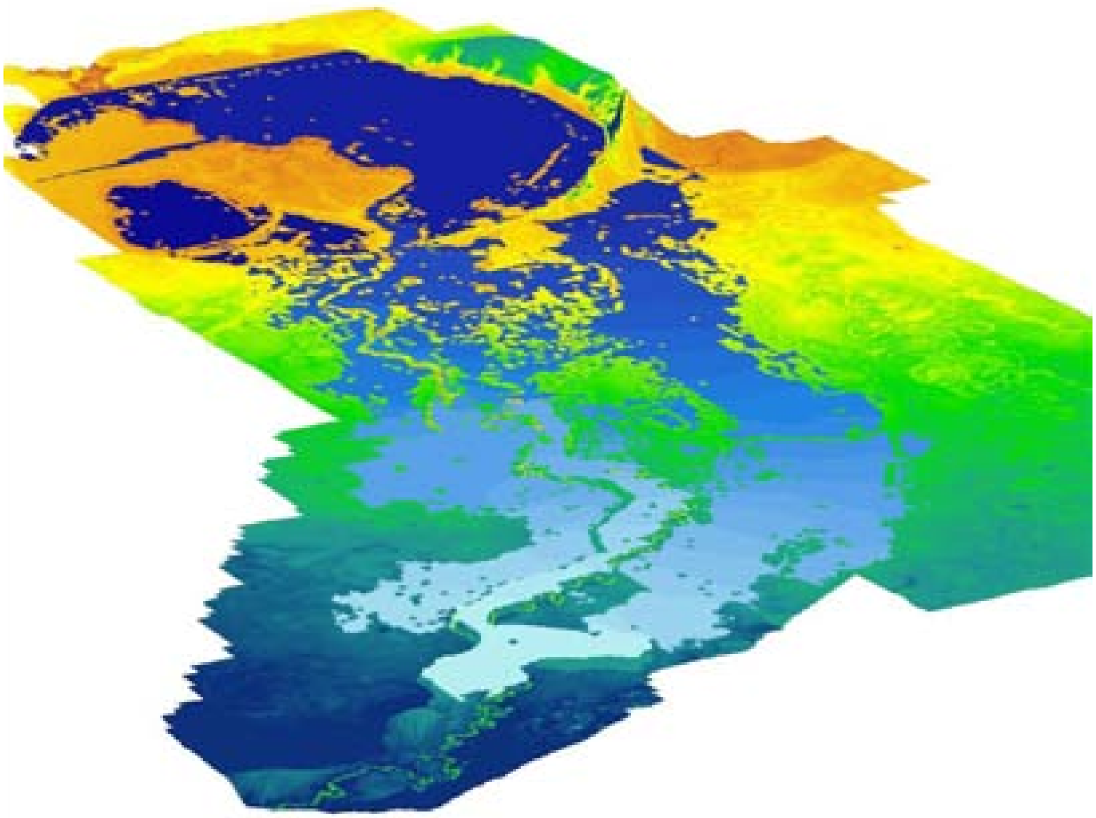
Lower Goulburn Floodplain Rehabilitation Scheme

Hydraulic Modelling Report



Report No. J018/R1 Final A

December, 2005

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GLOSSARY

GBCMA	Goulburn Broken Catchment Management Authority
SKM	Sinclair Knight Merz
ARI	Average Recurrence Interval: term used in hydrology to describe the average interval in years between floods of a given magnitude or greater.
LICS	Land Information Cartographic Services
DHI	Danish Hydraulic Institute
DEM	Digital Elevation Model
ALS	Airborne Laser Scanning
DSNR	Department of Sustainable Natural Resources (NSW)
SR&WSC	State Rivers and Water Supply Commission
RMSE	Root Mean Square Error
DCNR	Department of Conservation and Natural Resources (Vic)
ML/d	Mega litres per day
m^3/s	Cubic metres per second (or cumecs)
m	metres
AHD	Australian Height Datum

Executive Summary

Flooding within the Lower Goulburn River has been a problem as far back as the mid 1850s. Issues associated with repeated flooding of the Lower Goulburn floodplain were well documented in a 1968 parliamentary inquiry. More recently, the large floods of 1974 led to numerous investigations into the flooding problems on the Lower Goulburn. These investigations culminated in the development of a floodplain management strategy in 1987, which identified potential measures to alleviate flooding on the Lower Goulburn floodplain. The strategy however failed to reach consensus by stakeholders and has not been implemented.

Following the destructive 1993 floods, the failure to implement the 1987 strategy was of particular concern to the State Government. Natural Disaster Funds were released to reinstate the failed levees on the understanding that an authority be established to find and implement a solution to address the flooding problems on the Lower Goulburn. The authority responsible for floodplain management on the Lower Goulburn is the Goulburn Broken Catchment Management Authority (GBCMA). The GBCMA adopted to proceed with the Lower Goulburn Floodplain Rehabilitation Scheme in 1999.

The Lower Goulburn Floodplain Rehabilitation Scheme aims to reconnect the northern floodplain back to the Goulburn River to provide a more natural flood flow regime. It is envisaged the scheme would at a minimum protect the Lower Goulburn region from an equivalent flood to that which occurred in October 1993 (approximately a 27-year ARI flood).

To optimise the scheme design and determine the level of protection the scheme would provide in the future, Water Technology Pty Ltd, in conjunction with Sinclair Knight Merz was commissioned to develop a state of the art hydraulic model to simulate the flooding behaviour of the Lower Goulburn floodplain. It is considered that the Lower Goulburn floodplain is one of the largest and most complicated systems to be modelled in this detail to date in the world. The establishment of a hydraulic model required a detailed Digital Elevation Model (DEM) of the study area to be developed based on Airborne Laser Scanning (ALS) data, supplemented with field survey.

In order to have confidence in the model's ability to accurately simulate the flooding behaviour of the floodplain, the model was calibrated against the July 1981 and October 1993 historical floods. An extensive model calibration process was undertaken to ensure that an appropriate combination of model configuration and model parameters were developed to enable the model to reproduce observed flood behaviour. Key indicators of observed flood behaviour included observed stage and discharge relationships along the Lower Goulburn and Murray Rivers and flood extents delineated from aerial photography for each flood.

Overall, the calibration of the hydraulic model is considered to be good and the hydraulic model has been deemed appropriate for use as a predictive tool for the purposes of this project. The calibration process has also greatly increased the understanding of the behaviour of flood flows in the floodplain and identified key floodplain features that significantly affect natural flood paths.

The calibrated hydraulic model was used to predict the flooding behaviour of the Lower Goulburn floodplain before European settlement and associated levee construction and other man made modifications to the floodplain. The results of the 'natural' condition hydraulic model with these feature removed from the model terrain highlighted the degree to which much of the floodplain was flood prone, even during the more frequent floods. The modelling confirmed that under natural conditions the northern floodplain received a majority of flood flows in excess of the main channel and near channel floodplain capacity.

The calibrated hydraulic model was also used to predict the existing flooding behaviour of the Lower Goulburn floodplain. The results of the existing condition hydraulic modelling illustrated the modest protection the existing levee system provides to the floodplain for minor floods, less than the 10-year ARI. For larger floods, equal to and greater than the 10-year ARI, the continued decline in the standard of levees and in the capacity of the levee system below Loch Garry results in levee failures and significant inundation of the surrounding floodplain. The extent of the levee failures is exacerbated by the fact the Loch Garry Regulator does not achieve the discharge it was designed for.

To achieve the objectives of the scheme, the calibrated hydraulic model was used to make an assessment of the proposed scheme and determine the size and arrangement of spillway(s) to allow flood waters to more naturally utilise the northern floodplain and provide flood protection from at least a repeat of the October 1993 flood. A large number of simulations were undertaken to determine the most appropriate arrangement of spillway(s) to meet the objectives of the scheme.

From the results of the modelling undertaken to assess the scheme, an arrangement of spillways and bund alignments are proposed that are aimed at providing flood protection to the Lower Goulburn for floods up to a 35-year ARI flood. For floods approximately larger than the 35-year ARI flood, the levee system is likely to over top and fail, allowing flood flows to be distributed to both the northern and southern floodplains.

The main structural elements of the proposed scheme include:

- Ground level spillway at the existing Loch Garry Outlet
- Ground level spillway close to the existing Deep Creek Outlet
- Spillway at Delma Lagoon and associated earthen bund to Madowla Lagoon
- Earthen bunds along both sides of the northern floodplain
- Realignment of several existing levees to improve conveyance and/or to restore levee integrity.

Acknowledgements

A number of organisations and individuals have contributed both time and valuable information during the development and calibration of the Lower Goulburn Hydraulic Model. The study team acknowledges the contributions made by these groups and individuals, in particular:

- The staff of Goulburn Broken Catchment Management Authority, in particular Guy Tierney
- The staff of Thiess Hydrographic Services
- The staff of DIPNR NSW, in particular Mr Peter Nankivell
- The staff of Land Victoria, in particular Adam Choma and Rick Frisina
- The staff of AAM/Hatch
- The landholders in the study area, in particular Laurie Fitzimmons, Ron Pearce, Leon Ash and Russell Pell.

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Figures

1 Introduction

As part of the Goulburn Broken Catchment Management Authority's (GBCMA), Lower Goulburn Floodplain Rehabilitation Scheme, Sinclair Knight Merz in association with Water Technology Pty Ltd were commissioned to develop a hydraulic model to simulate the flooding behaviour of the Lower Goulburn Floodplain. The hydraulic model is to be used as one of the key design and assessment tools for determining the required modifications to the Loch Garry Regulator and levees and other spillways and optimising the final bund and levee alignments for the proposed scheme. The results of the hydraulic model will also be used to assist in assessing the likely geomorphic and vegetation responses to the changed flooding regime as a result of the implementation of the scheme. Results from the hydraulic model will also provide inputs into the proposed planning scheme amendments.

The construction of a hydraulic model enables the simulation of the behaviour of flows within the Lower Goulburn Floodplain. Accurate reproduction of the behaviour of such a large, relatively flat floodplain with significant man made alterations required a calibration process to ensure that features in the floodplain that can significantly alter natural flood paths are identified and incorporated into the model. Such features included levees, irrigation supply channels, roads and other man made infrastructure.

In order to have confidence in the ability of the hydraulic model to accurately simulate the flooding behaviour of the floodplain, the model was calibrated against two historical floods. The July 1981 flood was selected as representative of a flood generally contained within the existing levee system. The October 1993 flood was selected as representative of a flood exceeding the capacity of the existing levee system. Both these floods occurred relatively recently and good documentation of the floods exists with which to calibrate the hydraulic model.

To improve the understanding of the flooding behaviour of the Lower Goulburn floodplain the calibrated hydraulic model was used to simulate the 'natural' (before European settlement) flooding behaviour and existing flooding behaviour of the floodplain. The information from these simulations significantly increased the understanding of the flooding behaviour of the floodplain over a large range of flood magnitudes.

The calibrated hydraulic model was subsequently used to undertake an extensive assessment of the proposed scheme to determine the required spillway(s) and bund alignment to meet the objectives the scheme.

2 Study Context

2.1 Background

The Lower Goulburn Floodplain is located in north eastern Victoria and extends from Shepparton to the Murray River near Echuca. Downstream of Shepparton the floodplain gradient reduces and the river is flanked by an almost continuous system of levees. The levee system has provided a limited standard of flood mitigation to the economically important agricultural development that has taken place on the floodplain. For floods equal to or larger than approximately a 10-year ARI flood however, the levees overtop and/or fail randomly along the river. The unplanned and virtually arbitrary overtopping and breaching of the levees along the river produces destructive flooding causing substantial damage to agriculture, infrastructure and the levees themselves. Presently the annual cost of levee repairs alone is equal to approximately $74,000 (GBCMA, 2001). In the past, damaged levees were repaired using Natural Disaster Funds (NDF), but the Federal Government has advised that unless flood damage minimisation strategies are implemented, NDF funding will no longer be available.

The Goulburn Broken Catchment Management Authority is the authority responsible for floodplain management on the Lower Goulburn and has adopted to proceed with the Lower Goulburn Floodplain Rehabilitation. The Lower Goulburn Floodplain Rehabilitation Scheme entails rehabilitating the northern floodplain containing the Bunbartha and Deep Creek Systems to allow flood flows to utilise this floodplain more naturally. The scheme will require the development of a bunded floodway of approximately 10,500 ha with a potential buy back of up to 9,700 ha of land from the relevant landholders.

The key aim of the scheme was to have the capacity to convey a repeat of the October 1993 flood i.e. 150,000 ML/d (1736m^3/s) or a 27-year ARI flood relative to the Shepparton Gauge. Prior to this study, it was envisaged that the scheme may have the capacity to convey a flow of up to 180,000 ML/d (2083m^3/s) at the Shepparton Gauge i.e. approximately a 50-year ARI flood.

The scheme was to be designed to limit the peak flow from 50,000 to 60,000 ML/d (579 to 694m^3/s) between the levee system at McCoys Bridge with a minimum of 300mm freeboard with respect to levee crests, as detailed in the Levee Audit Report (SMEC 1999). The design discharge to the northern floodplain was therefore estimated at 110,000 ML/d (1273m^3/s).

More specifically, the management objectives of the Scheme are to:

- Provide for the safe passage of floodwater in a balanced system to reduce on-going damage costs and associated trauma to communities in the long term.
- Provide a sustainable and environmentally acceptable riverine environment with direct benefit for nature conservation including a range of depleted and threatened species and vegetation types that will enhance floodplain and waterway health.
- Provide water quality gains to the Murray River.
- Manage the rates of floodplain and channel change of the river and its tributaries.
- Provide for recreational use of the river and its floodplain.

2.2 Study Objectives

The objectives of the hydraulic modelling portion of the study can be broadly defined as follows:

- Identify key hydraulic features that significantly affect the behaviour of flood flows within the floodplain and incorporate them into the hydraulic model.
- Accurately reproduce the behaviour of the July 1981 and October 1993 flood in terms of flooding extents, peak levels and discharges.
- Simulate the flooding behaviour of the floodplain under natural conditions for a broad range of design floods.
- Simulate the flooding behaviour of the floodplain under existing conditions for a broad range of design floods.
- Develop a hydraulically balanced scheme configuration that meets the objectives of the project.
- Simulate the flooding behaviour of the floodplain under the proposed scheme conditions for a broad range of design floods.

3 Previous Investigations

There have been numerous investigations undertaken previously that are of significant relevance to modelling the behaviour of the Lower Goulburn floodplain. Many of the findings of these investigations have been incorporated into the development of the hydraulic model. A brief discussion of the most relevant portions of these investigations in relation to the calibration of the hydraulic model is included below.

3.1 Lower Goulburn Floodplain Management Study, Shepparton to Kanyapella

Cameron McNamara, October 1987

The Shepparton to Kanyapella Floodplain Management Study was undertaken with the following terms of reference:

(a) *Identify the nature, cause, frequency, extent and effects of flooding (including hydrology, flow characteristics (natural conditions), flow characteristics (existing conditions) and impacts of flooding).*
(b) *Identify and examine alternative structural and non-structural measures to alleviate flooding.*
(c) *Develop a comprehensive and appropriate floodplain management strategy for the Study Area aimed at resolution of existing problems and at future planning taking into account all relevant interests.*

During the assessment of floodplain management alternatives the existing floodplain behaviour was itemised as follows:

- *The river channel has only the capacity to contain the 50% flood (1 in 2 year)*
- *The existing levee system has only the capacity to contain a flood between the 25% (1 in 4 year) and the 20% event (1 in 5 year). Larger floods will spill into the adjacent floodplain.*
- *Both the river channel and levee system have decreasing flood carrying capacity in the downstream direction. Spill will occur because of this decreasing capacity.*
- *Spill from the river to the north floodplain between Loch Garry to near Rathbones Road leaves the Goulburn River and flows direct to the Murray River via the Deep Creek system.*
- *Spill from the river to the south in the Coomboona area tends back towards the river.*
- *Wells Creek allows spill from the river upstream to the south to re-enter the Goulburn River.*
- *Spill from the river to the north between Wakiti Creek and Yambuna forest can, in part, leave the Goulburn system and flow towards the Deep Creek system or pass through the Bama Sand Hills at Madowla Lagoon.*
- *The Yambuna Choke has a limited capacity*
- *Below the Bama Sand Hills, Goulburn River floodwaters tend northerly towards the Murray River.*

The report included an analysis of water level information and flows in the Murray River to enable the conditions at Echuca and the inflows at Barmah to be determined for the development of a cells-type model of the study area. The inflows at Barmah for the range of floods considered in the modelling varied from $250m^3/s$ to $340m^3/s$. It was noted that floods can occur in the Goulburn River with flows in the Murray River at Barmah less than those adopted during the modelling. In which case:

> *…the direction of flow between Deep Creek and Barmah could be reversed as has been reported.*

3.2 Lower Goulburn Waterway and Floodplain Management Plan

Sinclair Knight Merz, report prepared for Lower Goulburn Waterways, May 1998

The key objective of this investigation was:

> *… the development of an appropriate Management Plan for the Lower Goulburn in relation to waterway management and floodplain management.*

In developing the floodplain management plan, Sinclair Knight Merz reviewed the current floodway capacity between the leveed river and the distribution of flows through the system and concluded:

> *….the capacity of the leveed river floodway downstream of Shepparton is inadequate to convey even moderate floods.*

Table 3-1presents the results of the review of the leveed river capacity.

Table 3-1 Capacity of River Floodway (assuming no levee failure)

Description of River Reach	Capacity (ML/d)	AEP	ARI (yr)
Upstream of Loch Garry (Medland Rd)	185,000	2.5%	40
Loch Garry to Deep Creek Outlet	85,000	15.0%	7
Deep Creek Outlet u/s of McCoys Bridge	75,000	50.0%	5
McCoys Bridge	65,000	25.0%	4
d/s McCoys Brdige to u/s Yambuna Forest	60,000	30.0%	3
Yambuna Choke	37,000	50.0%	2

(reproduced from SKM, 1998)

Table 3-2 presents the results of the review on the existing capacity of the outlet structures.

Table 3-2 Estimated Outlet Capacities

Outlet	Capacity (ML/day)***
Loch Garry Regulator	60,000
Deep Creek Outlet	3,000
Wakiti Creek Outlet	3,100
Hagens Creek Outlet	100
Hancocks Creek Outlet	3,700

(reproduce from SKM, 1998)

*** *These figures are not necessarily supported by the detailed modelling undertaken as part of the present study.*

Note that the estimated capacities in Table 3-2 are maximum capacities and can only be achieved during major floods, when the outlets are surcharged. Flows through Loch Garry for example would be significantly reduced for small to medium sized floods.

A review of historical flooding was also conducted as part of the investigation and it was noted:

> *…that the effect of flooding at Echuca from the Murray River upstream of Barmah is restricted by the effect of the Barmah Choke, so that little more than the choke capacity, of approximately 35,000 ML/d, can pass along the Murray without forcing additional flow north along the Edward River into NSW.*

It was considered that the Goulburn River is the dominant river determining the flooding extents at Echuca and the surrounding Echuca depression.

3.3 Moama-Echuca Flood Study

Sinclair Knight Merz, for Shire of Murray & Shire of Campaspe, May 1997.

The purpose of the study was to define the flood behaviour along the Murray River and its floodplain in the vicinity of Moama and Echuca. A hydraulic model of the study area was constructed using a MIKE-11, one dimensional model.

The model was calibrated using the October 1993 flood. The July 1981 flood was also modelled in the validation process.

The SKM calibrated MIKE-11 model developed in Moama-Echuca Flood Study was incorporated into the MIKE FLOOD model for the present study.

3.4 Lower Goulburn River Flood, October 1993, *Volume 5*.

HydroTechnology, report prepared for DCNR, March 1995

This report is one of a series of five detailed regional summaries produced in *Documentation and Review of 1993 Victorian Flooding.*

The objective of the report was to document information on the 1993 floods in Victoria. Information documented in the reports included estimated flood discharges and flood levels, flooding extents as delineated from aerial photography and other means and collation of information available on flood damages.

Information contained within the report of particular relevance to the calibration of the hydraulic model is listed below:

- Detailed day by day chronology of the October 1993 flood including approximate timing of peaks and levee failures in the system.
- Aerial photography, presented as photo mosaics, over the entire study area.
- Summary of damages to levees in each shire including length of breach or failure, depth and crest width.

For these reasons the report provided an invaluable source of information on the October 1993 floods and greatly assisted the calibration process.

3.5 Lower Goulburn Levee Audit Study, June 1999

SMEC report prepared for Goulburn Broken Catchment Management Authority

The aim of the study was to determine the standard of protection currently offered by the levees on the Goulburn River downstream of Shepparton and evaluate floodplain management options.

The study included a detailed survey of all strategic levees on the Lower Goulburn Floodplain. The levee survey undertaken as part of this study was a key input into the MIKE FLOOD model developed for this study.

4 Waterway and Floodplain Features

The present Lower Goulburn floodplain consists of a variety of natural and artificial features that affect the behaviour of flows passing through the floodplain. The major natural and artificial features of the floodplain are briefly outlined below and are illustrated in Figure 4-1. A number of cross sections of the Lower Goulburn Floodplain have also been developed and are displayed in Figure 4-2.

4.1 Natural Features

The Lower Goulburn floodplain is characterised by its low gradients. This flat landscape has directly led to the Lower Goulburn's meandering course and created a river that naturally discharged a large proportion of its flood flows to the floodplain. Consequently the capacity of the river channel steadily diminishes downstream towards its confluence with the Murray River.

