying rural areas that would be impacted. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

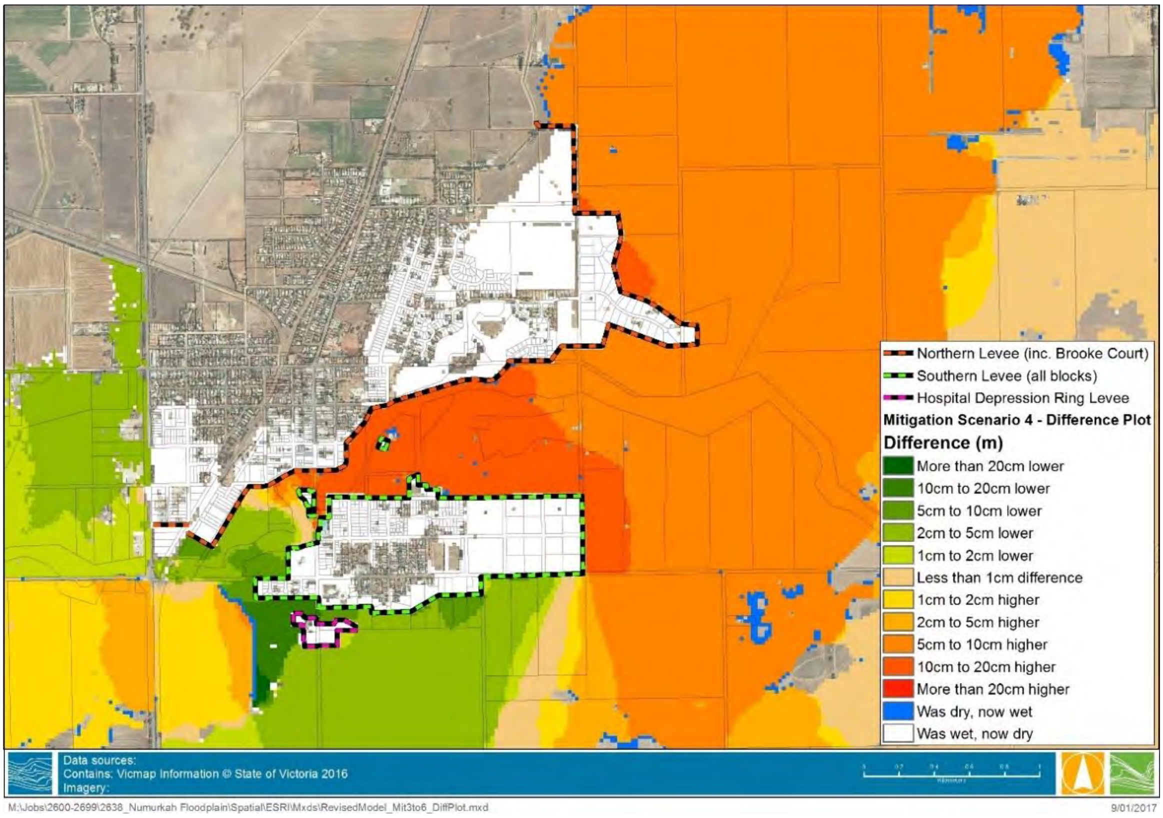


Figure 12-18 Final Mitigation Package C - 1% AEP Difference Plot – Zoom View

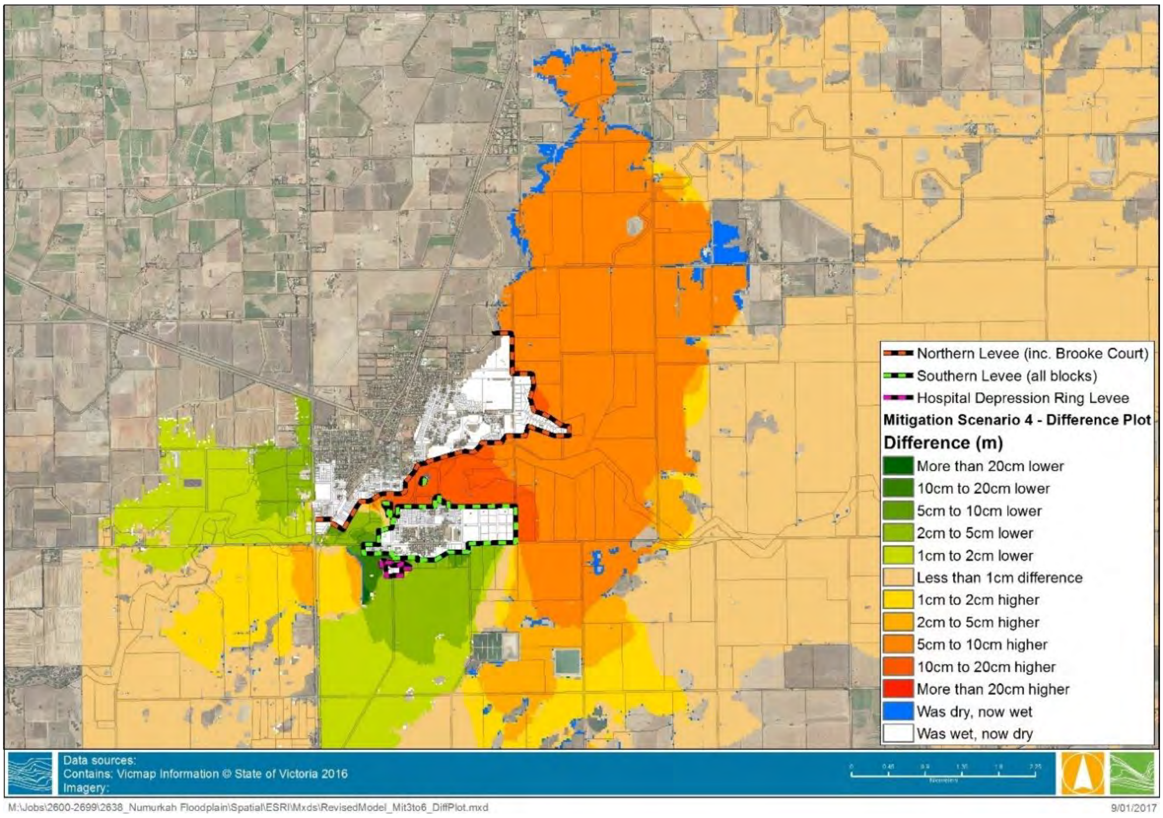


Figure 12-19 Final Mitigation Package C - 1% AEP Difference Plot – Floodplain View

Final Mitigation Package C Summary

Overall it can be seen that the final Mitigation Package C protects a significant proportion of residential properties through Numurkah, including all of those located in the southern residential area. Brooke Court and the larger southern residential blocks remain inside the levee with this package. The package is associated with very significant impacts upstream of the levees which are worse than both Package A and Package B.

The impacts upstream of the township are significant and local mitigation options would need to be further investigated if this option was to be implemented. This would occur as part of a functional and detailed design phase.

Detailed costings for this package are provided in Section 14 and Appendix B.

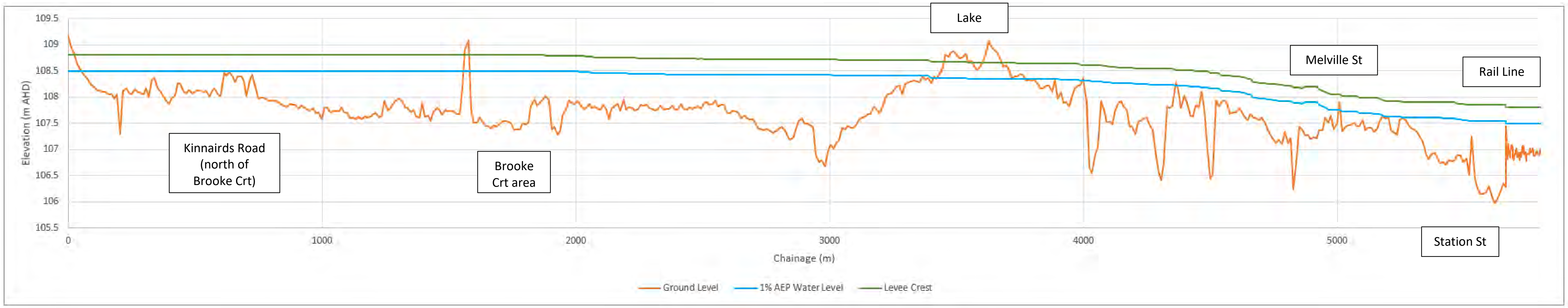


Figure 12-20 Long-section along northern levee alignment for Mitigation Package C

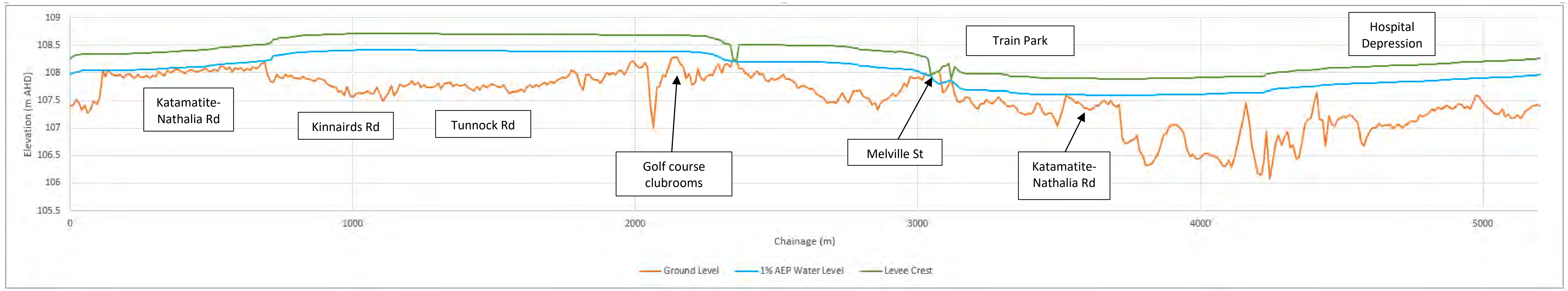


Figure 12-21 Long-section along southern levee alignment for Mitigation Package C

12.2.4 Original Mitigation Package - Northern Levee

Overview

The package below was presented to the community at a period of community consultation in February 2016. One of the key areas of feedback from the community option was that it did not include any structural mitigation for the southern residential areas of Numurkah. Based on this feedback the additional modelling was undertaken which led to the final packages described above. It should be noted that this option does not have the support of the community reference group and generally received poor feedback from the broader community

The key components of Original Mitigation Package (Northern Levee) are shown in Figure 12-22 and consists of:

- Construction of a Northern Levee extending from the Goulburn Valley Highway, along the northern bank of Broken Creek, across Melville Street near the central township and along the alignment of the existing irrigation channel banks to the east of the township. The Brooke Court area would be excluded from the levee. It is known that a flow path exists across Brooke Court and that no above floor flooding occurred on Brooke Court in the March 2012 event. There are however two older, low-lying houses near to Brooke Court which would flood in the 1% AEP event. The northern levee would be constructed with 300 mm of freeboard above the 1% AEP water level. The irrigation channel banks to the east, which currently provide a level of protection in large events, would need to be replaced and/or upgraded to new design standards. The constructed levee would be 4.5 km in length and have an average height of 0.8 metres. Moira Shire Council would be the construction authority for the levee, which includes management of the operation and maintenance plan.
- There are six locations where the northern levee would cross minor roads or access tracks and a system of headwalls and drop boards would be required at those points.
- Removal of earthen embankments to the east of Numurkah in the vicinity of the Go Kart Track.
- Installation of non-return valves on all major stormwater outlets into Broken Creek from the northern section of the township. This is to ensure flood water does not back up in large flood events resulting in flood water on the protected side of the levee.

This package of works has been costed and the total capital cost is estimated to be $3,491,000 (ex. GST) (inclusive of land acquisition, contingencies, administration and engineering). The cost excludes any local mitigation measures that might be required as a result of the increased water levels downstream.

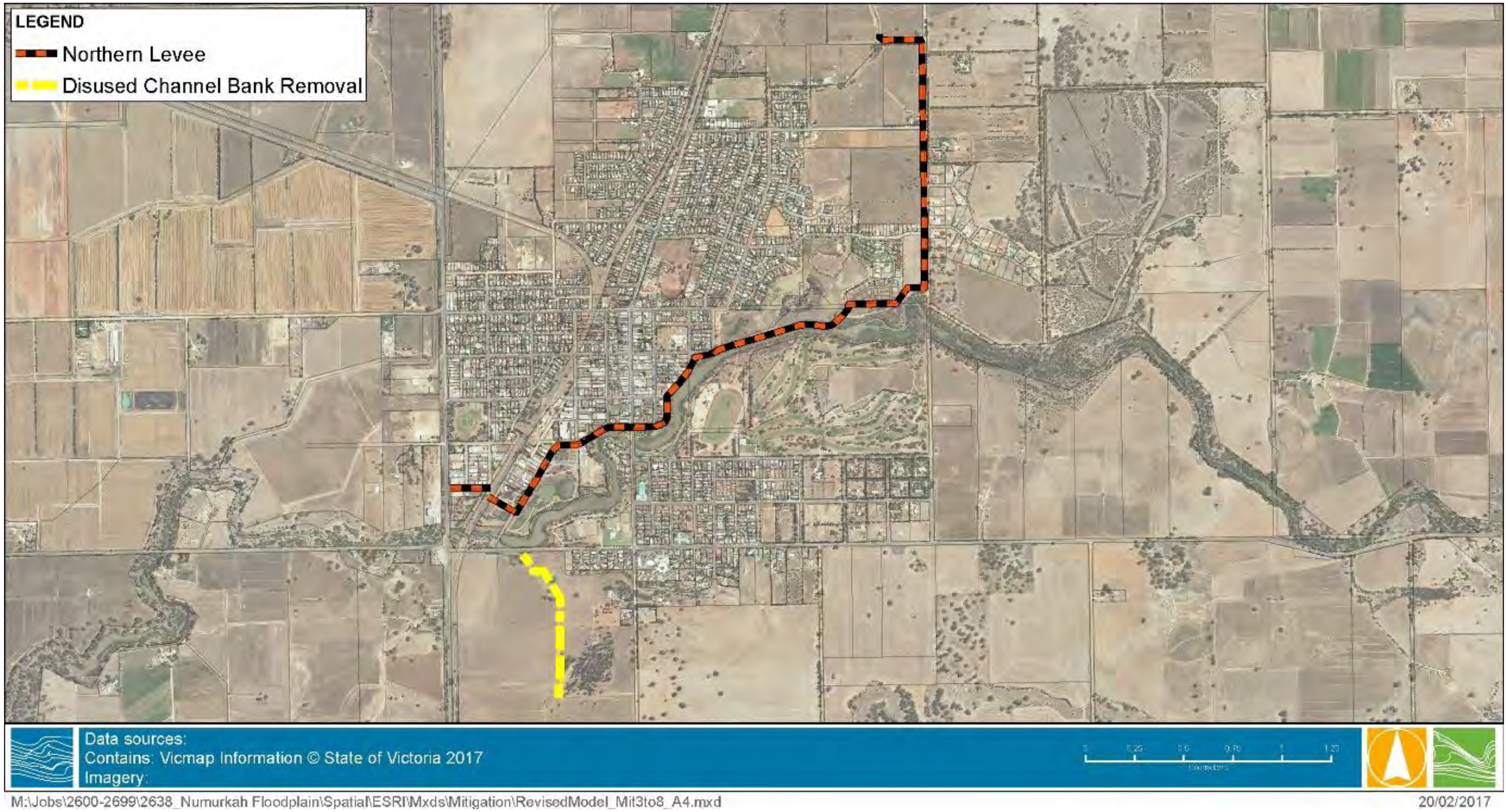


Figure 12-22 Original Mitigation Package Options

Original Mitigation Package Results

The Original Mitigation Package option 1% AEP event depth results (under mitigation conditions) are displayed in Figure 12-23. Difference plots are provided in Figure 12-24 and Figure 12-25. The results demonstrate that the works are effective in protecting much of the northern township in the 1% AEP event. The key observations from the modelling results are:

- The results demonstrate that the levee is effective at protecting the northern part of Numurkah in the 1% AEP event with 94 properties protected from above flood flooding and 466 properties protected from below floor flooding. The levee does not cause any impacts to upstream water levels.
- Removal of the south-west disused channel banks has resulted in lower water levels to properties near the hospital depression of between 15 and 65 mm. Two properties in that area would be protected from above floor flooding while several would be protected from below floor flooding.
- The results demonstrate that removal of the channel banks causes increased water levels to agricultural areas downstream of the banks, as well as one residential and one commercial property. At both properties water levels are increased by approximately 25 mm.
- During a 1% AEP event, the package reduces the total number of properties inundated from 834 properties to 368 properties, with the number of properties flooded above floor reduced from 125 to 31.

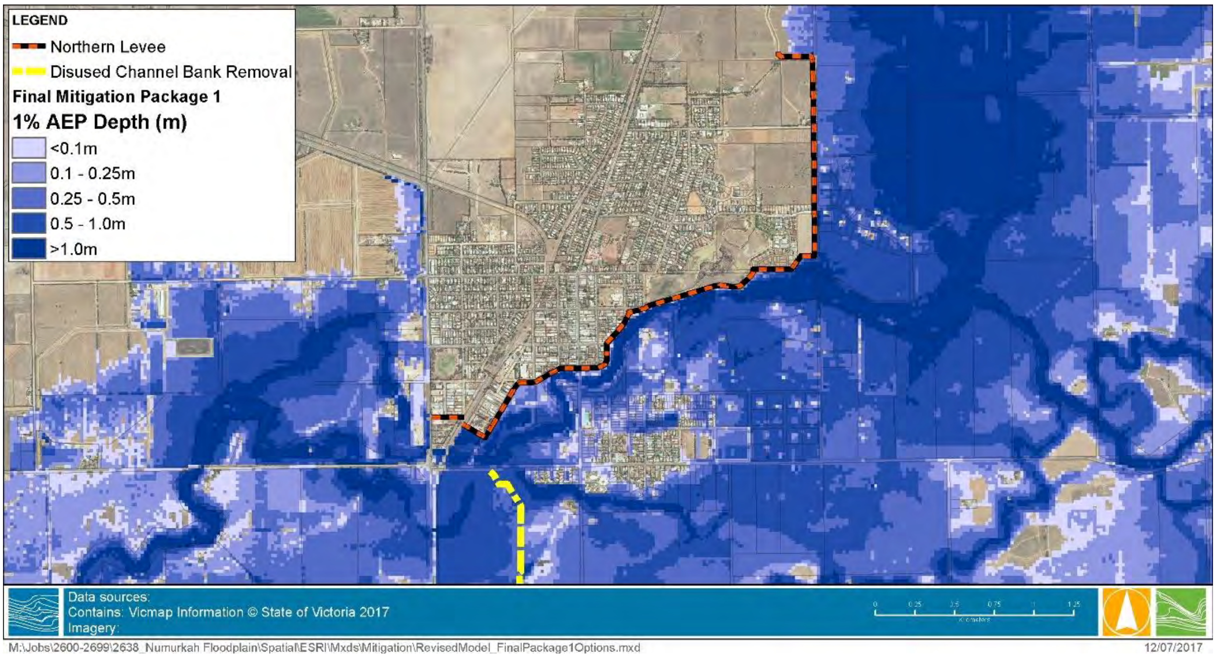


Figure 12-23 Original mitigation package and 1% AEP depth results

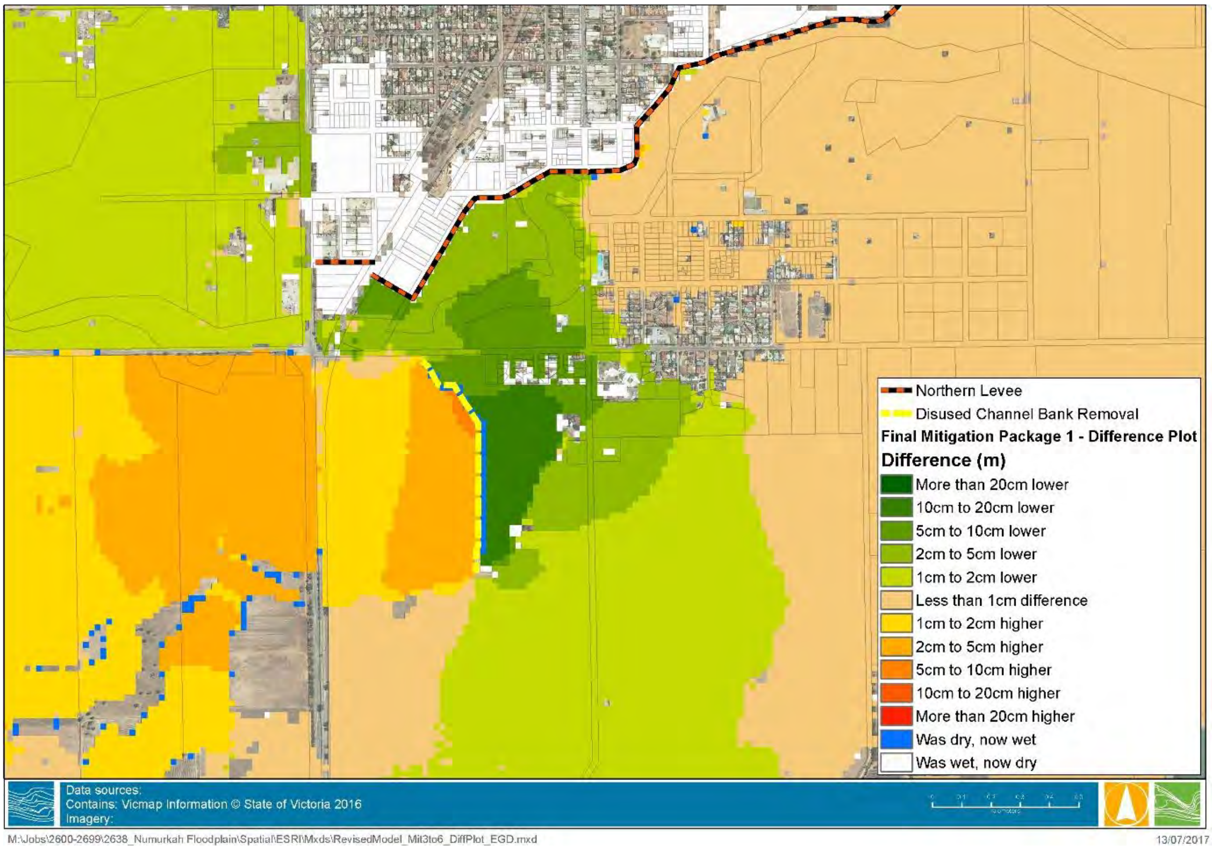


Figure 12-24 Original Mitigation Package Difference Plot – Zoom View

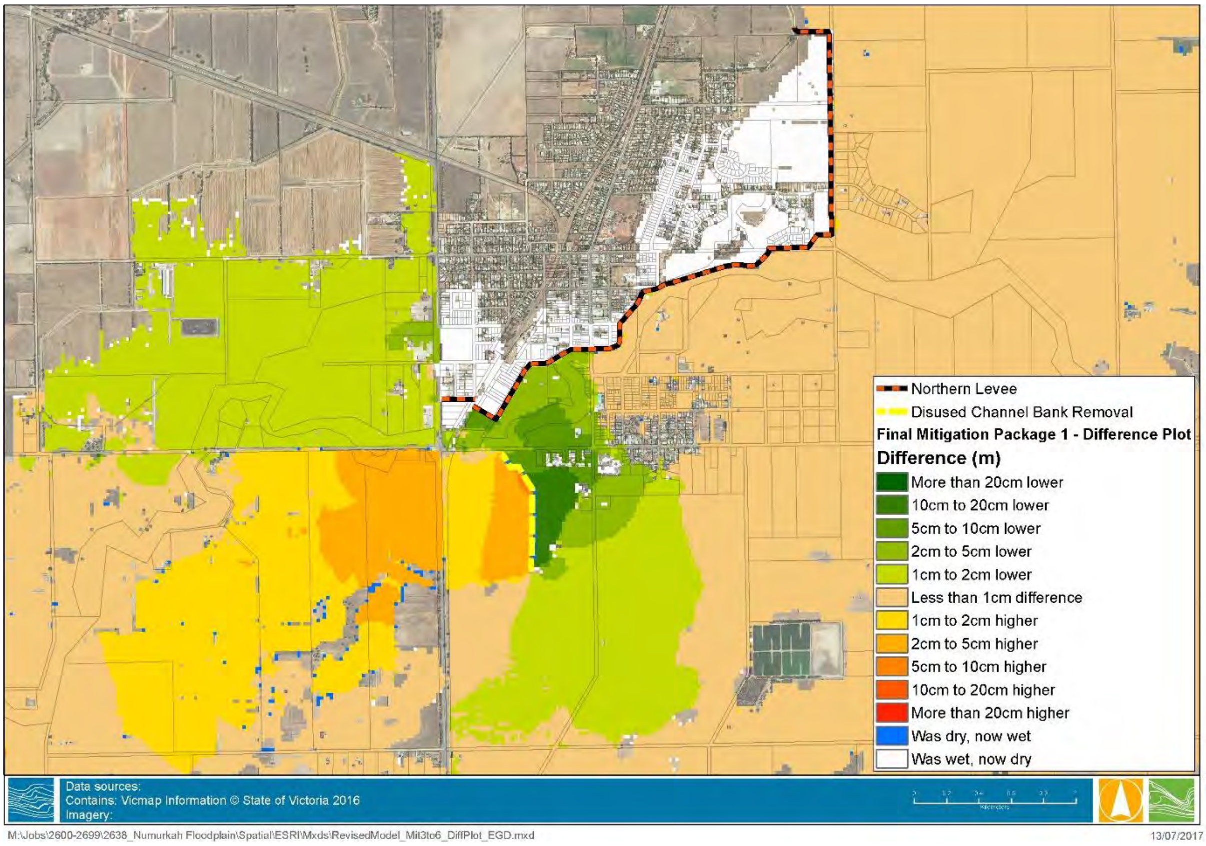


Figure 12-25 Original Mitigation Package Difference Plot

Original Mitigation Package Summary

The results show that the Original Mitigation Package significantly reduces flood risk in Numurkah with the northern section of the town protected in a 1% AEP flood event as shown in Figure 12-25.

The works are more effective for residents living north of Broken Creek however there is some benefit to properties in the south of Numurkah who are located within close proximity to the hospital depression, as a result of removal of the disused irrigation channel banks. Impacts downstream of the south-west disused channel banks are noted, and local mitigation options for these downstream properties would need to be further investigated as part of a functional and detailed design phase if this package of works was implemented.

Detailed costings for this package are provided in Section 14 and Appendix B.

12.2.5 Mitigation Common Features

Levee Road Crossings

There are a number of locations where roads intersect the proposed levees (both north and south levees) and these crossings have been costed as specific works with a unit cost of $30,000 each. The specific works that these crossing will consist of will vary but may include trafficable crossings by raising the road or temporary structures such as drop boards or flood walls. The specific type and cost of the works will be determined as part of detailed and functional design. Some examples are provided below of trafficable crossings and temporary flood barrier structures.

Figure 12-26 Trafficable road crossing (raised road) in Wangaratta

Figure 12-27 Examples of temporary flood gates and demountable walls in Deniliquin, NSW and Nathalia, VIC

Broken Creek Channel Works

Channel enlargement of Broken Creek has been included through all mitigation and aims to achieve more conveyance through the constricted section of Broken Creek in the vicinity of Melville Road and up to near the football club rooms. The modelled scenarios involved the removal of 10,000m^3 of material along an 800 metre reach of Broken Creek and predominately involves widening the banks. The exact extent and dimensions of the channel enlargement would be determined as part of functional and detailed design. A similar increase in channel capacity would need to be achieved in order to achieve the same benefit as the modelling.

Earthen Bank Removal

The approximately vicinity of the proposed removal of earthen banks to the east of Numurkah near the Go Kart track is shown Figure 12-28. The earthworks have been costed at $88,590 and have assumed 9,000 m^3 of material is removed. This was the volume of earth removed from the model and was based on levelling banks clearly visible in the laser survey (LiDAR) of this area. The specific location and extent of works will be determined as part of the functional design phase and in conjunction with the community reference group. The modelling showed that the works have an impact on local flood levels but have a minor impact on flood levels within Numurkah.