The Goulburn River has occupied its present course for approximately only 10,000 to 15,000 years and a number of previous courses of the river have been identified within the study area. Of these, the present Wakiti Creek is recognised as a more recent course of the Goulburn River. The development of numerous meanders and breakaways from the main channel has, as a result, produced extensive wetlands and billabongs along these ancestral courses.

Loch Garry appears to be a geologically recent meander and had the area not been leveed it has been suggested in previous studies that, over time, a new Goulburn course may have developed here, following the present day Bunbartha and Deep Creek system.

Downstream of Loch Garry, the near channel floodplain is generally at a higher elevation than the broader floodplain and is somewhat separated from the surrounding floodplain by a series of natural and now man made levees. Flood flows escaping the near channel floodplain downstream of Loch Garry therefore tend to drain away from the river and onto the surrounding floodplain. Floodplain cross sections B, C and D in Figure 4-2 clearly display the perched nature of the near channel floodplain of the Lower Goulburn River.

Within the study area the Goulburn River tends to traverse the floodplain to the north-west rather than directly north, down the slope of the general Riverine Plain. As a result, flood flows escaping to the north generally flow away from the river and a number of ephemeral waterways, collectively known as the Deep Creek system, channel these flows to the Murray River.

A major natural feature of the Lower Goulburn floodplain is the Bama Sandhills, a lunette deposit that arcs around the north-eastern edge of the ancient Lake Kanyapella. The Bama Sand Hills are an important control on both Goulburn and Murray River flows. Presently flood flows from the Goulburn River can only pass through four gaps in the Bama Sandhills:

- at the Yambuna Choke on the present course of the Goulburn River;
- through an earlier Goulburn course associated with Madowla Lagoon;
- via Yambuna Creek during high river stage; and
- through overflows to the Deep Creek system which joins the Murray River and passes through the sandhills at Lower Moira.

Cross section E in Figure 4-2 displays the cross section available to flood flows through the Bama Sandhills. Note the significant reduction in the cross sectional area available to convey flood flows greater than the main channel capacities of both the Murray and Goulburn Rivers.

4.2 Artificial Features

European settlement on the floodplain has had a significant affect on the passage of floods through the study area. The majority of the land has been cleared for agriculture and grazing and roads, bridges, levees and a network of irrigation channels have been built across the floodplain.

Levee system

Levee construction is believed to have begun on a significant scale in the late 1890's and has continued intermittently until the present. Levees have now been constructed along almost the full length of the Lower Goulburn to protect the floodplain from the impacts of floods. A number of other levees have also been constructed to protect individual farms and small groups of farms. The levee system is presently a mix of well constructed and maintained levees, old breached and abandoned levees and poorly constructed or maintained levees.

Levee construction has been carried out where expedient, which is often on the higher ground close to the river causing lengths of constricted floodplain. This has the result of raising water levels and velocities within the leveed section making the levees and riverbed and banks susceptible to erosion.

Levee construction works have also been undertaken to control the extent of inundation on the floodplain. Levees extend approximately 7km on either side of the lower reaches of Wells Creek to prevent backwater from the Goulburn River inundating surrounding properties. On the lower reaches of Deep Creek, levees have also been constructed to control the extent of flooding both to the north and south of the creek.

Outlet Structures

A number of outlet structures have been incorporated into the levee system to release controlled volumes of water into the creek the systems on the northern floodplain. These include:

- **Deep Creek Outlet**

  This structure actually discharges to Bunbartha Creek and comprises a box culvert 7.2m wide by 3.26m high, with an invert at 103.82m AHD. Local landholders have since constructed a stop log mechanism, similar to the Loch Garry Regulator, within the culvert to raise the invert level by 1.4m after the 1993 floods. This has significantly reduced the frequency of flows to Bunbartha Creek through this structure.

- **Wakiti Creek Outlet**

  This structure is a U shaped break in the levee system. Floodwaters from Wakiti Creek outlet structure flow along Wakiti Creek and fill water holes and the Wakiti Lagoons.

- **Hancocks Creek Outlet**

  This structure consists of three 1.65m diameter reinforced concrete pipes. Water from the Hancocks Creek Outlet structure flows along Hancocks Creek towards the Yambuna State Forest.

Loch Garry Regulator

Repeated failure of levees constructed near the riverbank at Loch Garry, particularly in the 1916 floods, and frequent flooding for prolonged durations of landholders downstream of Loch Garry led to the creation of the Loch Garry Minor Flood Protection Scheme.

The proposal required the construction of a levee surrounding the Loch Garry wetlands with an associated regulator structure to control flows into Bunbartha Creek.

The intent of the scheme, which was adopted in 1925, is to protect Bunbartha Creek and the surrounding lands from minor (nuisance) floods (less than or equal to a 2.5-year ARI) overflowing from Loch Garry up to a 2.5-year ARI flood. For floods greater than 10.36m (34 feet) on the Shepparton gauge (2.5-year ARI flood), the scheme was to release the same proportion of flow out of Loch Garry and into the Deep Creek floodplain as flowed into Loch Garry prior to the establishment of the scheme.

Based on the available information at the time leading up to the schemes adoption in 1925, the flow of 44,000 ML/d (509 m^3/s) was calculated and designed to pass through the Loch Garry regulator onto the Deep Creek floodplain during a repeat of the 1916 flood. This operation, which is still in place today, attempts to restore flow distribution and prevent levee failures along the Goulburn River.

The Loch Garry regulator comprises a concrete structure with 48 bays, each approximately 2.2 metres wide, which contains slots that enable bars to be inserted or removed as required.

The current operating rules for operation of the regulator require that 24 hours after the Shepparton gauge exceeds 10.36m (110.487m AHD), 23 bars are removed and for every additional 0.031m rise in the river level at the Shepparton gauge 23 more bars are removed. If the river continues to rise, all bars are to be removed 24 hours after the river reaches 10.96m (36 feet) at Shepparton.

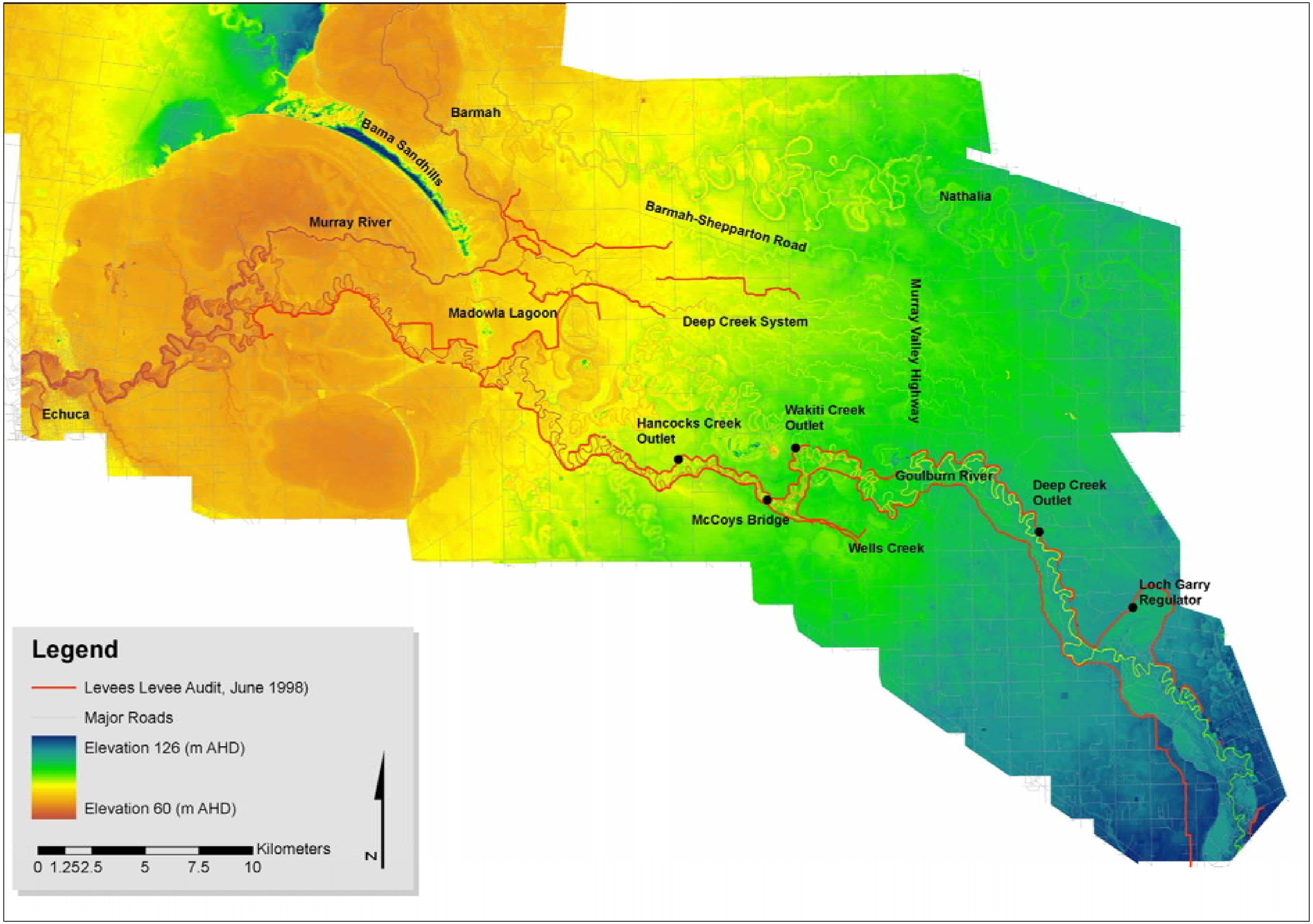


Figure 4-1 Natural and Artificial Features of the Floodplain

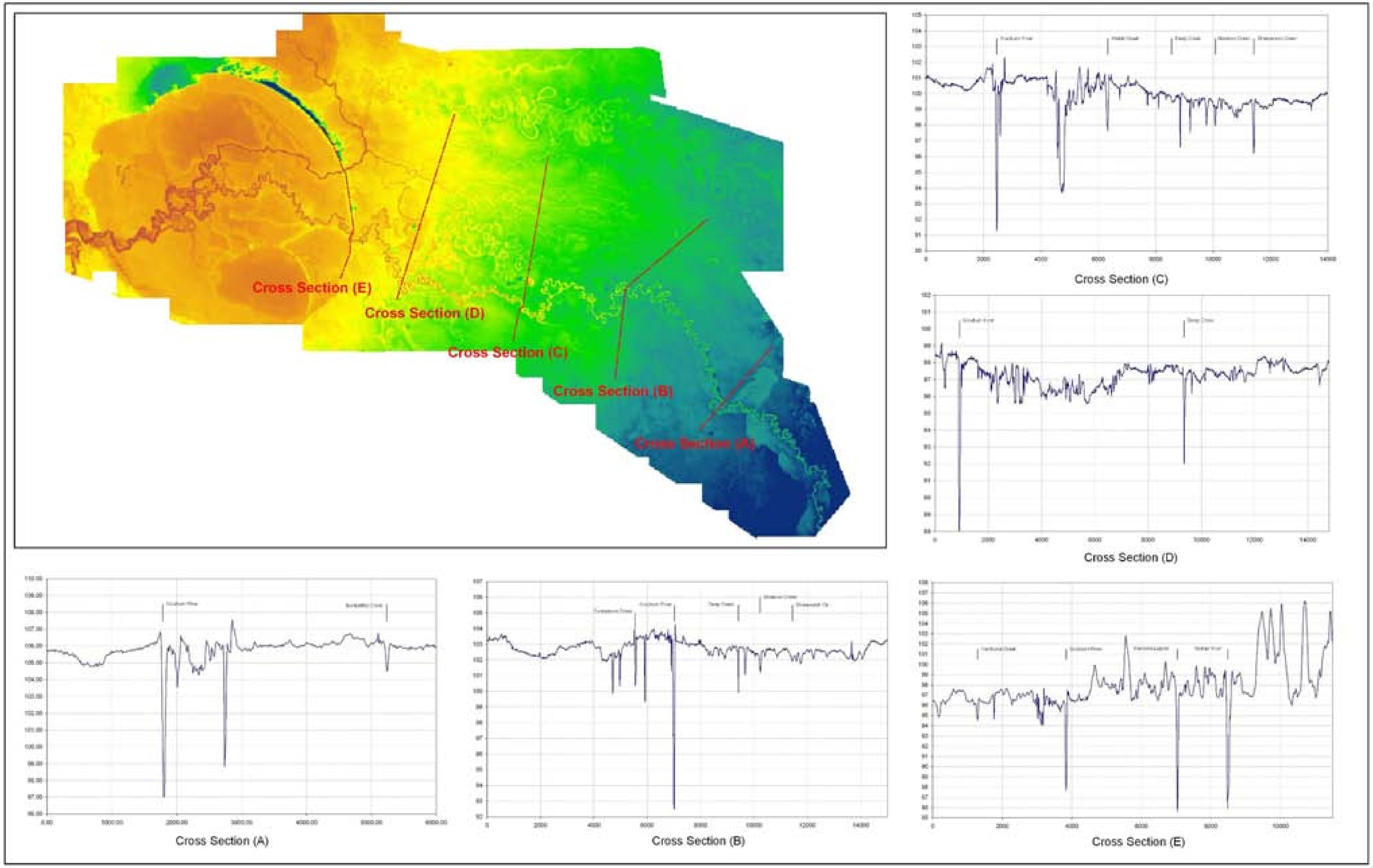


Figure 4-2 Lower Goulburn Floodplain Cross Sections

5 Topographic Survey Information

The main sources of topographic information gathered during the course of this investigation have included:

1. Airborne Laser Scanning (ALS)
2. Breaklines derived from ALS
3. Infrared Aerial Photography
4. SR&WSC Survey Data
5. LICS Additional Survey Data
6. SMEC levee audit survey

5.1 Airborne Laser Scanning

The basis of the topography for the hydraulic model grid was derived from Airborne Laser Scanning (ALS) information collected for the Murray Darling Basin Commission together with the Southern Murray Darling Lidar Project Consortium. The raw ALS data had an average spacing of 2.4m and had a vertical accuracy of 0.15m Root Mean Square Error (RMSE) and horizontal accuracy of 1.0m RMSE. Due to the size of the study area and the level of detail in the raw ALS data, Land Victoria developed a digital elevation model (DEM) using the raw data and interpolated it onto a 10m grid. This allowed practical manipulation of the data and formed the basis of the hydraulic model topography. The DEM is displayed in Figure 4.2.

Overall the ALS DEM provided excellent topographic detail of the study area from which to base the hydraulic model. However, two different systematic errors were discovered in the DEM that have the potential to reduce the accuracy of the hydraulic model. These two errors are described below:

Swathe overlap

During the model construction process, errors associated with swathe overlap between flight paths became evident. These errors or bands of "noise" within the swathe overlaps are evident across parts of the study area. In most areas, these errors or bands of "noise" produce discrepancies in the natural surface elevation of the order of 0.1m. However, in some isolated cases, these errors have been found to be of the order of 0.6m.

A "buffering" approach was used to remove the bands of "noise" associated with the swathe overlaps. More specifically, the general ALS data was "buffered" around the flight lines to remove the areas of swathe overlap from the data set. Once this was achieved, a terrain model could be generated by interpolating (or triangulating) across the "gaps" left by the removal of the swathe overlaps.

Following the removal of the swath overlap during the generation of the terrain model, the key terrain features of the floodplain that influence flow (levees, banks, creeks, roads etc) were superimposed onto the terrain model.

Tile Boundaries

Along the boundaries of some tiles grid values existed that appeared inconsistent with the surrounding surface terrain. It is understood that these errors were caused during the interpolation of the raw ALS data onto the 10m grid. The presence of these erroneous grid values was restricted to only a few very small sections of the 10m grid and where discovered were manually removed from the hydraulic model topography.

5.2 ALS Breaklines

To minimise the loss of topographical information in the interpolation of ALS data onto the 10m grid, Land Victoria carried out a curvature analysis on the ALS data. With this analysis, breaklines were developed along lines of both convex curvature, defining the crests of levees, road embankments etc, and concave curvature defining the inverts of channels, ditches and drains. The breakline data was used to supplement the 10m grid ALS data and helped to define topographic features during the development of the hydraulic model topography discussed later. A more detailed explanation of the curvature analysis methods employed on the ALS data are attached in Appendix A.

5.3 Infrared Aerial Photography

Infrared aerial photography of the study area was taken in conjuction with the ALS and was primarily used in the development of the hydraulic roughness map.

5.4 SR&WSC Survey Data

The State Rivers and Water Supply Commission undertook extensive topographic survey in the early 1980's over the entire study area. The topographic survey undertaken included the following:

- 0.5 m contour plans based on photogrammetric survey;
- Cross section survey of the Goulburn and Murray River as well as floodplain watercourses;
- Levee survey; and
- Detailed survey of culverts, bridges and Goulburn River outlet structures.

The survey methods employed for the latter three bullet points were direct levelling techniques.

5.5 LICS Additional Field Survey

Land Information and Cartographic Services (LICS) undertook extensive levee survey for the Lower Goulburn Levee Audit (SMEC, 1999). Additional field survey was also undertaken by LICS where the ALS derived breaklines and SR&WSC survey did not prove adequate in defining topographic features in the study area. LICS also undertook additional field survey, specifically for this study, of the Rodney Main Channel Bank and took cross sections along You You Creek.

6 Hydraulic Analysis

6.1 Numerical Modelling System

Hydraulic modelling of the study area has been undertaken utilising DHI Software's MIKE FLOOD modelling system. MIKE FLOOD is a state of the art tool for flooplain modelling that has been formed by the dynamic coupling of DHI's well proven MIKE 11 river modelling and MIKE 21 fully two-dimensional modelling systems. Through this coupling it is possible to extend the range of the 2D MIKE 21 model to include:

- A comprehensive range of hydraulic structures (including weirs, culverts, bridges, etc).
- The ability to accurately model sub-grid scale channels.
- The ability to accurately model dambreak or levee failures.

For the present study a two dimensional (2D) MIKE 21 model has been setup to model the overall floodplain flows. A coupled one dimensional (1D) MIKE 11 model has also been utilised to model the in bank channel flow of the Goulburn and Murray Rivers, the Loch Garry regulator and other floodplain outlet structures, levee failures and the in bank channel flow of You You and Tessie Creek systems. It is considered that this modelling approach provides the best possible model configuration to accurately simulate such a large and complex floodplain.

MIKE 21 solves the full non-linear equations describing conservation of mass and momentum in two horizontal dimensions. It is commonly referred to as a full two dimensional or 2D hydraulic model. MIKE 21 has been developed by DHI for modelling two-dimensional flows in estuaries, bays and coastal seas. Recent developments have broadened its application to complex two-dimensional flows in river and floodplain systems. For the present study area, the use of a fully two-dimensional model enables the following:

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

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

MIKE 11 is a professional engineering package for the simulation of flows in rivers and channels. MIKE 11 solves the vertically integrated equations for the conservation of continuity and momentum, ie. The Saint Venant equations.

6.2 Model Establishment

Due to computational constraints, the 10 metre grid ALS data set was interpolated onto a 60 metre MIKE 21 grid. This represented the best possible balance between computational constraints and ability to accurately schematise the terrain.

The Goulburn River levees surveyed in the LICS levee audit were also incorporated onto a sixty metre grid and included in the model terrain.

Important floodplain features, such as levees and channel banks in the Kanyapella and Comboona district, were interpolated from the positive and negative break line analysis of the ALS data.

Additional survey of the Murray Valley Highway and the Rodney Main Drain channel bank were also incorporated into the hydraulic model terrain.

The two dimensional model terrain is illustrated in Figure 6-1.

As the main channel capacity of the Goulburn and Murray Rivers could not be adequately resolved within the 60 metre grid, cross sections of these rivers as surveyed by the SR&WSC (1982) were incorporated into a MIKE 11 one dimensional model.

During the initial model establishment, the MIKE 11 model of the Goulburn extended upstream to the Shepparton Gauge. During the course of the calibration process however, comparisons between the flows in the MIKE 11 model and flows at the downstream boundary of the MIKE 21 model developed for the Shepparton Mooroopna flood study, indicated that the MIKE 11 model was not providing enough attenuation to the flood waves between Shepparton and upstream boundary of the Lower Goulburn model. It is considered that the simple one dimensional model originally developed for this study is not well suited to describing the attenuation to the flood waves produced by the backfilling of depression storages such as Gemmills and Reedy Swamps downstream of Shepparton. The one dimensional model could also not be easily modified to describe breakouts from the near channel floodplain downstream of the Shepparton Gauge during large floods. It was therefore considered necessary to employ flows from the downstream boundary of the Shepparton Mooroopna model as described by SKM (2001) to drive the upstream boundary of the Lower Goulburn model.

The MIKE 11 model of the Murray River extended from the junction of the Edward River, to take into account the large storage available in the Barmah and Moira State Forests, to the gauge at Echuca, which provided the models downstream boundary. At cross sections along the main channel of both the Goulburn and Murray rivers, flows were dynamically coupled between the two dimensional and one dimensional model, allowing the transfer of mass and momentum between models. During the study is was it was determined that overflows into the Edward River from the Murray River may be an important mechanism for distributing floodwaters caused by the backwater effect of the Murray River at Barmah. To take into account this effect, a portion of a MIKE 11 model describing the Edward River and associated floodplain developed during the Tuppal Bulatale Flood Study (ID&A, 2002) was incorporated into the one dimensional model.

The Loch Garry regulator was simulated as a MIKE 11 structure within the two dimensional model. As the operation of the regulator is governed by the stage height at the Shepparton gauge the simulation of the operation of the regulator was determined by relating the flows at the Shepparton Gauge from the Shepparton Mooroopna model to a stage height.

Other hydraulic structures in the floodplain such as Goulburn River outlet structures and the Murray Valley Highway culverts were also simulated as MIKE 11 structures within the two dimensional model.

As a result of the extensive levee breaching and failures, particularly in the October 1993 flood, levee failures were incorporated into the hydraulic model in order to reproduce the extensive inundation of areas affected by the levee failures. Major levee failures were simulated as MIKE 11 moveable weir structures nested within the two dimensional model.

The timing and degree of levee failures was based on discussions with GBCMA staff, local landholders and on the summary of levee damage as collated by the DCNR, Floodplain Management Section (HydroTechnology, 1995).

A hydraulic roughness grid of the study area was developed based on the infrared photography (2002), cadastral information and various field inspections. Roughness coefficients for each terrain category were developed and refined during the calibration process. Table 6.1 summarises the hydraulic roughness coefficients as schematised in the hydraulic roughness grid.

The hydraulic model covers an area in excess of 1350km^2 (135,000 ha) and requires up to 30 hours (cpu time) to simulate a period of 11 days (real time) for large floods. Each model simulation produces result files of approximately 1,750 MB.

Table 6-1 Adopted Hydraulic Roughness Parameters

Floodplain Element	Manning's M	Corresponding n
General floodplain roughness (lightly vegetated pasture)	17.5	0.057
Main channels, lagoons	25 – 16.67	0.04 – 0.06
Thickly vegetated	12.5	0.08
Urban areas (houses, Buildings)	5	0.2
Clear, paved areas (roads)	66.7	0.015

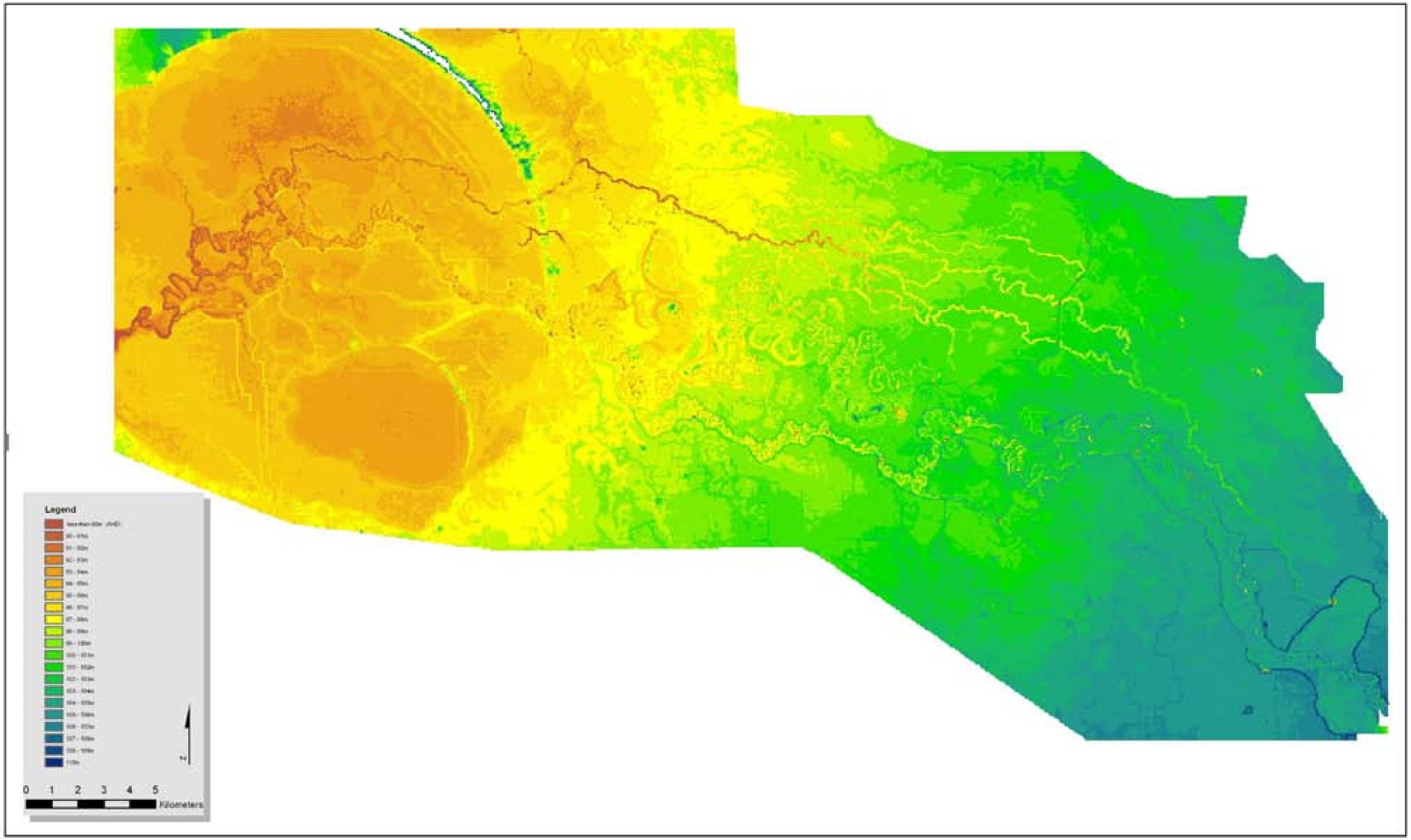


Figure 6-1 Hydraulic Model Topography

7 Calibration

The calibration process consists of systematically comparing observed flooding behaviour against the hydraulic models reproduction of that flood. This process incorporated comparisons between gauged stream flow data, observed maximum flood levels and maximum areas of inundation as shown by aerial photography or by eye witnesses recounts. Where the model does not adequately represent what was observed, the reason for the discrepancy is identified and inputs into the model are adjusted as required.

Two historical floods were selected for calibration of the model:

- The July 1981 flood, representative of the behaviour of a flood nominally below the capacity of the existing levee system.
- The October 1993 flood, representative of the behaviour of a flood that exceeded the capacity of the existing levee system.

Model calibration was primarily achieved by adjusting model parameters to fit a number of stage and discharge hydrographs along the Goulburn and Murray Rivers for each flood. Where available, flow measurements taken during the floods were also utilised in the calibration process.

A table of the gauging stations used in the calibration process is given in Table 7-1.

Table 7-1 Gauging Stations

Gauge Index No.	Location
Goulburn River	
405 204C	Shepparton
405 276A	Hurricane Bend
405 232A	McCoys Bridge
405 277A	D/S Yambuna Drain Outfall
Murray River	
409 215B	Barmah
409 221A	Lower Moira
4090 200	Echuca
Madowla Lagoon	
405 275A	Lower Moira

Comparisons between observed peak flood levels within the leveed section of the Goulburn River as well as on the floodplain were also used in the calibration process. Levels taken on the floodplain particularly assisted in attempting to model the volume of water that flowed onto the floodplain through the various levee failures.

Aerial photography of varying quality for both floods was used to assess the agreement between observed and modelled flood extents within the study area. This assisted the calibration process by identifying altered flow paths that significantly affected the extent of inundation and insured that the general pattern of observed flooding was being reproduced by the model.

7.1 Loch Garry Rating

Considerable uncertainties remain in the estimation of the discharge rating of the regulator structure at Loch Garry. A review of the previous studies on the Lower Goulburn showed a number of estimates of discharges through the structure have been made based on the broad crested weir formula and through extrapolation of the original hydraulic computations of the design flow. However, the degree of discrepancy between the various estimates is excessive.

The arrangement of the regulator structure is quite complicated and includes an elaborate concrete apron extending approximately 7 metres downstream of the sill. The cross section of the apron varies quite markedly with the cross section of the sill so that the difference between the sill and apron height can vary by as much as 1.5 metres along the width of the structure. With this arrangement the nature of the flow through the regulator is considered to be quite complicated and the assumption of an ideal broad crested weir type flow is not considered entirely accurate. It is also considered that when all the bars are removed from the structure, the height of the weir crest (the sill level) is essentially level with the approach. Under these conditions the approach velocity of flow cannot be assumed to be zero, and the broad crested weir formulation is likely to underestimate flows through the structure.

In order to develop a discharge rating curve for the structure for this study, an iterative approach was adopted. This was based on the results of the detailed hydraulic modelling undertaken as part of this study combined with the analysis of the flow splits between the Shepparton Gauge and the Hurricane Bend Gauge for the October 1993 and July 1981 floods. With this method a discharge rating curve was developed for estimating flows through the regulator when all the bars have been removed. In order to produce a discharge rating curve that fitted the derived flows for the October 1993 and July 1981 floods, the parameters describing the flow through the structure were modified to those generally adopted for flow over a broad crested weir. The resulting discharge rating curve developed for this study is displayed in Figure 7-1.

Included in Figure 7-1 is the design flow determined during the original 1925 hydraulic computations for the regulator. The original intent of the design was for the structure to pass 44,000 ML/d (509m^3/s) with 900mm freeboard. It is understood that the levee crests surveyed in the 1980's (SRWSC dwg. 141430) conform closely to the design levels (SKM, 1998). Therefore the design head in Loch Garry, with the provision of 900mm freeboard, is derived to be approximately 107.3m AHD. From Figure 7-1 it can be seen that the original hydraulic computations significantly overestimated the discharge capacity of the structure compared to the discharge rating determined in this study. This is significant as it means the levee system has been put under considerably more pressure than would have otherwise occurred had the regulator achieved the discharge it was designed for.

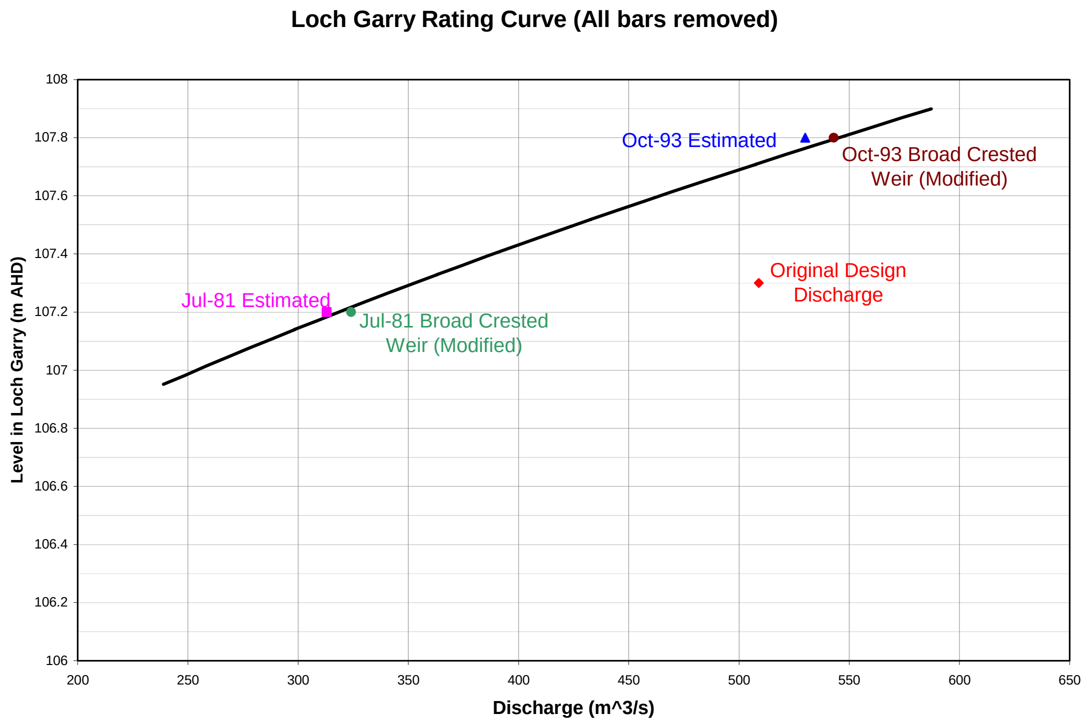


Figure 7-1 Loch Garry Rating Curve (All bars removed)

7.2 July 1981 Flood

7.2.1 General Description

The July 1981 flood was a moderate flood with an estimated 1 in 7-year ARI at Shepparton. The flood peaked at 87,300 ML/d at the Shepparton gauge. The flood was largely contained within the existing levee system and through controlled discharges to the Deep Creek System via the Loch Garry regulator and outlet structures. However levee failures did occur downstream of Hancock's Creek as seen in the photo in Figure 7-2 taken during the July 1981 flood.

Figure 7-2 Levee Failures Downstream of Hancocks Creek Outlet, July 1981 Flood

Photo courtesy of the Goulburn Broken Catchment Management Authority

7.2.2 Model Boundaries

The discharge hydrograph at Shepparton for the July 81 flood is presented in Figure 7-3. The stage height at Shepparton is also included as the operation of Loch Garry is dependent upon this stage.

No hydrologic data could be sourced for the Murray River at Barmah for the July 1981 flood. Therefore, for the purposes of the calibration, a constant discharge of $400m^3/s$ (34,560 ML/d) was assumed at the upstream boundary of the Murray at the confluence with the Edward River.

The stage height record at the Echuca Gauge for the period of the simulation was applied as the models downstream boundary condition.

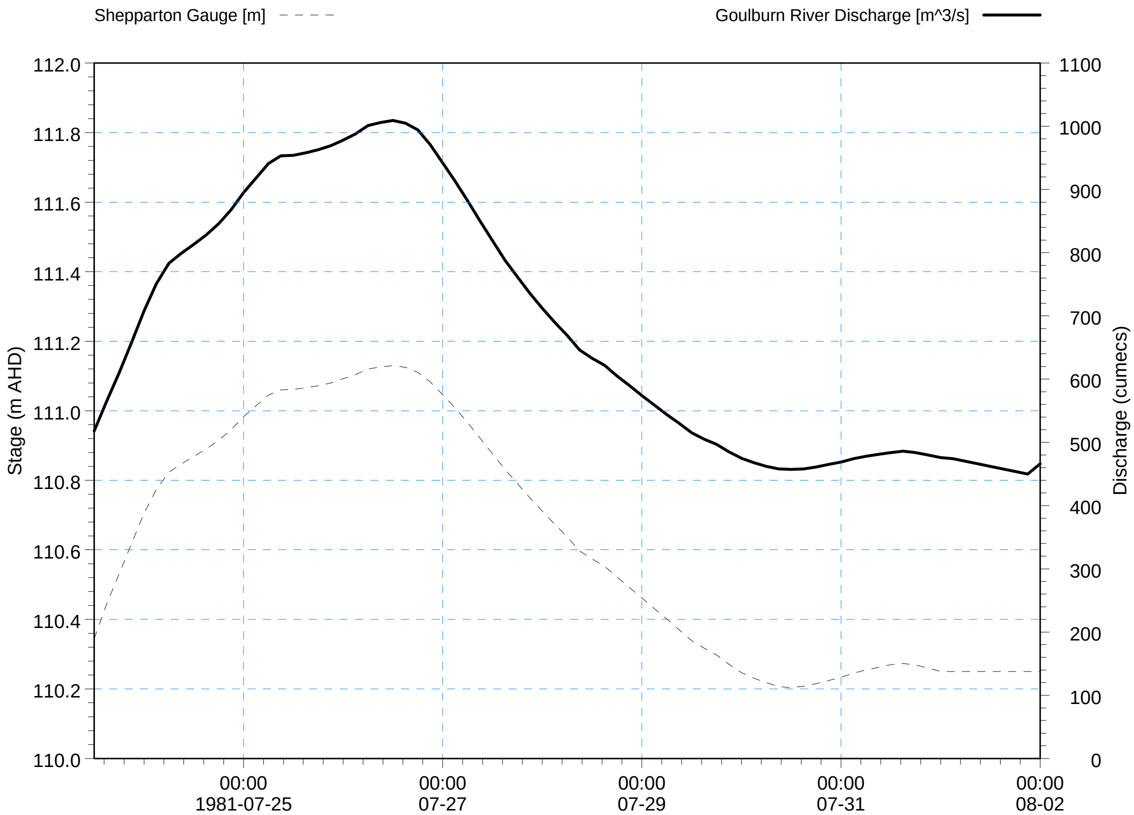


Figure 7-3 Goulburn River at Shepparton – July 1981 Flood (405204C)

7.2.3 Levee Failures

Levee failures that occurred during the July 1981 flood were simulated in the model by breaching the levees down to natural surface within an hour of the time of overtopping. The extent of the breaching has been based on discussions with landholders and GBCMA staff.

More specifically, levee breaches have been modelled at:

- Hancocks Creek

  A 90m section of levee was breached to natural surface commencing at 12:00AM on the 26/07/1981

- Madowla Park

  A section of poorly constructed or previously breached levee was further lowered to natural surface level beginning 12:00PM on the 27/07/1981

7.2.4 Gauge Results

Comparisons between observed and modelled water levels at the various gauges are presented in Figure 7-4 to Figure 7-8. Modelled flows at the various gauges have also been included and compared with physically measured flows and the gauge rating curves, where they appear reliable.

Good calibration fits have been achieved for the July 1981 flood. Levels are generally within 150mm of the peak and there is also good agreement between the timing of the peaks. Discharges at the gauges also appear to be consistent with the physical measurements and rating curves.

The behaviour of the Murray River in response to flows entering it from Deep Creek is complex and appears to be particularly sensitive to conditions upstream in the Barmah and Moira State Forest areas. Without data on the Murray River at Barmah for the July 1981 flood it was difficult to determine initial conditions in the Murray and some discrepancies appear between the stage and flow measurements and the model results at Lower Moira. Despite this, it is felt that a reasonable approximation of the conditions in the Murray during the flood has been achieved.

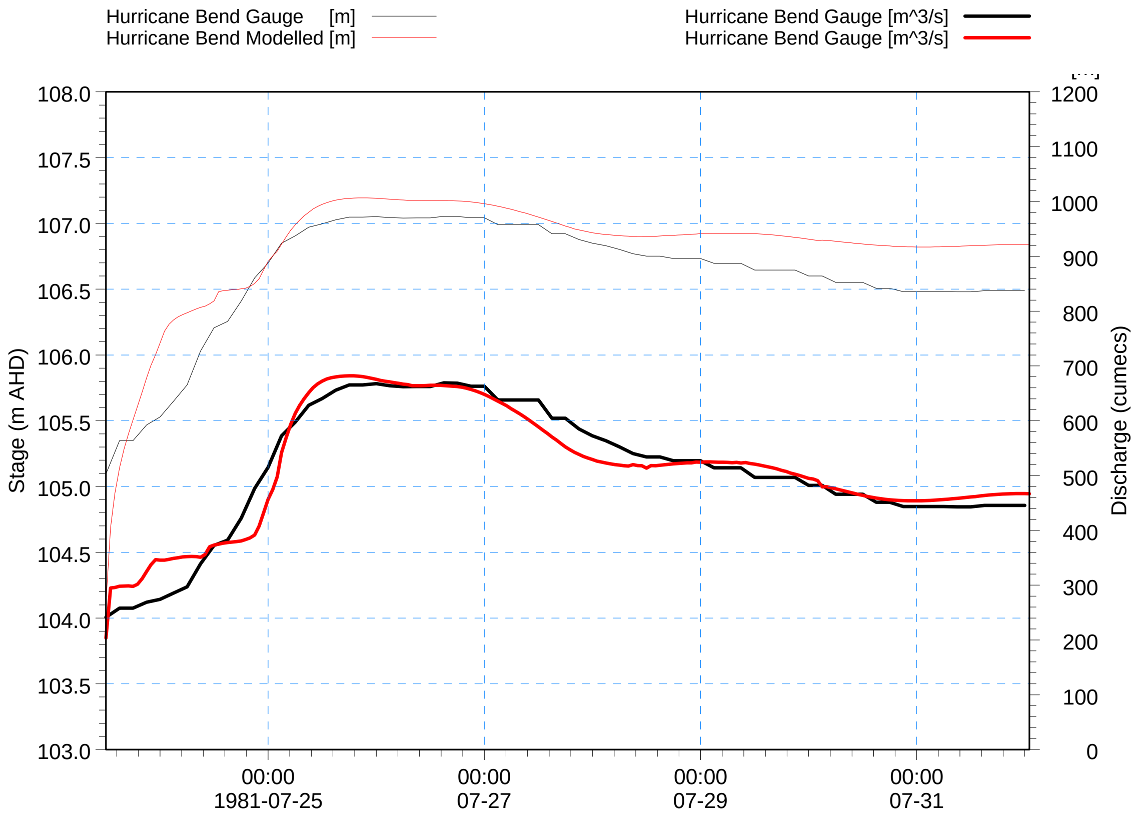


Figure 7-4 July 1981 Flood, Hurricane Bend Gauge (405276A)