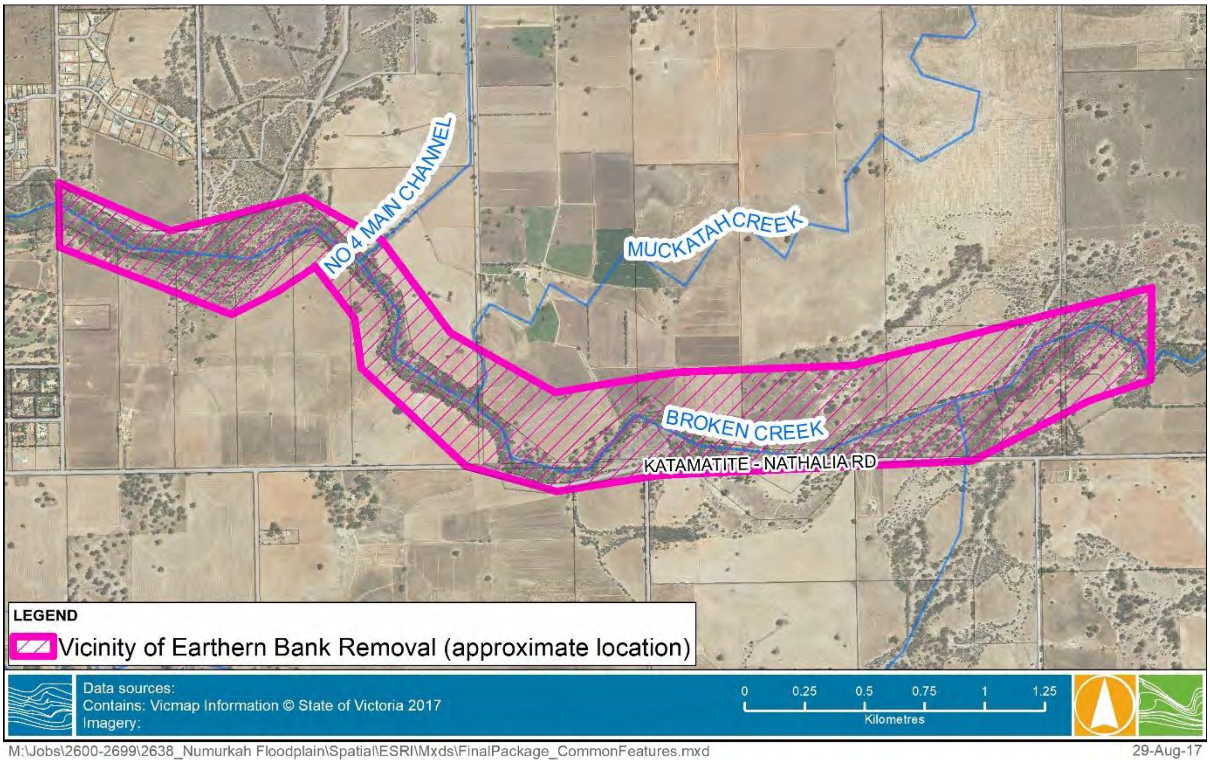


Figure 12-28 Approximate vicinity of earthen bank removal to east of Numurkah

Floodways

Two floodways are proposed along Katamatite-Nathalia Road to aid the flow of flood water across the roadway. The eastern floodway would be located approximately 400 metres east of Kinnairds Road and would facilitate additional flow flowing from Broken Creek to the north towards the Hospital Depression and Box Creek to the south. The location of the eastern floodway is shown in Figure 12-29 and an image of this location is shown in Figure 12-30. The western floodway is located where the lower end of the hospital depression intersects the Katamatite-Nathalia Road. An image of this location is shown in Figure 12-31. In order to ensure safe access to the southern residential areas during flood event, a culvert/bridge structure may replace the western floodway and this will be determined during detailed design. Safe access will be required to ensure the Numurkah District Health Service and Ambulance Station are accessible during flood events.

The modelled floodways were approximately 60 metres in width and involved lowering the roadway so it was level with the surrounding floodplain. A total cost of $150,000 has been assumed for the floodways however more detailed costing and design would occur during functional and detail design phases.

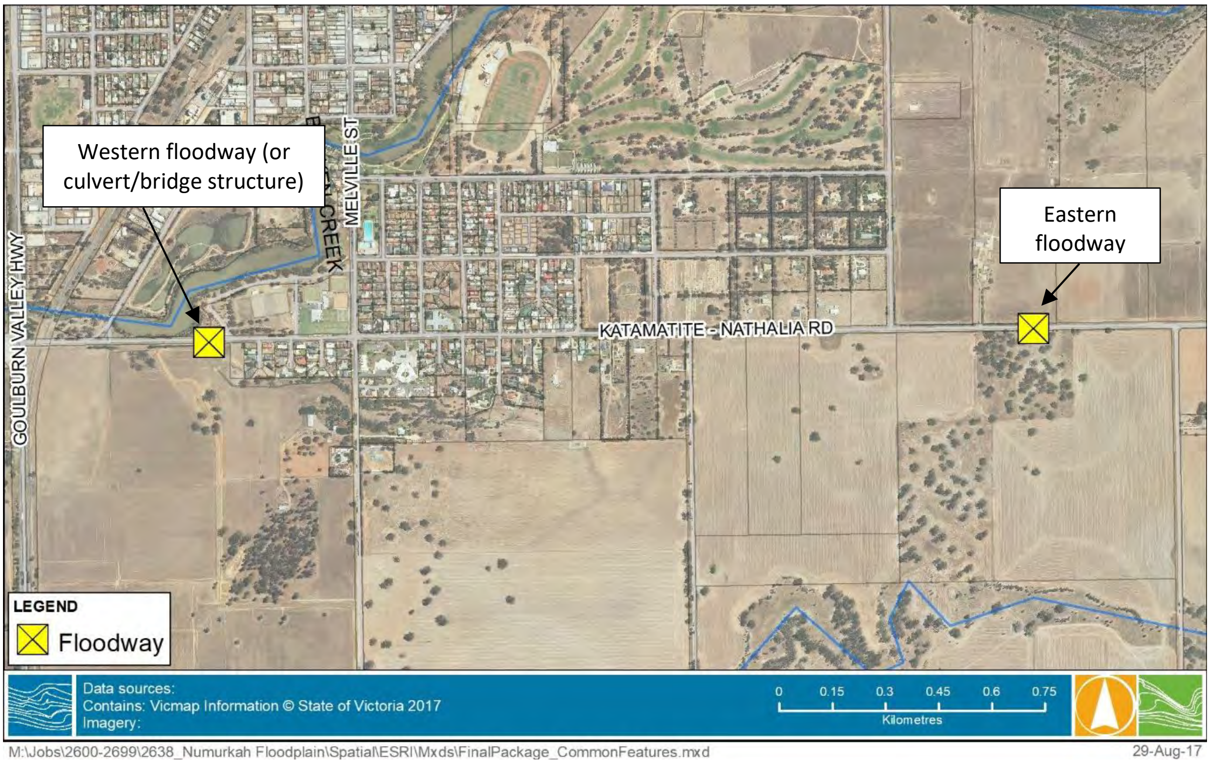


Figure 12-29 Location of Katamatite-Nathalia Road floodways

Figure 12-30 Approximate location of western floodway on Katamatite-Nathalia Road at lower end of hospital depression looking east (Google 2017)

Figure 12-31 Approximate location of eastern floodway on Katamatite-Nathalia Road approximately 400 metres east of Kinnairds Road looking east (Google 2017)

Access to the Hospital and Southern Residential Areas

A proposed access route to the southern residential areas has not been recommended as part of the final mitigation packages and will be determined in the future, as part of the functional and detailed design phase of a preferred mitigation scheme. A route will need to be determined which allows safe, flood-free access to the Numurkah District Health Service and Ambulance Station precinct. The route will depend on feasibility, practicality and available funding and will need to be examined in close consultation with the community reference group and relevant stakeholders including Vicroads, Moira Shire Council and Goulburn Broken Catchment Management Authority. Likely access routes include along Katamatite-Nathalia Road to the Goulburn Valley Highway, ensuring the roadway is safely trafficable or to the north along Melville Street, which would require an upgrade of the existing Broken Creek bridge.

12.3 Land Use Planning

There are a range of non-structural mitigation options that can be implemented including land use planning, flood warning, flood response and flood awareness. This section discusses land use planning while the flood warning System for Numurkah is discussed in Section 12.4.

The Victorian Planning Provisions (VPPs) contain a number of controls that can be employed to provide guidance for the use and development of land that is affected by inundation from floodwaters. These controls include the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO), the Special Building Overlay (SBO), the Urban Floodway Zone (UFZ) and the Environmental Significance Overlay (ESO).

Section 6(e) of the Planning and Environment Act 1987 enables planning schemes to 'regulate or prohibit any use or development in hazardous areas, or areas likely to become hazardous'. As a result, planning schemes contain State planning policy for floodplain management requiring, among other things, that flood risk be considered in the preparation of planning schemes and in land use decisions.

Guidance for applying flood controls to Planning Schemes is available from the Department of Planning and Community Development's (DPCD) Practice Note on Applying Flood Controls in Planning Schemes. Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. It is recommended that the planning scheme for Numurkah is amended to reflect the flood risk identified by this project.

Suggested LSIO and FO maps are included below in Figure 12-32. The proposed LSIO adopts the 1% AEP flood extent, with the FO comprising the envelope of the 10% AEP extent, the 1% AEP extent where depths are greater than 0.5 m and the 1% AEP extent where velocity is greater than 1.5 m/s. This is as per the Advisory Notes to Delineating Floodways (NRE 1998).

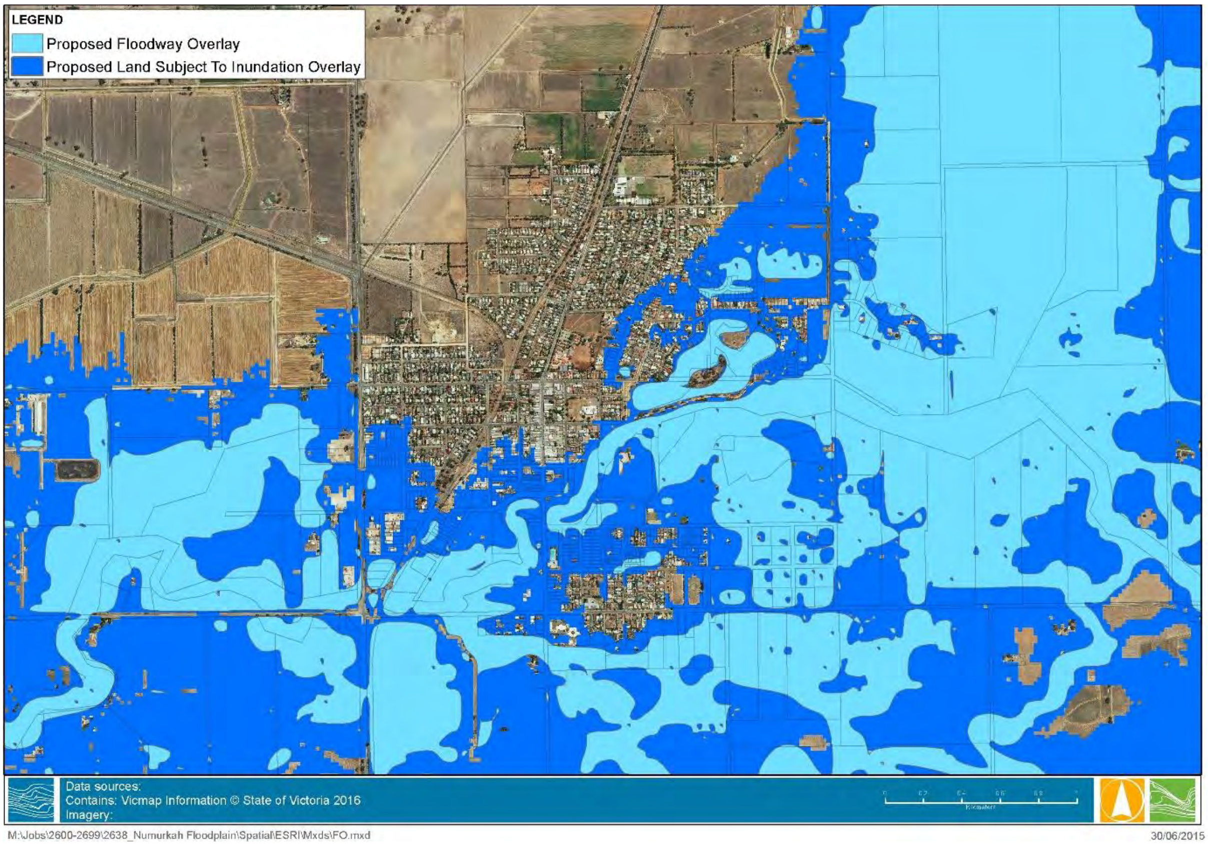


Figure 12-32 Proposed LSIO and FO Planning Scheme Mapping

It is recommended that following the completion of this study that Moira Shire Council undertakes a planning scheme amendment, updating the FO and LSIO maps within the planning scheme. A LSIO and FO schedule already exists within the Moira Shire Planning Scheme, so the amendment is likely to be a simple map change.

12.4 Flood Warning System

The full flood warning assessment and recommendations report is provided in Appendix C. The list of recommendations from that report is provided below.

12.4.1 Aim and Function

Flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus, flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding.

It is essential that flood warning systems consider not only the production of accurate and timely forecasts / alerts but also the efficient dissemination of those forecasts / alerts to response agencies and threatened communities in a manner and in words that elicit appropriate responses based on well-developed mechanisms that maintain flood awareness. Thus, equally important to the development of flood warning mechanisms is the need for quality, robust flood awareness (education) programs to ensure communities are capable of response.

12.4.2 Flood Warning Recommendations

A staged approach to the development of a flood warning system for Numurkah is recommended. As stated previously a firm commitment has been made by Goulburn Broken CMA, DELWP, BOM and Moira Council to implement the recommendations and planning for the warning system has commenced, including consideration for permanent gauges.

The proposed stages for implementation have been ordered and the tasks within each stage grouped to facilitate growth of all elements of the Total Flood Warning System (TFWS) in a balanced manner. While it may be tempting to immediately move to install additional rain and river gauges and to develop a forecast capability, there are other more fundamental matters that experience tells us need to be addressed first. Early attention is directed at ensuring roles and responsibilities are agreed, understood and accepted and that there is a firm foundation for the development of an effective flood warning system: one that does not fail when it is needed most.

Attention is then directed to establishing a robust framework for communicating and disseminating flood related information so that immediate and maximum use can be made of available information as the ability to detect and predict flooding at Numurkah improves. Next, attention is focussed on securing the funding needed to buy, install and operate field equipment as well as other services needed to build elements of the TFWS. The installation of data collection equipment follows. Development of other technical elements and the build and delivery of on-going flood awareness activities can then occur in the knowledge that required data is / will be available and that robust and sustainable arrangements are in place that will enable maximum benefit to be derived from any information or programs delivered to the community.

It is of note that a number of these actions are already in progress and it is understood that many are scheduled to be completed by early 2018. This includes the installation of three streamflow gauges, with two proposed for Muckatah Creek and one gauge on Nine Mile Creek.

Stage 1

1. GBCMA and Moira Shire, with support from VICSES, to formally advise DELWP of the need for a flood warning service for Numurkah and request that:
   - Data tables, accessible through the BoM web site, be established for Broken Creek;
   - Flood class levels determined for Numurkah at the Melville Street Bridge gauge are adopted and published by BoM;
   - Numurkah be classified as a key river level site / location and a quantitative flood forecast location;
   - BoM be asked to refine and extend the Broken Creek rainfall-runoff forecasting model developed to provide quantitative flood forecasts for Nathalia to include Numurkah; and
   - BoM commence delivery of and support for a quantitative flood forecasts service for Numurkah.
2. Council, GBCMA, VICSES, DELWP, BoM and other entities to determine the responsible entity in relation to “ownership” of each element of the flood warning system for Numurkah. Ownership is considered to denote overall responsibility for funding as well as the functioning of the system element and, in the event of failure, either fault-fix or the organisation of appropriate fault-fix actions and payments. VFWCC provides guidance on the matter although recommendation 1 from the Comrie Review Report suggests that some clarifications may be required.

Stage 2

3. Council to establish an agreement with GBCMA / DELWP that provides access to PALS gauges when required and that comprehensively addresses the issue of who pays for equipment installation, operation, recovery and related matters. This would be in addition to new permanent gauges which are currently being considered by relevant stakeholders.
4. Council in conjunction with VICSES to clearly establish the role for the community flood action group in Numurkah along with its authority with due regard for liability issues. Essentially the group could:
   - Collect, collate and pass on rain and water level data;
   - Monitor this data as well as other rain and creek information via the Bureau's website.
   - Make initial assessments of the likelihood and scale of flooding at Numurkah based on available rainfall data, water levels and trends and the indicative "quick look" tools developed for Numurkah and included in the Moira Shire MFEP.
   - In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the RDO or IC, call the Moira Shire MERO.
   - Maintain a watching brief on flood response arrangements within Numurkah and provide feedback to Council on the adequacy and efficacy of arrangements in place at the time.
5. Council to share the MFEP with the Numurkah community.
6. Council, in conjunction with VICSES, to establish and document in the MFEP arrangements for the timely supply of sandbags and sand within Numurkah with sufficient lead time to enable buildings at risk of minimum over-floor flooding to be sandbagged / protected.
7. Council and VICSES to encourage and assist residents and businesses to develop individual flood response plans.
8. Council to load and maintain flood related material (including the MFEP) on its website.
9. Council in conjunction with VICSES to determine whether alerts on exceedance of rain or creek level alarm criteria are required to be sent to key Municipal and / or VICSES personnel and / or key community members by either the loggers at Tungamah and Katamatite and / or an Enviromon base station at the Shire offices. Costs will also need to be determined.
10. Council to decide whether to extend the Shire's Xpedite system and FM-88 to cover the Numurkah community following consideration of technical feasibility and associated costs and benefits and / or to subscribe to or promote systems like the Early Warning Network (www.ewn.com.au).
11. Council with the support of VICSES, GBCMA and the Numurkah community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a TFWS for the Broken Creek catchment to Numurkah.

Stage 3

12. Install staff gauges to AHD at all proposed PALS locations and determine gauge zeros to AHD.
13. Council to liaise with the owner of the Melville Street Bridge gauge and arrange a check survey of the gauge zero and location coordinates.
14. Council and VICSES to confirm proposed flood class levels for Numurkah at the Melville Street Bridge gauge.
15. Council in conjunction with VICSES to update the MFEP with staff gauge datums, PALS site location coordinates and other relevant details.
16. If and as required, Council to establish manually read rain gauges in the upper part of the Boosey Creek catchment in the area to the south east of Devenish near Bungeet West, in the upper

reaches of Majors Creek to the east of Dookie township near the intersection of Dookie - Devenish Road and Benalla Boundary Road (or perhaps as far east as the Benalla – Tocumwal Road) and two in the Muckatah Depression located in the vicinity of the Naring Fire Station and another located at Muckatah or to the north of Katamatite.

17. Council with input from VICSES, gauge readers, community flood action group and BoM to establish protocols for delivering manually read data to BoM and other stakeholder entities.
18. VICSES to initiate a community engagement program at Numurkah in order to communicate how the flood warning system will work. This will need to be repeated as the system matures.

Stage 4

19. Undertake radio path testing and install an ERTS river (perhaps with rain) gauge at the Melville Street Bridge site.
20. Undertake radio path testing and install 4 x ERTS rain only gauges at locations as indicated for the manually read gauges (refer to 16 above).
21. Establish on-going maintenance arrangements for all new equipment and staff gauges, ideally through the Surface Water Monitoring Partnership.
22. BoM to add all sites to appropriate data tables accessible via the BoM website.

Stage 5

23. Develop, review and update protocols for who does what and when, and processes to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP.
24. BoM to extend the rainfall-runoff based flood forecast model for Broken Creek to Numurkah.

Stage 6

25. VICSES to update and redistribute the Numurkah Local Flood Guide and Muckatah Depression Fact Sheet as required in order to be consistent with:
    - Flood intelligence included in the Moira Shire MFEP
    - Changes to the flood warning system for Numurkah
    - Updates to the data collection network and data availability.

Stage 7

26. Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within the Numurkah study area.

Stage 8

27. Install flood depth indicator boards at key locations in and around Numurkah (e.g. either side of the Melville Street Bridge, along Kinnairds Road, Madeline Street, Tunnock Road, Walshs Bridge Road, the Katamatite – Nathalia Road and at other strategic locations as indicated by the flood hazard maps delivered by the Numurkah Floodplain Management Study and Plan) and further afield.

13. FLOOD DAMAGES ASSESSMENT

13.1 Overview

A flood damages assessment was undertaken for the study area under existing conditions. The flood damage assessment determined the monetary flood damages for design floods (20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events). The flood damage assessment was also undertaken for the final mitigation package.

Water Technology has developed an industry best practice damage assessment methodology that has been utilised for a number of studies in Victoria, combining aspects of the Rapid Appraisal Method, ANUFLOOD and other relevant flood damage literature. A recent review of ANUFLOOD stage damage curves has demonstrated that they significantly underestimate flood damages, particularly at shallow above floor depths and below floor flooding. The stage damage curves developed by the New South Wales Office of Water have been used for this project. The model results for all mapped flood events were processed to calculate the numbers and locations of properties affected. This included properties with buildings inundated above floor, properties with buildings inundated below floor and properties where the building was not impacted but the grounds of the property were. In addition to the flood affected properties, lengths of flood affected roads for each event were also calculated. Details of the flood damage assessment methodology are provided in Appendix D.

13.2 Existing Conditions

The 1% AEP flood damage estimate for existing conditions was calculated to be just under $19.5 million. A total of 834 properties are flooded in a 1% AEP event, with 125 of those properties flooded above floor level. The March 2012 event is estimated to be slightly larger than a 1% AEP event although some temporary mitigation works were implemented during the event to protect parts of the town. The total number of properties flooded in the 1% AEP event is similar to the reports of numbers flooded during the March 2012 event, in those areas that weren't protected by temporary measures.

The Average Annual Damage (AAD) was determined as part of the flood damage assessment. The AAD is a measure of the flood damage per year averaged over an extended period. The AAD for existing conditions for the study area is estimated at approximately **$716,500**. This is effectively a measure of the amount of money that must be put aside each year in readiness for the event that a flood may happen in the future.

Table 13-1 Flood damage assessment for existing conditions

		Annual Exceedance Probability					
		0.5%	1%	2%	5%	10%	20%
Existing Conditions	Buildings Flooded Above Floor	297	125	56	5	5	2
	Properties Flooded Below Floor	790	709	509	184	139	77
	Total Properties Flooded	**1087**	**834**	**565**	**189**	**144**	**79**
	Total Damage Cost	**$19,466,135**	**$11,584,940**	**$7,496,927**	**$3,864,705**	**$2,670,056**	**$1,524,287**

13.3 Final Mitigation Package A

The AAD for Final Mitigation Package A as described in Section 12 was calculated to be approximately **$340,600**. During a 1% AEP event, the package reduces the total number of properties inundated from

834 properties to 74 properties, with the number of properties flooded above floor reduced from 125 to 6. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$376,000** per year by implementing this package of works.

Table 13-2 Flood damage assessment for Final Mitigation Package A

		Annual Exceedance Probability					
		0.5%	1%	2%	5%	10%	20%
Mitigation Conditions	Buildings Flooded Above Floor	17	6	3	1	0	0
	Properties Flooded Below Floor	57	68	71	66	52	45
	Total Properties Flooded	**74**	**74**	**74**	**67**	**52**	**45**
	Total Damage Cost	**$5,835,843**	**$4,935,884**	**$4,311,131**	**$3,171,268**	**$2,250,253**	**$1,346,910**

13.1 Original Mitigation Package

The AAD for the Original Mitigation Package as described in Section 12 was calculated to be approximately **$614,300**. During a 1% AEP event, the package reduces the total number of properties inundated from 834 properties to 368 properties, with the number of properties flooded above floor reduced from 125 to 31. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$102,200** per year by implementing this package of works.

Table 13-3 Flood damage assessment for Original Mitigation Package

		Annual Exceedance Probability					
		0.5%	1%	2%	5%	10%	20%
Mitigation Conditions	Buildings Flooded Above Floor	74	31	17	6	5	2
	Properties Flooded Below Floor	371	337	287	172	134	79
	Total Properties Flooded	**445**	**368**	**304**	**178**	**139**	**81**
	Total Damage Cost	**$9,754,389**	**$7,057,708**	**$5,570,591**	**$3,800,505**	**$2,628,025**	**$1,529,857**

13.2 Average Annual Damage Summary

The damage assessment shows that Final Mitigation Package A has a significant impact on reducing flood damages and AAD in Numurkah with a reduction in AAD of just under $380,000 compared to existing conditions. The Original Mitigation Package achieves considerably less reduction in AAD. A summary table of the AAD for existing conditions, Package A and the Original Mitigation Package is shown in Table 13-4. Final Mitigation Package B and C have not undergone a detailed damages and benefit cost analysis however it would be expected that they would reduce the AAD by a similar amount. Package C also protects the larger, southern, residential blocks however there is little above floor flooding in that area so it would have a minor impact on the AAD and therefore AAD would be similar to Packages A and B.

Table 13-4 Average Annual Damage Summary for Numurkah

Options	Average Annual Damage	Reduction in AAD
Existing Conditions	$716,548	
Final Mitigation Package A	$340,591	$379,957
Original Mitigation Package	$614,346	$102,202

13.3 Non-Economic Flood Damages

The previous discussion relating to flood damages has concentrated on monetary damages, that is damages that are easily quantified. In addition to those damages, it is widely recognised that individuals and communities also suffer significant non-monetary damage, i.e. emotional distress, health issues, etc. There has been extensive research undertaken and documented in the scientific literature relating to the individuals and communities response to natural disasters. A recent publication entitled *"Understanding floods: Questions and Answers"* by the Queensland Floods Science Engineering and Technology Panel, when discussing the large social consequences floods have on individuals and community's states:

"Floods can also traumatise victims and their families for long periods of time. The loss of loved ones has deep impacts, especially on children. Displacement from one's home, loss of property and disruption to business and social affairs can cause continuing stress. For some people the psychological impacts can be long lasting."

The *Disaster Loss Assessment Guidelines* (EMA, 2002) make the following key points:

- *Intangibles are often found to be more important than tangible losses.*
- *Most research shows that people value the intangible losses from a flooded home—principally loss of memorabilia, stress and resultant ill-health—as at least as great as their tangible dollar losses.*
- *There are no agreed methods for valuing these losses.*

There is no doubt that the Numurkah community has suffered greatly as a result of the March 2012 floods and will continue to do so with potential future floods. The intangible non-monetary flood related damage in Numurkah is very high. The benefit-cost analysis presented later in this report (Section 0) has not considered this cost. Any decisions made that are based on the benefit-cost ratios need to understand that the true cost of floods in Numurkah is far higher than the economic damages alone. This would have the effect of increasing the benefit cost ratio, improving the argument for approving a mitigation scheme at Numurkah.

14. BENEFIT COST ANALYSIS

14.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the final mitigation packages. The estimated benefit-cost ratio is based on the construction cost estimates and average annual damages. For the analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life.

14.2 Mitigation Option Costs

The mitigation works were costed based on a number of key references:

- Melbourne Water's standard rates for earthworks and pipe/headwall construction costs.
- Rawlinson's Australian Construction Handbook Rates
- Advice from VicRoads and Vic Track regarding bridge and culvert works costs
- Comparison to cost estimates for similar mitigation works for other flood studies
- Council and CMA estimates of works costs

A summary of the cost estimates for the final mitigation package is shown in Table 14-1 below. A detailed breakdown of the costing for each mitigation option is included in Appendix B.

The largest cost element for each mitigation package is for construction of the northern and southern levees and land acquisition costs. The cost for the levee has been calculated based on the estimated volume of material required to construct the structure, as well as costs for headwalls and drop boards at road crossings. Sections which have a narrow corridor and would more likely involve a flood or retaining wall have been costed based on a unit cost per length of wall. Similarly, the cost for channel bank removal and channel enlargement works on Broken Creek has been determined using a standard excavation rate based on the earthwork volumes. Land acquisition costs have been based on applicable land values with a 15 metre corridor adopted for earthen levee sections and 5-10 metre corridors adopted for retaining wall sections. Allowance for environmental and cultural heritage management plans has also been included.

A 15% contingency cost has been added along with engineering and administration costs. Annual maintenance costs of 0.5% of the construction cost was factored in for retaining/flood wall sections of levee while 1.5% of construction was factored in for earthen levees and all other drainage works.

Table 14-1 Mitigation Cost Breakdown

Option	Total Construction Cost	Annual Maintenance
Final Mitigation Package A	$16,935,254	$63,191
Final Mitigation Package B	$23,102,453	$74,975
Final Mitigation Package C	$25,487,483	$112,106
Original Mitigation Package	$3,490,893	$13,871

14.3 Benefit Cost Analysis

A benefit cost analysis was undertaken of the results for both Mitigation Package A and the original mitigation package. The results of the benefit cost analysis are shown below in Table 14-2. The analysis found low benefit cost ratios across both packages with the Original Mitigation Package achieving a slightly higher ratio of 0.4. Typically, a ratio greater than 1 is preferred in order to justify funding.

The low ratios are a reflection of the significant costs associated with both construction and land acquisition of the schemes, and also due to the benefits of the schemes not being seen until relative large flood events.

Final Mitigation Packages B and C have not undergone full benefit cost analysis but given they are both significantly more expensive and achieve similar benefit it is likely their benefit cost ratios would be lower than that determined for Package A.

Table 14-2 Benefit Cost Analysis Results

	Existing Conditions	Final Mitigation Package A	Original Mitigation Package
Average Annual Damage	$716,548	$340,591	$614,346
Annual Maintenance Cost		$63,191	$13,871
Annual Cost Saving		$312,766	$88,331
Net Present Value (6%)		$4,398,238	$1,242,142
Capital Cost of Mitigation		$16,935,254	$3,490,893
Benefit – Cost Ratio		**0.3**	**0.4**

The levees included in the Final Mitigation Packages A, B and C result in upstream impacts to the east and north-east of Numurkah. These impacted properties will require further landholder consultation and potentially site specific mitigation works in some locations. These costs have not been included in into the final benefit-cost analysis and will further reduce the benefit-cost ratios.

15. COMMUNITY CONSULTATION

Throughout the study a community-based reference group (CRG) with approximately twelve local residents, has been actively involved with the project, meeting regularly with stakeholders including Moira Shire Council and the Goulburn Broken Catchment Management Authority. The CRG has had significant input into project decision making including the range of mitigation options that were modelled. The Numurkah Flood Action Group has also been consulted with frequently and have provided their views and feedback at various stages of the project. The project team was also provided with community questionnaires regarding flooding in the area collated by Moira Shire Council shortly after the March 2012 event.

A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and one-one-sessions and through more formal feedback methods such as surveys. A public meeting held in August 2015 was strongly attended with approximately 150 community members present. Following the public meeting a series of ‘one on one’ discussions were also well attended, with 19 community members making appointments to speak with Council, CMA and Water Technology staff. After the one on one discussions, community feedback was also received through 74 written submissions to Council. Feedback from the period of community consultation guided the development of the Plan and the final recommended package of mitigation works.

The consultation was considered very successful and the key feedback from the community consultation was that:

- It was considered unacceptable to the community that the southern residential area was not protected by structural mitigation options. The improvements in flood warning and emergency response were not considered sufficient.
- Access to and from the hospital was of major concern and should be addressed.
- Formalising the northern levee was necessary and appropriate and should remain in the package of works.
- Upgrades to the railway and highway culverts should remain as a long term recommendation of this study and implemented when funding permits.