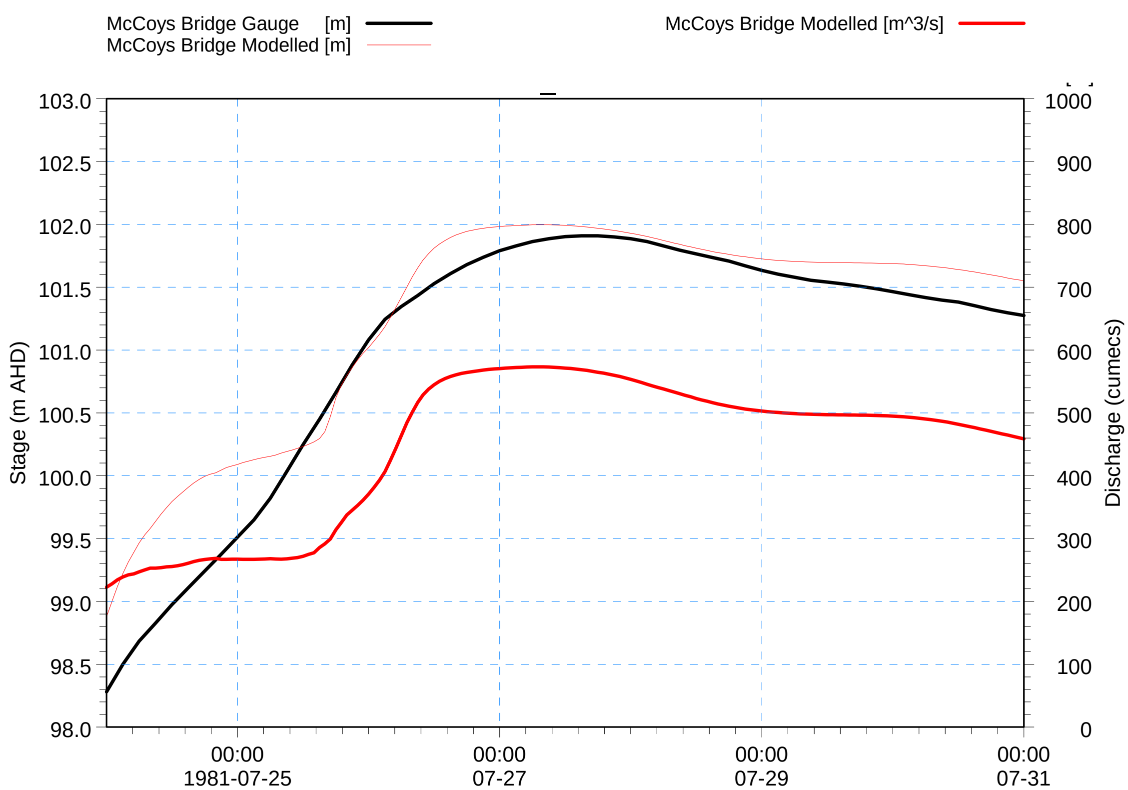


Figure 7-5 July 1981 Flood, McCoys Bridge (405232A)

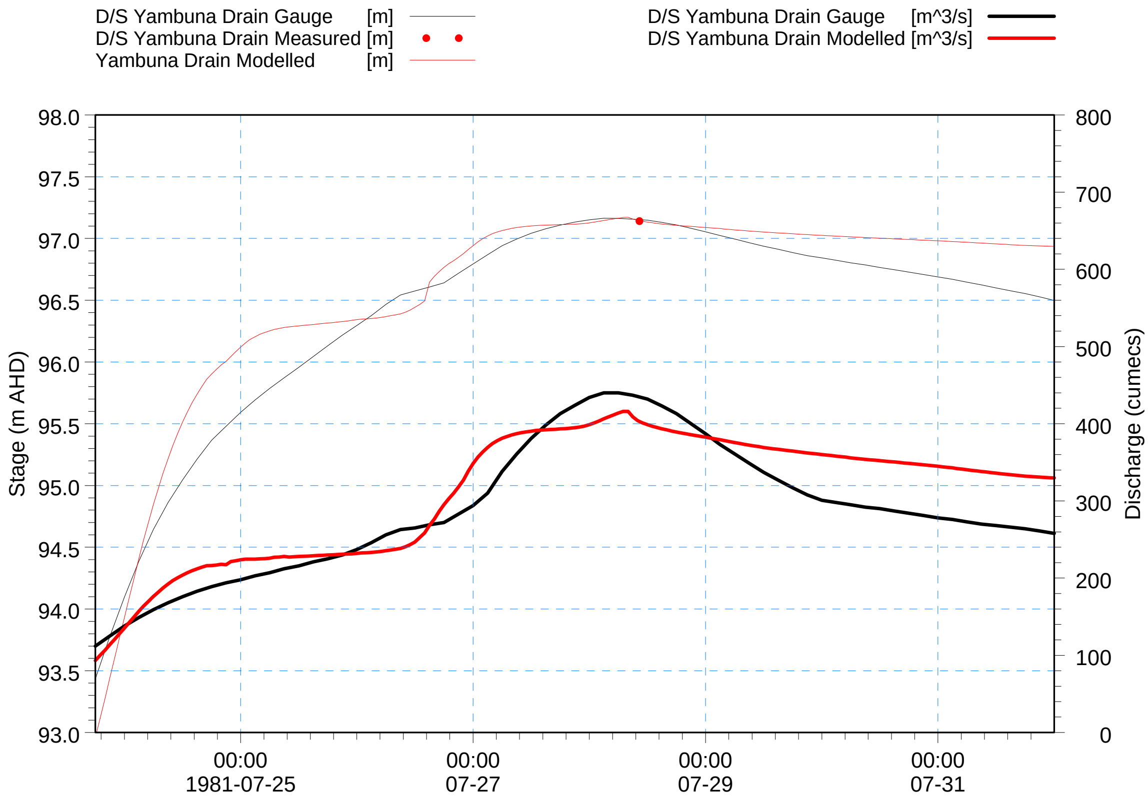


Figure 7-6 July 1981 Flood, D/S Yambuna Drain (405277A)

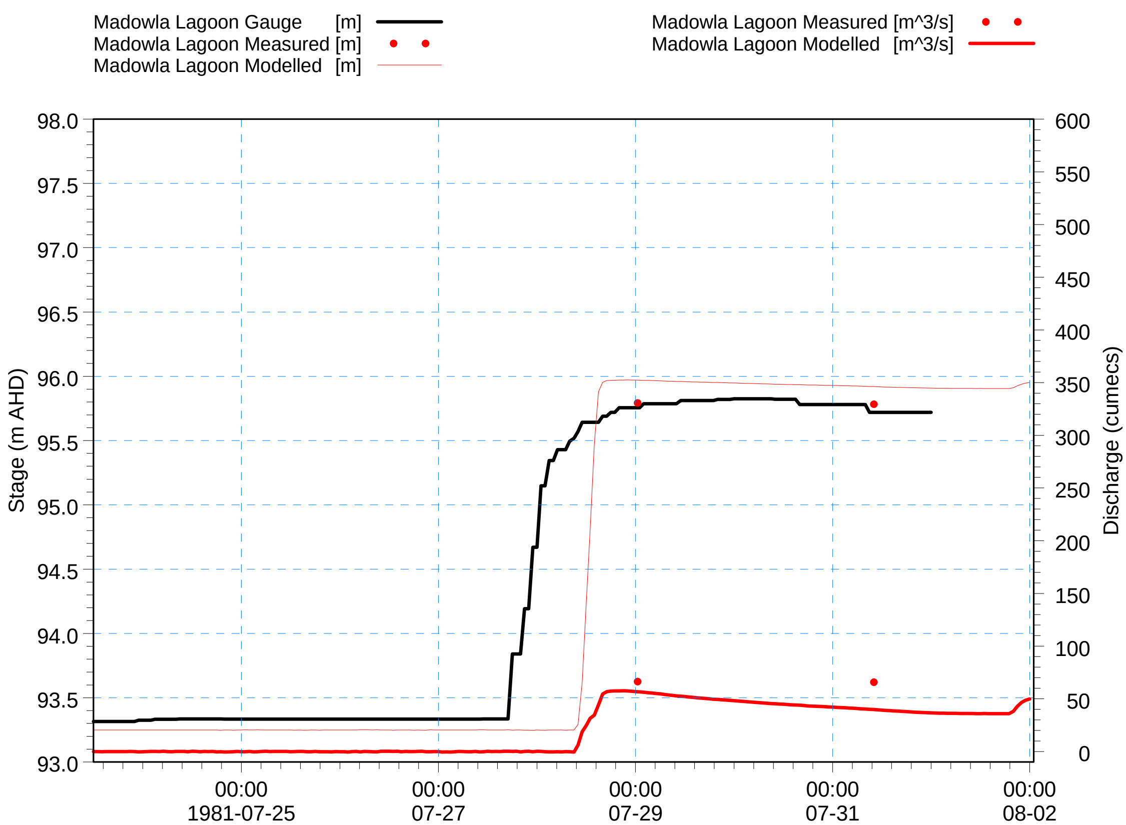


Figure 7-7 July 1981 Flood, Madowla Lagoon (405275A)

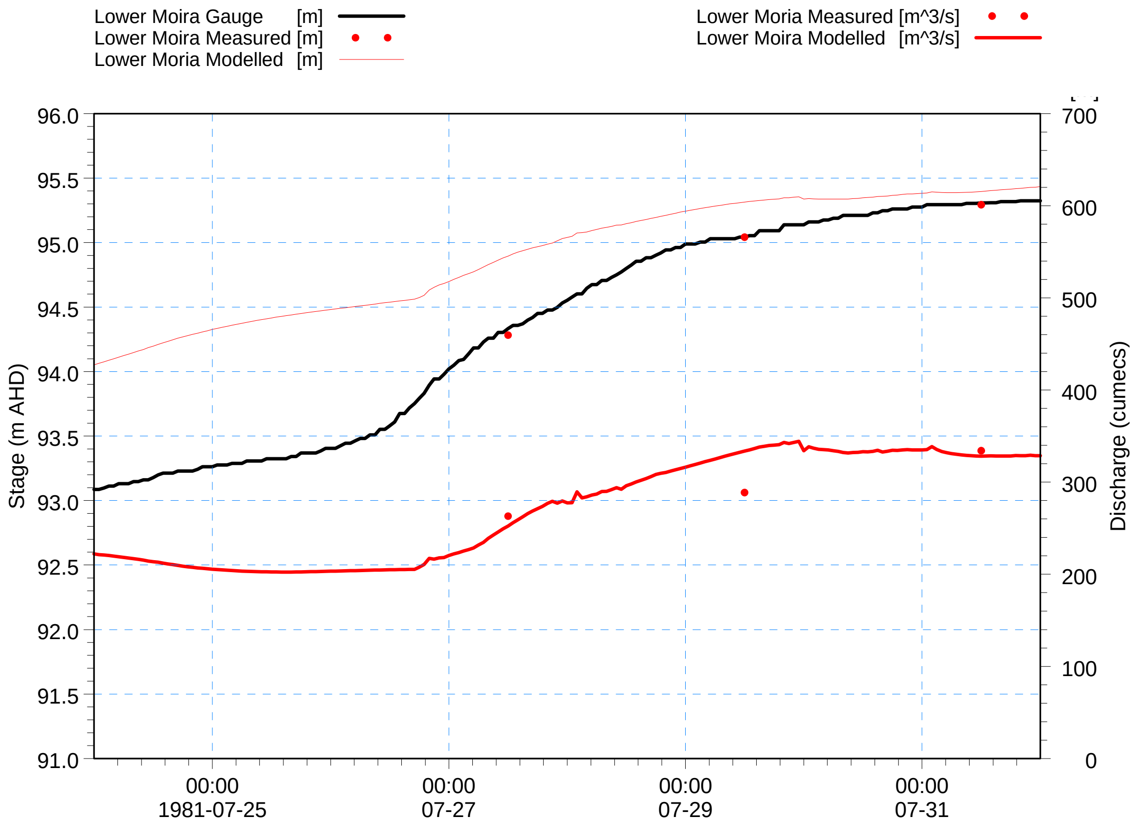
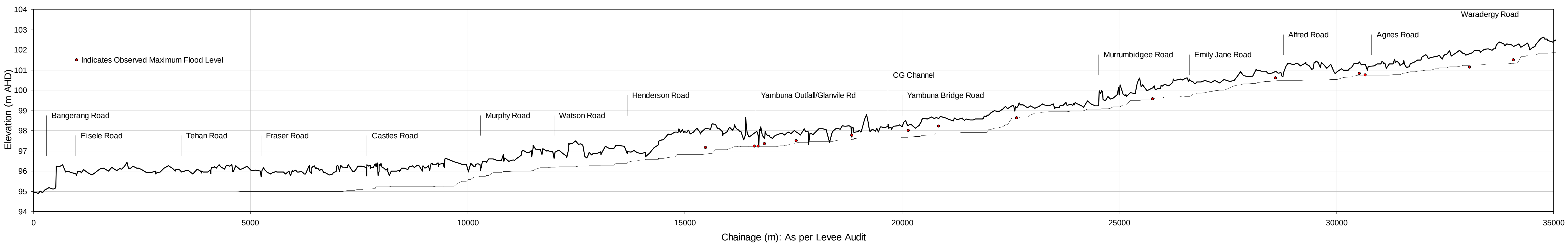


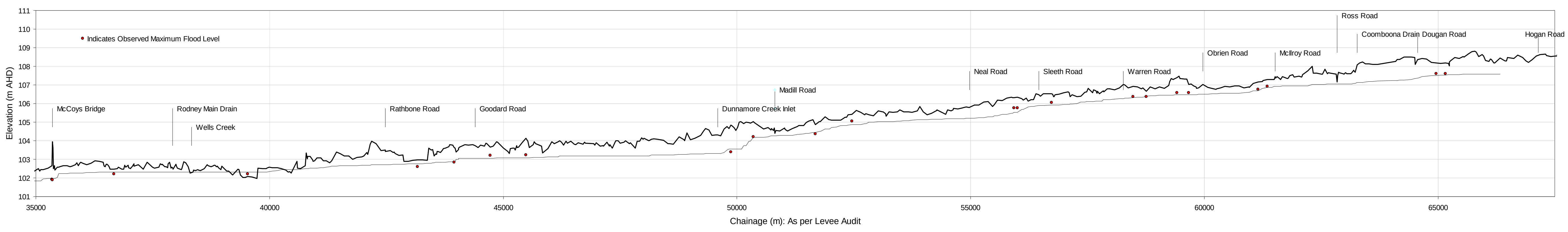
Figure 7-8 July 1981 Flood, Lower Moira (409221A)

7.2.5 Goulburn River Profile

A profile of maximum water surface elevations of the Goulburn River inside the leveed section for the July 1981 flood has been developed and is displayed in Figure 7-9. The left bank or southern side levee crests and observed maximum flood levels for the July 1981 flood have been included in the figure.

From Figure 7-9 it can be seen that the modelled water surface profile is generally lower than the left (south) bank levee crests. This corresponds with observations that the July 1981 flood was generally contained within the capacity of the current levee system and by controlled discharges through the Loch Garry regulator and other outlet structures. The modelled water surface profile also appears to be consistent with the general water surface profile produced by the observed maximum flood levels.





Note: Observed Maximum Flood Levels Not Obviously Fitting the General River Profile Have Been Excluded From This Figure.

Figure 7-9 Goulburn River – Longitudinal Profile, July 1981 Flood

7.2.6 Flooding Extents

The extent of flooding produced by the model was compared with the flooding extents captured by the aerial photography. The aerial photography consisted of black and white photographic mosaics. Precise comparison between the model results and the photographs was difficult because of the poor contrast between flooded areas and un-flooded areas and the fact that sections of the study area were obscured by clouds. Despite this, the photos assisted in determining the amount of inundation caused by the levee failure downstream of Hancocks Creek, as well as other changes to the levee system that significantly altered the extent of inundation in the July 1981 flood.

The maximum extent and depth of inundation produced by the model for the July 1981 flood is presented in Figure 7-10. A small number of flood levels on the floodplain were surveyed after the flood and these have been compared with the model results and also presented in Figure 7-10.

The following comments regarding the extent and depth of inundation produced by the model can be made with reference to Figure 7-10:

- The extent of inundation is generally confined between the levee system and on the northern floodplain as a result of controlled releases from Loch Garry and Goulburn River outlet structures. This is in line with general observations of the flood.
- The depth of inundation on the floodplain appears consistent with the small number of observed maximum flood levels surveyed.
- A levee failure downstream of Hancocks Creek outlet produced considerable flooding of properties in the vicinity of Hancocks Creek in the Shire of Nathalia (now Moira Shire).
- Sections of previously breached or poorly constructed levees surrounding Delma Lagoon allowed floodwaters to flow through Madowla Lagoon.

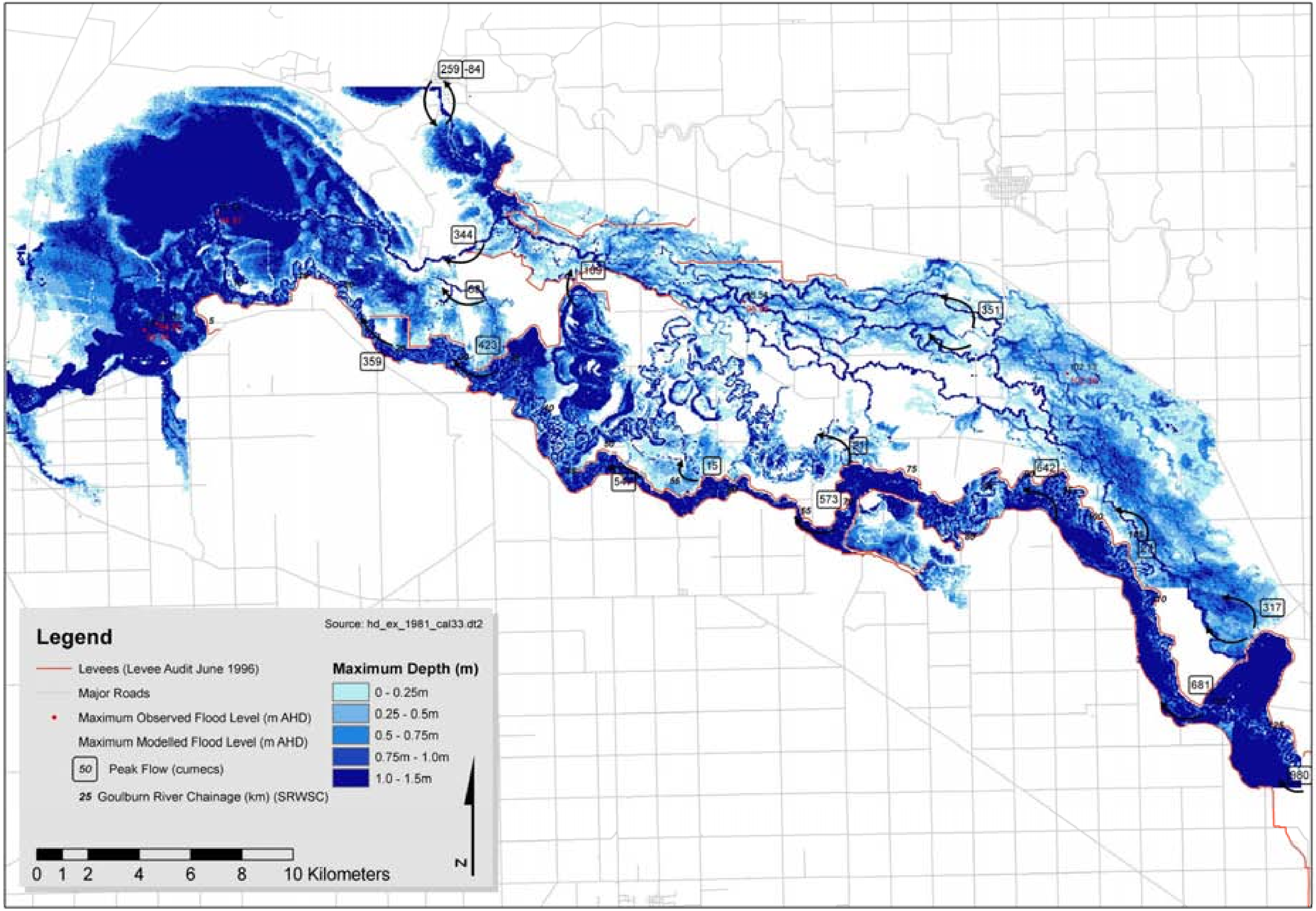


Figure 7-10 Maximum Extent and Depth of Inundation, July 1981 Flood

7.3 October 1993 Flood

7.3.1 General Description

The October 1993 flood was preceded by a smaller flood which peaked at 85,000ML/d at the Shepparton gauge on the 19th of September. Consequently, when heavy rain fell in northeast Victoria on the 3rd of October, much of the floodplain was saturated and water was already ponding within floodplain storages. The rainfall caused the highest flood on record in the Broken River which outfalls into the Goulburn River at Shepparton. The peak discharge on the Goulburn River at Shepparton was 150,000ML/d (1736m^3/s) and the flood at Shepparton was estimated to be a 27-year ARI flood. Levees were breached or damaged in 45 separate locations on the south bank downstream of Coomboona and eight separate locations on the north bank upstream of McCoys Bridge. Levees were also breached at Madowla Park and downstream of McCoys Bridge and Hancocks Creek outlet (HydroTechnology, 1995). The combination of two consecutive floods in the Goulburn River during 1993 produced the second highest flood levels recorded in the last century at both the Echuca and Barmah Gauges. Figure 7-11 shows the extent of levee failures along one section of the Goulburn River levees during the October 1993 flood.

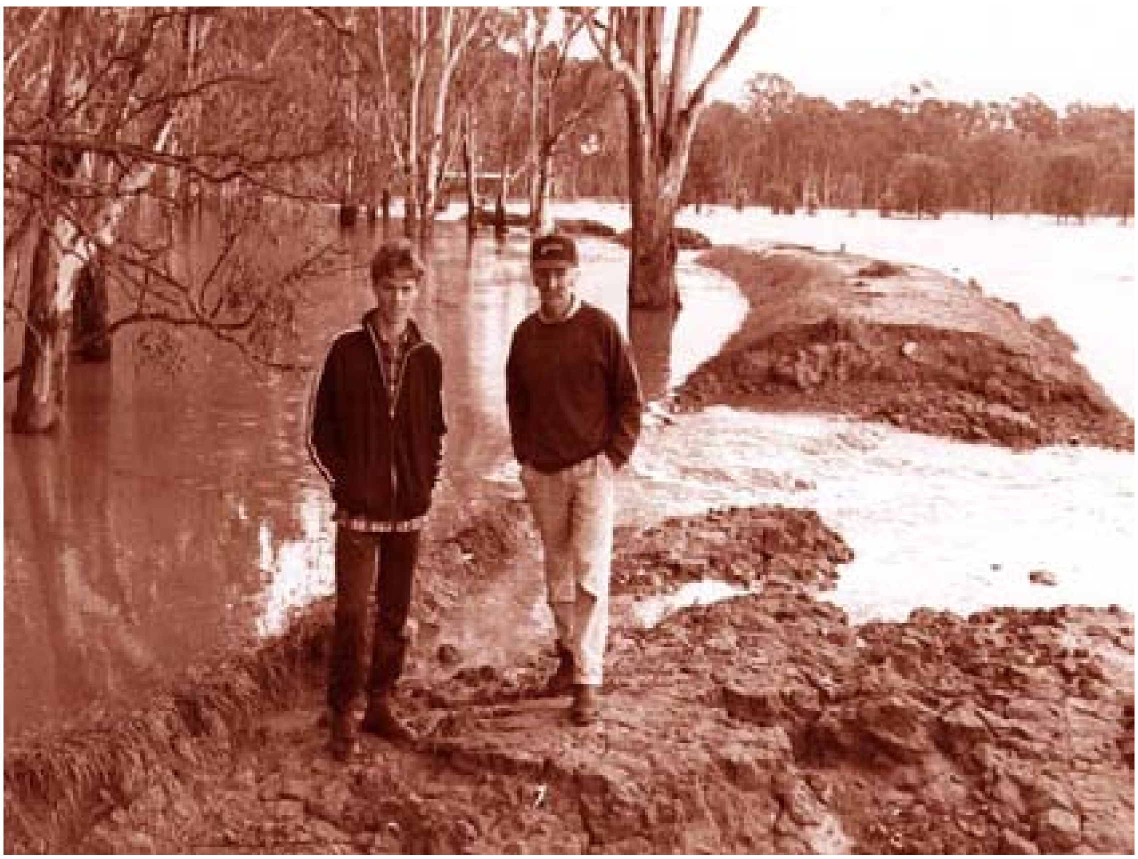


Figure 7-11 Levee Failures on Goulburn River, October 1993 Flood.

Photo courtesy of the Shepparton News

7.3.2 Model Boundaries

The stage and discharge hydrograph at Shepparton is presented in Figure 7-12 for the October 1993 flood.

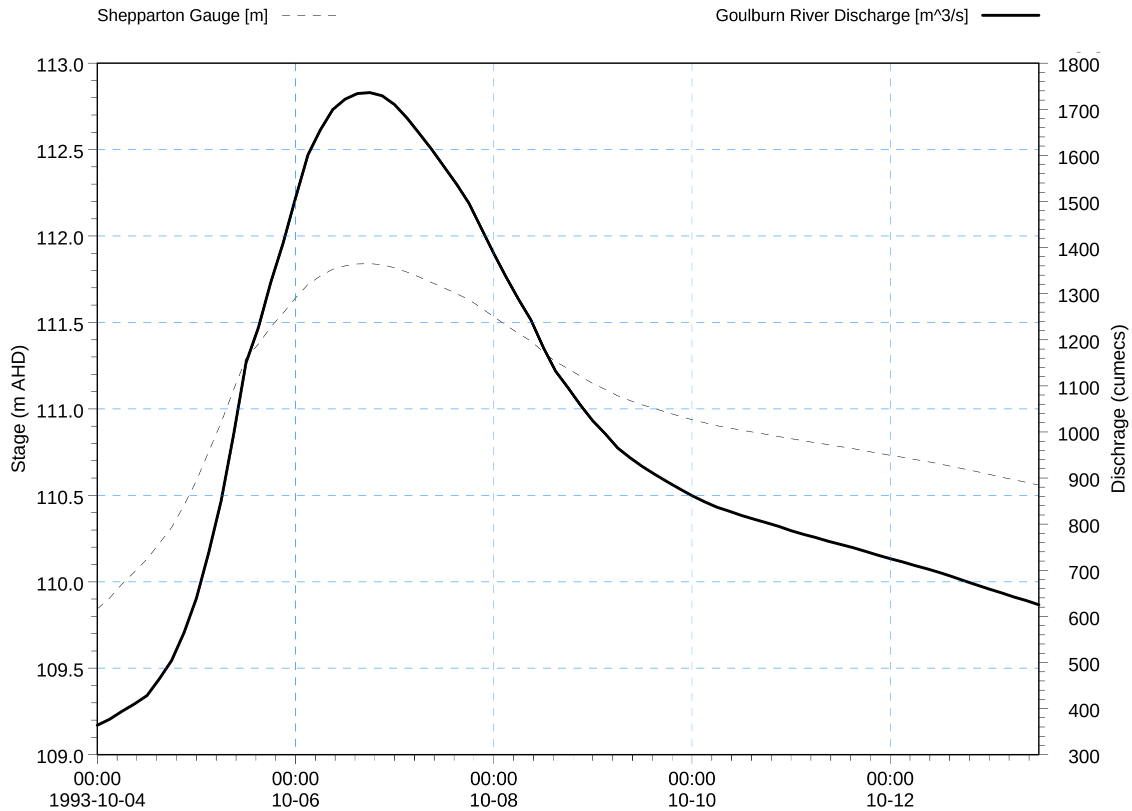


Figure 7-12 Goulburn River at Shepparton – 1993 Flood (405204C)

As for the 1981 flood, the downstream boundary of the model utilised the Echuca Gauge stage height record for the period of the simulation.

A discharge of 400 m^3/s at the upstream boundary of the Murray was assumed for the beginning of the simulation, this was subsequently ramped down to 250 m^3/s during the flow reversal of the Murray River at Barmah and returned to 400 m^3/s once flows had returned to positive at Barmah.

7.3.3 Levee Failures

Numerous levee failures have been simulated in the October 1993 model in order to reproduce the extensive areas of inundation observed during the flood. The extent of the breaching has been based on discussions with landholders, CMA staff and the summary of levee damage as collated by the DCNR, Floodplain Management Section (HydroTechnology, 1995).

More specifically, levee breaches have been modelled at:

- Coomboona

  The extensive levee breaches along this section of the river were modelled as one large failure 180 metres wide.

- Brickworks Site

Numerous levee failures near Munro Road were modelled as one large failure 120m wide.

- McCoys Bridge

  A number of levee failures on the north bank near McCoys Bridge were modelled as one large failure 150 metres wide.

- Hancocks Creek

  Two levee failures on the north bank near Hancocks Creek were modelled as one large failure 70m wide.

- Madowla Park

  A section of previously breached levee 90 metres wide was further breached down to natural surface.

- Rodney Main Drain

  The Rodney Main Drain channel bank was failed along 30 metres.

7.3.4 Gauge Results

Comparisons between observed and modelled water levels at the various gauges are presented in Figure 7-13 to Figure 7-18 below.

Good calibration fits have been obtained for the October 1993 flood. Levels are generally within 100mm of the peak and there is again good timing of the peaks throughout the model. Discharges at the gauges also appear to be consistent with the physical measurements and rating curves.

The model indicates that flow in the Murray River at Barmah was reversed during the flood. While no measurements of this occurrence exist, anecdotal evidence from local residents at Barmah suggests that the Murray did in fact reverse for a period during the October 1993 flood. Discussions with Thiess hydrographers and former DNRE Floodplain Management Unit staff also confirm these observations.

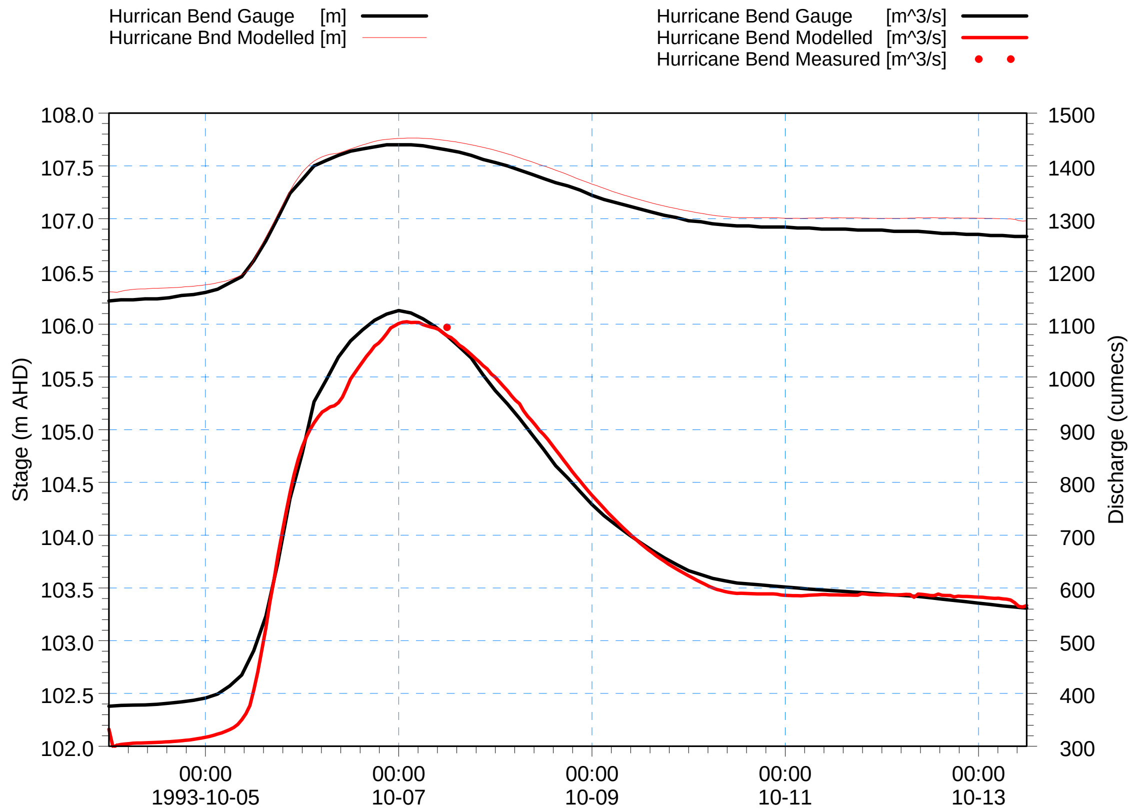


Figure 7-13 October 1993 Flood, Hurricane Bend Gauge (405276A)

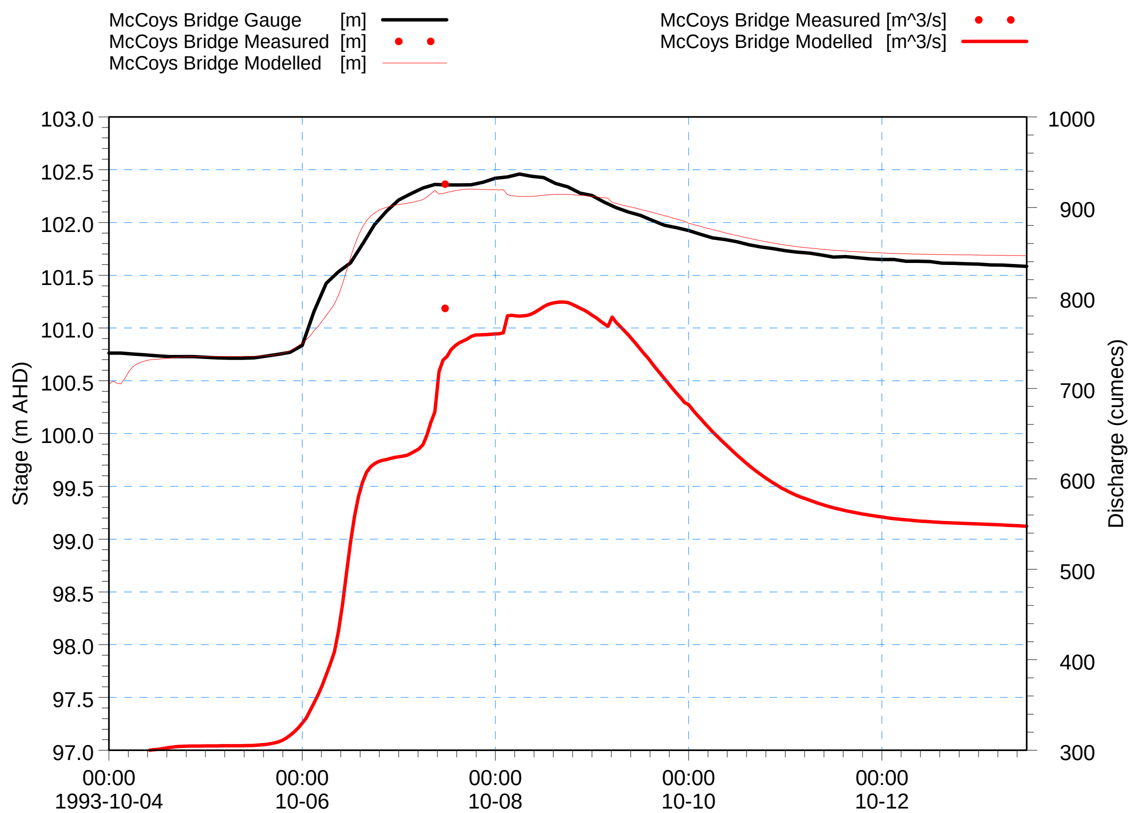


Figure 7-14 October 1993 Food, McCoys Bridge (405232A)

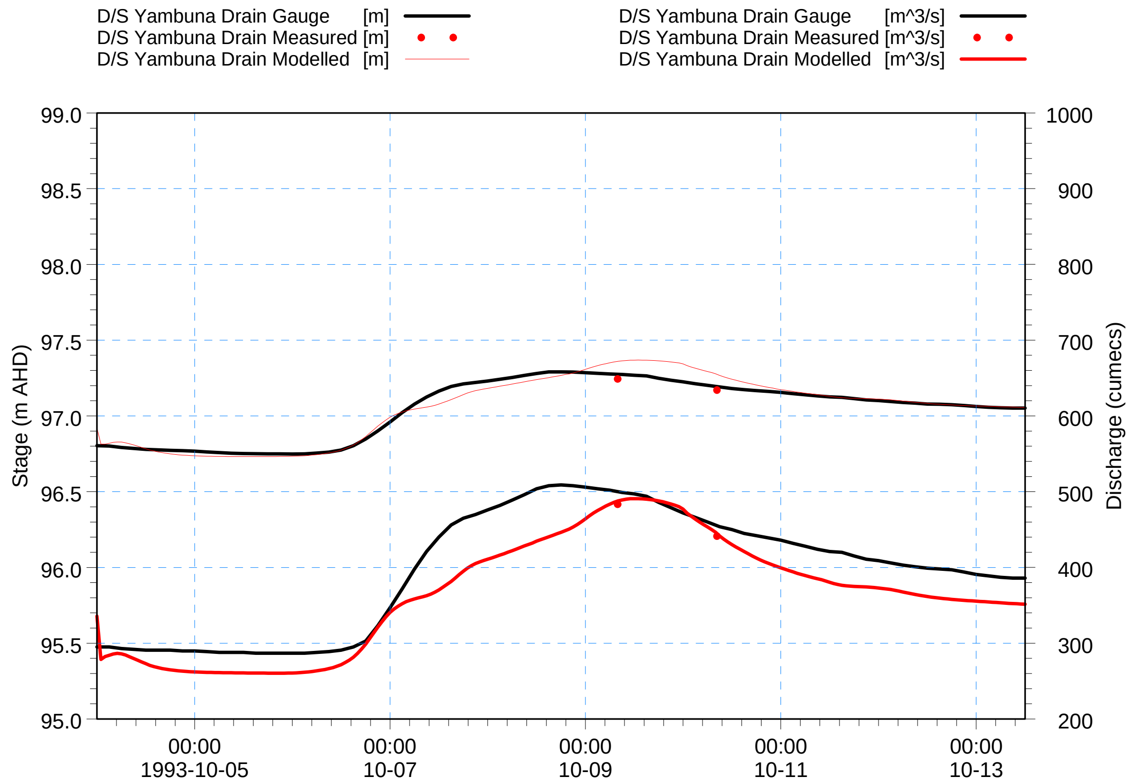


Figure 7-15 October 1993 Flood, D/S Yambuna Drain (405277A)

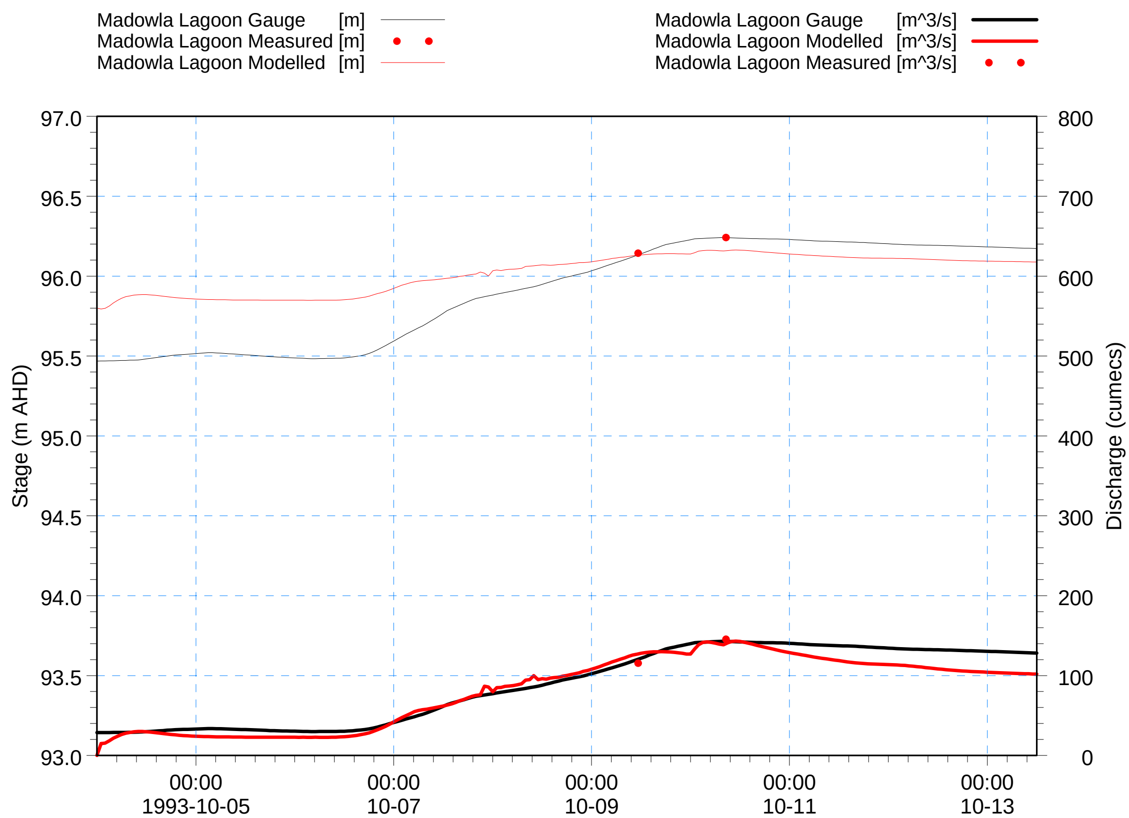


Figure 7-16 October 1993 Flood, Madowla Lagoon (405275A)

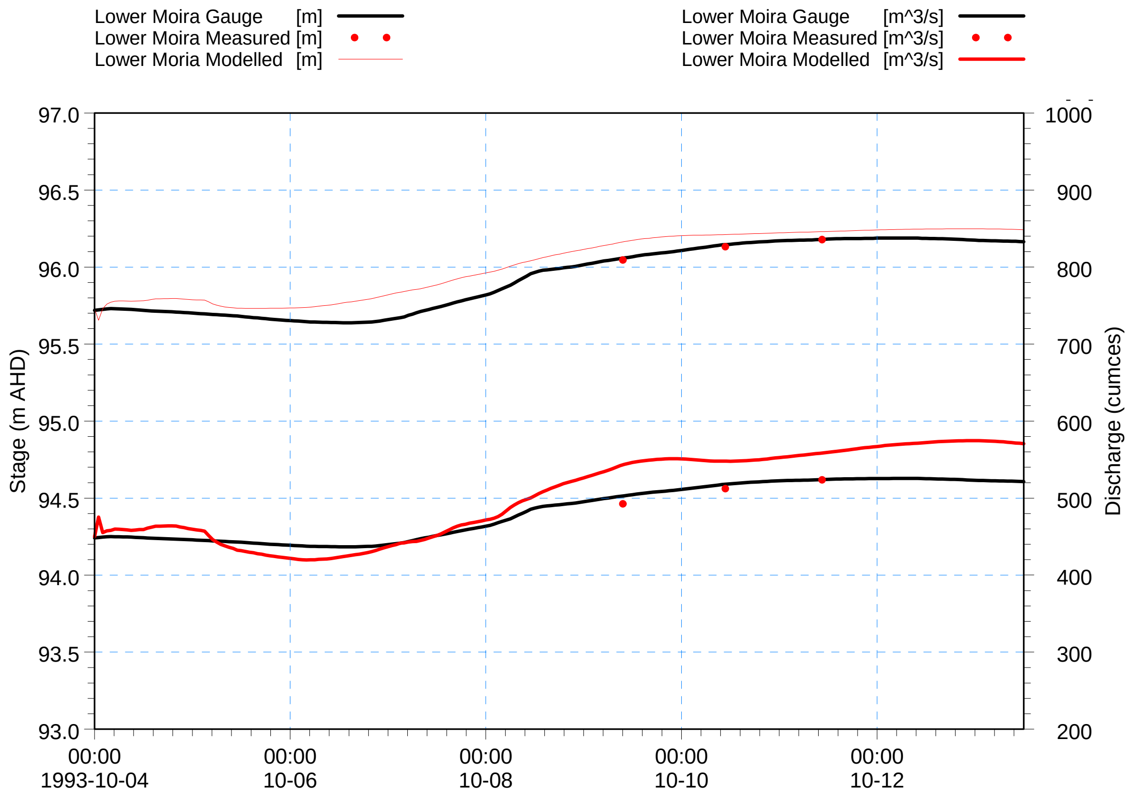


Figure 7-17 October 1993 Flood, Lower Moira (409221A)