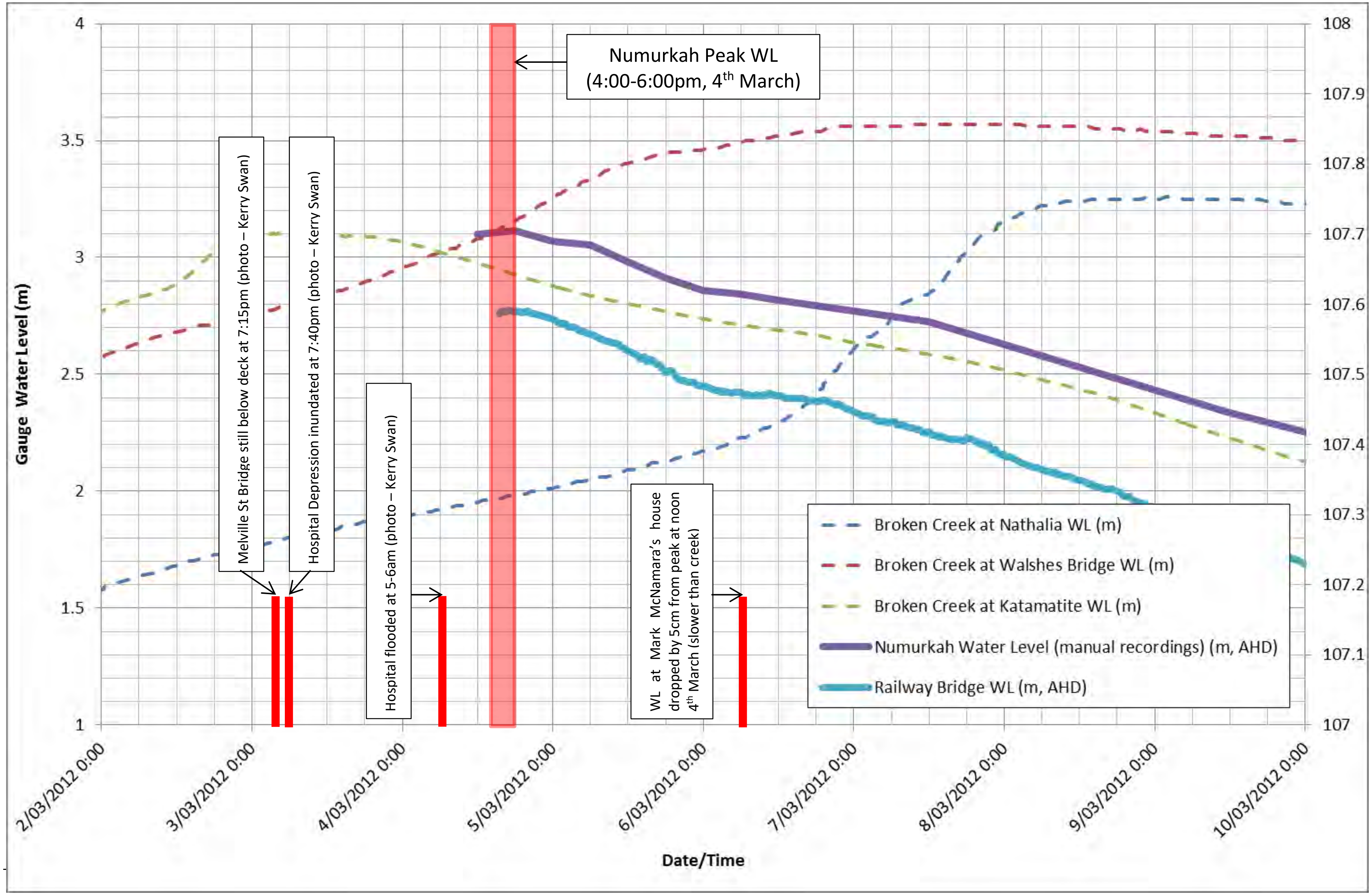
The above feedback has been considered in the final mitigation packages that have been developed. Community engagement has played a key role in the development of these packages.

16. KEY COMMUNITY CONCERNS ADDRESSED

A number of specific concerns were raised during the period of community consultation and addressed during the completion of this study. The following points detail the key community concerns:

- It is perceived by some members of the CRG and the general community, that the railway line is a significant cause of flooding in Numurkah. Modelling has demonstrated that the railway does have an impact on water levels upstream to Melville Street, but has minimal impact upstream of Melville Street. The area impacted by the railway line is largely rural undeveloped land. It is noted, however, that both the railway and highway culverts are under-sized for the 10% AEP event and greater, with water backing up behind the railway in those events. This indicates a culvert upgrade could be justified in future when funding allows. Some members of the CRG have concluded that the upgrade of culverts under the railway and highway remains a priority. These members have requested that as an outcome of this study, the upgrade of the culverts are included as part of the long-term drainage plan for Numurkah. It is acknowledged by the committee that funding is unlikely to be available in the short-term but in the future, when funding permits, it is requested that upgrades to the railway culverts be investigated. Upgrading of flood capacity through the railway and highway will not greatly impact on peak flood levels in a 1% AEP event but may reduce the duration of time that land is inundated on the rising and falling limbs of a flood.
- The CRG identified removal of the earthen banks near the Go Kart track to the east of Numurkah as a preferred mitigation option. The CRG feel that the earthen banks disrupt the natural flow and behaviour of the watercourse and they should be removed. This is a relatively low cost option which has been included as one of the recommendations of the study, to restore normal flow and flood behaviour along Broken Creek.
- Concerns were raised by some members of the CRG around uncertainty in the estimate of flows from the Muckatah Catchment for the March 2012 event. The adopted flows were based on extensive testing detailed in the hydrology section of the study report. While it is acknowledged that there is a level of uncertainty in the adopted flows, largely due to the limitations in data availability, there is no justification to increase the adopted flows given the extensive testing undertaken and the accuracy of the hydraulic calibration achieved for the March 2012 event. The concerns of those CRG is acknowledged, but based on the extensive body of sensitivity testing, feedback from stakeholders and comments in the expert independent review it was concluded that there is no justification to modify the flows from those that were adopted.
- The sequence of events during the March 2012 event has been a significant point of discussion in CRG Committee meetings. In particular, it is the belief of some members of the CRG and broader community that breeches in the railway line during the event led to a significant lowering of upstream water levels over a relatively short period of time. A review of available data, including temporary PALS water level gauges located at the railway line and manually-read water level records, does not support this notion. In the records that are available, which includes manual records from residents and temporary gauge records, a flat peak in water level is observed between approximately 4-6pm on Sunday 4th March. The peak is followed by a gradual and steady lowering in water levels over the next 10 days. It is believed that the railway line breech occurred in the last few hours of the 4th March. The record shows that at the time of the railway breech water levels had peaked and were beginning to recede, and continued to recede at a steady rate. While it has been reported by some committee members that a significant drop occurred by the next morning, the gauge records do not support this. It is the belief of Water Technology that the role the railway breeches had in lowering water levels was relatively minor. The sequence of key events and recorded water levels are displayed in the chart on the following page.

- Concerns around the downstream impacts which could occur as a result of removal of the disused channel banks south of the town in the area of the hospital depression have been raised by the affected landholder. It is understood that these banks have already been partially removed in recent years. Downstream impacts were only found to occur as part of the Original Mitigation Package. The southern ring levees included as part of Mitigation Packages A, B and and C prevent those downstream impacts occurring in the final mitigation scenarios.


Numurkah Peak WL
(4:00-6:00pm, 4th March)
Melville St Bridge still below deck at 7:15pm (photo – Kerry Swan)
Hospital Depression inundated at 7:40pm (photo – Kerry Swan)
Hospital flooded at 5-6am (photo – Kerry Swan)
WL at Mark McNamara's house dropped by 5cm from peak at noon 4th March (slower than creek)
Broken Creek at Nathalia WL (m)
Broken Creek at Walshes Bridge WL (m)
Broken Creek at Katamatite WL (m)
Numurkah Water Level (manual recordings) (m, AHD)
Railway Bridge WL (m, AHD)
Gauge Water Level (m)
4
3.5
3
2.5
2
1.5
1
108
107.9
107.8
107.7
107.6
107.5
107.4
107.3
107.2
107.1
107
2/03/2012 0:00
3/03/2012 0:00
4/03/2012 0:00
5/03/2012 0:00
6/03/2012 0:00
7/03/2012 0:00
8/03/2012 0:00
9/03/2012 0:00
10/03/2012 0:00
Date/Time

17. KEY FINDINGS AND RECOMMENDATIONS

The following points detail the key findings and recommendations of the study:

- Design flood levels were determined and can be used to guide future planning decisions in Numurkah.
- Three final packages of mitigation works have been identified which significantly reduce flood risk for Numurkah. The packages consist of:
    - Mitigation Package A consists of formalising the northern levee, a larger southern ring levee and hospital depression levee as well as channel enlargement of Broken Creek. This package benefits both the northern and southern portions of the township and results in a very significant reduction on flood damages. The scheme has some moderate impacts upstream of the levee systems which extend for several kilometres across the floodplain. This package of works has been costed at slightly less than $17 million and has a low benefit-cost ratio of 0.3.
    - Mitigation Package B consists of formalising the northern levee as well as a southern ring levee and three other smaller ring levees. This package benefits both the northern and southern portions (excluding the larger southern residential lots) of the township and results in a very significant reduction in flood damages. The scheme has some moderate impacts upstream of the levee systems. This package of works has been costed at slightly more than $23 million.
    - Mitigation Package C consists of formalising the northern levee as well as a southern ring levee and three other smaller ring levees. This package benefits both the northern and southern portions (including the larger southern residential lots) of the township and results in a very significant reduction in flood damages. The scheme has some significant impacts upstream of the levee systems which extend for several kilometres across the floodplain and are worse than Packages A and B. This package of works has been costed at slightly less than $25.5 million.
- It is recommended that the three final mitigation packages are presented to the community through a period of community consultation in order to seek community feedback on the preferred mitigation package.
- If any of the above packages of works are implemented the next step will be for the package to undergo functional and detailed design. Some of the packages have been noted to have impacts on a significant number of upstream and downstream properties and local mitigation works where appropriate will need to be investigated as part of the functional and detailed design phase.
- The Original Mitigation Package has also been presented in this report and consists of formalising the northern levee as well as a number of other minor works. This package predominately benefits the northern portion of the township and results in a significant reduction in flood damages. This package of works has been costed at slightly less than $3.5 million and has a modest benefit-cost ratio of 0.4. It should be noted that this option does not have the support of the community reference group and received low levels of support during the last period of community consultation.
- It is recommended that any future decommissioning of irrigation channels must consider the impact on flood risk to Numurkah and surrounds. In particular, the study has highlighted the importance of the irrigation channel to the east of Numurkah which runs parallel to Kinnairds Road and has a significant role in protecting the township in large flood events. Any future decommissioning works of the Kinnairds Road channel must consider these impacts and replace the channel banks with a formal levee.

- The CRG requests that culverts along Broken Creek are upgraded in the future to improve drainage around Numurkah. In particular, when funding permits, the committee wishes to see the Goulburn Valley Highway and Railway culverts be upgraded with increased capacity to reduce water banking up on the upstream side in large flood events. It is acknowledged by the committee that funding is unlikely to be available in the short-term but it is recommended that the works be implemented as part of a long-term drainage plan for Numurkah. In the short-term it is recommended that the culverts undergo maintenance to ensure they are cleared of debris and sediment and are operating at full capacity.
- The CRG requests that VicTrack be notified that damage to the railway line in the vicinity of Numurkah from large flood events is likely to continue periodically into the future. The committee would like VicTrack to consider that, when funding permits, the culverts under the railway line be upgraded with either an increased number of culverts or bridged sections to increase the capacity of flow under the line. Such works will reduce the frequency of overtopping and are likely to reduce the long-term cost associated with flood damage to the railway line along with the associated economic losses to the greater community. It is acknowledged that funding is unlikely to be available in the short-term but it is recommended that the works be implemented as part of a long-term drainage plan for Numurkah. A copy of the draft report will be forwarded to VicTrack at the completion of the project with these points highlighted to them.
- It is recommended that future road maintenance and upgrade programs by both Council and VicRoads must consider the impact of flooding in completing such works. It is noted that roads can have a significant impact on floodplain behaviour, particularly in areas of flat terrain such as Numurkah. Floodplain behaviour must not be altered or made worse around Numurkah through the raising of road crest levels that often occurs in road maintenance programs.
- VICSES, Moira Shire Council and Goulburn Broken CMA should explore further the recommendations for enhanced flood response through utilising the flood inundation maps and flood intelligence tools included in the Municipal Flood Emergency Plan (MFEP).
- The study has recommended a flood warning system for Numurkah which includes additional permanent rainfall and streamflow gauges. A firm commitment has been made by Goulburn Broken CMA, DELWP, BOM and Moira Council to implement the recommendations and planning for the warning system has commenced. The flood warning system should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system.
- The CRG strongly support permanent gauges being installed on the Broken Creek between Katamatite and Numurkah and in the Muckatah Channel. They feel that this would reduce the reliance on temporary gauges that may not be available in a flood situation. It is recommended that Moira Shire Council and Goulburn Broken CMA explore the opportunity with Bureau of Meteorology what the benefit of permanent gauges would be for any future flood warning system upgrade, and identify locations that would be suitable. As part of this process consultation should also occur with Goulburn Murray Water who also have some preferred permanent gauging sites.

APPENDIX A PRELIMINARY MITIGATION MODELLING SUMMARY

Table 17-1 Summary table of mitigation modelling

Mitigation ID	Option description
1	Northern and Southern levees
2	Northern levee, Floodway and additional culverts
3	Northern levee and Eastern/Southern levee
4	Northern levee, Eastern/Southern levee and additional culverts
5 **(Original Mitigation package)**	Preliminary Mitigation Package
6	Lowering of high ground scenario
7	Revised floodway scenario
8	Revised floodway and Northern levee scenario
9	Whole town levee
10	Northern levee excluding Brooke Court & Southern ring Levee protecting the smaller southern residential lots
11	Northern levee excluding Brooke Court & Southern ring Levee protecting all southern residential lots
12 **(Final Mitigation Package B)**	Northern levee including Brooke Court & Southern ring Levee protecting the smaller southern residential lots
13 **(Final Mitigation Package C)**	Northern levee including Brooke Court & Southern ring Levee protecting all southern residential lots
14	Northern levee including Brooke Court & alternate Southern ring levee protecting all Southern residential lots
15 **(Final Mitigation Package A)**	Northern levee including Brooke Court & alternate Southern ring levee which protects the smaller, Southern residential lots

Preliminary Modelling

Overview

A number of individual mitigation options and combined mitigation packages were modelled prior to the final packages being selected for modelling. As part of this preliminary package modelling, only the 1% AEP event was modelled. Some of the package modelling occurred concurrently with the tested options described in the previous section, and so some of those options are included in the following packages.

Preliminary Package 1 – Northern and Southern Levees (ID:1)

Description: Package consisted of a levee along the northern bank of Broken Creek and a ring levee protecting the southern residential area. Modelled levee alignments were provided by Goulburn Broken CMA and have been shown previously in Figure 13-1.

Cost: Moderate-high, likely in the region of $1-1.5 million.

Results: Protects large number of properties in both northern and southern residential areas. Exact numbers protected from above floor flooding unknown at the time due to floor level survey not yet being available however it was estimated that more than 80 properties are protected from above floor flooding and 200-300 protected from below floor. Increased upstream flood levels were observed in the results, with increases of 65-75 mm immediately upstream of the Melville Street Bridge and increases of 14-16 mm observed at properties around Brooke Court.

Summary: The modelling demonstrated that the northern and southern levees could protect large parts of Numurkah in the 1% AEP event. Full analysis of the benefits was not possible at the time due to surveyed flood levels not being available. While the southern levee was effective there were some practicality issues identified around several road crossings that would need to be addressed and the large number of driveways that may potentially be intersected by the levee. The southern levee was not well supported by the Reference Group due to concerns around practicalities and visual amenity. The northern levee was well supported by the Reference Group. Some sections of the levee are currently in place, supported with temporary works during large flood events.

In summary, the modelling of this package indicated that both levees could protect significant parts of Numurkah but floor survey was needed to confirm the exact benefit. The levees, when modelled together, had some increased upstream water levels which would need to be addressed in subsequent packages. The southern levee was not well-supported by the Reference Group.

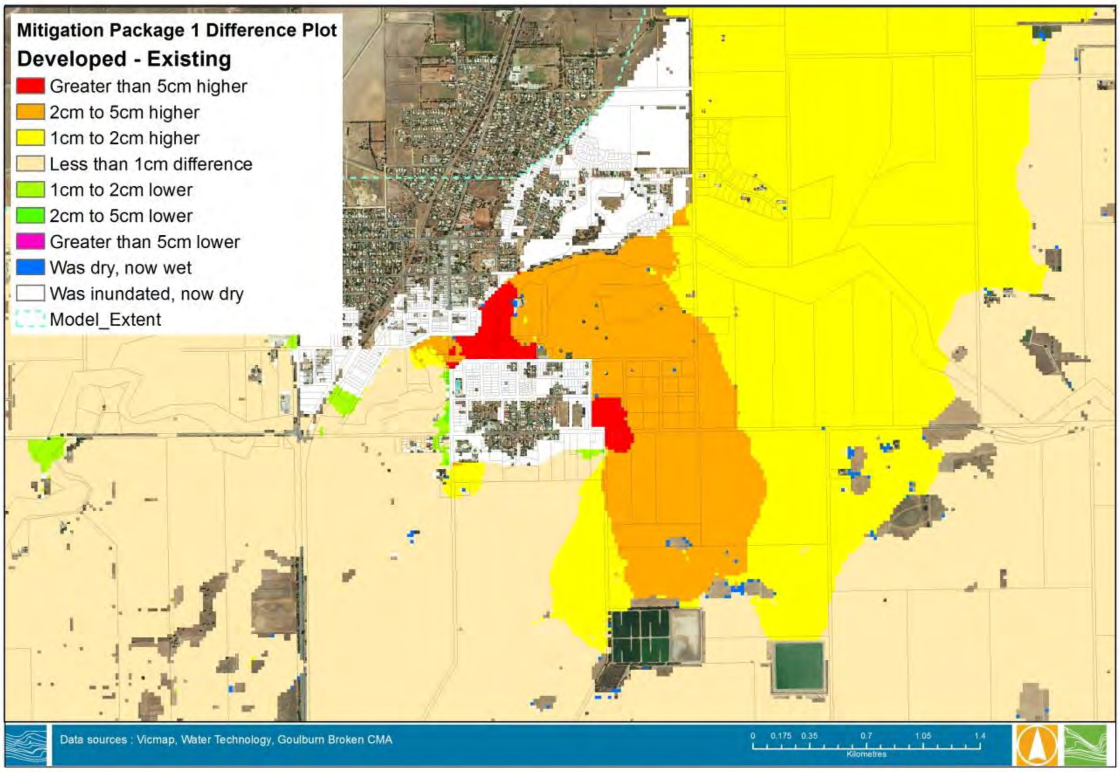


Figure 17-1 Mitigation Package 1 Difference Plot

Preliminary Package 2 – Northern Levee, Floodway and Additional Culverts (ID:2)

Description: This package consisted of a combination of options requested by the Numurkah Flood Action Group for modelling. The following options were modelled in this package.

- A levee along the northern bank of Broken Creek
- Floodway through the Train Park, Skate Park and across Melville St. The modelled floodway was approximately 50 m in width and involved lowering the topography through that area by up to 300mm.
- Extra culverts under Hwy & Railway bridges (as per Option C discussed earlier) and 400 m bank of culverts under Hwy and Railway (as per Option A discussed earlier)
- Removal of a number of earthen banks near the Go Kart track, located 5 km to the east of Numurkah. The banks were levelled to the adjacent topography. This option was suggested by members of the Reference Group as it was felt that it was preventing flood water flowing to the south which could be leading to increased water levels in Numurkah township.

Results: As with Preliminary Package 1, the northern levee protected much of the northern residential area. An area in the west of the residential area experienced some inundation as a result of a small gap in the modelled levee which was fixed for subsequent packages. The additional railway culverts lowered flood levels immediately upstream of those structures with the improvement extending as far upstream as Melville Street, similar to what was observed in the preliminary option modelling. The floodway led to 60-70mm lower flood levels immediately upstream of Melville St bridge, with the impact extending for approximately 400m upstream.

While a full damages assessment has not been undertaken on this option, it is estimated that the floodway protects 2-3 properties from above floor flooding in the 1% AEP event while the additional culverts protect one property from above floor flooding. The northern levee was estimated to protect 70-80 buildings from above floor flooding and more than 200 from below floor flooding. The removal of the earthen banks near the Go Kart track had no impact on flood levels in Numurkah and a minimal impact on local flood levels (less than 10mm). It can be seen that this combination of options, compared with modelling both a southern and northern levee, did not result in upstream impacts, such as around Brooke Court, as occurred in Package A.

Summary: The modelling further demonstrated that the northern levee protects much of the township. The floodway and additional culverts were shown to have some local impact on upstream flood levels but provided limited benefit to flooded properties. Removal of the earthen banks near the Go Kart track did not provide any benefit to Numurkah.

In summary, this package further demonstrated the benefit of the northern levees but indicated that the floodway and culverts have limited benefit and, given their cost and low feasibility, would be unlikely to receive funding in the short-term.

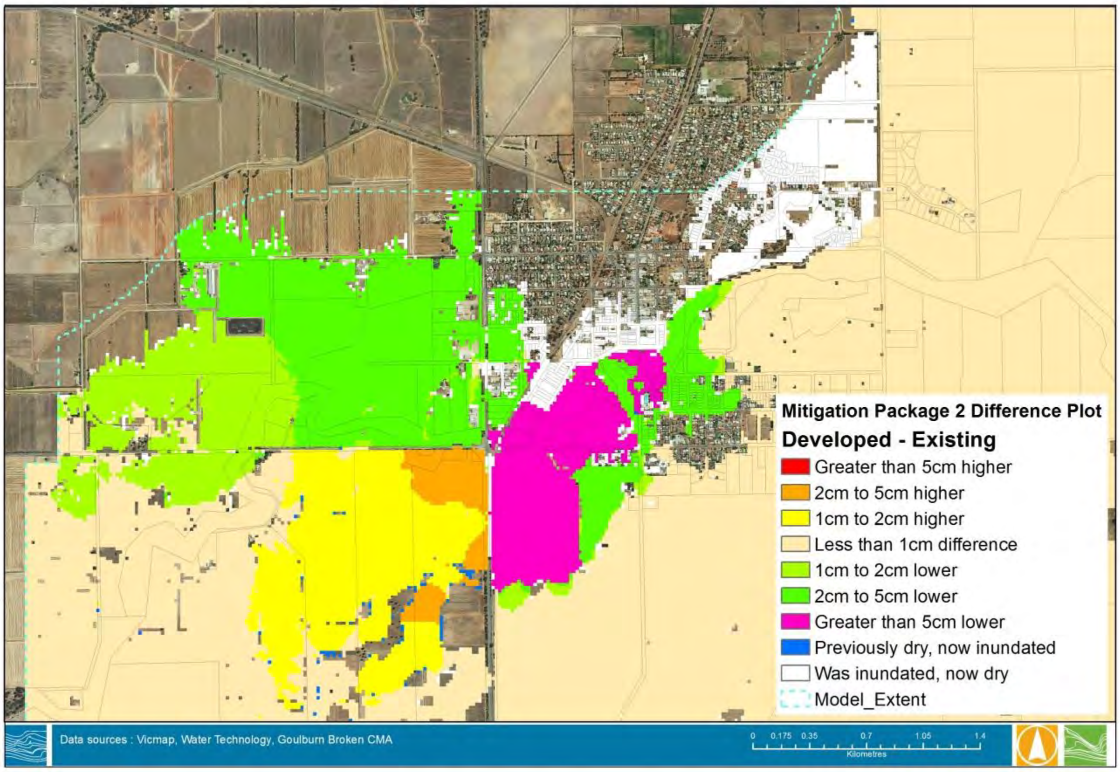


Figure 17-2 Mitigation Package 2 Difference Plot

Preliminary Package 3 – Northern Levee and Eastern/Southern Levee (ID:3)

Description: The following options were modelled in this package:

- A levee along the northern bank of Broken Creek
- An eastern/southern levee located to the south of Broken Creek with an alignment parallel to Kinnaird Road and then along the northern side of the hospital depression.
- Removal of disused channel banks located in a paddock in the south-west of Numurkah, near the downstream end of the hospital depression.
- A narrower floodway through the Train Park and across Melville Street which would require one property acquisition (currently a derelict house).

Results: The eastern/southern levee results in significant impacts to a significant part of the southern residential area as well as to upstream flood levels around Brooke Court. Flood levels were up to 400 mm in the southern residential area due to flood water being unable to flow south and banking up behind the southern levee. The obstruction of water flowing across the floodplain to the south, also led to water levels immediately upstream of the eastern levee being 75-80 mm higher, and 65-75 mm higher through the Brooke Court area. The impacts of the other measures in this package were difficult to ascertain due to the gross impacts of the eastern/southern levee. The results suggested that removal of the disused channel banks in the south-west of Numurkah may have lowered flood levels through the hospital depression, however that was difficult to confirm without subsequent modelling.

Summary: The modelling demonstrated that an eastern/southern levee would have significant impacts to flood levels in the southern residential area and upstream around Brooke Court. The levee was therefore deemed not appropriate for further modelling. Removal of the south-western disused channel banks seemed to lower flood levels along the hospital depression however additional modelling was required to confirm this.

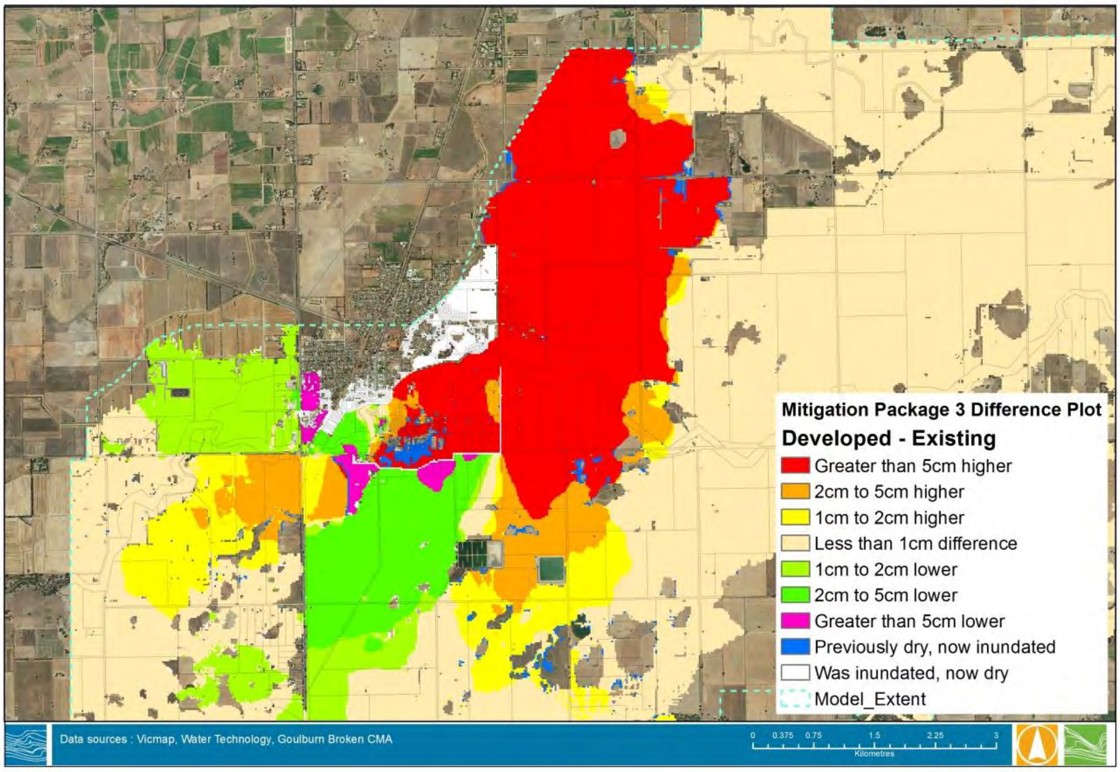


Figure 17-3 Mitigation Package 3 Difference Plot

Preliminary Package 4 – Northern Levee and Eastern/Southern Levee and Additional Culverts (ID:4)

Description: The following options were modelled in this package -

- A levee along the northern bank of Broken Creek
- A southern ring levee protecting the southern residential area.
- Removal of disused channel banks located in a paddock in the south-west of Numurkah, near the downstream end of the hospital depression.

- A narrower floodway through the Train Park and across Melville Street which would require one property acquisition (currently a derelict house) which was partially aimed to mitigating the increase in upstream water levels that result when both northern and southern levee are modelled together.

Results: As with Preliminary Package 1, the northern levee protected much of the northern residential area. The southern levee protected a number of properties however, as with Package A, the combination of both northern and southern levees together led to slight increased upstream water levels, with an increase of 10-15mm in the Brooke Court area. There were larger increases in water levels, of 30-60mm, immediately to the east of the southern levee around the cemetery and the larger residential properties between the cemetery and Kinnaird's Road. Removal of the south-western disused irrigation channel banks led to lower levels around the hospital depression of between 20 and 120 mm. Again it is difficult to attribute the lowered levels to removal of the banks alone, as the southern ring levee is also likely to have lowered levels in that area. Removal of the channel banks seems to have led to some increased downstream water levels with increases of 20-25mm on the western side of the railway and highway, where one residential and one commercial property are located.

While a full damages assessment has not been undertaken on this option, it is estimated that the southern levee protects approximately 14 properties from above floor flooding and approximately 150 properties from below flood flooding. Given the cost associated with the southern levee, which is estimated to be higher than the northern levee due to the number of road and driveway crossings, it is unlikely the option would be feasible. There was also little support for the southern levee from the Reference Group and community members on the Reference Group indicated this would likely be the case in the community as well. The narrow floodway had limited benefit in this package, and did not prevent the upstream impacts of the southern and northern levees when modelled together.

Summary: The results indicate that when the southern and northern levees are modelled together they result in upstream impacts on water levels. Given the southern levee has a relatively high cost, protects a limited number of properties from above flood flooding and leads to upstream impacts it was deemed unlikely to be feasible and not considered in the final mitigation packages. There was little support for the southern levee from the Reference Group at this time. The removal of the irrigation channel banks was retained for the final mitigation package, as without a southern levee, it was felt the works could benefit properties in the southern residential area. The downstream impacts of the channel bank removal would need to be investigated further in subsequent modelling. The Melville Street floodways were deemed to have low feasibility, due to their high cost and limited benefit and were not considered in the final mitigation package.

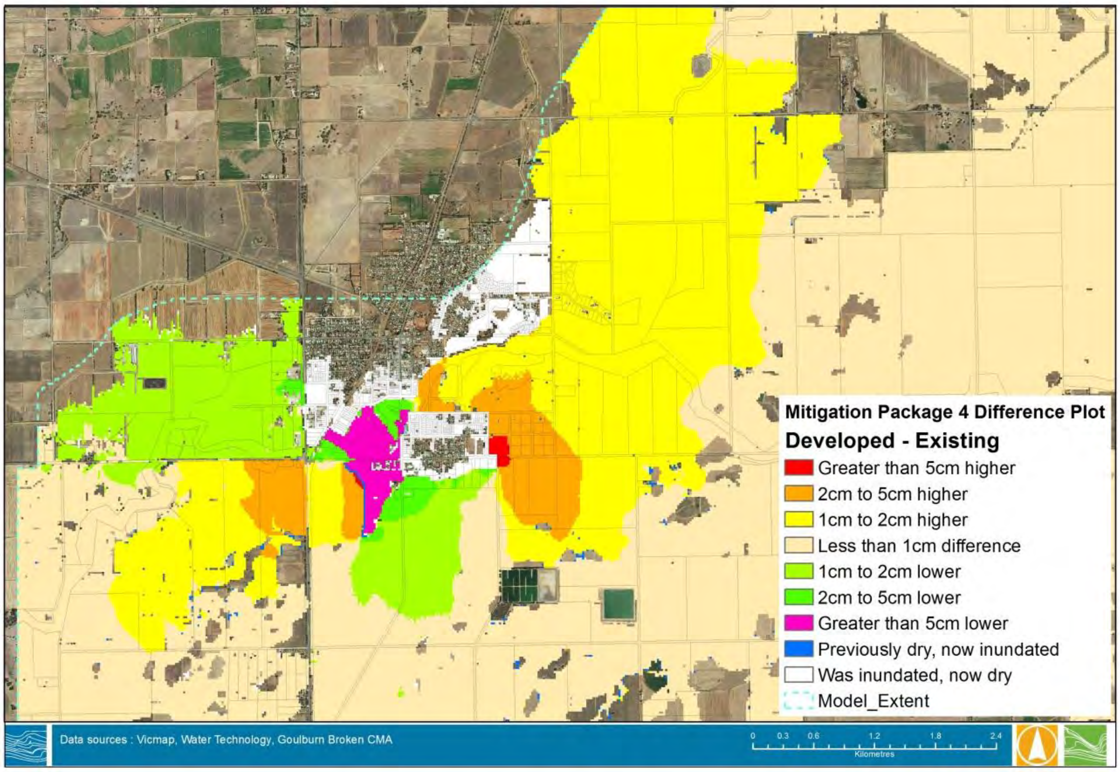


Figure 17-4 Mitigation Package 4 Difference Plot

Once floor level survey had become available, the mitigation results were further analysed to better understand the impact each option had in protecting properties in Numurkah. The results of that analysis are shown below in Table 17-2 with an explanation provided as to why each option was considered in the final package of modelling.

Table 17-2 Summary of Properties protected by each mitigation options

Option	Properties protected in 1% AEP event		Outcome
	Above floor protection	Below floor protection	
Northern Levee	77	207	Relatively high cost option but protects significant number of properties. **Included in final package for modelling.**
Southern Levee	14	155	Protects a limited number of properties given the high construction cost (> $1 million). A number of practicality issues given the number of roads and driveways that would be impacted. Upstream impacts. **Not included in the final package for modelling.**
400m bank of culverts under	9	16	Very high cost option (> $20 million) with limited number of properties benefiting. All properties protected from above floor

Option	Properties protected in 1% AEP event		Outcome
	Above floor protection	Below floor protection	
highway and railway			flooding would be protected by the Northern Levee anyway. **Not included in the final package for modelling but included as part of a long-term drainage plan for Numurkah.**
Additional box culverts under highway/railway	2	4	High cost option (Approx. $2-3 million) with limited number of properties benefited. All properties protected from above floor flooding would be protected by the Northern Levee anyway. **Not included in final package for modelling but included as part of a long-term drainage plan for Numurkah.**
Removal of earthen banks near Go Kart Track	0	0	No benefit to properties in Numurkah. **Not included in final package for modelling but banks could be removed relatively cheaply (following discussions with landholder).**
Melville Street floodway	2-3 (estimated)	5-6 (estimated)	Limited benefit to properties, high cost. **Not included for in final package for modelling.**

Original Mitigation Package (ID:5)

Overview

Based on the preliminary options and package modelling, floor level survey results and discussions with the Reference Group the following preliminary recommended mitigation package were selected for detailed modelling. The package consisted of:

- Construction of a Northern Levee extending from the Goulburn Valley Highway, along the northern bank of Broken Creek, across Melville Street near the central township and along the alignment of the existing irrigation channel banks to the east of the township. The levee would be constructed with 300mm of freeboard above the 1% AEP water level. The irrigation channel banks to the east, which currently provide a level of protection in large events, would need to be replaced and/or upgraded to the new design standard. The constructed levee would be 4.4 km in length and has an estimated capital cost of $321,900. Moira Shire Council would be the construction authority for the levee, which includes management of the operation and maintenance plan.
- There are four locations where the Northern Levee would cross minor roads and a system of headwalls and drop boards would be required at those points. The estimated cost for those works is $120,000.
- Removal of disused channel banks in the south of the township, located immediately to the south-west of the hospital depression. The estimated cost for removal the channel banks is $53,000.
- Installation of non-return valves on all major stormwater outlets into Broken Creek from the northern section of the township. This is to ensure flood water does not back up in large flood events resulting in flood water on the protected side of the levee. The preliminary estimated cost for the valves is $40,000 although a final cost will be confirmed upon review by Moire Shire Council.

Results

The locations of the preliminary recommended mitigation options overlaid with the 1% AEP event depth results (under mitigation conditions) are displayed in Figure 17-5. A difference plot is provided in Figure 17-6. The results demonstrate that the levee is effective in protecting much of the northern township in the 1% AEP event. The key observations from the modelling results are:

- The results demonstrate that the levee is effective at protecting the northern part of Numurkah in the 1% AEP event with 77 properties protected from above flood flooding and 207 properties protected from below floor flooding. The levee does not cause any impacts to upstream water levels.
- Removal of the south-west disused channel banks has resulted in lower water levels to properties near the hospital depression of between 15 and 65mm. Two properties in that area would be protected from above floor flooding while several would be protected from below flood flooding.
- The results demonstrate that removal of the channel banks causes increase water levels to agricultural areas downstream of the banks, as well as one residential and one commercial property. At both properties water levels are increased by approximately 25mm. The option has been retained in the final package however if this option was to be implemented discussions with affected landholders would be required and local mitigation options such as ring levees investigated.

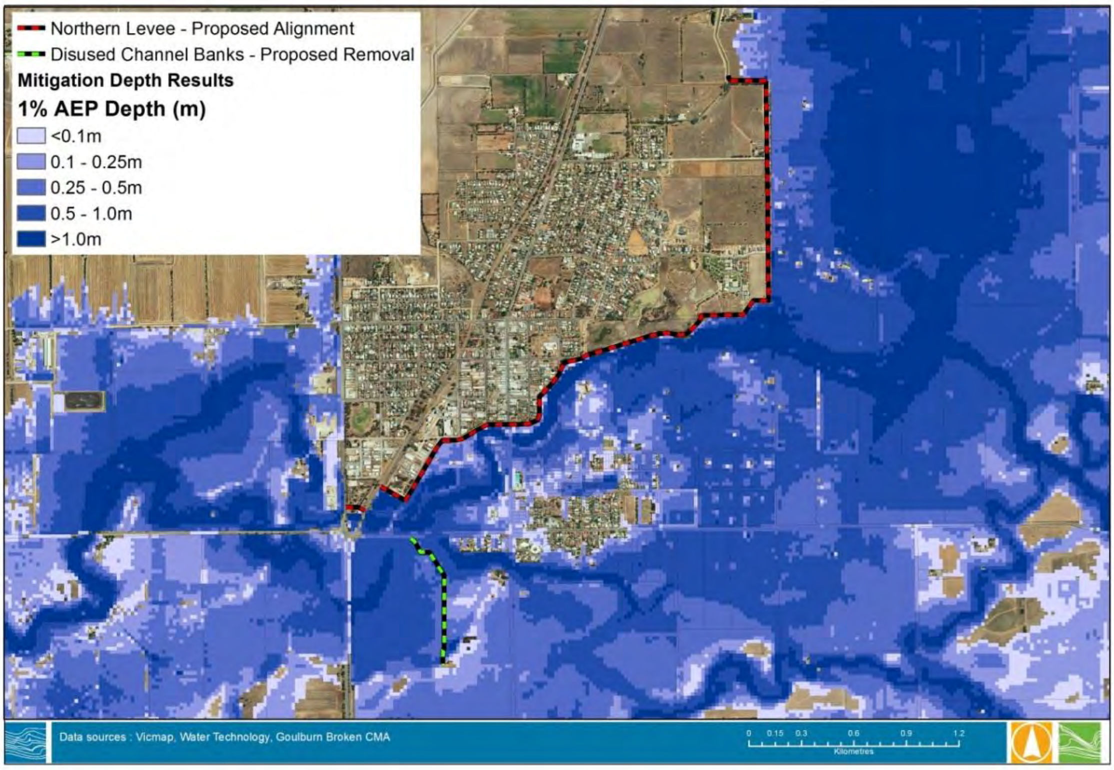


Figure 17-5 Preliminary recommended mitigation package and 1% AEP depth results

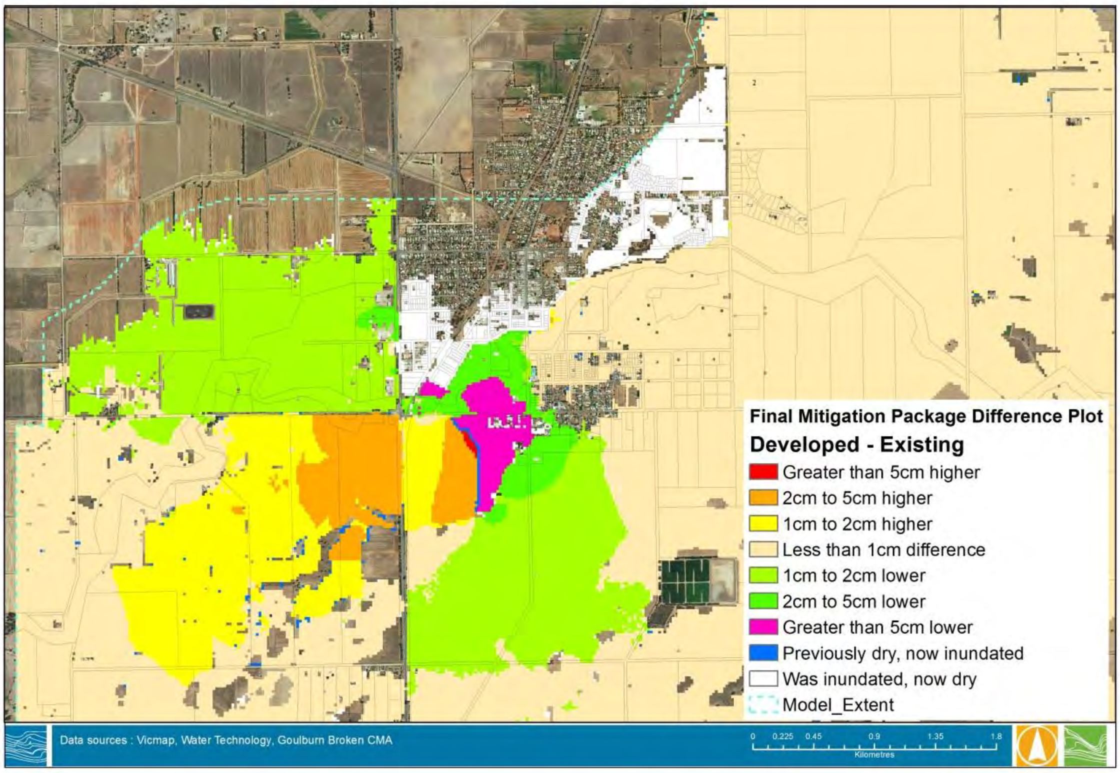


Figure 17-6 Preliminary Recommended Mitigation Package Difference Plot

Summary

The preliminary recommended mitigation package was found to significantly reduce flood risk in Numurkah with much of the town protected in a 1% AEP flood events as shown in Figure 17-6.

It is acknowledged that the works are more effective for residents living north of Broken Creek however there is some benefit to properties in the south of Numurkah who are located in or close to the hospital depression, as a result of removal of the disused irrigation channel banks. A number of options were tested to improve flood risk for residents in the southern residential area however none of the options tested were effective at protecting properties while also being feasible and practical to construct. Advise impacts downstream of the south-west disused channel banks are acknowledged and local mitigation options would need to be further investigated if that option was to be implemented.

While there are no structural mitigation options recommended which offer full protect to the southern residential area in the 1% AEP event flood risk will be reduced regardless in future flood events through improved flood warning and emergency management. Flood warning recommendations and updates to the Municipal Flood Emergency Plan (MFEP) are significant outcomes of the study which will provide benefit to residents and reduce flood damages in future events.

Ultimately this package was deemed unacceptable by the community because it did not offer structural protection to the southern residential areas of Numurkah. As a result additional modelling was undertaken and is described further below.

Additional Mitigation Modelling

Following completion of the preliminary recommend mitigation package modelling and further consultation, it was agreed that a number of additional mitigation options would be modelled. This was to ensure that all mitigations options were explored prior to finalisation of the study and adoption of the final recommended package of works. The section below describes those additional modelling scenarios and results.

Lowering of high ground scenario (ID:6)

A review of the topography in central Numurkah found that there is an area of higher ground in the southern residential area including the football oval which appeared to create a constriction in Broken Creek in that area (see Figure 17-7). It was suspected that this was more of a significant control on upstream water levels than the Melville Street Bridge.

An additional scenario was modelled to investigate if lowering the area of high ground around the football oval, thereby reducing the constriction, would have any significant impact on upstream water levels and water levels through the southern residential area in the 1% AEP event. The higher ground around the football oval was removed from the topography by lowering surface levels by an average of 360 mm across that area to match in with the surrounding ground levels.

The results are presented in Figure 17-8 and Figure 17-9 and showed that the works were effective in lowering upstream water levels. However these works also increase water levels downstream significantly, resulting in a number of additional properties being inundated above floor level. Under existing conditions in the 1% AEP event 108 properties are inundated above floor level compared with 139 flooded above floor in this scenario. Upstream water levels were lowered by as much as 60 mm while downstream waters increased by up to 90 mm.

The results supported the observation that the area of higher ground around the football oval has created a constriction in Broken Creek flows and is a significant control point for upstream water levels. They also indicated that the constriction plays a role in protecting central Numurkah and parts of the southern residential area from higher flood levels and as such should not be lowered as part of a mitigation option.

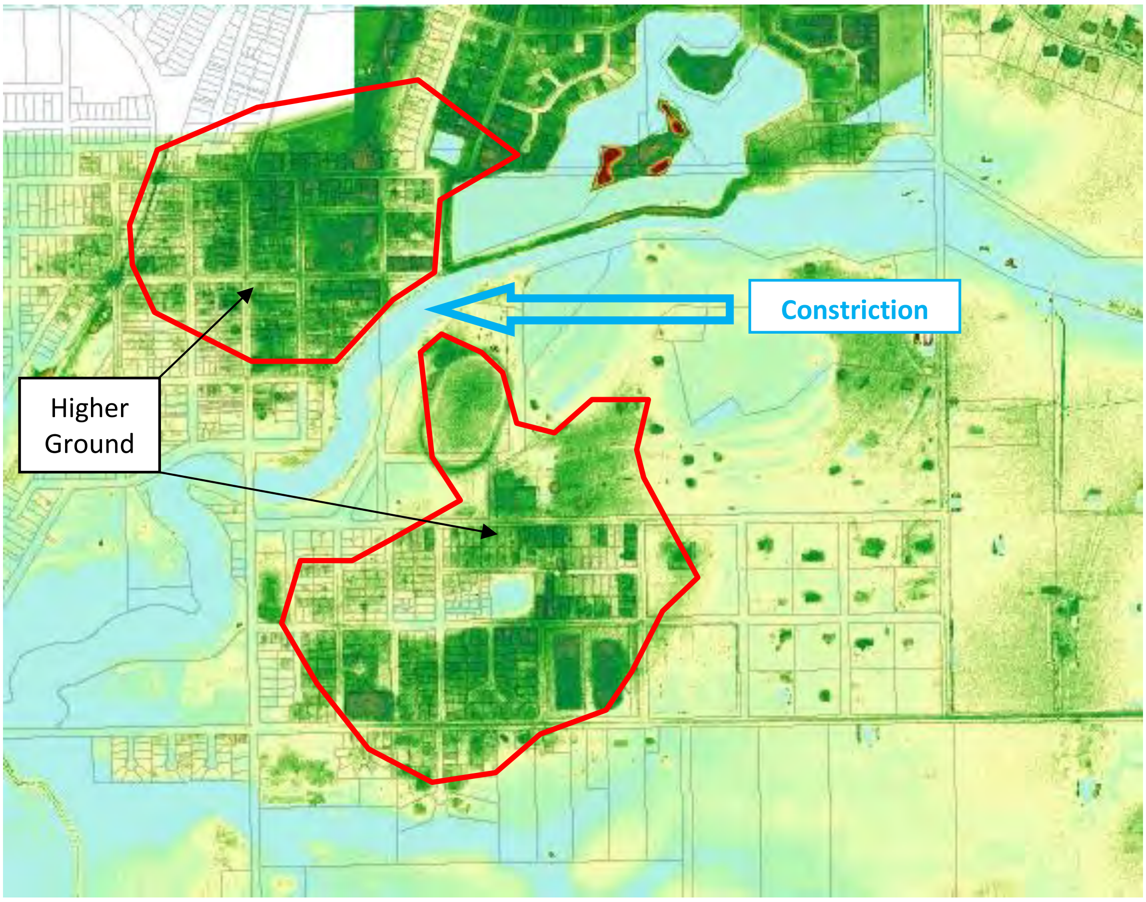


Figure 17-7 Topography of central Numurkah demonstrating natural constriction upstream of central township

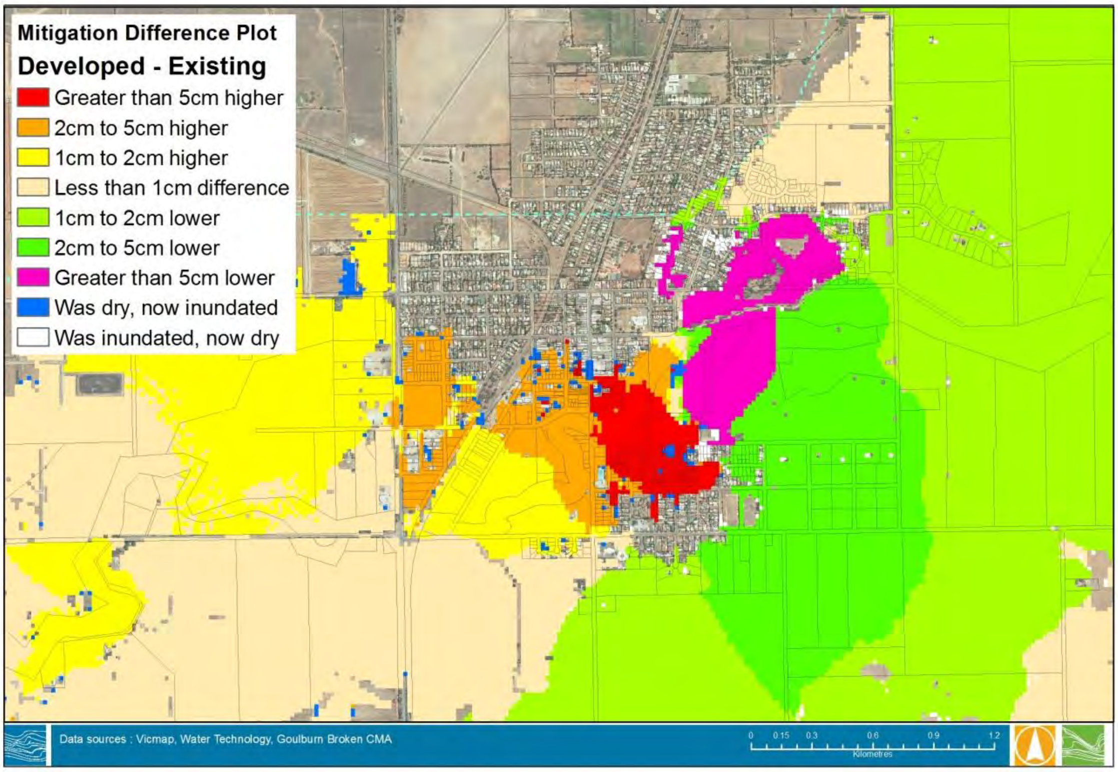


Figure 17-8 Difference plot for 1% AEP event for mitigation scenario

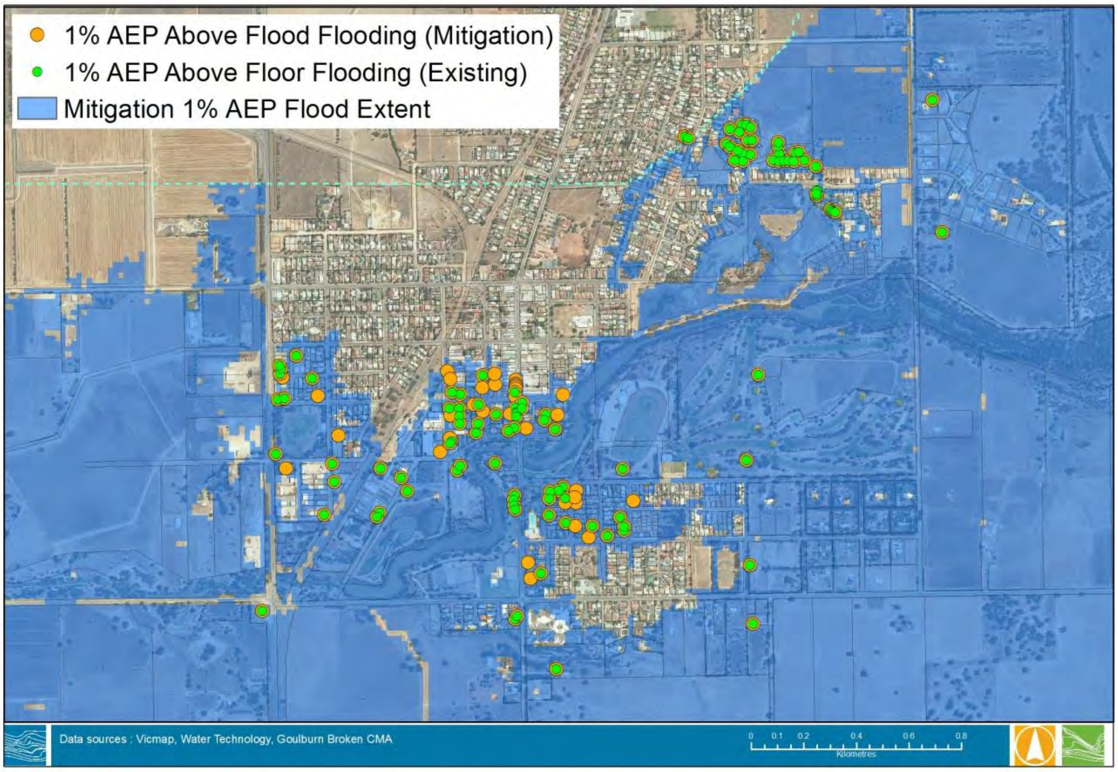


Figure 17-9 Comparison of buildings flooded above floor under mitigation scenario

Revised Floodway Scenario (ID: 7)

Following further discussions between stakeholders including the community Reference Group an additional mitigation scenario was run which involved the following:

- A floodway through the skate park, northern section of Apex Park, across Melville Road and through the train park. The modelled floodway was approximately 60m in width and trapezoidal in shape. The floodway was 260 metres in length with an upstream elevation of 107.75 m AHD and a downstream elevation of 106.25 m AHD resulting in an average gradient of 1:170. The average depth of cut required for the modelled floodway is 0.70 metres and involves a total excavation of approximately 10,100 m^3 of earth.
- The modelled floodway passed through a number of features which would be impacted by the works including the derelict house at 174 Melville Street, the skate park, the Apex Park (including the playground), Tunnock Road, Melville Street and part of the parcel of land in which the public swimming pool is located. Underground assets such as sewerage and drainage pipes may also be impacted and need reconfiguration.
- The model was run for the 1% AEP only with no other mitigation options included in the scenario. The northern bank of the Broken Creek was modelled assuming existing conditions and so no northern levee in place other than the permanent sections that currently exist. It should be noted that any benefit that this option offers to properties north of Broken Creek would also be provided by the upgrade to the northern levee.

The location of the modelled floodway and the resulting 1% AEP flood extent is provided in Figure 17-10.

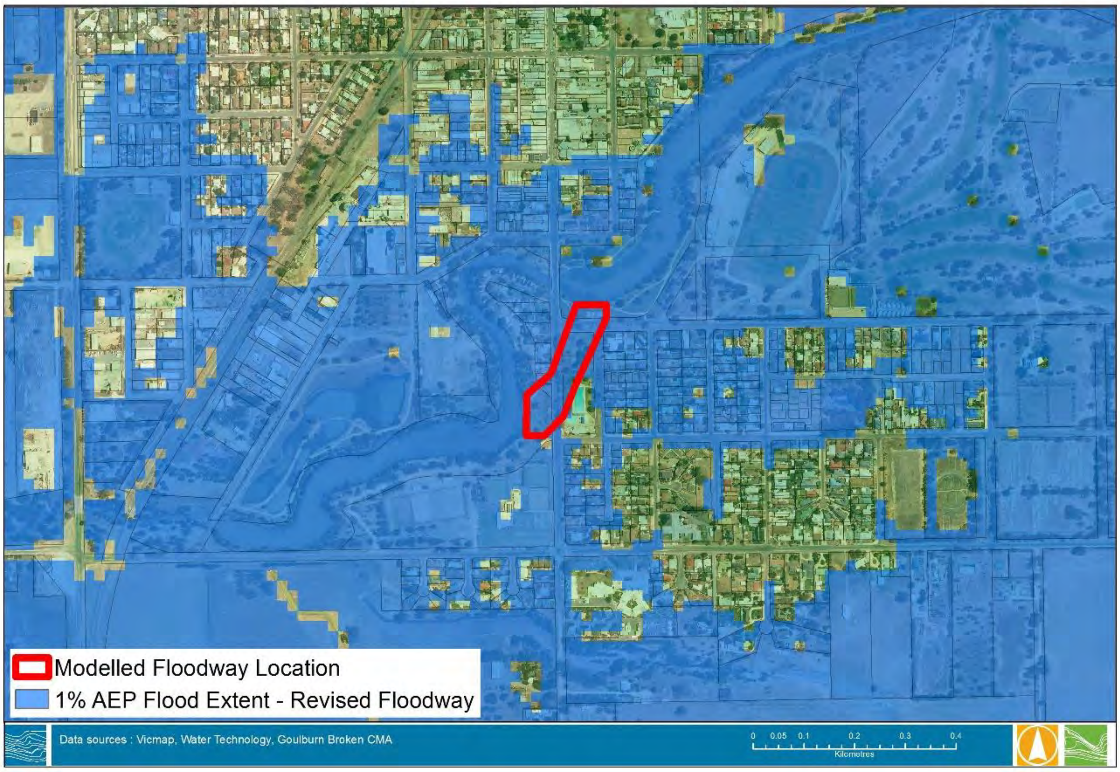


Figure 17-10 Location of modelled floodway and 1% AEP flood extent under mitigation conditions

A basic damages assessment was undertaken to determine how many properties are protected from above floor flooding with the revised floodway scenario compared with existing conditions. The results demonstrated that:

- The modelled floodway protects six properties to the north of Broken Creek and four properties to the south of Broken Creek from above floor flooding. Of those ten properties nine will continue to experience below floor flooding, whilst one property to the north of Broken Creek becomes free of inundation.
- The results indicated the floodway will protect approximately 15 properties from below floor flooding to the north of Broken Creek and two properties to the south of Broken Creek.
- Flood levels are up to 5-6 cm lower through the central business area and up to 7-8 cm lower through the southern residential area. The lowering of flood levels extends for approximately 250 metres upstream and eastwards through the southern residential area.
- If it is assumed that the northern levee is to be constructed, the results indicate that the floodway will provide some modest benefit to the southern residential area only. 4 properties will be reduced from above floor flooding to below floor flooding and 2 properties will be protected from below floor flooding. 18 properties will remain flooded above floor in the southern residential area in the 1% AEP event.
- These results demonstrate that this option reduces flood risk in the 1% AEP event however the benefit is relative modest if it is assumed the northern levee is to be constructed. To determine the benefit-cost ratio for the floodway the full range of design events would need to be modelled and detailed costings determined for the works, however it is likely that the benefit-cost ratio would be very low.
- The option would be associated with high costs including significant earthworks, road works to Tunnock Rd and Melville Streets, property acquisition costs, vegetation removal and relocation/rebuilding costs of the skate park and playground in the Apex Park. The swimming pool is also likely to be impacted by the works. Underground assets such as sewerage and drainage pipes may also be impacted and need major reconfiguration.