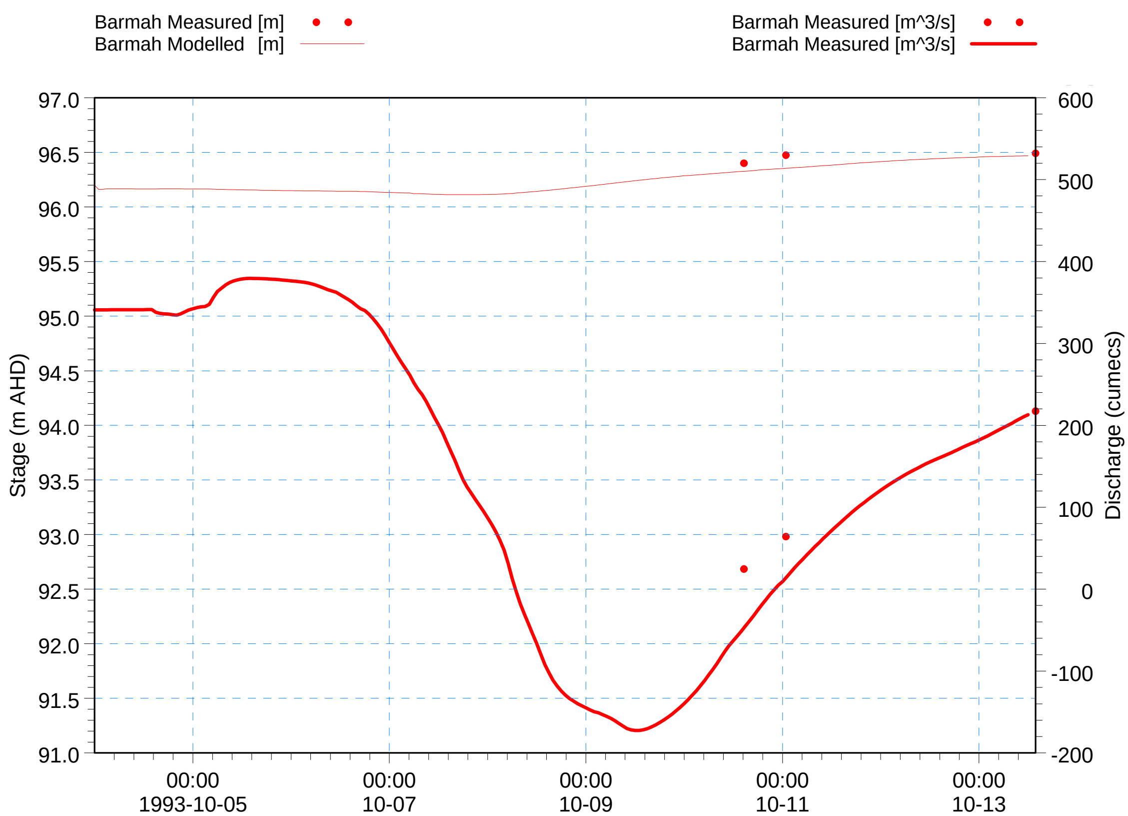


Figure 7-18 October1993 Flood, Barmah (409215B)

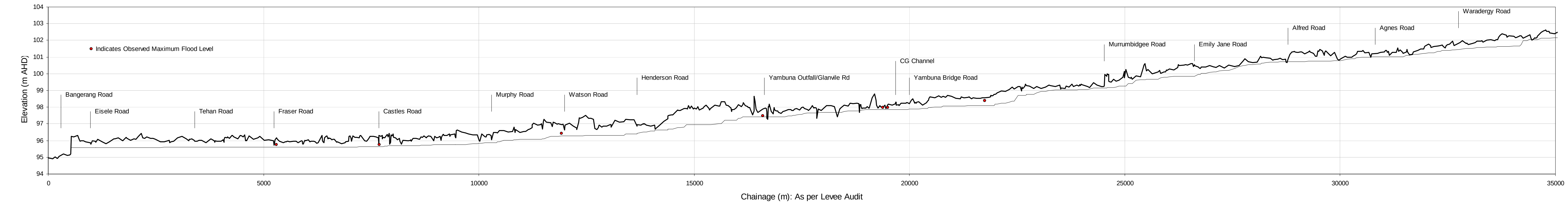
* Note flow reversal at the Barmah Gauge (409215B) on the Murray River.

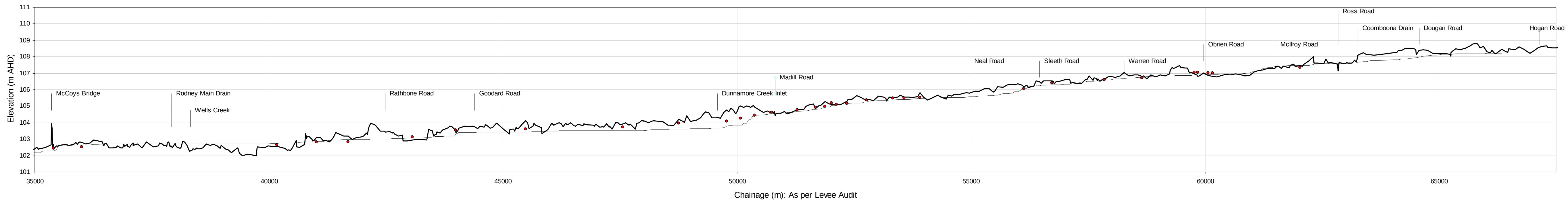
7.3.5 Goulburn River Profile

A profile of maximum water surface elevations of the Goulburn River inside the leveed section has been developed and is displayed in Figure 7-19. The left bank or southern side levee crests and observed maximum flood levels for the October 1993 flood have been included in the figure.

The following observations can be made with reference to Figure 7-19.

- The modelled water surface profile is above the south side levee crests in the area between Coomboona Drain (63.271km) and Obrien Road (59.975km). It was along this section of the Lower Goulburn that levees were overtopped and breached along considerable lengths, resulting in extensive flooding of surrounding property.
- The modelled water surface profile is above the south side levee crests in the vicinity of Wells Creek (38.330km). This corresponds well with observations that floodwaters that had left the leveed section of the river through levee failures in the Shire of Rodney, pooled against the Rodney Main Channel bank and flowed over the Wells Creek levees and back into the Goulburn River.
- The modelled water surface profile appears to be consistent with the general water surface profile produced by the observed maximum flood levels.





Note: Observed Maximum Flood Levels Not Obviously Fitting the General River Profile Have Been Excluded From This Figure.

Figure 7-19 Goulburn River – Longitudinal Profile, October 1993 Flood

7.3.6 Chronology of Flooding

Because of the importance of the levee failures in the pattern of flooding observed in the October 1993 flood, particular effort went into the timing of levee failures in the hydraulic model. This was to ensure that the model not only accurately reproduced the observed maximum flood extents and levels on the floodplain but that the model also accurately reproduced the progression of the flood wave through the study area. A number of key events during the flood have been compared to the models reproduction of them at that particular time. The comparisons are based on the aerial photography, the chronology of flooding as detailed in the Documentation and Review of 1993 Victorian Floods, Lower Goulburn River Flood, October 1993, Volume 5 (*Hydro Technology 1995*) and local input provided during the course of the study.

Tuesday 5th October 12:00 AM (Figure 7-20)

The main flood wave had yet to reach the study area although due to the previous flood in September, large volumes of floodwaters were still pooled on the floodplain. Note that due to the occurrence of the flood in September, precise initial conditions were difficult to reproduce in the model. The extents shown should therefore only be considered indicative at this point in the model simulations.

Flows in the Goulburn River were still above the bankfull capacity and significant enough that flows out of Deep Creek, Wakiti Creek and Hancocks Creek outlet were occurring. Loch Garry had yet to operate however the flood had reached 10.37m on the Shepparton Gauge, triggering the operation of Loch Garry in the next 24 hours.

Wednesday 6th October 05:00 AM (Figure 7-21)

After 24 hours the bars had begun to be removed from the Loch Garry regulator and floodwaters poured out onto the northern floodplain, down Bunbartha Creek. The flood peaked at the Shepparton at 6:00 PM on Wednesday.

Thursday 7th October 12:00 AM (Figure 7-22)

The first levees on the Goulburn River were breached on the south side of the river in the Shire of Rodney. Levees were overtopped and breached along considerable lengths in this area of the river resulting in extensive flooding of surrounding properties. The numerous levee failures that occurred in this section of the river were modelled as one large levee failure to simplify the control of the volume of water released onto the floodplain. The model shows that the levees surrounding Loch Garry were slightly overtopped at this time despite all the bars in the regulator at Loch Garry being removed by approximately 9:00 PM that day. The overtopping of the levees surrounding Loch Garry in the October 1993 flood was documented in the Lower Goulburn Waterway and Floodplain Management Plan (SKM 1998).

In the Shire of Nathalia, sandbagging efforts ceased at approximately 4:00 AM when floodwaters were spilling over large lengths of the levee. The first structural failure of the levees is understood to have occurred at 6:00 PM Levee failures upstream of McCoys Bridge were modelled at approximately this time and resulted in extensive flooding of surrounding properties. A levee failure downstream of Hancocks Creek Outlet was also modelled at this time.

Friday 8th October 06:00 PM (Figure 7-23)

The Goulburn River peak reached McCoys Bridge at 5:30 AM on Friday. Floodwaters that spilled from breaches to the south side of the river in the Shire of Rodney pooled against the Rodney Main Channel bank. The model shows floodwaters flowing over the levees at Wells Creek and back into the Goulburn River.

Sandbagging was undertaken to prevent floodwaters overtopping the Rodney Main Channel bank and flooding properties to the west. It is understood that at approximately 8:00 PM the Rodney Main Channel Bank failed, without overtopping. The extent of the sandbagging undertaken is not known and no allowance for this effect has been made in the model. Without the sandbagging, the model shows the Rodney Main Channel Bank being overtopped at approximately 8:00 AM. The aerial photography taken at 10:45 AM (Sheet 2, 201925) however also shows an area of flooded land to the west of the Rodney Main Channel Bank. At the time of this photograph the flood waters had yet to extend over the Murray Valley Highway. The aerial photography taken the day before on the 7th at 3:00 PM (Sheet 2, 201924) does not show this same area flooded. Despite some uncertainties on the exact series of events that led to the flooding of properties west of the Rodney Main Channel, the model appears to be producing the pattern of flooding indicated in the aerial photography.

A structural failure of the Rodney Main Channel was modelled at 8:00 PM on Friday the 8th and floodwaters flowed west and crossed the Murray Valley Highway before pooling against the Goulburn River levees near Murrumbidgee Road. On Sunday the 10th local landholders breached approximately 150m of Goulburn levees near Murrumbidgee Road down to the water level on the Goulburn River side of the levees to allow floodwaters pooled outside the levees to re-enter the Goulburn River.