Figure 17-11 below shows which properties are protected by the floodway compared with existing conditions while Figure 17-12 shows the difference in water levels as a result of the mitigation works.

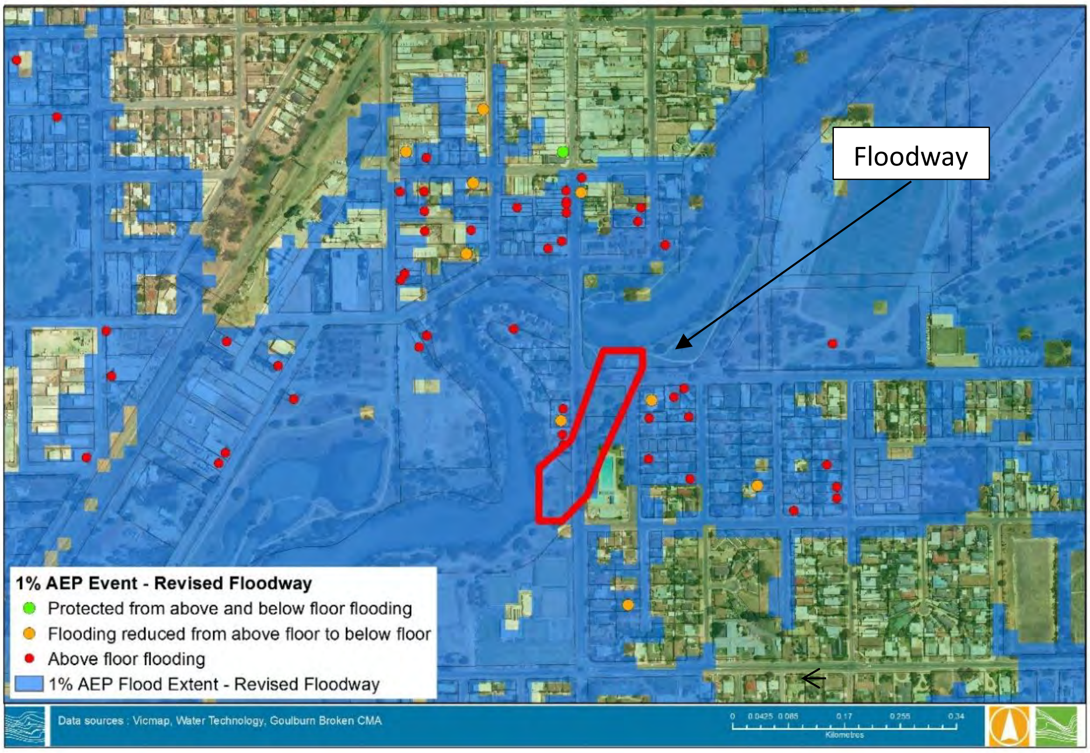


Figure 17-11 Impacts of the floodway on properties flooded above floor in the 1% AEP event

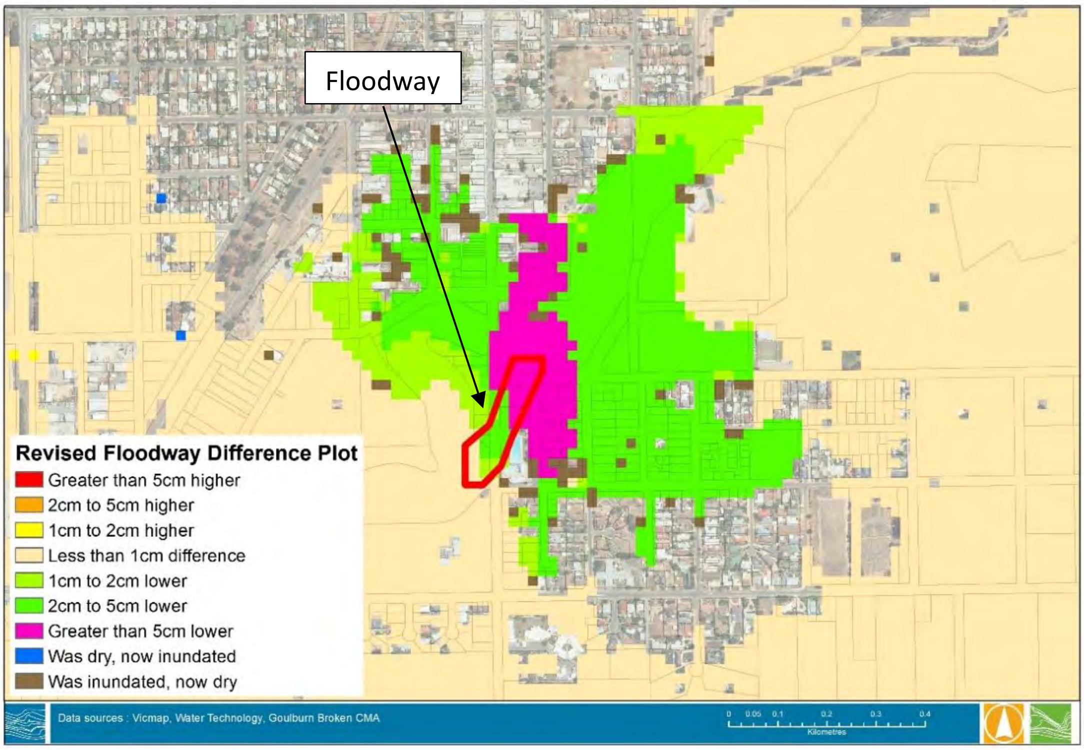


Figure 17-12 1% AEP difference plot for the revised floodway scenario

Revised Floodway and Northern Levee Scenario (ID: 8)

Following further discussion between stakeholders including the community Reference Group an additional mitigation scenario was run which included the following mitigation options:

- A floodway from Tunnock Road, through the northern section of Apex Park, across Melville Road and through the train park. The modelled floodway was approximately 60m in width and trapezoidal in shape. The floodway was 220 metres in length with an upstream elevation of 106.65 m AHD and a downstream elevation of 106.25 m AHD.
- The northern levee was included as detailed in previous mitigation modelling scenarios.
- An additional levee was included on the southern bank of the Broken Creek from near the skate park to the pedestrian bridge located approximately 300 m upstream.
- The grade of Tunnock Road was modified to slope east to west from Newby Street to the revised floodway.
- The modelled revised floodway passed through a number of features which would be impacted by the works including the derelict house at 174 Melville Street, the Apex Park (including the playground), Melville Street and part of the parcel of land in which the public swimming pool is located. Underground assets such as sewerage and drainage pipes may also be impacted and need reconfiguration.
- The model was run for the 1% AEP only.

The mitigation options included in this scenario and the resulting 1% AEP Flood Extent is provided in Figure 17-13.

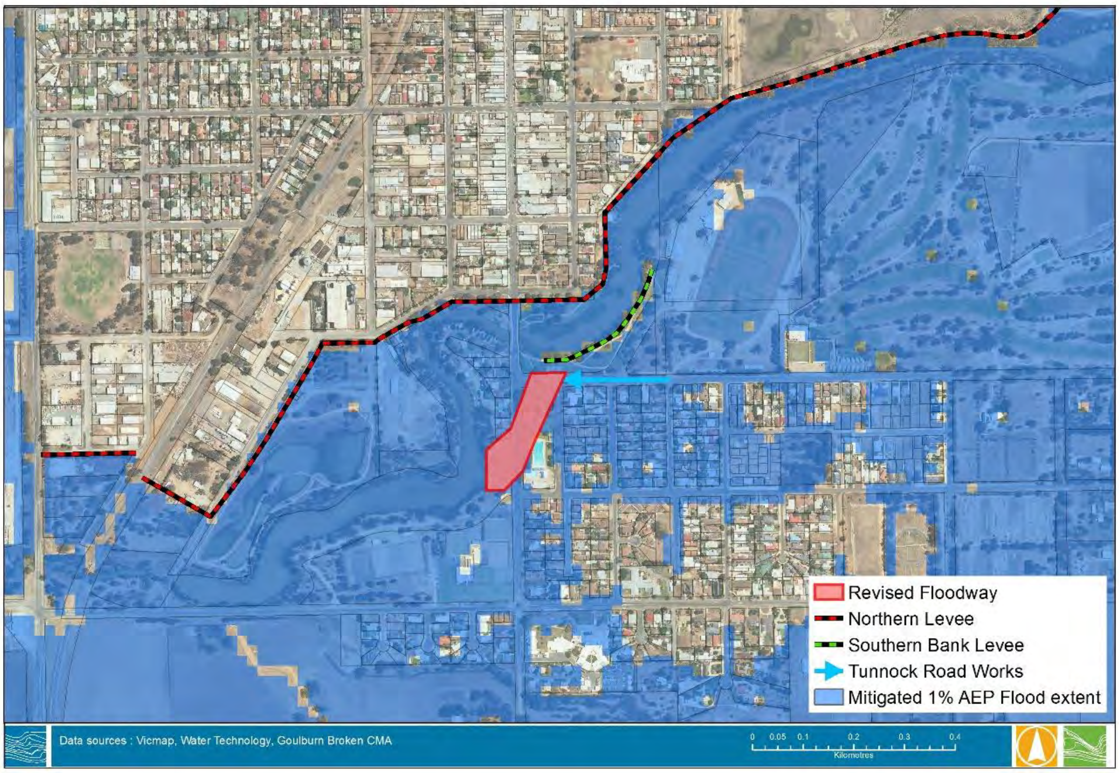


Figure 17-13 Location of modelled floodway and 1% AEP flood extent under mitigation conditions

A basic damages assessment was undertaken to determine how many properties are protected from above floor flooding with this scenario compared with existing conditions. The results showed that:

- As previous modelling has established the northern levee protects 77 properties from above floor flooding to the north of Broken Creek.
- The combination of the floodway, regrading of Tunnock Rd and additional levee on the south bank protects three properties in the southern residential area from above floor flooding. All three properties will continue to experience below floor flooding. Two properties at 191 and 197 Melville Street are shown to flood above floor with this scenario that were only flooded below floor under existing conditions as a result of raised water levels in that area. Therefore, there is a net improvement in above floor flooding of only one house in the southern residential area compared with existing conditions.
- Flood levels are up to 9-10 cm lower immediately to the east of the revised floodway through the southern residential area. The improvement in flood levels diminishes fairly quickly and extends for approximately 300 metres upstream and eastwards through the southern residential area.
- Flood levels are higher downstream of the floodway, with levels around Reed, Harding and Shaw Courts 30-50 mm higher.
- These results demonstrate that this option results in a very limited reduction in flood risk to properties in the southern residential area compared with existing conditions. There is a net improvement in above floor flooding of only one property with flooding worse at a number of properties downstream of the floodway.
- In the southern residential area 65 dwellings are flooded below floor but within 150 mm of floor level, while an additional 107 properties are flooded within 300 mm of floor level. This is partly a result of the flat topography in this area with relatively small differences in both flood and floor level elevations across the southern residential area.
- The package would be associated with high costs including significant earthworks, road works to Tunnock Rd and Melville Streets, regrading of driveways, property acquisition costs, vegetation removal and construction of the additional levee along the southern bank. The swimming pool is also likely to be impacted by the works. Underground assets such as sewerage and drainage pipes may also be impacted and need major reconfiguration. The cost of these works would be significantly higher than the total cost of the northern levee.
- To determine the benefit-cost ratio for this package the full range of design events would need to be modelled, however based on the results of the 1% AEP event there is little justification to examine the package further given the limited benefit in the southern residential area and negative impacts to some areas of the township.
- Including the removal of the disused irrigation channel banks to the south-west of the township within this package may improve some of the negative impacts of this scenario by reducing flood levels downstream of the floodway, but it will not reduce the risk enough to make this option viable.

Figure 17-14 below shows which properties are protected by the floodway compared with existing conditions while Figure 17-15 shows those buildings flooded within 150 mm and 300 mm of floor level. Figure 17-16 shows the difference in water levels as a result of the mitigation works.

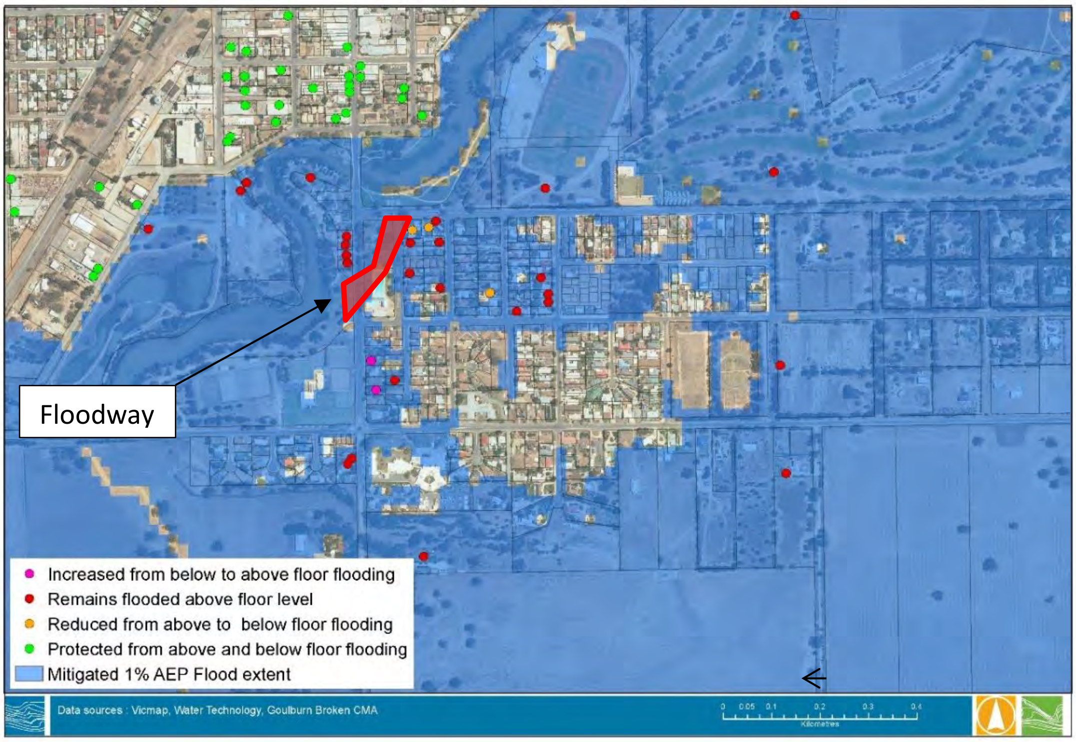


Figure 17-14 Impacts of the mitigation works on properties flooded above floor in the 1% AEP event compared to existing conditions

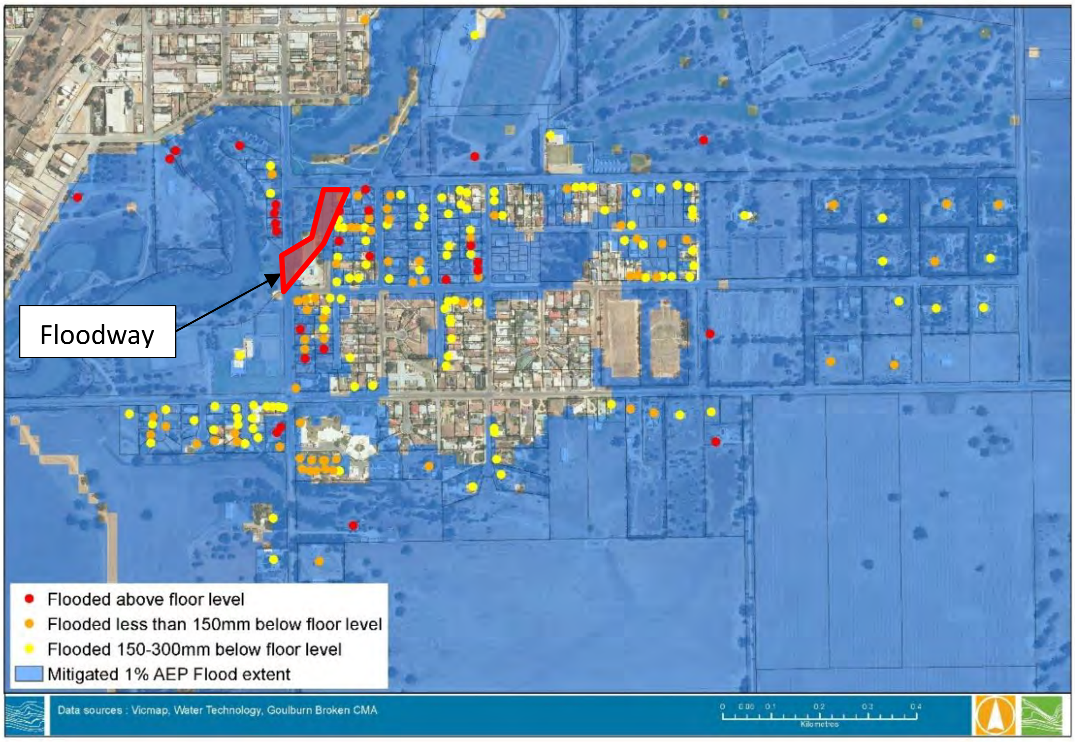


Figure 17-15 Properties flooded below floor but within 150mm and 300mm in the mitigated 1% AEP event

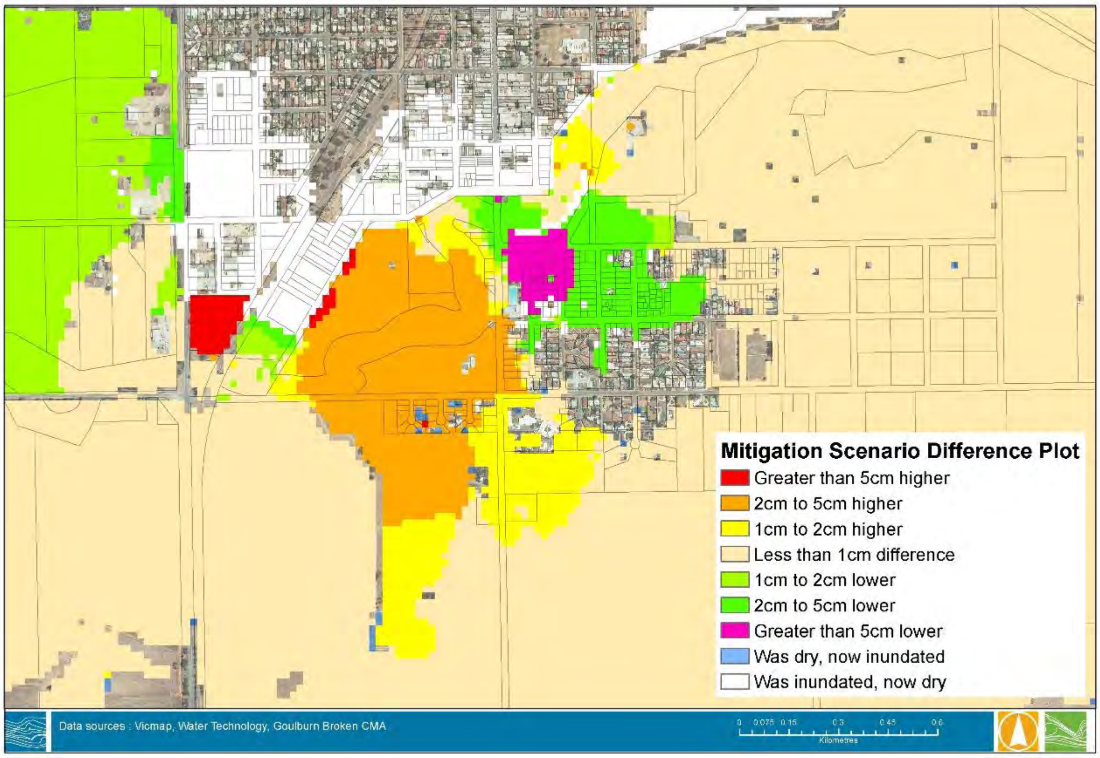


Figure 17-16 Difference plot for the mitigation scenario

Whole Town Levee Mitigation Package (ID:9)

Overview

Based on the preliminary option modelling detailed above, floor level survey results and extensive community consultation the following Whole Town Levee mitigation package was selected for detailed modelling. The package is shown in Figure 17-17 and consisted of:

- A series of levees and raised roads which work together to protect all residential areas of the township. They include:
    - Construction of an Eastern Levee extending from Kinnairds Road to the north-east of the township, to the east of Brooke Court, across Broken Creek, then along Power Road to the intersection with the Nathalia Road. The levee includes two sections of raised road along Kinnairds and Power Roads. The levee would be constructed with 300 mm of freeboard above the 1% AEP water level. The constructed levee would be 4.1 km in length.
    - Construction of a Southern Levee extending from the corner of Power and Nathalia Road, along the hospital depression, then along the Nathalia Road, across Broken Creek at Station Street then along the northern bank of Broken Creek to the Goulburn Valley Highway. The levee would be constructed with 300 mm of freeboard above the 1% AEP water level. The constructed levee would be 2.9 km in length.
    - Regulating structures would be required where the Broken Creek flows through the Eastern and Southern Levees. The estimated combined cost for the regulators is $2,800,000 which is based on recent costings for similar structures on small creeks leaving the lower Goulburn River as part of the Goulburn Constraints Program. The

structures would consist of remotely-controlled gates which would be closed in readiness for a flood event. For the purposes of design modelling it has been assumed that both structures are fully closed in all modelled events so no flow is able to pass along Broken Creek through the central township. The ownership and operation of these regulators is to be determined.

  - Construction of a ring levee protecting several properties in the hospital depression near Melville Street. The levee would be constructed with 300 mm of freeboard above the 1% AEP water level.
  - Moira Shire Council would be the construction authority for the levees, which includes management of the operation and maintenance plan.

- There are six locations where the levees would cross minor roads and a system of headwalls and drop boards would be required at those points.
- Removal of disused channel banks in the south of the township, located immediately to the south-west of the hospital depression. The estimated cost for removal of the channel banks is $53,000. It is understood that some of this work has already taken place by the landholder.
- It should be noted that the detailed costings do not include costs associated with local mitigation works and/or compensation for those properties impacted. There are a significant number of residential and agricultural properties upstream of Numurkah which are likely to be impacted by the recommended package of works, and costs for local mitigation works for those properties (where required) will need to be determined as part of a functional design phase of this mitigation package.

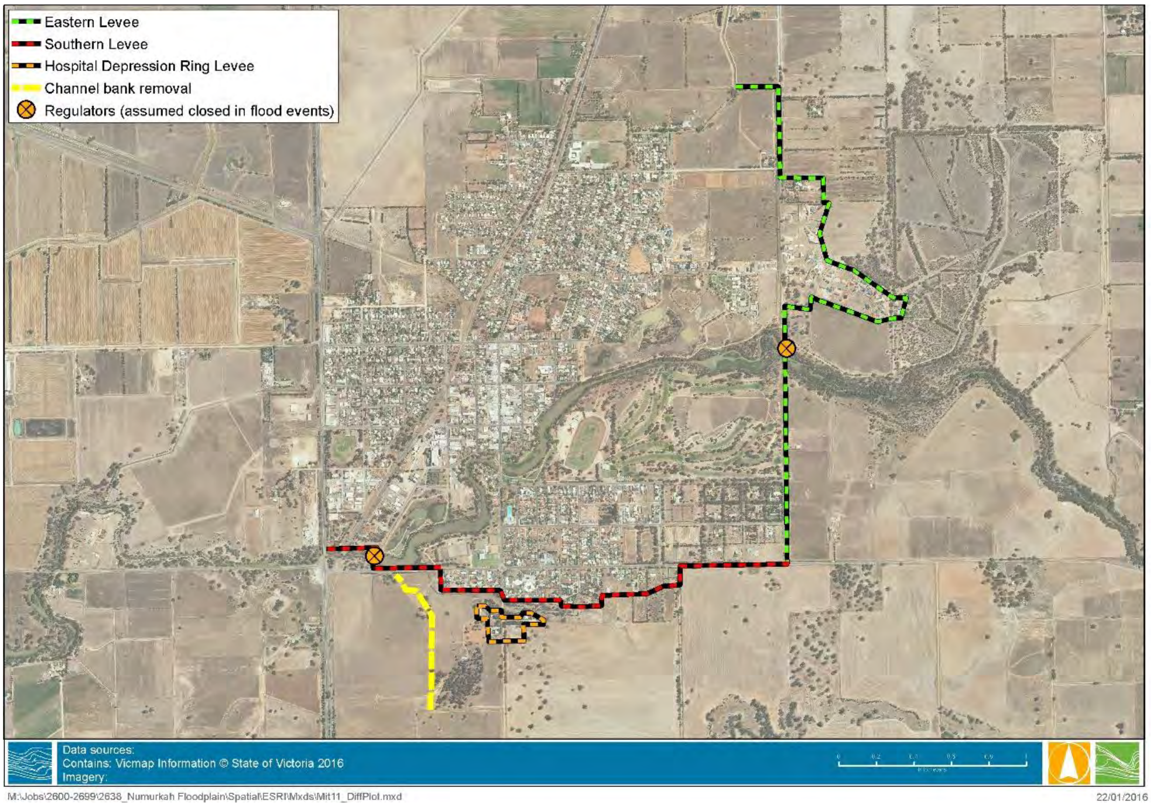


Figure 17-17 Final Mitigation Package Options

Results

The location of the proposed levees overlaid with the 1% AEP event depth results (under mitigation conditions) are displayed in Figure 17-18. Difference plots for the 1% AEP events are provided in Figure

17-18 and Figure 17-20. The results demonstrate that the package of works is effective in protecting almost the entire township in the 1% AEP event. The key observations from the modelling results are:

- The results demonstrate that the combination of levees is effective at protecting both the northern and southern residential areas of Numurkah in the 1% AEP event with 105 properties protected from above floor flooding and 615 properties protected from below floor flooding within Numurkah and outlying areas compared to existing conditions.
- Three buildings remain flooded above floor in the 1% AEP event under mitigation conditions and local mitigation works could be investigated for those properties. Those buildings are located at:
    - 3221 Goulburn Valley Highway (service station)
    - 3197 Goulburn Valley Highway (note: floor survey not available, assumed to be 200 mm above natural surface)
    - Lot 4 Katamatite-Nathalia Road (note: floor survey not available, assumed to be 200 mm above natural surface)
- The levees cause significant impacts upstream with increased 1% AEP flood levels extending for approximately 2.7 km upstream along Broken Creek and 4.5 km northwards towards the Muckatah Depression.
- In smaller events more flow occurs through a smaller depression to the south-west of Numurkah approximately 400 m south of the Goulburn Valley Highway/Nathalia Road intersection. Flood conditions are made worse for a property adjacent to this drainage line in the 2% AEP event and smaller, and local mitigation works would need to be addressed if this package was to be implemented.

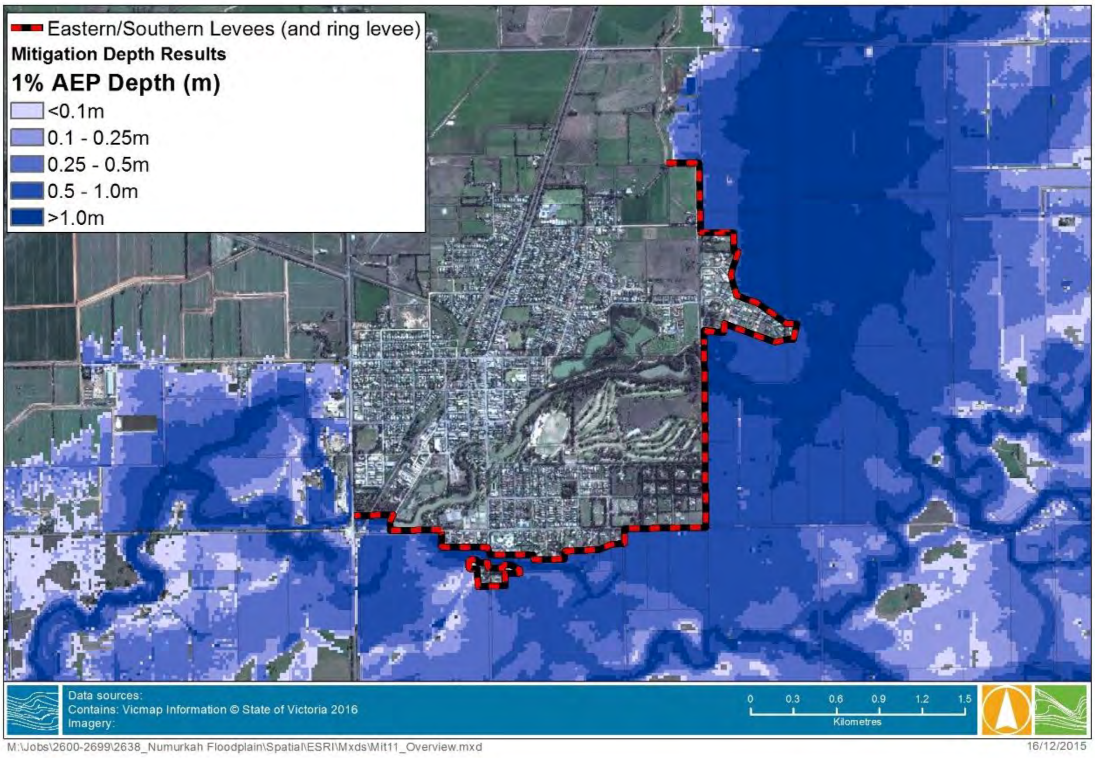


Figure 17-18 Final Mitigation Package 1% AEP depth results

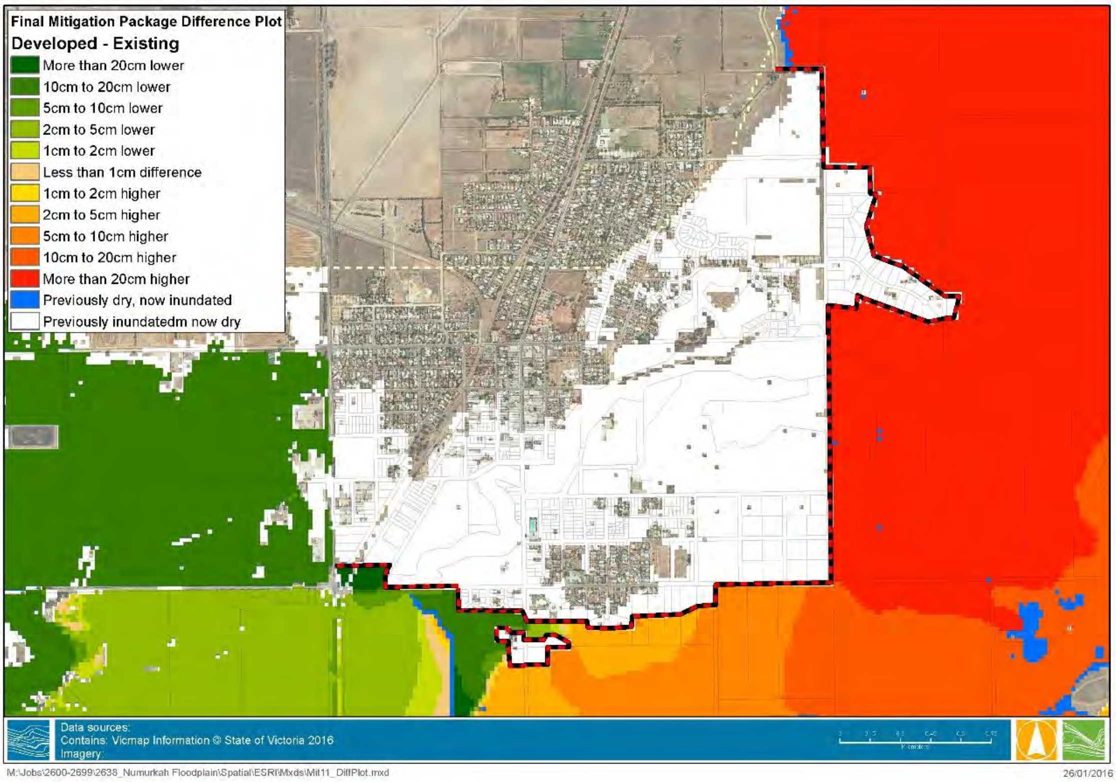


Figure 17-19 Final Mitigation Package 1% AEP Difference Plot – Zoom View

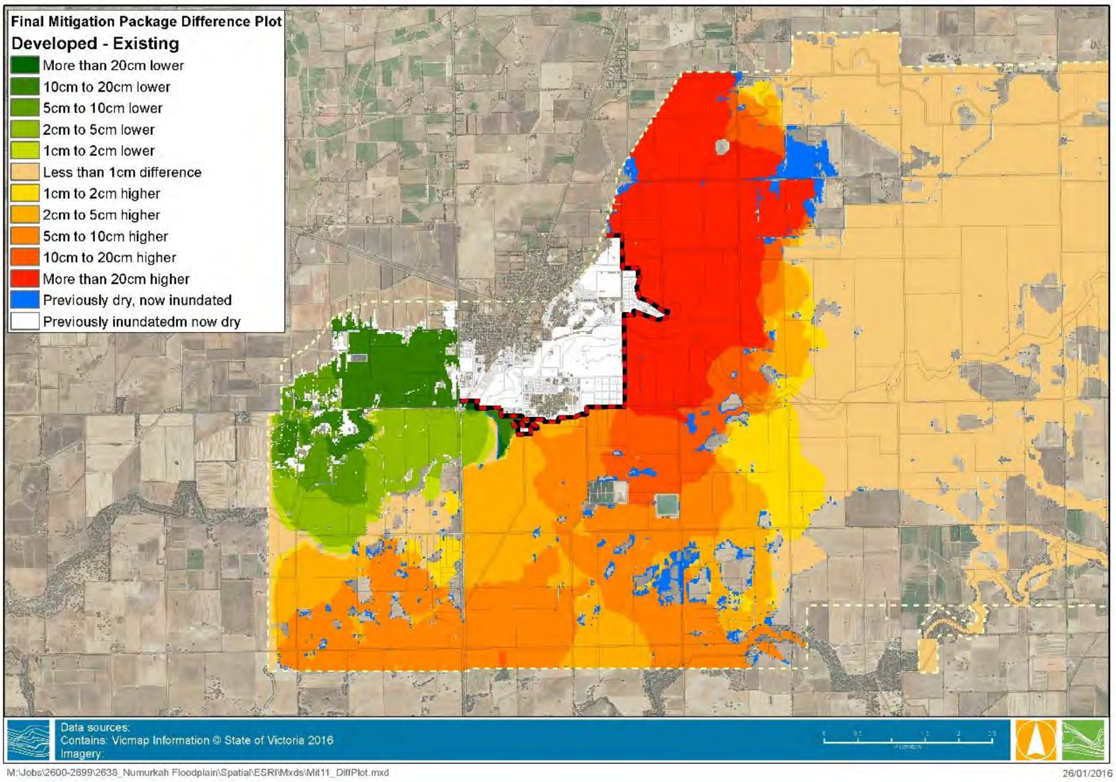


Figure 17-20 Final Mitigation Package 1% AEP Difference Plot

Summary

The whole town levee mitigation package significantly reduces flood risk in Numurkah with almost the entire township protected in a 1% AEP flood event as shown in Figure 17-18. Protection is also provided to a number of outlying properties in the hospital depression through the inclusion of a ring levee. It should be noted that the mitigation package ensures safe access to the hospital precinct during flood events.

Impacts for this scheme are significant, particularly upstream of Numurkah and local mitigation options would need to be further investigated if this option was to be implemented. This would occur as part of a functional design phase.

The results of this scheme highlighted the need for additional model coverage upstream and to the north-east of Numurkah so the impacts upstream could be fully understood. The development of the extended model has been described in the main body of the report while a number of additional scenarios using the extended model is described below.

This package did not progress further due to the very significant impacts and costs associated with it. Later scenarios considered separate northern and southern levees which allows flow through Broken Creek and reduces the impacts associated with this scheme.

Extended Model Scenarios

Overview

As discussed in the body of the report the hydraulic model was extended so the full impact of the mitigation options upstream of Numurkah could be understood.

This section describes the modelling and results of six mitigation scenarios in the extended hydraulic model which trialled different combinations of the north and south levees.

All six scenarios included the following works:

- Removal of disused irrigation bank to the south-west of town.
- Removal of earthen banks near Go Kart Track.
- Ring levee protecting several properties in the hospital depression.
- Broken Creek channel enlargement in the vicinity of the caravan park, Melville Street, skate park and football club to reduce the hydraulic constriction that occurs through there.
- Floodways across the Katamatite-Nathalia Road at two locations - at the lower end of the Hospital Depression and at the upper end of the depression near the intersection with Kinnaird’s Road.

The six modelled scenarios are described below. Scenario 5 and 6 were added later and based on feedback that Scenarios 1 to 4 are unlikely to be accepted by the community due to the practicalities and visual amenity that the proposed southern levee alignment would impact.

Scenario 1 – Northern levee excluding Brooke Court & Southern ring Levee protecting the smaller southern residential lots (ID:10)

Overview

Scenario 1 included the following works:

- The northern levee as per previous scenarios with Brooke Court excluded from the levee. It is known that a flow path exists across the Brooke Court area and that no above floor flooding occurred on Brooke Court in the March 2012 event. There are however two older, low-lying houses near to Brooke Court which would flood in the 1% AEP event.
- A southern ring levee which encompasses all of the smaller residential lots in the southern residential area. The larger residential lots to the east were included within the levee.
- Ring levee protecting several properties from 160-172 Melville Street and the caravan park residence. This ring levee will allow the flow of water to continue across Melville Street and through the train park and reduces the constriction that occurs at the Melville Street Bridge. 174 Melville Street has been excluded from this ring levee and it is assumed in this scenario that this property would be acquired and form part of the flow path across Melville Street.
- Ring levee around football club
- The five measures common to all scenarios and described in Section 1.
- The scenario was run for the 1% AEP event only.

The location of the modelled features for this mitigation scenario are provided in Figure 1.

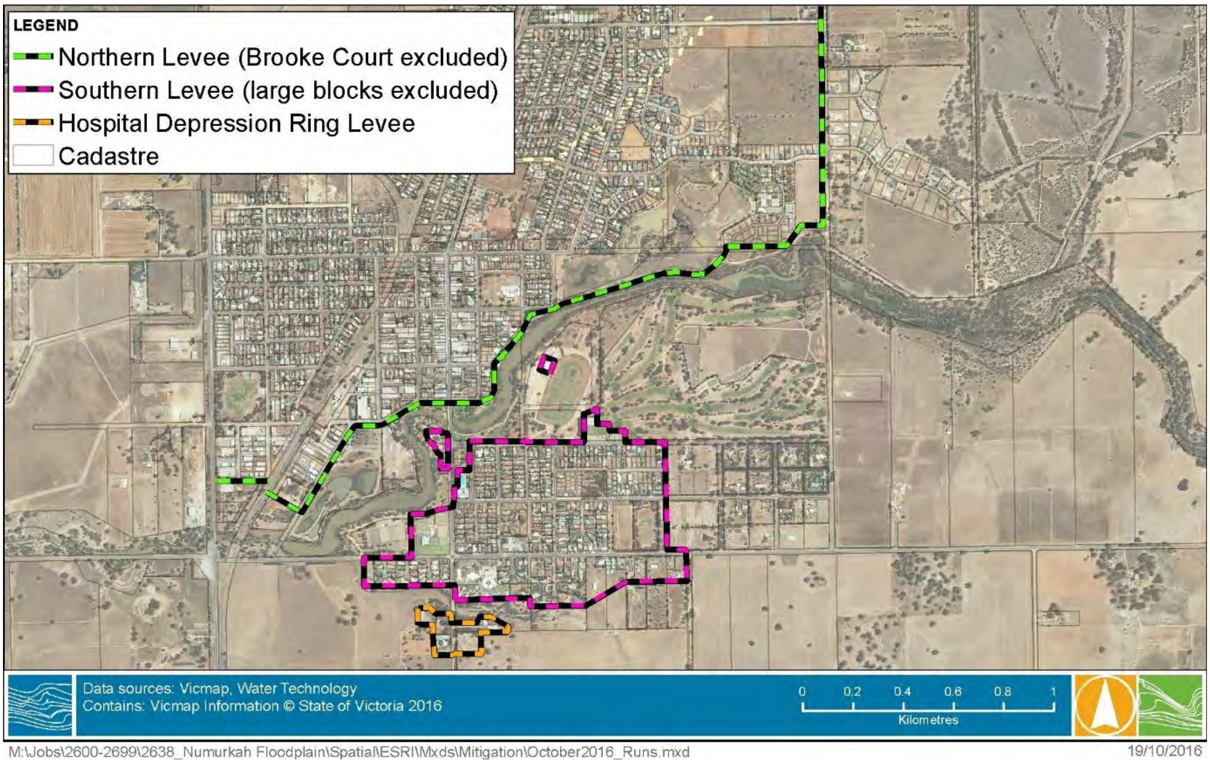


Figure 17-21 Location of mitigation features – Scenario 1

Scenario 1 Modelling Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 17-22 and Figure 17-23 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all of the smaller, southern residential lots and all properties in Numurkah township to the north of Broken Creek excluding those at Brooke Court.
- Water levels upstream of the levee systems are increased but by generally less than 15 mm. These impacts extend for approximately 2 km to the east and 4.5 km to the north up into the Muckatah Depression.
- Water levels increase by 13-15 mm through the Brooke Court area. The majority of floor levels are built up above the 1% AEP flood level through this area, with two properties flooded above floor under existing conditions. The raised water levels in this scenario increase the water levels slightly but do not increase the number of above floor flooded houses in Brooke Court. Older properties and sheds are impacted to a greater extent as they are generally built at a lower level. The Brooke Court area is flooded under existing conditions with a number of properties with floor levels slightly above the 1% AEP flood level. Any increases in flood levels in this area would be detrimental.
- Water level increases are slightly greater through the larger residential blocks in the southern residential area with increases up 20-30 mm. Most of these larger blocks have built up floor levels and there would be no above floor flooding through this area.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 20-25 mm downstream of the Goulburn Valley Highway extending for approximately 3 km.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah with some impacts upstream of the levees. Brooke Court and the larger southern residential blocks remain outside the levee with increases in water levels in these areas. The water level increases do not lead to more properties being flooded above floor, with floor levels generally being built up through those areas.

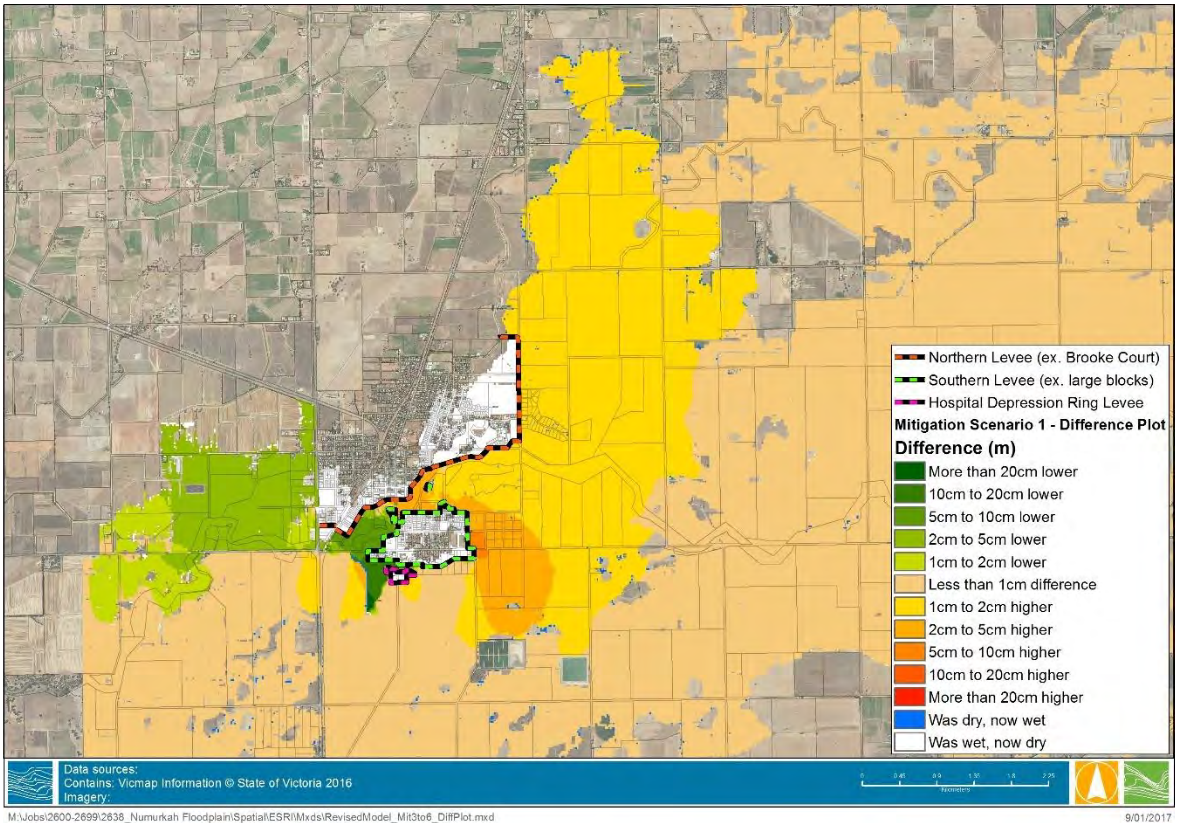


Figure 17-22 1% AEP Difference plot comparing Scenario 1 to existing conditions

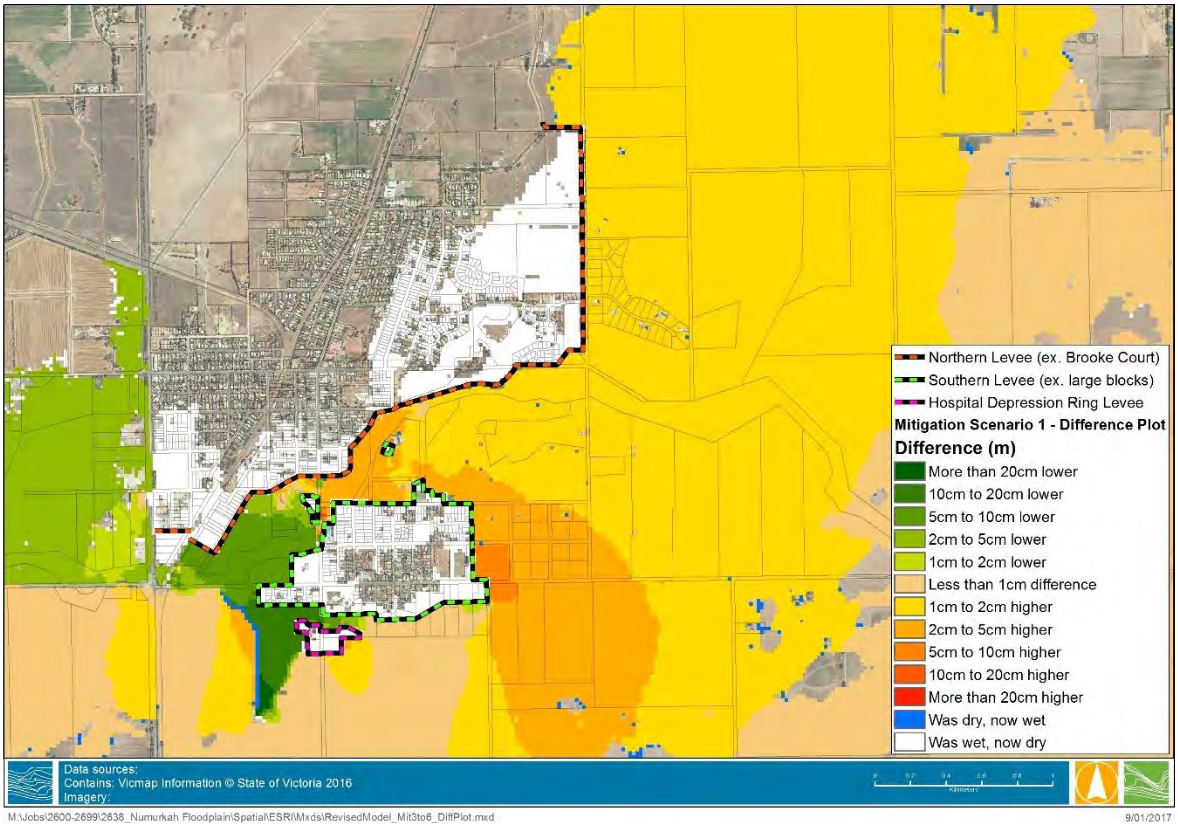


Figure 17-23 1% AEP Difference plot comparing Scenario 1 to existing conditions – zoom view

Scenario 2 – Northern levee Excluding Brooke Court & Southern ring Levee protecting ALL Southern residential lots (ID:11)

Overview

Scenario 2 included the following works:

- The northern levee as per Scenario 1 with Brooke Court excluded from the levee.
- A southern ring levee encompassed all the residential lots in the southern residential area. including the larger residential lots to the east.
- Ring levee protecting several properties from 160-172 Melville Street and the caravan park residence. This ring levee will allow the flow of water to continue across Melville Street and through the train park and reduces the constriction that occurs at the Melville Street Bridge. 174 Melville Street has been excluded from this ring levee and it is assumed in this scenario that this property would be acquired and form part of the flow path across Melville Street.
- Ring levee around football club
- The five measures common to all scenarios and described in Section 1.
- The scenario was run for the 1% AEP event only.

The location of the modelled features for this mitigation scenario are provided in Figure 17-24.

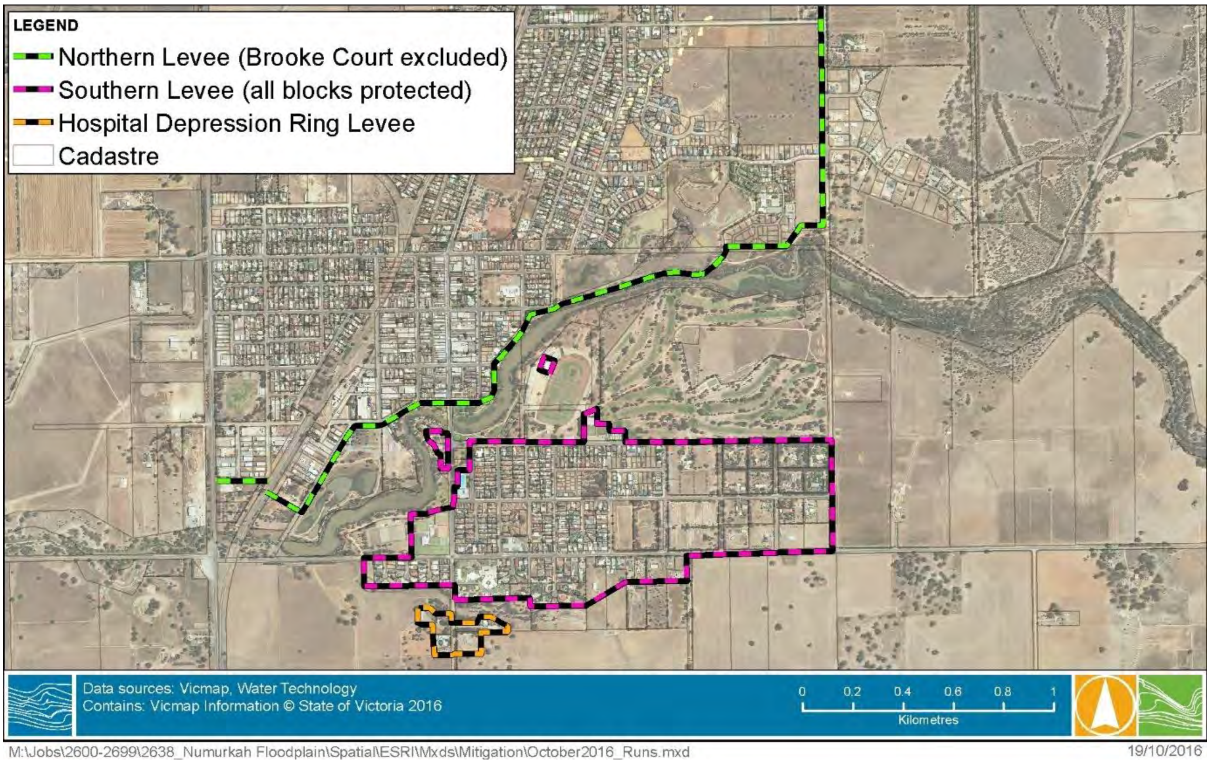


Figure 17-24 Location of mitigation features – Scenario 2

Scenario 2 Modelling Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 17-25 and Figure 17-26 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all southern residential lots (small and large) and all properties in Numurkah township to the north of Broken Creek excluding those at Brooke Court.
- Water levels upstream of the levee systems are increased by generally 50-100 mm. These impacts extend for approximately 2.2 km to the east and 5.8 km to the north up into the Muckatah Depression. Water levels also increase across the floodplain to the south of Numurkah with increases of more than 10 mm which would likely extend to Wunghnu.
- Water level increases of 70-90 mm through the Brooke Court area however nearly all floor levels are built up through this area. Three buildings would flood above floor through this area under this scenario of which two flood under existing conditions. An older, low-lying property at 95 Creek Road would become flooded above floor by the raised water levels in this scenario. Local mitigation measures would be required to mitigate these impacts.
- Significant increases in water levels of 100-200 mm between the north and south levees upstream of Melville Street including through the golf course and football oval areas. All residential and commercial buildings would be protected.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 10-20 mm downstream of the Goulburn Valley Highway extending for approximately 2 km.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah but with more impacts than Scenario 1, particularly through Brooke Court. The upstream water levels are significantly greater and extend much further to the north and south of Numurkah. Two properties at Brooke Court which currently experience above floor flooding would be flooded above floor to a deeper level. One additional property would be subject to above floor flooding in the Brooke Court area. There are properties in outlying rural areas that would be impacted. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

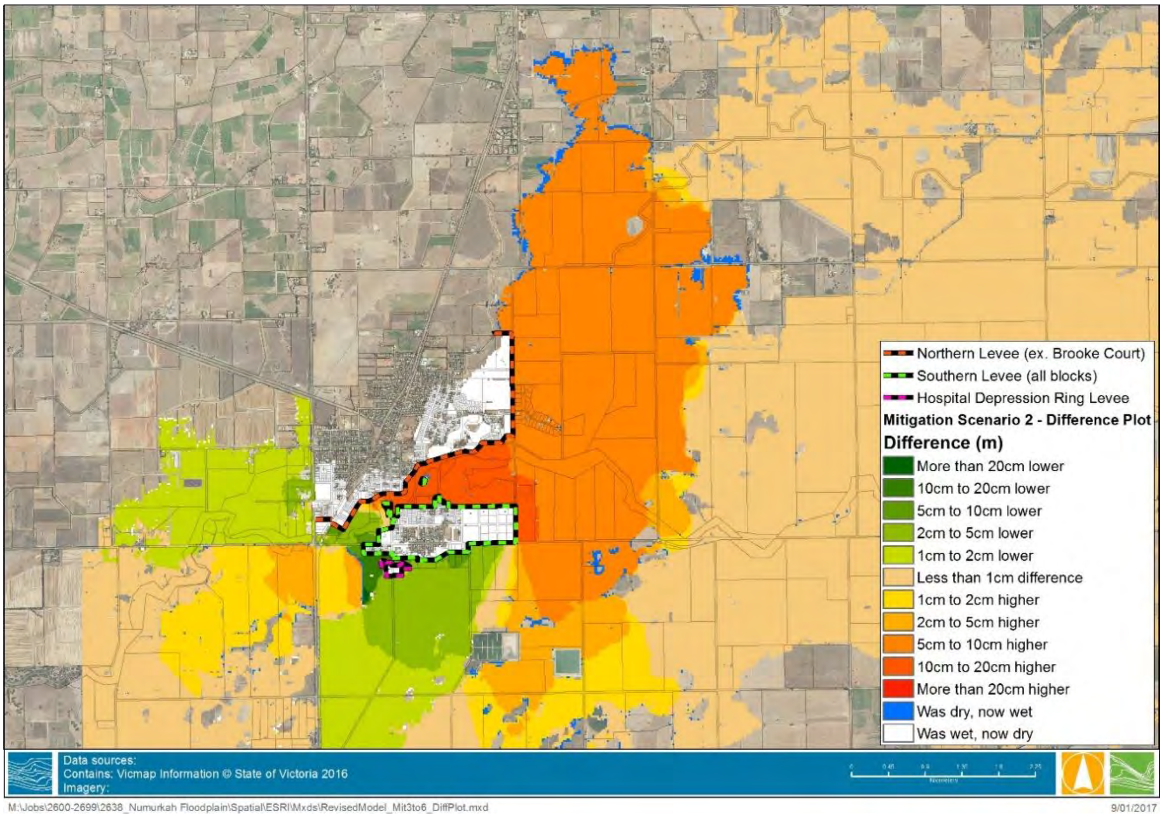


Figure 17-25 1% AEP Difference plot comparing Scenario 2 to existing conditions

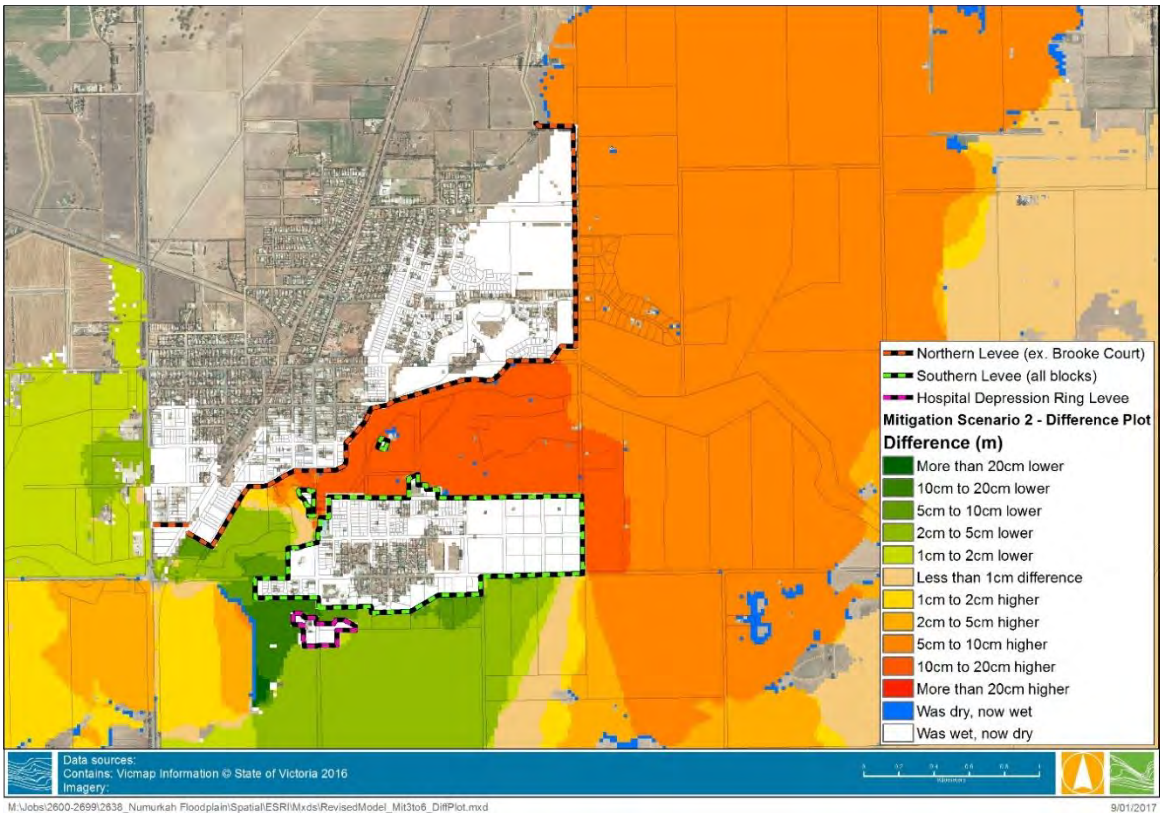


Figure 17-26 1% AEP Difference plot comparing Scenario 2 to existing conditions – zoom view

Scenario 3 – Northern levee including Brooke Court & Southern ring Levee protecting the smaller southern residential lots (ID:12) – Final Package B

Overview

Scenario 3 has become Final Mitigation Package B and included the following works:

- The northern levee but with Brooke Court included within the levee.
- A southern ring levee which encompassed the smaller residential lots only in the southern residential area. The larger residential lots to the east were not included within the levee.
- Ring levee protecting several properties from 160-172 Melville Street and the caravan park residence. This ring levee will allow the flow of water to continue across Melville Street and through the train park and reduces the constriction that occurs at the Melville Street Bridge. 174 Melville Street has been excluded from this ring levee and it is assumed in this scenario that this property would be acquired and form part of the flow path across Melville Street.
- Ring levee around football club
- The five measures common to all scenarios and described in Section 1.
- The scenario was run for the 1% AEP only.