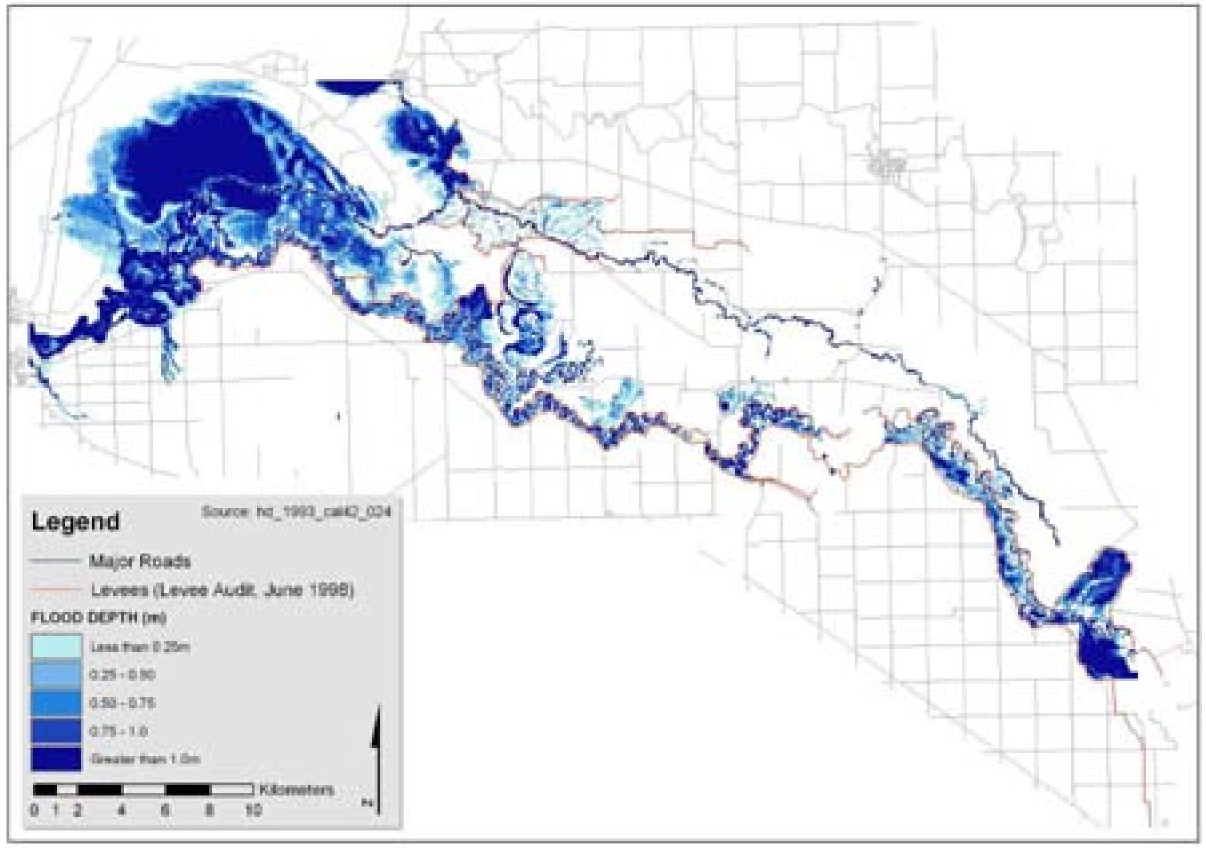


Figure 7-20 Tuesday 5th October 1993 12:00 AM

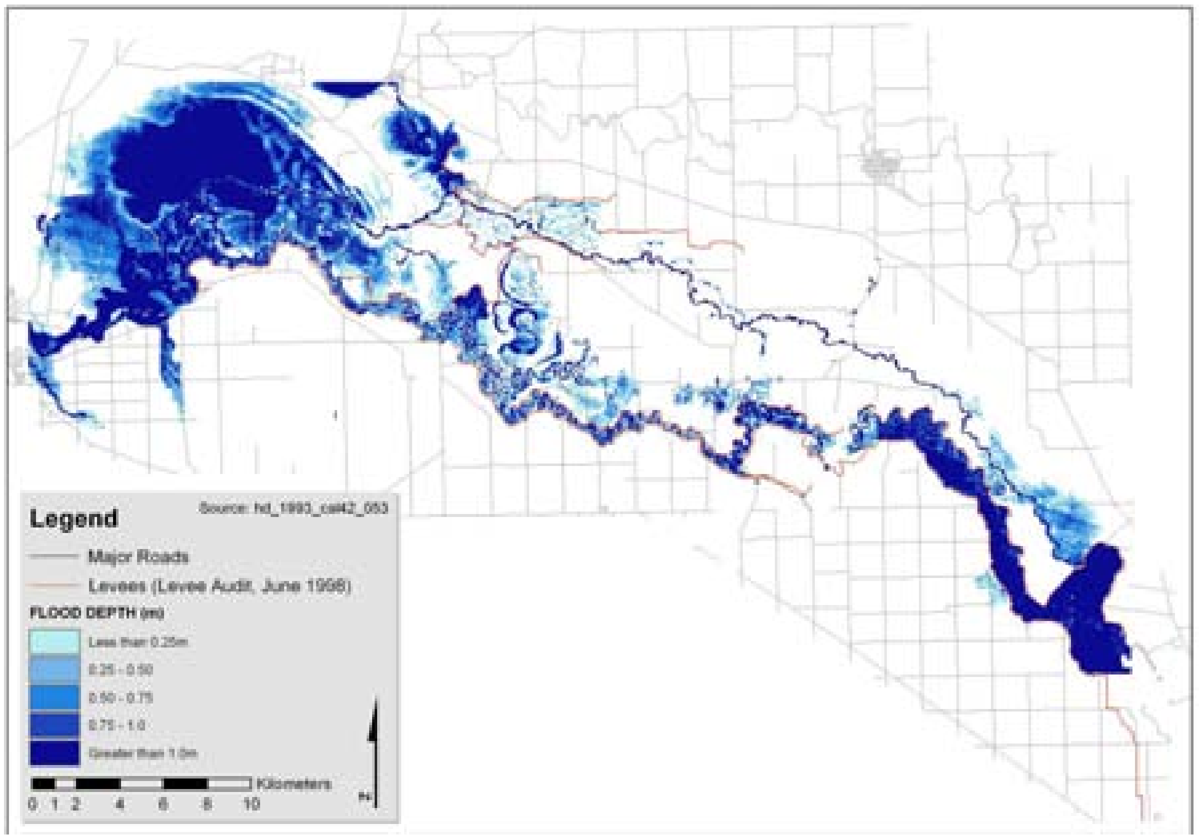


Figure 7-21 Wednesday 6th October 1993 12:00 AM

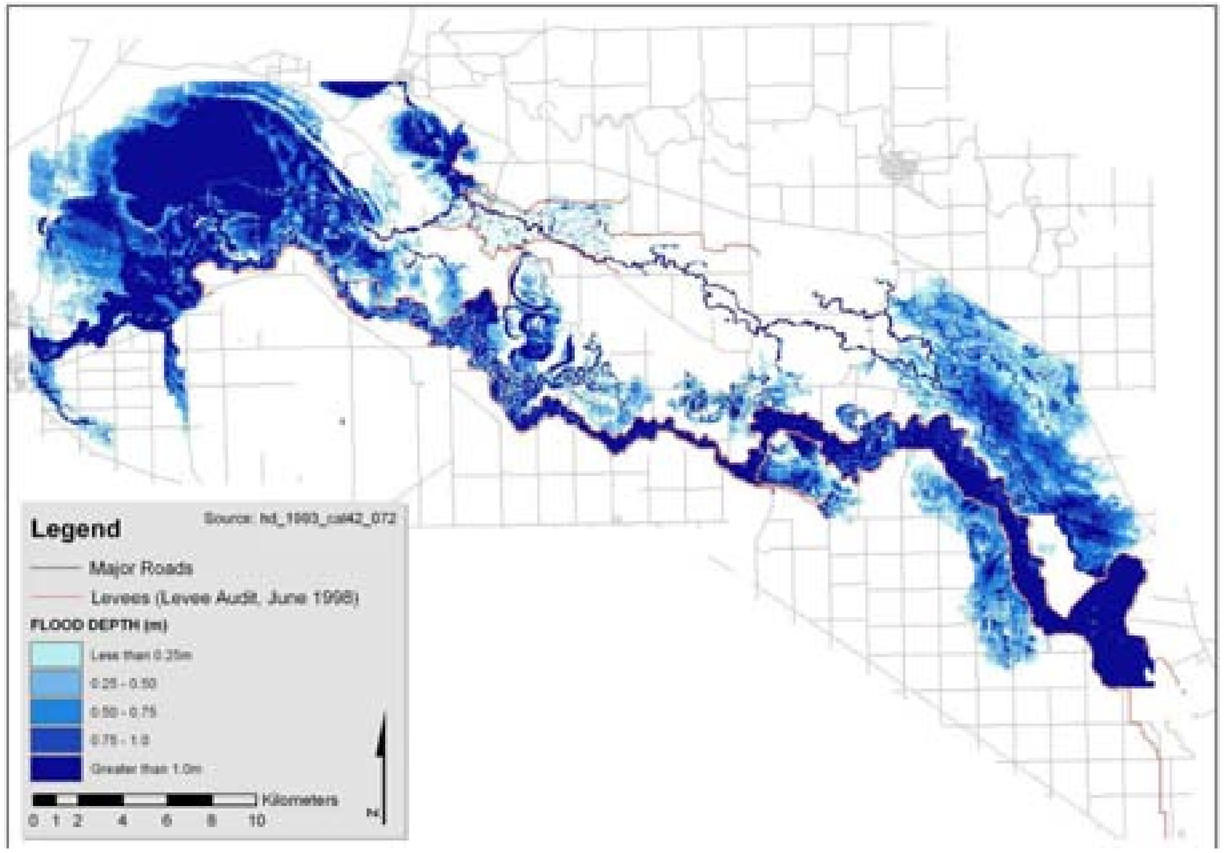


Figure 7-22 Thursday 7th October 1993 05:00AM

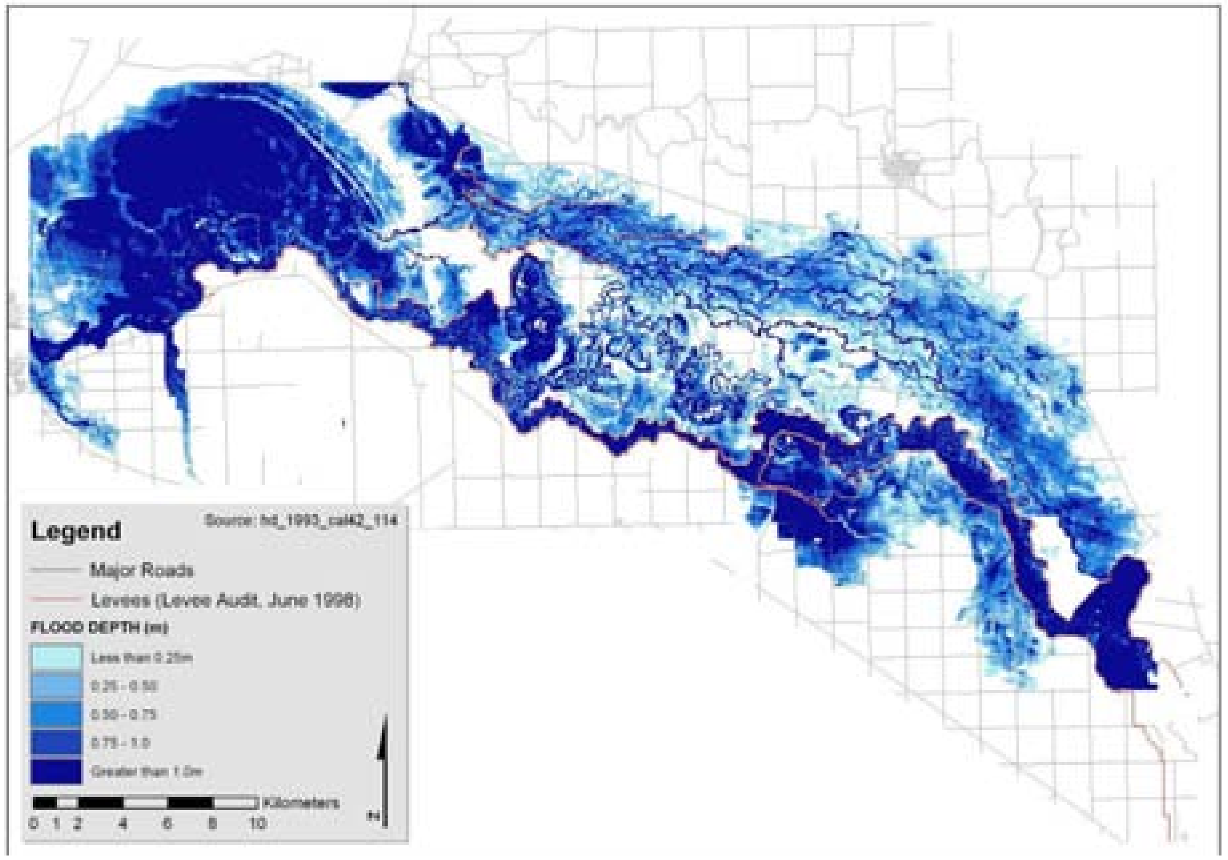


Figure 7-23 Friday 8th October 1993 06:00 PM

7.3.7 Flooding Extents

The maximum extent of flooding in the study area produced by the model was compared with the flooding extents captured by the aerial photography. The aerial photography consisted of colour photographic mosaics. The coincidence of the flood photography with the flood peak was good at McCoys Bridge but preceded the flood peak by up to two days further downstream. The aerial photography particularly assisted in determining the extent of inundation caused by the large levee failures in the Coomboona district on the left bank or south side levees.

The maximum extent and depth of inundation produced by the model for the October 1993 flood is presented in Figure 7-24. A number of flood levels on the floodplain were surveyed after the flood and these have also been compared with the model results.

The following comments regarding the extent and depth of inundation produce by the model are made with reference to Figure 7-24.

- The modelled maximum flood levels appear to be generally consistent with the observed maximum flood levels taken throughout the study area.
- Although there are some small differences in the detail based on direct comparisons with the flood extents depicted in the aerial photography, it is considered that overall the model is producing the pattern of flooding and overall extents quite well.

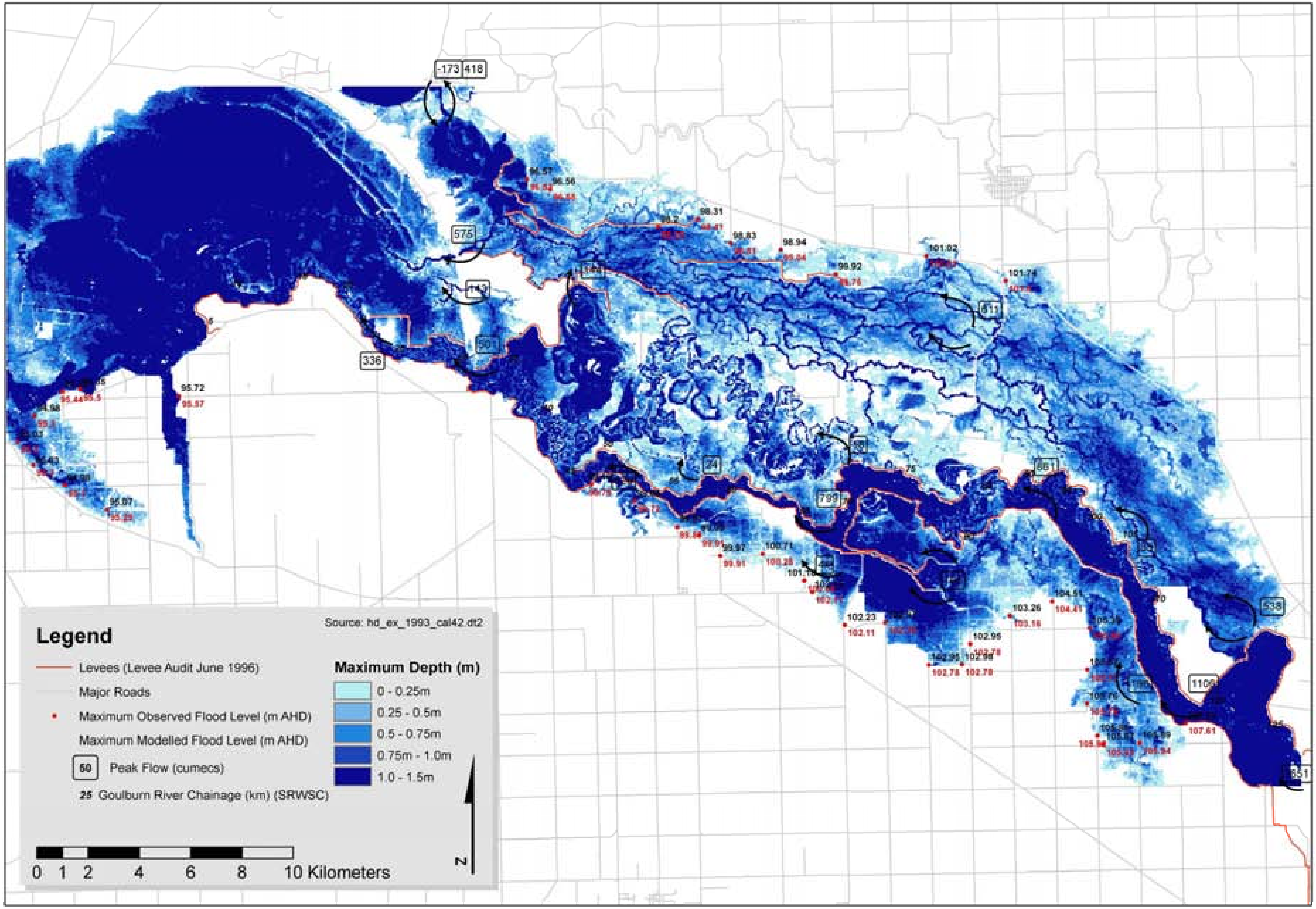


Figure 7-24 Maximum Extent and Depth of Inundation, October 1993 Flood

8 Discussion of Calibration Results

8.1 General

Through the calibration process, the behaviour of flood flows throughout the floodplain has been modelled for two floods of significantly different magnitudes and whose initial conditions and flooding behaviour were considerably different. This has helped increase the understanding of the behaviour of flood flows in the floodplain and identified characteristics of floods in the Goulburn and Murray Rivers that are especially important when attempting to model floods on the Lower Goulburn Floodplain.

Overall, the calibration of the hydraulic model is considered to be good. For moderate to large floods the model is capable of providing a good reproduction of flood levels, extents and flow distributions throughout the study area. During the calibration process, however, it became clear that the behaviour of floods in the study area can be very dependent on the following:

- position, timing and extent of levee failures
- the presence (or otherwise) of initial flood conditions in the study area

These points are discussed in more detail below.

Levee Failures

It is well understood that the current levee system does not have the capacity to contain a flood greater than or equal to a 10-year ARI flood. Experience during the July 1981 flood, however, suggests the capacity of levees downstream of Hancocks Creek outlet is actually less than a 10-year ARI flood. For floods equal to or greater than approximately a 20-year ARI flood, levee failures are likely to be extensive, as occurred in the October 1993 flood. The system will then basically revert to natural conditions, particularly in terms of flooding extents. It is unrealistic to model the system for floods greater than approximately a 10-year ARI flood without the incorporation of levee failures into the model description. The location, timing and extent of levee failures is difficult to predict although previous floods should provide an indication of the likely location of future levee failures.

Initial Conditions

A feature of the October 1993 flood was the occurrence of a moderate flood in the weeks before the modelled flood. This meant that there were significant flood waters already ponding in floodplain storages and that at the beginning of the simulation, the Goulburn River was still flowing above bankfull capacity in places. It also appears that flows in the Murray River had already been reduced by the backwater effect of flows entering the Murray River from Deep Creek, at Lower Moira, caused by the operation of the Loch Garry regulator during the September flood.

The probability of a large flood being preceded by smaller floods in the Lower Goulburn has not been quantified as part of this investigation, however, it is understood that the May 1974 flood was also preceded by a smaller flood. The occurrence of smaller floods preceding larger floods is likely (based on the October 1993 flood) to significantly impact on the flow splits through the various openings in the Bama Sandhills and through possible flow reversal in the Murray River at Barmah. In turn, based on the modelling done to date, the extent of the reversal of flows in the Murray at Barmah appears heavily dependent on conditions in the Murray in the Barmah and Moira State Forests area.

8.2 Hydraulic Model Suitability

The hydraulic model established during the calibration process has been developed for modelling moderate to major floods on the Lower Goulburn Floodplain. Through the calibration process the model has been found to be able to accurately quantify the effect of changes to the levee systems, hydraulic structures and different levee failure scenarios on flood flow behaviour on the floodplain. However, a number of limitations do exist in the ability of the hydraulic model to simulate flood flows in the study area. These include the following:

- For minor floods, less than approximately a 1 in 5 ARI flood, the ability of the model to accurately describe the minor flow paths that initiate flow into lagoon systems and down minor creek systems on the floodplain is restricted by what features can be resolved in the topographic grid, and by the extent of the coupling between the 1D channel model and the 2D floodplain model. While the model should be able to provide good estimates of flow distributions and levels in the Goulburn and Murray Rivers for minor floods, flooding extents produced by the model should be viewed with some caution.
- The hydraulic model has been developed to model flood flows originating from the Goulburn and Murray Rivers. The model has not been developed to describe flooding caused by local rainfall floods or the inundation of land caused by overflows from irrigation channels in the study area.
- The hydraulic model description of the Murray River in the Millewa and Barmah State Forest area has been only broadly schematised. To accurately model the flooding behaviour of this area the model would need to be extended further upstream along the Murray River and include the Tuppal Bulatale Creek systems.

8.3 Conclusion

It is considered that a state of the art hydraulic model of the Lower Goulburn Floodplain has been developed. The model has been able to accurately reproduce the July 1981 and October 1993 historical floods in terms of flood levels, extents and flow distributions. The understanding of flooding behaviour in the Lower Goulburn floodplain has been greatly improved and important floodplain features that significantly effect natural flow paths have been identified and incorporated into the model. Provided reasonable descriptions of levee failure scenarios and initial conditions are incorporated into the hydraulic model description, the model should be able to accurately simulate the flooding behaviour of the floodplain for a large range of floods. With the hydraulic model the flooding behaviour of the floodplain under natural and existing conditions can be simulated and the scheme can also be optimised and the final arrangement of spillways and bund alignments can be finalised.

9 Existing Condition Modelling

The calibrated hydraulic model has been utilised to simulate the existing flooding behaviour of the floodplain over a large range of design floods. The results of the existing condition modelling will provide the basis for flood mapping of the study area. The existing condition modelling will also help to determine the level of flood protection the community has received with the existing levee system. The results of this analysis will be incorporated into a rating model to be developed for the implementation of the scheme.

9.1 Existing Condition Model Setup

The calibrated hydraulic model developed under existing conditions was employed directly in the existing condition modelling with only some minor modifications made to the levee system in the model to reflect changes that have occurred since the levee audit was completed in 1998. Table 9-1 displays the design events modelled for the existing condition simulations. Note that the model results from the June 1981 and October 1993 calibration floods have been included in the existing condition modelling.

Table 9-1 Existing Condition Design Floods

ARI/Flood	Peak Discharge		Shepparton Gauge
yrs	m^3/s	ML/d	m
2	453	39,139	10.04
5	862	74,442	10.75
7(1981 Flood)	1009	87,178	11.00
10	1228	106,065	11.22
20	1567	135,423	11.56
27(1993 Flood)	1736	149,990	11.73
35	1820	157,248	11.75
50	2011	173,716	11.89
100	2333	201,571	12.13

For all design floods modelled a constant discharge of 30,240 ML/d ($350m^3/s$) was assumed in the Murray River. Initial conditions in both the Goulburn and Murray Rivers were determined by running the starting discharge of the flood hydrographs until steady state conditions had been achieved in a MIKE 11 model of the main river channels only. An average rating curve for the Echuca Wharf Gauge developed as part of the Moama-Echuca Flood Study (SKM, 1997) was utilised for the models downstream boundary. The rating curve seeks to take into account the average backwater effect caused by Campaspe River flows entering the Murray River approximately four kilometres downstream of the Echuca Wharf Gauge.

9.1.1 Levee Failures

In order to more realistically model floods greater than a 5-year ARI flood under existing conditions, levee failures were incorporated into the model simulations. The levee failure scenarios simulated were developed based on failures experienced during historical floods, a review of the geotechinal analysis of the levee system undertaken during the Levee Audit Report (SMEC, 1999) and through consultation with GBCMA staff. The location and size of the levee failures for each of the various design floods are listed in Appendix B. Due to the extensive range of levee failures that could be expected to occur on the Lower Goulburn during a 100-year ARI flood, an envelope approach was adopted whereby the 100-year ARI flood was simulated twice, once with predominately north bank levee failures and once with predominately south bank levee failures. The two different flood extents were then combined to provide an envelope extent for a 100-year ARI flood. The envelope extent is required as an input for the proposed planning scheme amendments.

It should be noted that in an attempt to produce the most likely flooding behaviour for a given flood, significant attention was payed to the description of the levee failure scenarios for the design floods above the 5-year ARI flood. In some cases the floods were simulated a number of times, with various levee failure scenarios, until the model produced results considered representative of the likely flooding behaviour for each design flood.

9.2 Existing Condition Model Results

The processed model results from all design floods modelled have been included in the following appendices:

- Appendix C – Maximum flood depths, heights, extents and peak flow splits;
- Appendix D – Maximum water surface profiles inside the levee system compared against north and south bank levees for design floods greater than the 5-year ARI flood.

Figure 9-1 displays the change in flooding extents compared to flood magnitude on the floodplain up to the 35-year ARI flood for existing conditions.

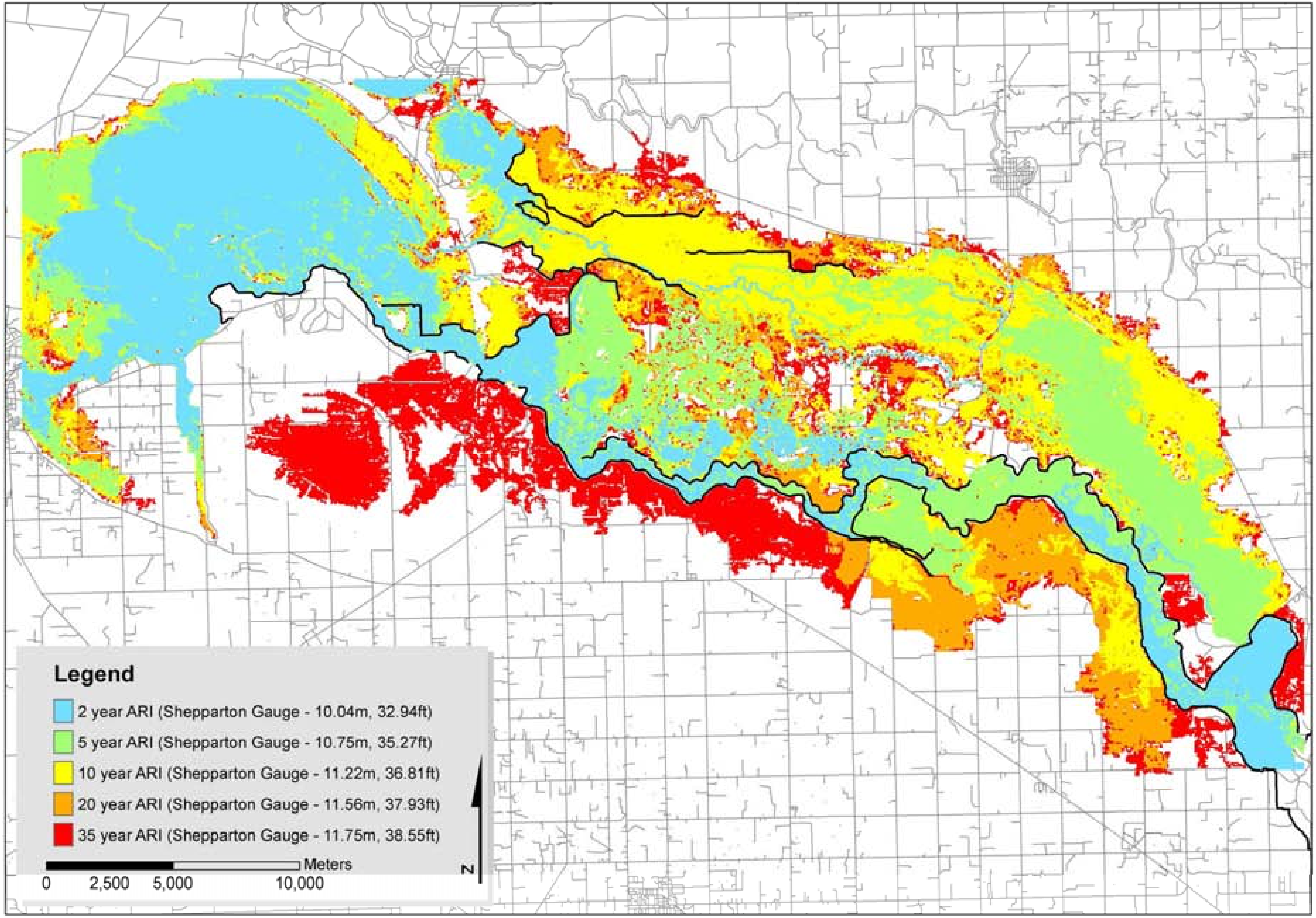


Figure 9-1 **Difference in Flood Extent Compared to Flood Magnitude for Existing Conditions**

9.2.1 Existing Condition Flooding Behaviour

The existing condition modelling undertaken has shown the benefits that the current levee system has provided to some sections of the floodplain when compared to the flooding that would have been experienced under natural floodplain conditions, particularly for the more frequent floods. For floods greater than approximately a 10-year ARI flood, however, the existing levee system is likely to operate essentially without freeboard and/or overtop, resulting in levee failures. It should be noted that due to the poor construction and maintenance standards of significant sections of the levee system identified in the Levee Audit Report (SMEC 1999), levee failures on the Goulburn could be expected to occur with less than 300mm of freeboard. In this respect it is noted that the model indicates that the north bank levees near Hancocks Creek and at Delma Lagoon are likely to operate with less than 300mm freeboard in as frequent as an 8-year ARI flood. It is therefore considered that the actual capacity of the leveed floodway below McCoys Bridge may be somewhat less than an 8-year ARI flood, ie similar to the July 1981 flood (refer Figure 7-10).