The location of the modelled features for this mitigation scenario are provided in Figure 17-27.

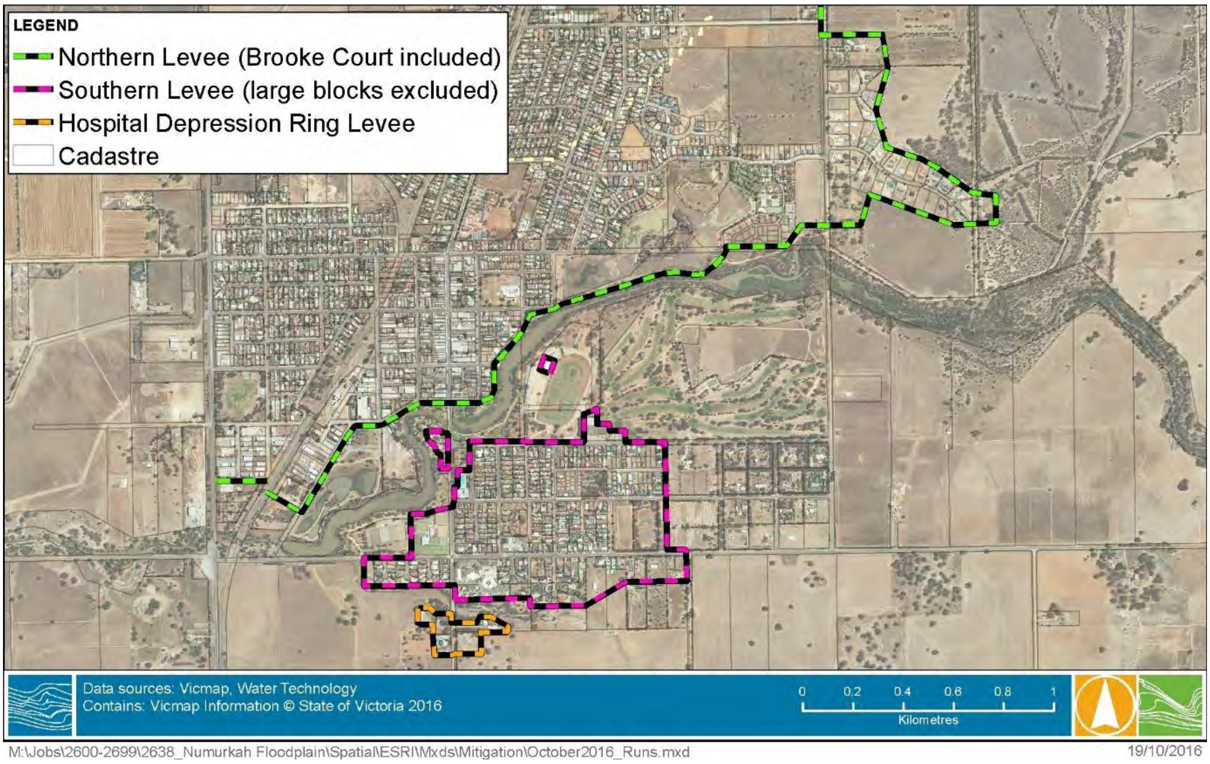


Figure 17-27 Location of mitigation features – Scenario 3

Scenario 3 (Final Package B) Modelling Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 17-28 and Figure 17-29 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all the smaller southern residential lots and all properties in Numurkah township to the north of Broken Creek including those at Brooke Court. It is of note that whilst outside of the levee the larger southern residential properties have floor levels built up and there would be no above floor flooding at these properties under existing or Scenario 3 mitigated conditions.
- Water levels upstream of the levee systems are increased by generally 20-50 mm with the largest impacts to the north of the Brooke Court levee. These impacts extend for approximately 2.8 km to the east and 5.8 km to the north up into the Muckatah Depression. Water levels increase for approximately 1.3 km across the floodplain to the south of Numurkah. The impacts to the south are considerably less than Scenario 2.
- Minor increases in water levels of 10-30 mm between the north and south levees upstream of Melville Street including through the golf course and football oval areas. The impacts through this area are considerably less than Scenario 2.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 20-30 mm downstream of the Goulburn Valley Highway extending for approximately 3.2 km.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah but with more impacts than Scenario 1 but less impacts than Scenario 2. Upstream water levels are generally 30-50 mm higher to the east and north-east of Numurkah. The impacts do not extend as far across the floodplain to the south of Numurkah as Scenario 2. Above floor flooding would not be made worse for properties within Numurkah however there are some properties in outlying rural areas that would be impacted. Given the increases in water level are relatively minor it would be unlikely that there would be many properties that would be significantly worse off compared to existing conditions. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

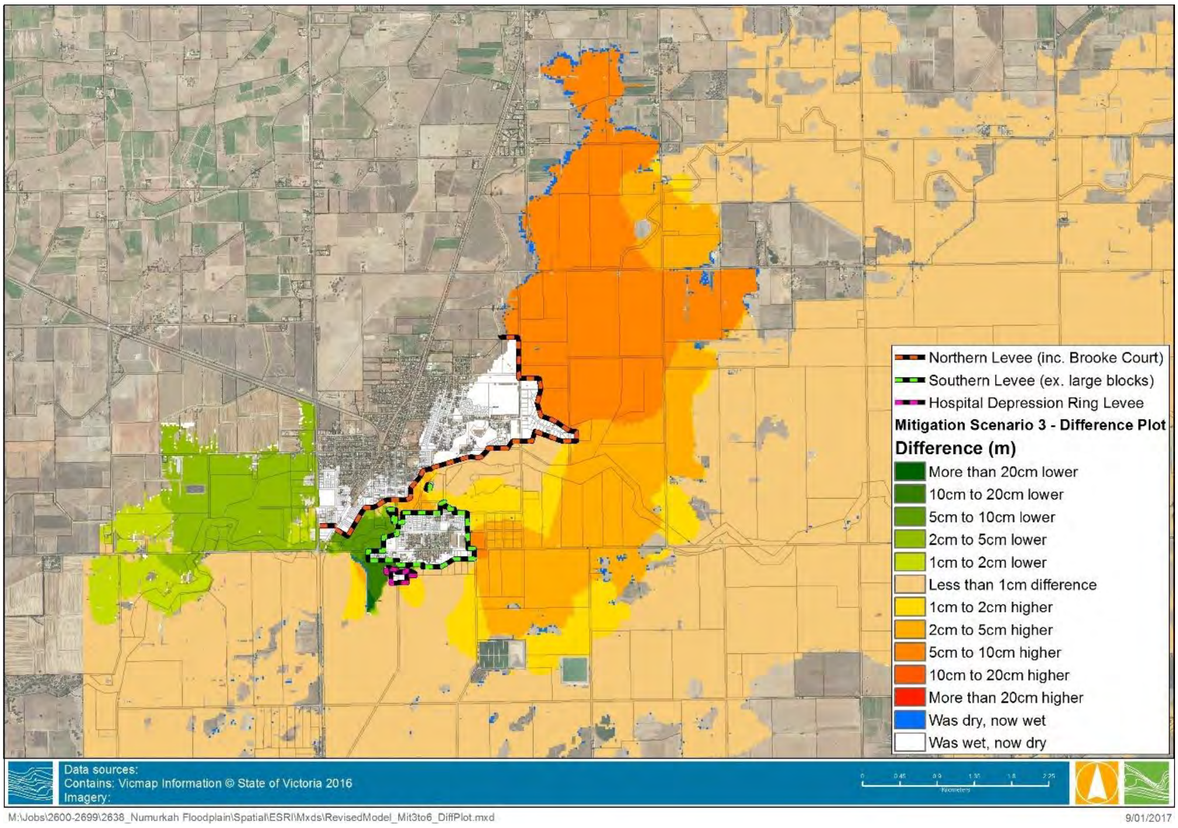


Figure 17-28 1% AEP Difference plot comparing Scenario 3 to existing conditions

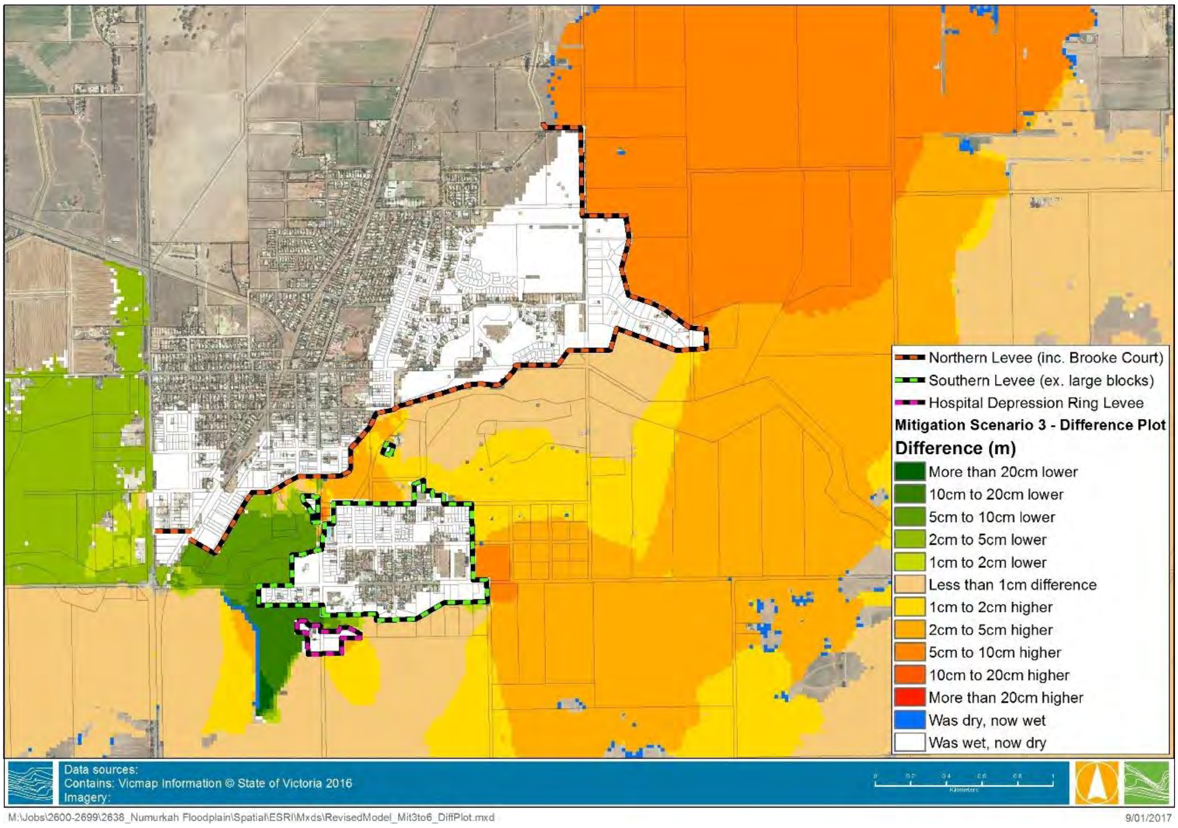


Figure 17-29 1% AEP Difference plot comparing Scenario 3 to existing conditions – zoom view

Scenario 4 – Northern levee including Brooke Court & Southern ring Levee protecting ALL Southern residential lots (ID:13) - Final Package C

Overview

Scenario 4 has become Final Mitigation Package C and included the following works:

- The northern levee with Brooke Court included within the levee.
- A southern ring levee which encompassed all lots in the southern residential area including the larger residential lots to the east.
- Ring levee protecting several properties from 160-172 Melville Street and the caravan park residence. This ring levee will allow the flow of water to continue across Melville Street and through the train park and reduces the constriction that occurs at the Melville Street Bridge. 174 Melville Street has been excluded from this ring levee and it is assumed in this scenario that this property would be acquired and form part of the flow path across Melville Street.
- Ring levee around football club
- The five measures common to all scenarios and described in the Section 1 above.
- To scenario was run for the 1% AEP only.

The location of the modelled features for this mitigation scenario are provided in Figure 17-30.

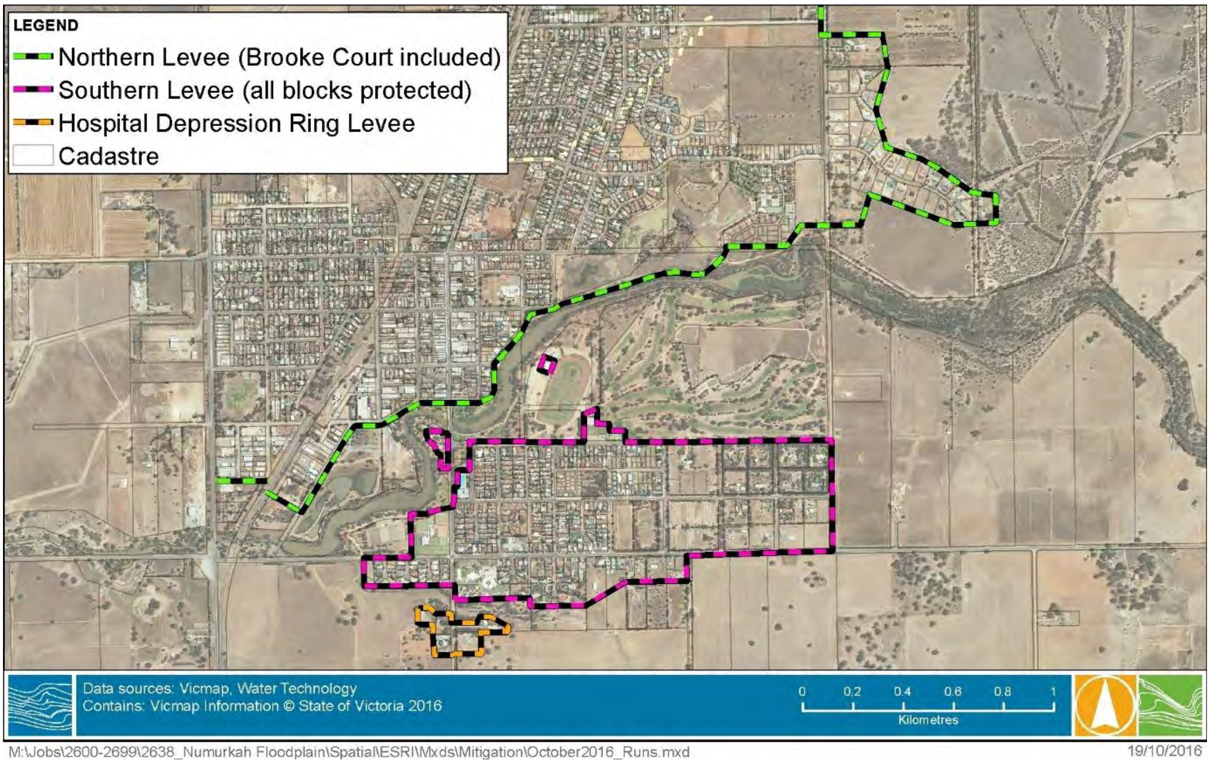


Figure 17-30 Location of mitigation features – Scenario 4

Scenario 4 (Final Package C) Modelling Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 17-31 and Figure 17-32 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all southern residential lots (small and large) and all properties in Numurkah township to the north of Broken Creek including those at Brooke Court.
- Water levels upstream of the levee systems are increased by generally 80-100 mm. These impacts extend for approximately 2.2 km to the east and 5.8 km to the north up into the Muckatah Depression. Water levels also increase across the floodplain to the south of Numurkah with increases of more than 10 mm likely to extend to Wunghnu.
- Significant increases in water levels of 100-200 mm between the north and south levees upstream of Melville Street including through the golf course and football oval areas. All residential and commercial buildings would be protected.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 10-20 mm downstream of the Goulburn Valley Highway extending for approximately 2 km.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah but with more impacts than Scenario 1, 2 and 3. The upstream water levels are significantly greater and extend much further to the north and south of Numurkah than Scenario 1 and 3. Above floor flooding would not be made worse for properties within Numurkah however there are properties in outlying rural areas that would be impacted. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

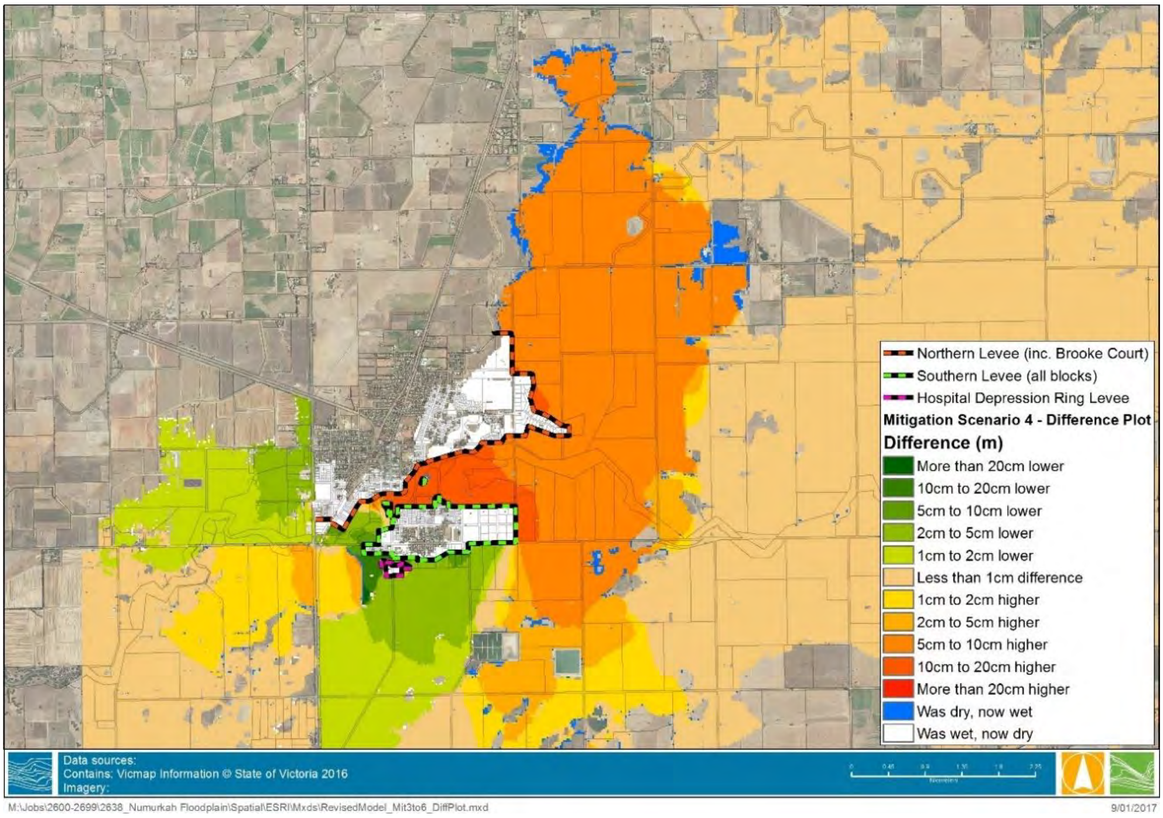


Figure 17-31 1% AEP Difference plot comparing Scenario 4 to existing conditions

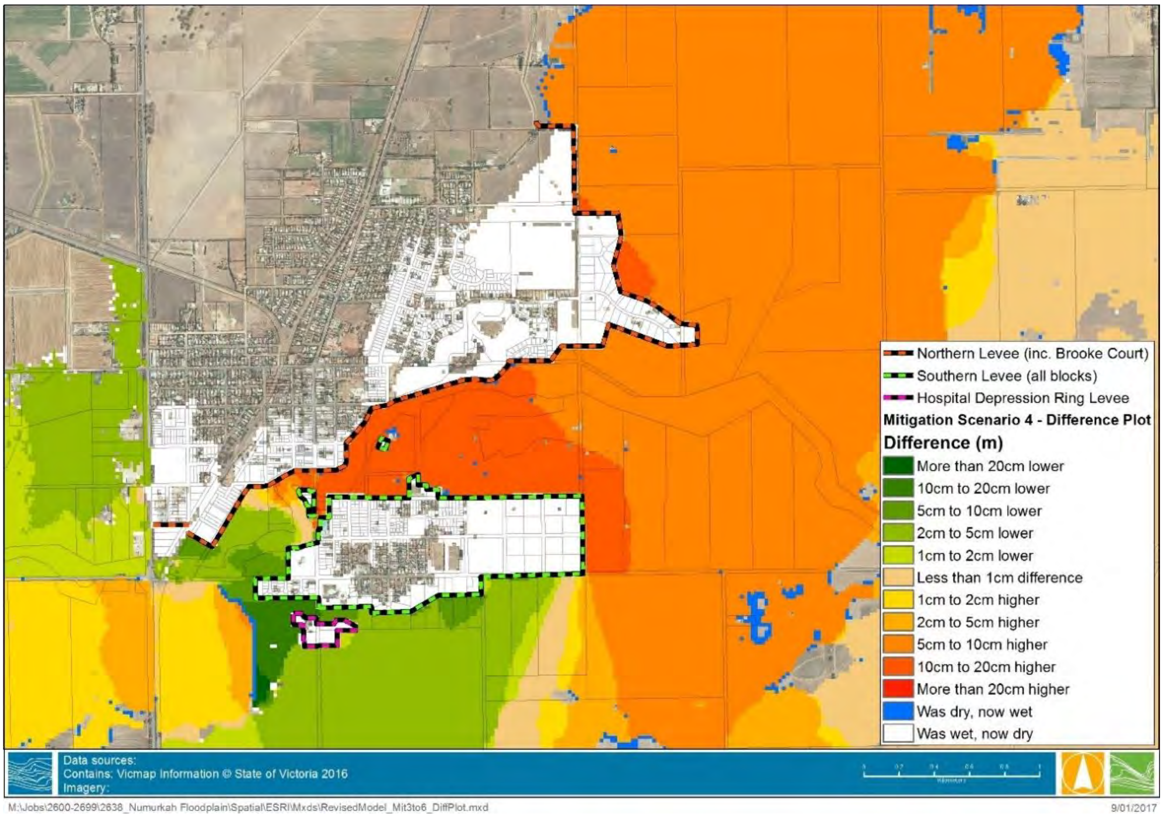


Figure 17-32 1% AEP Difference plot comparing Scenario 4 to existing conditions – zoom view

Scenario 5 – Northern levee including Brooke Court and alternate Southern ring Levee protecting all Southern residential lots (ID:14)

Overview

Scenario 5 included the following works:

- The northern levee with Brooke Court included within the levee.
- An alternate southern ring levee which encompassed all lots in the southern residential area including the larger residential lots to the east, the football clubrooms and oval and most of the golf course.
- The five measures common to all scenarios and described in Section 1.
- The scenario was run for the 1% AEP only.

The location of the modelled features for this mitigation scenario are provided Figure 17-33.

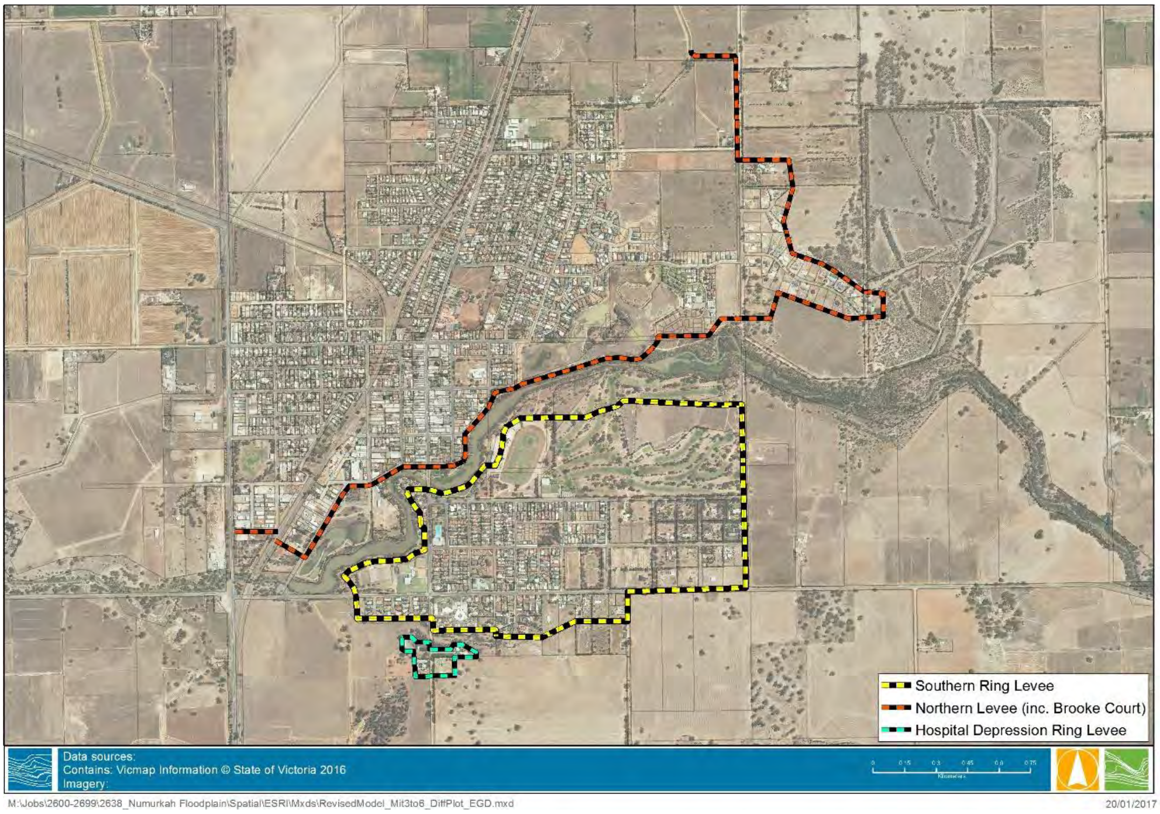


Figure 17-33 Location of mitigation features – Scenario 5

Scenario 5 Modelling Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 17-34 and Figure 17-35 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all southern residential lots (small and large) and all properties in Numurkah township to the north of Broken Creek including those at Brooke Court.
- Water levels upstream of the levee systems are increased by generally 100 - 150 mm. These impacts extend for approximately 2.4 km to the east and 5.8 km to the north up into the Muckatah Depression. Water levels also increase across the floodplain to the south of Numurkah with increases of more than 20 mm likely to extend to Wunghnu.
- Significant increases in water levels of 100-200 mm between the north and south levees upstream of Melville Street impacting parts of the golf course. The football oval and clubrooms are protected, along with all commercial and recreational buildings through this area.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 20-30 mm downstream of the Goulburn Valley Highway extending for approximately 3.5 km.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah but with more impacts than Scenario 1, 2, 3 and 4. The upstream water levels are significantly greater and extend significant distances to the north, east and south of Numurkah than all previous scenarios. Above floor flooding would not be made worse for properties within Numurkah however there are properties in the upstream, outlying, rural areas that would be impacted. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

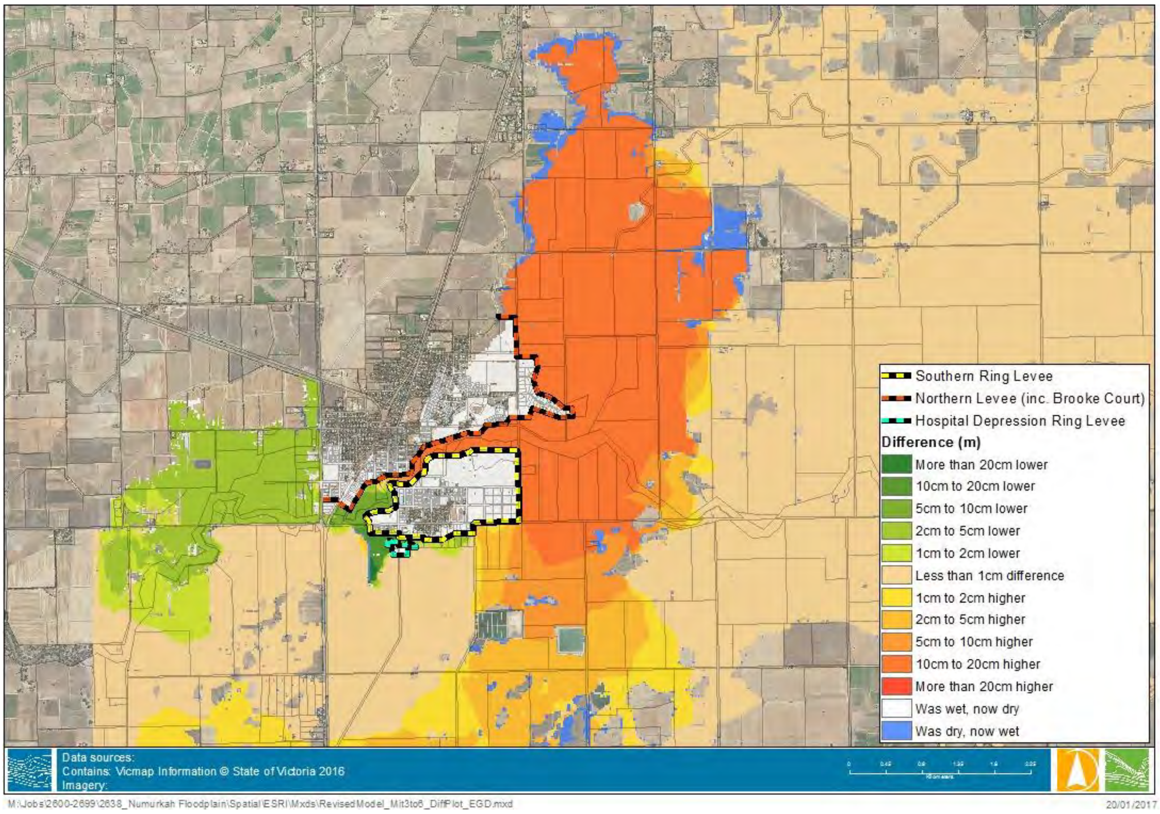


Figure 17-34 1% AEP Difference plot comparing Scenario 5 to existing conditions

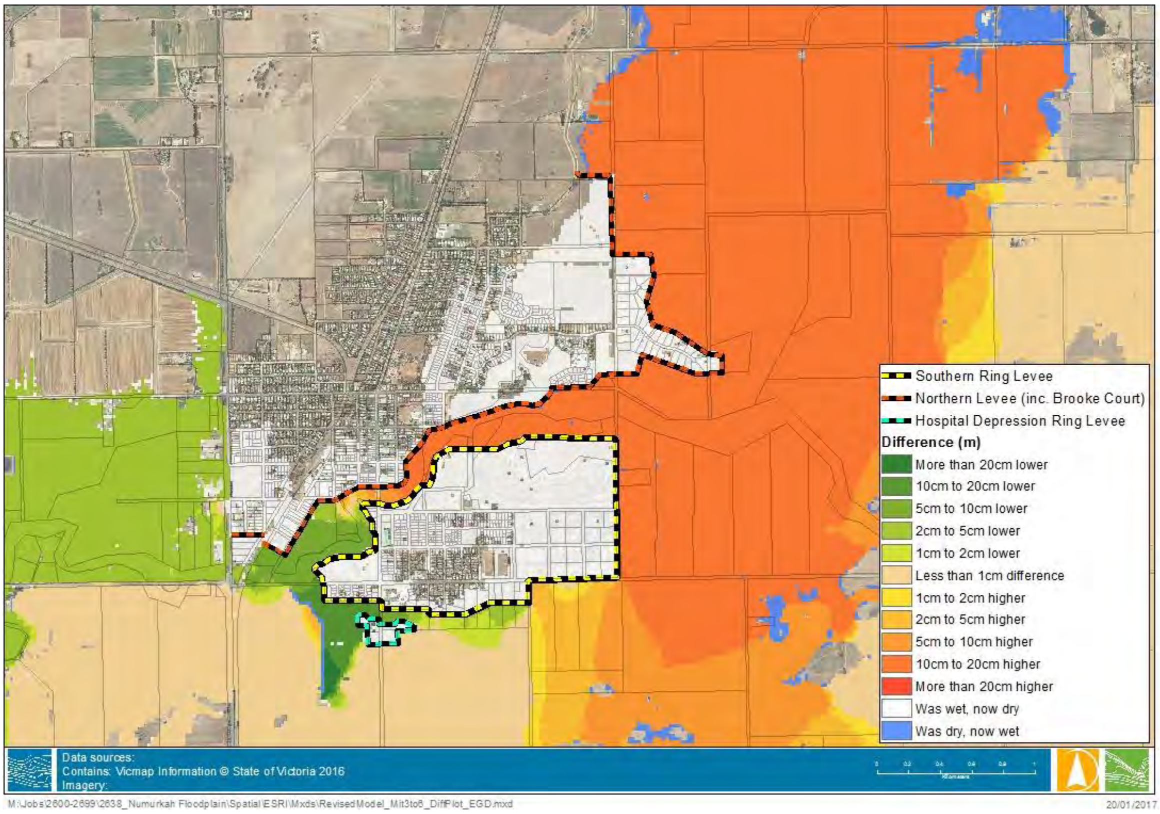


Figure 17-35 1% AEP Difference plot comparing Scenario 5 to existing conditions – zoom view

Scenario 6 – Northern levee including Brooke Court and alternate Southern Ring Levee which protects the smaller, Southern residential lots (ID:15) - Final Package A

Overview

Scenario 6 has become Final Mitigation Package A and included the following works:

- The northern levee with Brooke Court included within the levee.
- An alternate southern ring levee which encompassed the smaller lots in the southern residential area, the football clubrooms and oval and approximately half of the golf course. The levee extends as far east as Corke Street.
- The five measures common to all scenarios and described in Section 1.
- To scenario was run for the 1% AEP only.

The location of the modelled features for this mitigation scenario are provided in Figure 17-30.

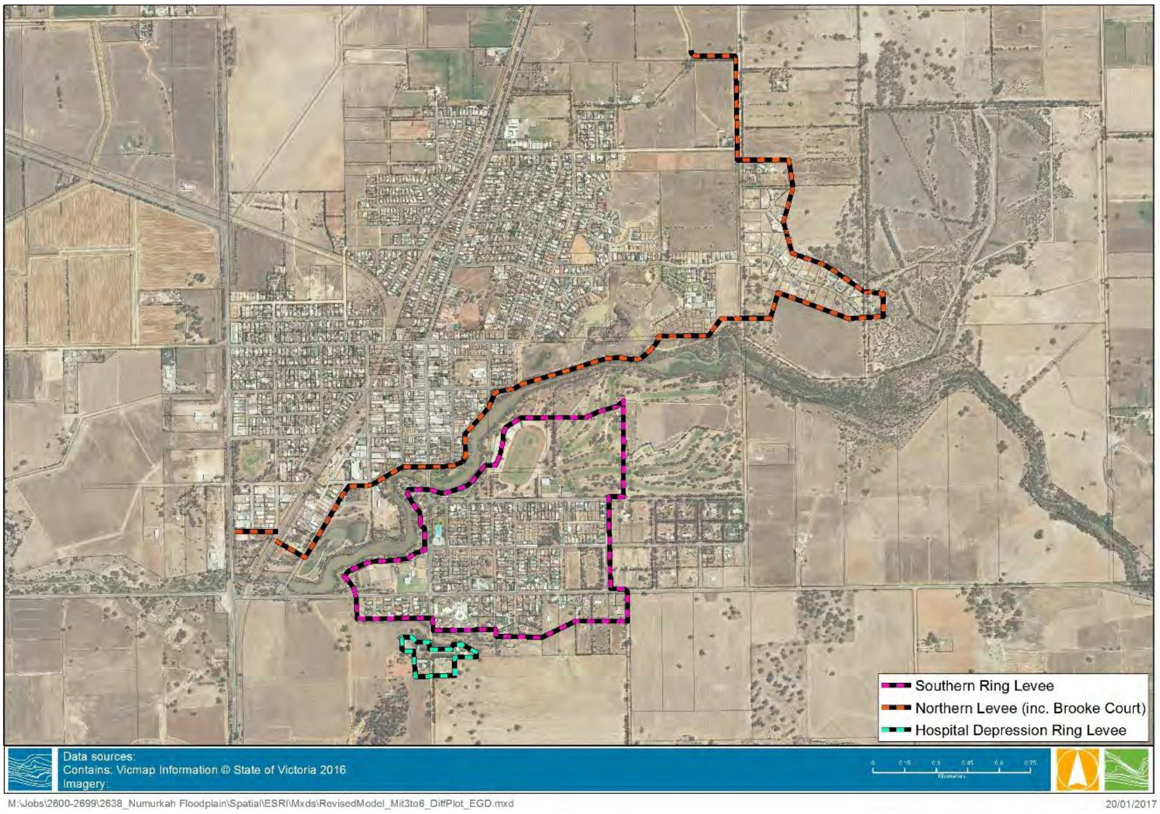


Figure 17-36 Location of mitigation features – Scenario 6

Scenario 6 (Final Package A) Modelling Results

The scenario was modelled for the 1% AEP event and the results are shown in Figure 17-37 and Figure 17-38 below. It can be seen that:

- The levees offer 1% AEP protection to all blocks inside the levee system which includes all the smaller southern residential lots and all properties in Numurkah township to the north of Broken Creek including those at Brooke Court.
- Water levels upstream of the levee systems are increased by generally 50 - 65 mm. These impacts extend for approximately 2.2 km to the east and 5.3 km to the north up into the Muckatah Depression. Water levels also increase across the floodplain to the south of Numurkah with increases of more than 10 mm likely to extend to Wunghnu.
- Increased water levels of up to 100mm within Numurkah immediately to the east of the southern levee through the larger, southern residential lots. Most buildings through this area are built up however there is one property at 2547 Katamatite-Nathalia Road which would flood above floor with this scenario but doesn't under existing conditions. Local measures would be required to mitigate the impact to this property.
- Moderate increases in water levels of 8 - 50 mm between the north and south levees upstream of Melville Street including through the golf course. All residential and commercial buildings would be protected.
- Lower flood levels through the hospital depression and immediately downstream of the southern levee with reductions of up to 200 mm. This is partly due to the southern levee limiting flow and the removal of the disused channel banks to the south-west of the levee.
- Reduction in flood levels of 20 – 50 mm downstream of the Goulburn Valley Highway extending for approximately 2 km.
- 10 – 50 mm increase in flood levels downstream of the Goulburn Highway south of Sampsons Road.

Overall it can be seen that this option protects a significant proportion of residential properties through Numurkah but with less impacts than Scenario 5 due to the exclusion of the large, southern residential lots from the levee. The increased water levels to the north and south are similar to Scenarios 1 and 3. One additional property would become flooded above floor within Numurkah at 2547 Katamatite-Nathalia Road. Flooding would be made worse for several properties within Numurkah as well as properties in outlying rural areas. Further analysis and consultation with landholders would be required to fully understand these impacts to outlying rural areas.

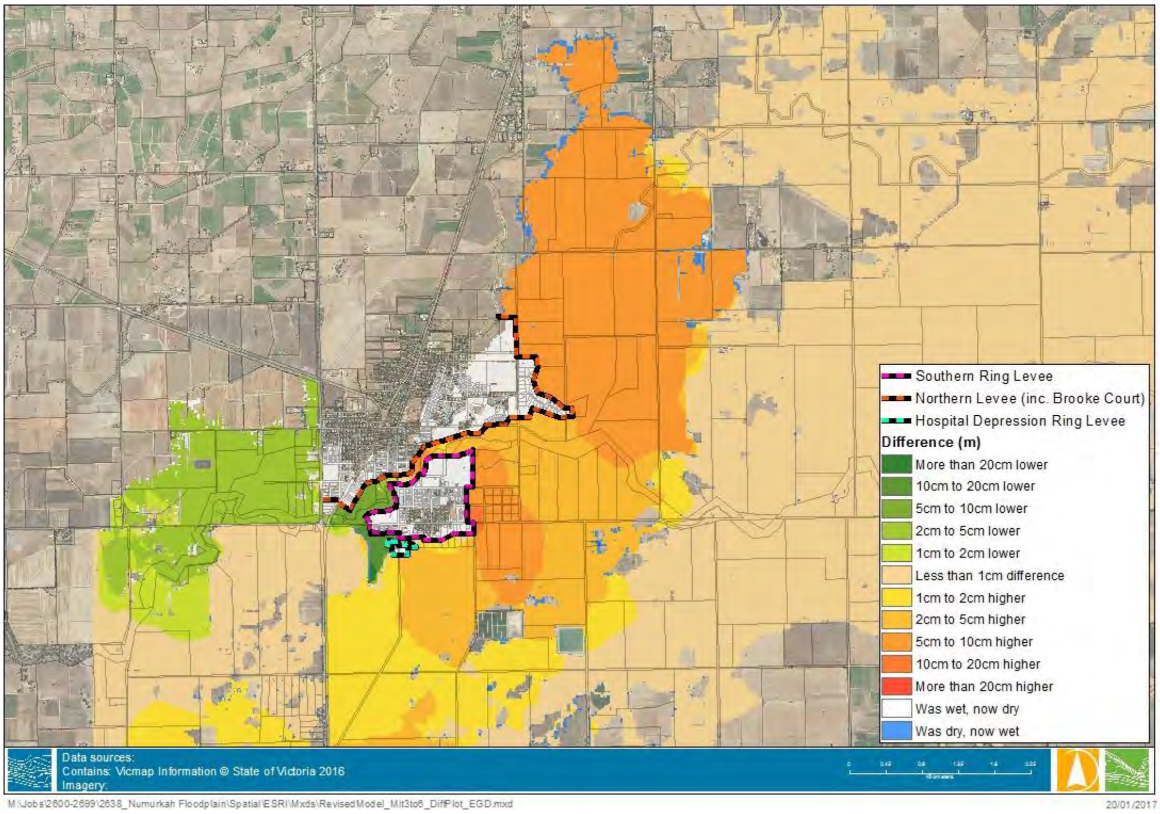


Figure 17-37 1% AEP Difference plot comparing Scenario 6 to existing conditions

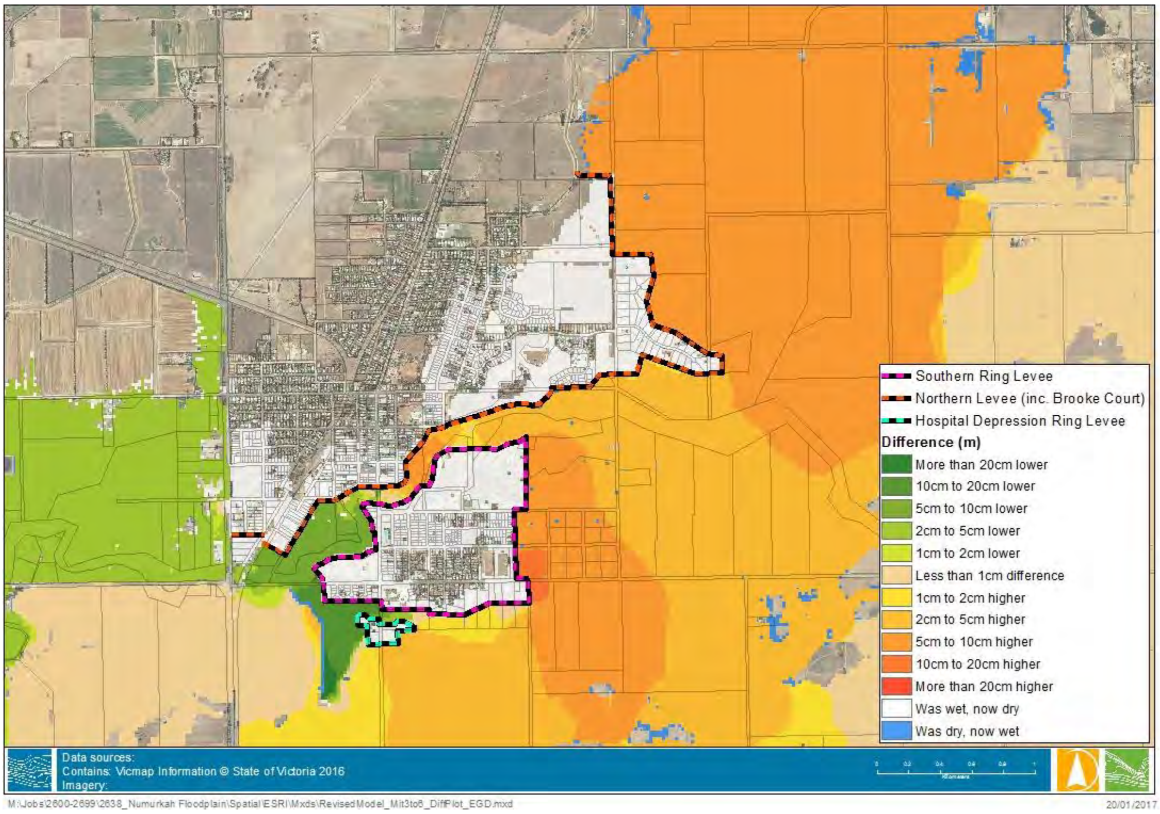


Figure 17-38 1% AEP Difference plot comparing Scenario 6 to existing conditions – zoom view

Summary of Extended Model Mitigation Scenarios

Figure 17-2 below summarises the extended model mitigation scenarios modelled and their impacts on flood behaviour in and around Numurkah.

Extended Model - Summary of Results

Table 17-3 below summarises the mitigation scenarios modelled in the extended model and the resulting impacts at Numurkah and across the floodplain.

Table 17-3 Summary of mitigation scenarios and impacts

Scenario	Description	Impact on upstream water levels	Impact on the Brooke Court area	Impact upstream of Melville Street	Impact on larger southern residential blocks	Impact to the south of Numurkah	Impact on Hospital Depression	Impact downstream of GVH
1	Northern levee excluding Brooke Crt and Southern ring levee protecting the smaller southern residential lots	Increases by less than 15mm, and extending 2km east and 4.5km north up into the Muckatah Depression	Increases by 13-15mm	Increases of 10-40 mm between the northern and southern levees	Increase by 20-30 mm	Increases by 10-30mm for 800m t	Reductions up to 200mm	Reductions up to 20-25mm
2	Northern levee excluding Brooke Crt and Southern ring levee protecting all southern residential lots	Increases by 50-100mm, and extending 2.2km east and 5.8km north	Increases by 70-90mm	Increases of 100-200 mm between the northern and southern levees	Protected by levee	Increase water levels more than 10mm extending to Wunghnu	Reductions up to 200mm	Reductions up to 10-20mm
3 (Final Mitigation Package B)	Northern levee including Brooke Crt and Southern ring levee protecting the smaller southern residential lots	Increases by 20-50mm, and extending 2.8km east and 5.8km north	Protected by levee	Increases of 10-30 mm between the northern and southern levees	Increase by 20-70 mm	Increase water levels for 1.3km and significantly less than Scenario 2	Reductions up to 200mm	Reductions up to 20-30mm
4 (Final Mitigation Package C)	Northern levee including Brooke Crt and Southern ring levee protecting all southern residential lots	Increases by 80-100mm, and extending 2.2km east and 5.8km north	Protected by levee	Increases of 10-30 mm between the northern and southern levees	Protected by levee	Increase water levels more than 10mm extending to Wunghnu	Reductions up to 200mm	Reductions up to 10-20mm
5	Northern levee including Brooke Crt and alternative Southern ring levee protecting all residential lots	Increases by 100-150mm, and extending 2.4km east and 5.8km north	Protected by levee	Increases of 100-200 mm between the northern and southern levees	Protected by levee	Increase water levels more than 20mm extending to Wunghnu	Reductions up to 200mm	Reductions up to 20-30mm
6 (Final Mitigation Package A)	Northern levee including Brooke Crt and alternative Southern ring levee protecting the smaller residential lots	Increases by 50-65mm, and extending 2.2km east and 5.3km north	Protected by levee	Increases of 8-50 mm between the northern and southern levees	Increases by 100 mm. 2547 Kat-Nathalia Road requires local measures	Increase water levels more than 10mm extending to Wunghnu	Reductions up to 200mm	Reductions up to 20-50mm

Extended model - Summary and recommendations

The following describes the key findings and recommendations of the extended model mitigation modelling:

- Including both Brooke Court and the large, southern residential blocks within the levee system (scenarios 4 and 5) results in significant upstream impacts of 80-150 mm which extend for several kilometres upstream.
- Including the large, southern residential blocks within the levee system can also result in significant increases in flood levels of 100-200 mm through the football ground and golf course areas upstream of Melville Street (if those areas are left outside of the levee). Having the larger residential blocks within the levee also results in impacts extending across the floodplain to the south, likely as far as Wunghnu. These impacts highlight the importance of maintaining the conveyance of flood flows through the area of larger blocks in the southern residential area.
- By excluding both Brookes Court and the larger southern residential blocks from the levee system as shown in Scenario 1, upstream impacts are reduced significantly with the increase in upstream water levels generally less than 15 mm.
- Based on the above key findings Scenario 1, 3 and 6 appeared the most viable scenarios which balance protection of much of the town whilst minimising upstream impacts. All three of these scenarios exclude the large southern residential blocks from the levee system but these houses are generally built up. In Scenario 6 one additional property floods above floor in the southern residential area. Scenario 3 and 6 protect the Brooke Court area from external flooding as well as protecting two older, low-lying houses near to Brooke Court from above floor flooding. It is recommended that if the impacts to the north of the town into the Muckatah Depression under Scenario 3 and 6 are found to be minimal, that one of those scenarios be selected as the preferred mitigation scheme.
- Based on consultation it was deemed that Scenarios 1 and 6 would be modelled in further detail and analysed and costed as part of a full benefit-cost analysis. These two scenarios became Final Mitigation Package 2 and 3 respectively.

APPENDIX B DETAILED COSTING OF FINAL MITIGATION PACKAGES

Scenario	Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Final Mitigation Package A	Northern - Earthen Levee (including 6 road crossings)	$1,272,293	$19,084
	Southern Ring Levee (includes 1 road crossing)	$5,232,100	$34,982
	Hospital Depression Ring Levee (includes 3 road crossings)	$266,762	$4,001
	Broken Creek Channel Works	$151,610	$2,274
	Floodways on Katamatite Road (x2)	$150,000	$2,250
	Go Kart Bank Removal	$88,590	
	Non-return Valves	$40,000	$600
	Environmental and Cultural Heritage Managemant Plans	$150,000	
	Land Acquisition	$5,685,000	
	Sub-total 'A'	$13,036,355	
	'A' x Engineering Fee @ 5%	$651,818	
	Sub-total 'B'	$13,688,173	
	'B' x Administration Fee @ 9%	$1,231,936	
	(Land Acq only) 'B' x Administration Fee @ 1%	$59,693	-
	Sub-total 'C'	$14,979,801	
	'A' x Contingencies @ 15%	$1,955,453	
	FORECAST EXPENDITURE	**$16,935,254**	**$63,191**

Scenario	Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Final Mitigation Package B	Northern - Earthen Levee (including 6 road crossings)	$1,198,498	$17,977
	Southern Ring Levee (includes 1 road crossings)	$5,618,830	$41,069
	Caravan Park Levee/Floodwall	$1,408,799	$7,044
	Footy Club Ring Levee	$25,030	$375
	Hospital Depression Ring Levee (includes 2 road crossings)	$225,676	$3,385
	Acquisition of unoccupied house	$140,000	
	Floodways on Katamatite Road (x2)	$150,000	$2,250
	Go Kart Bank Removal	$88,590	
	Non-return Valves	$40,000	$600
	Broken Creek Channel Works	$151,610	$2,274
	Environmental and Cultural Heritage Managemant Plans	$150,000	
	Land Acquisition Costs	$5,632,500	
	Sub-total 'A'	$14,829,533	
	'A' x Engineering Fee @ 15%	$2,224,430	
	Sub-total 'B'	$17,053,963	
	'B' x Administration Fee @ 9%	$1,534,857	
	(Land Acq only) 'B' x Administration Fee @ 1%	$64,774	-
	Sub-total 'C'	$18,653,593	
	'A' x Contingencies @ 30%	$4,448,860	
	FORECAST EXPENDITURE	**$23,102,453**	**$74,975**

Scenario	Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Final Mitigation Package C	Northern - Earthen Levee (including 6 road crossings)	$1,299,835	$19,498
	Southern Ring Levee (includes 1 road crossings)	$6,942,756	$60,941
	Caravan Park Levee/Floodwall	$1,408,799	$21,132
	Footy Club Ring Levee	$25,030	$375
	Hospital Depression Ring Levee (includes 2 road crossings)	$225,676	$3,385
	Acquisition of unoccupied house	$140,000	
	Floodways on Katamatite Road (x2)	$150,000	$2,250
	Go Kart Bank Removal	$88,590	
	Non-return Valves	$150,000	$2,250
	Broken Creek Channel Works	$151,610	$2,274
	Environmental and Cultural Heritage Managemant Plans	$150,000	
	Land Acquisition Costs	$5,632,500	
	Sub-total 'A'	$16,364,795	
	'A' x Engineering Fee @ 15%	$2,454,719	
	Sub-total 'B'	$18,819,515	
	'B' x Administration Fee @ 9%	$1,693,756	
	(Land Acq only) 'B' x Administration Fee @ 1%	$64,774	-
	Sub-total 'C'	$20,578,045	
	'A' x Contingencies @ 30%	$4,909,439	
	FORECAST EXPENDITURE	**$25,487,483**	**$112,106**

Notes

1 Annual maintenance of 1.5% assumed for earthen and raised road levee components, 0.5% assumed for retaining/flood walls

3 No provision for local mitigation works or compensation costs for properties adversely impacted

4 The above cost estimates prepared by Water Technology should be considered preliminary only

5 Water Technology recommends that Quantity Surveyors be engaged when more accurate costs are required and occur as part of functional and detailed design stages

APPENDIX C DAMAGES ASSESSMENT METHODOLOGY

Three primary sources for flood damage calculations were used, the original ANUFLOOD cost curves (CRES 1992), the RAM methodology (Reed Sturgess and Associates (RSA) 2000) and revised damages curves developed by the NSW OEH (2007). Further details on the ANUFLOOD methodology are provided in a guidance report produced by DNR (2002). ANUFLOOD cost curves cover residential and commercial direct costs applicable for townships. The RAM methodology incorporates the ANUFLOOD approach and extends it to include indirect and intangible costs resulting from flooding and provides guidance on costs for agricultural enterprises. A major study of the Economics of Natural Disasters in Australia by the Bureau of Transport Economics (BTE 2001) provides some further information on indirect costs and a recent study by Geoscience Australia (Middelmann-Fernandes 2010) provides information for accounting for the impact of velocity in flood damage assessments. A recent review by economists Aither on behalf of DELWP has led to the conclusion that ANUFLOOD stage damage curves underestimate flood damages, particularly at shallow above floor depths and below floor flooding. The stage damage curves developed by the New South Wales Office of Water have been recommended by Aither in personal communication and were used for this study for above floor flooding. The key references are described below.

- Bureau of Transport Economics (2001). Economic Costs of Natural Disasters in Australia. Report 103. Bureau of Transport Economics, Canberra.
- CRES (1992). ANUFLOOD : A field guide, prepared by D.I. Smith and M.A. Greenaway, Centre for Resource and Environmental Studies, ANU, Canberra.
- Department of Natural Resources and Mines (DNR) (2002). Guidance on assessment of Tangible Flood Damages. Queensland Department of Natural Resources and Mines, September 2002.
- Middelmann-Fernandes, M.H. (2010). Flood damage estimation beyond stage-damage functions: an Australian example. *Journal of Flood Risk Management* 3 (2010): 88-96.
- Reed Sturgess and Associates (2000). Rapid Appraisal Method (RAM) for floodplain management. May 2000. Report prepared for the Department of Natural Resources and Environment.

Before any stage damage curves from the literature were applied in the Numurkah flood damage assessment they were adjusted to today's value by scaling using a ratio of today's CPI and the CPI at the time of development of the stage-damage curve. A number of stage damage curves are included below, representing the value at the time of development (i.e. prior to CPI adjustment).

This appendix does not include a detailed methodology of how the damage assessment was carried out but does include the majority of the source data sets that were used in the development of the methodology.

Table D1 Above floor level stage damage relationships for residential properties (from NSW OEH (2007))

		Damages ($)
Depth over floor level	0 m	$22 361
	0.1 m	$49 329
	0.6 m	$61 292
	1.5 m	$82 824
	1.8 m	$90 002
	5	$110 313

Table D2 Size categories for commercial properties (from ANUFLOOD 1992; reproduced from DNR 2002)

Size category	Guideline
Small	< 186 m2
Medium	186 – 650 m2
Large	650 m2

Table D3 ANUFLOOD Commercial properties cost curve (reproduced from DNR 2002)

	Small commercial properties ($<186m^2$)					Medium commercial properties ($186-650m^2$)					Large commercial properties ($>650m^2$)*				
Value class	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.25	$2 202	$4 405	$8 809	$17 618	$35 237	$6 975	$13 948	$27 896	$55 791	$111 583	$7	$15	$32	$61	$122
0.75	$5 506	$11 011	$22 023	$44 046	$88 092	$16 884	$33 768	$67 537	$135 074	$270 147	$39	$78	$154	$308	$619
1.25	$8 258	$16 518	$33 034	$66 069	$132 137	$25 693	$51 387	$102 773	$205 574	$411 094	$81	$162	$326	$649	$1297Ł
1.75	$9 176	$18 352	$36 705	$73 410	$146 819	$28 445	$56 893	$113 785	$227 570	$455 140	$132	$267	$533	$1065	$2129
2	$9 726	$19 454	$38 907	$77 814	$155 628	$30 281	$60 564	$121 126	$242 252	$484 504	$159	$318	$636	$1 272	$2 545

* units of $\$/m^2$

Table D4 External / below floor damage per building (from DPIE Floodplain Management in Australia (1992))

Depth above ground (m)	External Damage ($)
0	0
0.065	0
0.26	$1 833
0.5	$4 000
0.75	$6 166
1	$8 333
2	$8 333

Table D5 Unit damages for roads and bridges (per kilometre of road inundated) (From DNR 2002)

	Initial road repair ($)	Subsequent accelerated deterioration of roads ($)	Initial bridge report and subsequent increased maintenance ($)	Total cost to be applied per km of road inundated ($)
Major sealed road	34, 860	17 430	11 985	64 275
Minor sealed road	10 895	5 450	3 815	20 160
Unsealed road	4 900	2 450	1 740	9 090

Table D6 Actual to Potential Damages Ratio from RAM (RSA 2002)

	Actual to Potential Damages Ratio	
Warning time (hrs)	Past Flood Experience	No Flood Experience
0	0.8	0.9
2	0.8	0.8
7	0.6	0.8
12	0.4	0.8
12	0.4	0.7
96	0.4	0.7

Table D7 Indirect costs following BTE (1999)

Indirect damages	Cost ($)	Note
Clean-up costs per Residential property		
-cost of materials	$330	
-cost of labour (40 hours)	$1,102	This is the 2007 average weekly wage from ABS
Clean-up costs per Commercial property		
-total cost to clean up	$2,400	
Alternative Housing per Residential property		
-relocation of household items	$53	
-alternative accommodation	$473	Based on 2.6 ppl per household & 7 nights
Emergency Response Costs		
-cost of labour	$4,000 - $20,000	Different magnitude events require different responses