The hydraulic model also indicates that the levee system immediately downstream of Loch Garry is likely to be slightly overtopped in as frequent as a 10-year ARI flood. This is important as it means the southern floodplain is significantly more flood prone than has been conventionally accepted. It would appear that previous studies on the Lower Goulburn overestimated the capacity of the Loch Garry regulator to redistribute flows to the northern floodplain which artificially reduced levels on the levee system downstream. It is also noted that previous studies utilised the original SRWSC 1981 levee surveys in their modelling, while this study used the Levee Audit survey undertaken in 1996. While precise comparisons have not been made, a visual comparison of the two surveys on the south bank below Loch Garry indicates the levee system is now significantly lower in many places, presumably as a result of the extensive overtopping and numerous breaches of the levee system that occurred in this area during the October 1993 flood.

For floods approximately equal to or larger than an 8-year ARI flood, the levees on the north bank at Delma Lagoon and Hancocks Creek have been assumed to fail. The failure of the levees at Delma Lagoon allows for a more even distribution of floodwaters through the Bama Sandhills by allowing floodwaters to pass through the sandhills at Madowla Lagoon.

For floods approximately equal to or larger than a 20-year ARI flood the levee system is overwhelmed and large levee failures will occur, causing extensive inundation of the surrounding floodplain. The levee failures adopted during a 20-year ARI flood at Coomboona have caused the Rodney Main Drain channel bank to be slightly overtopped. For floods equal to or larger than a 20-year ARI flood, significant levee failures have also been assumed to occur on the north bank at McCoys Bridge and on the south bank near Munro Road.

The model indicates that the controlled release of floodwaters to the northern floodplain through the Loch Garry regulator and outlet structures during floods greater than a 10-year ARI flood may cause some flow reversal of the Murray River at Barmah, although the extent of this reversal would depend on the flow conditions in the Murray further upstream.

It is considered important that local landholders and other key stakeholders are made aware of the current flood risk on the Lower Goulburn as determined during this study. In particular the affect of the continued decline in the standard of the levee system on the flood risks to the floodplain need to be conveyed. A schematic representation of the leveed floodway capacity between Shepparton and Yambuna relative to a flood in the Goulburn River at Shepparton is displayed in Figure 9-2. Floods greater than the ARI flood indicated for each section of the river in Figure 9-2 will result in floodwaters being uncontrollably discharged onto the floodplain.

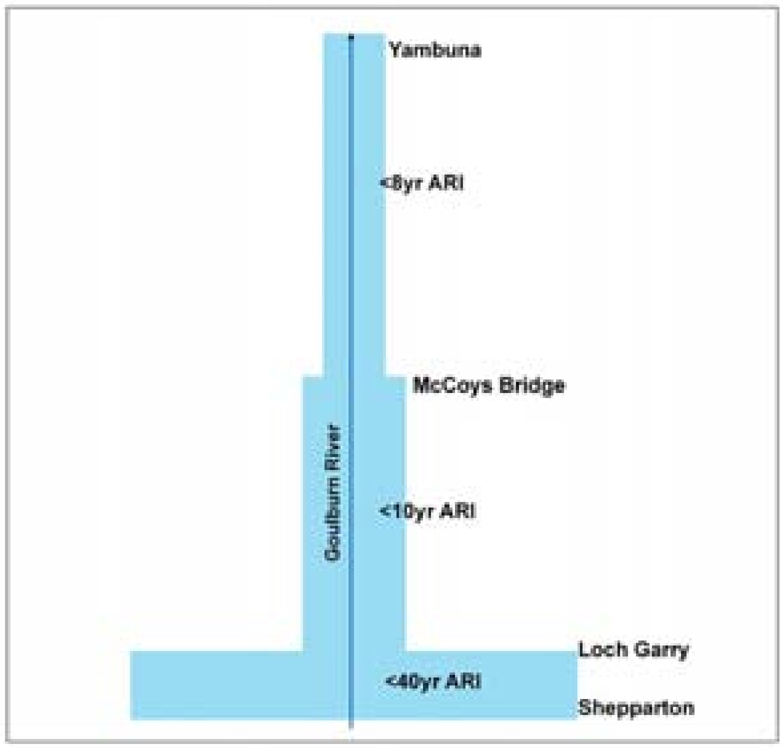


Figure 9-2 Existing Leveed Floodway Capacity

10 Natural Condition Modelling

The calibrated hydraulic model has been employed to simulate the flooding behaviour of the study area prior to European settlement and the associated construction of roads, bridges, levees and irrigation channels on the floodplain. The natural condition modelling will help to determine the level of flood protection the community has received with the existing levee system, and also the level of protection they are likely to receive as a result of the implementation of the scheme compared to natural conditions. The results of these comparisons will form one of the rating categories of a rating model to be developed for the implementation of the scheme. The natural condition modelling has also significantly increased the understanding of the flooding behaviour of the floodplain under natural conditions and has assisted in the optimisation of the bund alignments and the spillway locations for the proposed scheme.

10.1 Natural Condition Model Setup

To simulate the natural flooding behaviour of the floodplain, man made features such as floodplain outlet structures, bridges, culverts, roads and levees were removed from the model description. While a reasonable attempt has been made to remove man made features from the model terrain, some man made features remain inherent in the raw 10m grid ALS data set and can not be easily separated from the natural terrain. Nevertheless, it is considered that the natural condition model simulations still provide valuable information on the natural flooding behaviour of the floodplain. Table 10-1 presents the design floods modelled for the natural condition simulations.

Table 10-1 Natural Condition Design Floods

ARI/Flood	Peak Discharge		Shepparton Gauge
(yrs)	m^3/s	ML/d	m
2	453	39,139	10.04
5	8626	74,442	10.75
10	1228	106,065	11.22
20	1567	135,423	11.56
35	1820	157,248	11.75
50	2011	173,716	11.89
100	2333	201,571	12.13

A constant discharge of 30,240 ML/d (350m^3/s) was assumed in the Murray River for all simulations. Initial conditions in both the Goulburn and Murray Rivers were determined by running the starting discharge of the flood hydrographs until steady state conditions had been achieved in a MIKE 11 model of the main river channels only. An average rating curve for the Echuca Wharf Gauge developed as part of the Moama-Echuca Flood Study (SKM, 1997) was utilised for the models downstream boundary. This rating curve seeks to take into account the average backwater effect caused by Campaspe River flows entering the Murray River approximately four kilometres downstream of the Echuca Wharf Gauge. It should be noted that under natural conditions, flows in the Goulburn River between Shepparton and

Loch Garry can escape the near channel floodplain, particularly to the south. The MIKE 11 model between Shepparton and Loch Garry used in this study has not been developed to simulate this behaviour. Therefore, particularly for larger floods, flows are likely to be conservatively high within the study area compared to flows that would have occurred under strictly natural conditions.

10.2 Natural Condition Model Results

Natural condition maximum flood depths and extents and peak flow splits for all design floods modelled have been attached in Appendix E.

Figure 10-1 displays the change in flooding extents compared to flood magnitude on the floodplain up to the 35-year ARI flood for natural conditions.

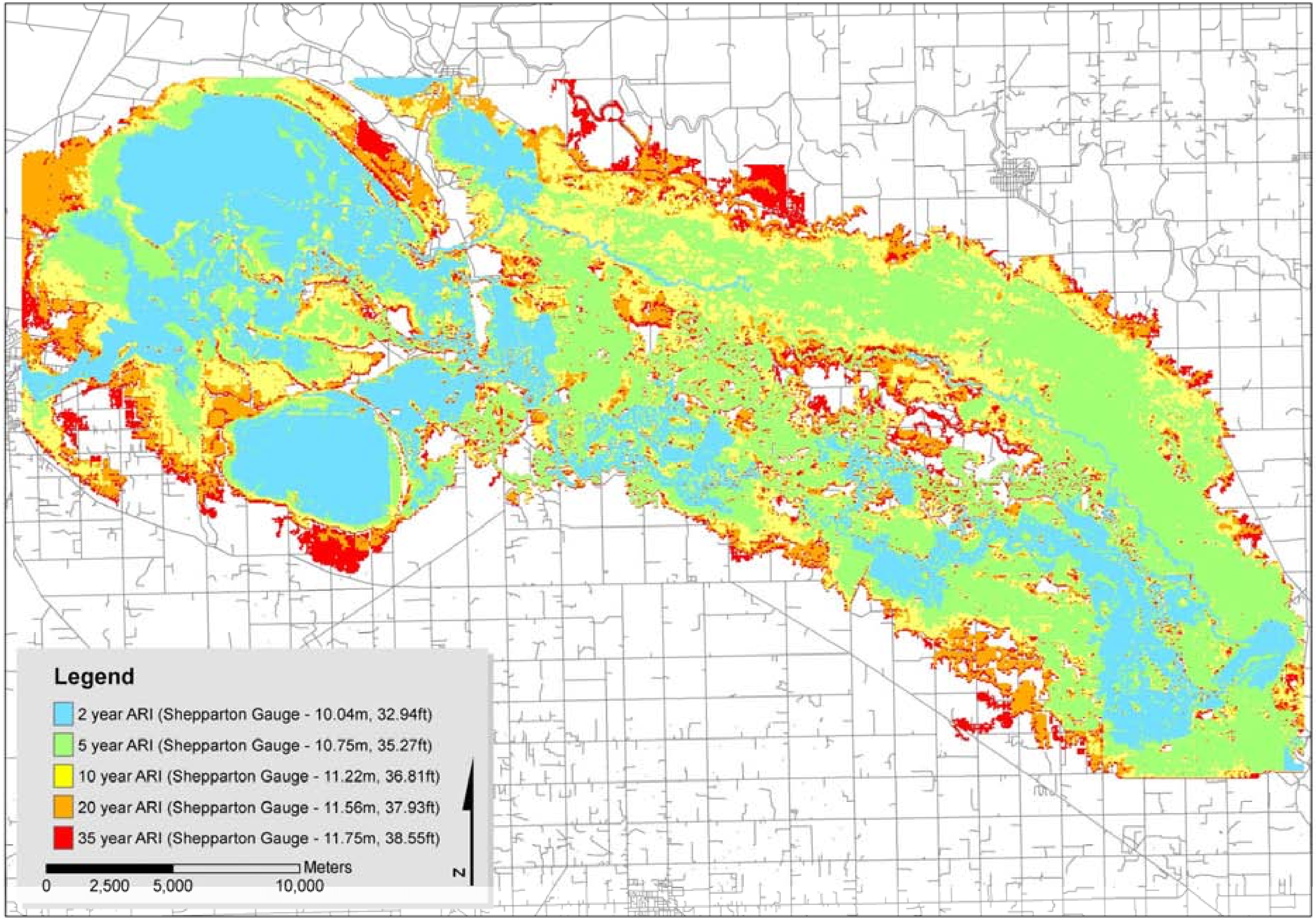


Figure 10-1 Difference in Flood Extent Compared to Flood Magnitude for Natural Conditions

10.2.1 Natural Flooding Behaviour

The natural flooding behaviour of the Lower Goulburn River is characterised by the continued discharge of floodwaters above the main channel capacity to the surrounding floodplain, as a result, under natural conditions the flood wave was significantly attenuated as it passed through the Lower Goulburn floodplain and much of the study area was significantly flood prone for floods as small as a 2-year ARI flood.

At Loch Garry the capacity of the main channel is approximately 28,510 – 30,240 ML/d (330-350m^3/s) and flows above this are discharged onto the surrounding floodplain. The model results indicate that under natural conditions the majority of the flows above the main channel capacity tend to breakout onto the southern floodplain first. The natural levees bordering the northern near channel floodplain, particularly at Loch Garry, appear to restrict the capacity of smaller flood flows to enter the northern floodplain until further downstream, where there are breaks in the natural levees near the existing Deep Creek Outlet structure.

Flood flows breaking out onto the southern floodplain cannot escape further to the south and tend back towards the river following the slope of the general riverine plain. These flood flows are collected by Wells Creek which drains flood flows back into the Goulburn River just upstream of the present day McCoys Bridge.

At the Yambuna Choke, where the Goulburn River flows through the Bama Sandhills, the capacity of the main channel has reduced to approximately 20,740 – 22,460 ML/d (240 - 260m^3/s). Flood flows above this capacity tend northerly into the Yambuna Forest area where they can pass through the Madowla Lagoon opening in the Bama Sandhills. The natural condition model results also indicate that flows in excess of the main channel capacity at the Yambuna Choke can also escape to the south through a break in the natural levees near the Yambuna Creek outfall. These flows can then enter into the Little Kanyapella Basin. The model results indicate that minor flows into the Kanyapella Basin may have occurred as frequently as in a 2-year ARI flood.

Floodwaters entering the Murray River from the northern floodplain at Deep Creek produce high tail water levels downstream of Barmah and under natural conditions the model indicates that some backwater flooding of the present day Barmah and Moira State Forest may have occurred as frequently as in a 5-year ARI flood.

10.2.2 Implications for the Proposed Scheme

Under natural conditions the northern floodplain took a large proportion of the flood flows above the capacity of the near channel floodplain of the Goulburn River. The majority of major flood flows enter the northern floodplain through overflows of Loch Garry and at a break in the natural levees in the vicinity of the existing Deep Creek Outlet structure. It would appear that these two locations are natural discharge points to the northern floodplain and would provide the most likely locations for spillways as part of the presently proposed scheme.

As discussed in the calibration of the October 1993 flood, floodwaters entering the Murray River from Deep Creek can reduce and even reverse flows in the Murray River by producing high tail water levels downstream of Barmah. The extent of flow reversal in the Murray River at Barmah appears to be very dependent on the conditions further upstream in the Barmah and Millewa State Forest area. The natural condition modelling undertaken indicates that this phenomenon may have occurred quite frequently, with flow reversal occurring during a 10-year ARI flood and significantly reduced flows at Barmah in the Murray being produced as frequently as in a 5-year ARI flood. Under natural conditions the resulting backwater flooding of the present day Barmah and Moira State Forest area upstream of Barmah may have been significant for the ecological health of these forests. The hydraulic model however only broadly schematises the flooding behaviour of these areas and the model would need to be improved to gain a more accurate understanding of the impact this flooding would produce in these areas.

The Madowla Lagoon opening through the Bama Sandhills appeared to provide for the passage of significant Goulburn River floodwaters through the sandhills and may have operated as frequently as in a 2-year ARI flood under natural conditions. Operation of Madowla Lagoon during floods should be considered as part of the scheme as it provides for a more balanced distribution of flood waters through the sandhills.

11 Scheme Design and Optimisation

11.1 Scheme Hydraulic Design Objective

While the overall scheme incorporates a number of objectives including improving environmental and recreational benefits, the fundamental hydraulic design objective of the scheme is for the scheme to have the capacity to safely and sustainably convey a repeat of the October 1993 flood i.e. 150,000 ML/d (1,736m^3/s) or a 27-year ARI flood relative to the Shepparton Gauge

It is proposed that the hydraulic objectives of the scheme will be achieved by utilising the existing northern floodplain to receive a greater portion of flood flows from the Goulburn River than is presently achieved through the operation of the Loch Garry Regulator. More specifically the scheme aims to limit the peak flow in the Goulburn River at McCoy's Bridge to between 50,000 and 60,000 ML/d (579 to 694m^3/s) while providing a minimum of 300mm freeboard with respect to levee crests, as detailed in the Levee Audit Report. The design discharge to the northern floodplain is therefore estimated at approximately 100,000 to 110,000 ML/d (1,157 to 1,273m^3/s).

11.2 Scheme Hydraulic Design

The hydraulic model has been used to make an assessment of the scheme and determine the size and arrangement of spillway(s) and the most appropriate alignment of the bunded floodway required to meet the objectives of the scheme.

A large number of simulations, trialling various spillway sizes and arrangements and bunded floodway alignments have been undertaken to assess the performance of the scheme over a large range of flood magnitudes. The key findings of the hydraulic assessment of the scheme are discussed below:

- The results of the hydraulic model indicate that with the creation of large spillways at Loch Garry and near the vicinity of the existing Deep Creek Outlet structure, the design discharge to the northern floodplain could be achieved during a 50-year ARI flood. However, for large floods, approximately greater than a 35-year ARI, it is considered that the scheme should provide for the redistribution of flood flows in the Goulburn to both the northern and southern floodplains.
- For floods up to approximately a 35-year ARI, the hydraulic model indicates that with the appropriate arrangement of spillways and bund alignment the hydraulic objectives of the scheme should be achieved and a more sustainable and balanced solution to the flooding problems on the Lower Goulburn realised.

From the results of the modelling undertaken to assess the scheme, an arrangement of spillways and bund alignments are proposed that will provide flood protection to the Lower Goulburn for floods up to a 35-year ARI flood.

The components of the scheme developed to achieve the aims of the scheme outlined above are discussed in detail in the following sections.

11.2.1 Loch Garry Spillway

The Loch Garry Regulator is proposed to be replaced by a wide, ground level spillway with a capacity of approximately 86,400 ML/d (1,000m^3/s). The hydraulic model indicates that flows out of the Loch Garry spillway will be essentially capped to approximately

86,400 ML/d (1,000m^3/s). Flows through the spillway above this are likely to result in less than 300 mm freeboard within the Goulburn levee system and failure of the south bank levees on the Goulburn would be expected. The preliminary structure sizing of the Loch Garry spillway using the hydraulic model indicated that a 1510 m wide spillway would be required at Loch Garry.

11.2.2 Secondary Spillway

A smaller ground level spillway is also proposed near the existing Deep Creek Outlet at north bank chainage 52605 – 52845 m. The natural condition simulations undertaken to date indicate that this area is a natural discharge point for Goulburn River floodwaters to enter the northern floodplain. The hydraulic model indicates that flows through the secondary spillway will be essentially capped to 9,940 ML/d (115 m^3/s) due to levee failures during large floods. The combination of the Loch Garry and secondary spillway therefore produce a combined discharge of 96,680 ML/d (1,119 m^3/s) to the northern floodplain. The preliminary structure sizing of the secondary spillway using the hydraulic model indicated that a 240 m wide spillway would be required.

11.2.3 Delma Lagoon

In order to optimize the distribution of flood flows through the Bama Sandhills, a ground level spillway has been modelled at Delma Lagoon to allow floodwaters to flow via a floodway to Madowla Lagoon and pass through the sandhills.

At the sandhills, Madowla Lagoon has a cross section similar to the Goulburn River at the Yambuna Choke, although its capacity is somewhat less due to the lack of a significant channel to convey floodwaters on the western side of the sandhills. The natural condition modelling undertaken indicates that Madowla Lagoon provided a major natural floodway for the passage of flood flows through the sandhills and may have operated as frequently as in a 2-year ARI flood.

The operation of Madowla Lagoon during flood events will improve the distribution of flood flows through the sandhills and reduce flood levels in the Yambuna Forest. This is significant as it is likely to reduce pressure on overflows via You You and Tessie Creeks to Deep Creek.

A 1,000 m wide spillway has been modelled at Delma Lagoon with a crest height set at 97.1 m AHD. With this arrangement, nuisance flooding of the properties surrounding Madowla Lagoon will be prevented for the more frequent floods, with relatively minor overflows not commencing until approximately a 5-year ARI flood. During larger floods however, significant overflows will occur through the spillway to help achieve a more balanced distribution of floodwaters through the Bama Sandhills.

The modelling undertaken to date indicates that with the proposed scheme in place and a 1,000 m wide spillway, set at 97.1 m AHD, approximately 15,640 ML/d (181 m^3/s) is expected to pass through Madowla Lagoon during a 35-year ARI flood. Additional modelling undertaken with the spillway set at natural surface indicated that flows through Madowla Lagoon could be increased by approximately 14% to 18,230 ML/d (211 m^3/s). The extra capacity through Madowla Lagoon with this spillway configuration however provides little additional benefit in terms of reduced flood levels and has the disadvantage of producing nuisance flooding of properties surrounding Madowla Lagoon in as frequent as a 2-year ARI flood.

11.3 Existing Levee Re-alignments

Minor re-alignments of the existing levees along the Goulburn River have been investigated as part of the optimisation of the scheme. As one of the key hydraulic objectives of the proposed scheme is to limit flows in the Goulburn of McCoys Bridge to approximately 65,000 ML/d (750 m^3/s), the pressure on the existing levee system is going to be significantly reduced with the scheme in place. Therefore, the need for realignments to improve the capacity of the existing levee system is not essential to meet the hydraulic design objectives of the scheme. However, where levee realignments would appear to produce significant improvements in flood levels and in the conveyance capacity of the levee system and where significant waterway management benefits may be realised, they should be considered as part of the optimisation of the overall scheme.

Levee realignments are proposed in areas where reductions in the width of levees causes constrictions to the capacity of the levee system, producing elevated flood levels upstream and increased velocities locally and further downstream. As part of the Lower Goulburn Waterway and Floodplain Management Plan (SKM, 1998) a number of levee realignments have already been proposed as part of the floodplain and waterway management strategy. The location of the proposed levee realignments are illustrated in Figure 10.1.

Through consultation with GBCMA staff and a review of the results of the hydraulic model with the preliminary scheme in place, a number of levee realignments have been recommended as part of the optimisation of the overall scheme. The following is a discussion on the various proposed levee realignments:

(1) ***Mitchell Lane*** It would appear that the Mitchell Lane levee realignment is likely to produce worthwhile improvements in the conveyance capacity of the levee system in this reach of the river. The levee system through this section of the Goulburn River is only approximately 270 m wide. Preliminary comparisons between modelled flood levels and levee crests with the scheme in place during a repeat of the October 1993 flood indicate that 300 mm freeboard is unlikely to be achieved along some sections of the north bank levees in this reach of the river, and further upstream near Hancocks Creek. The increased conveyance capacity of the levee system due to the realignment of the north bank levee at Mitchell Lane is likely to reduce levels for a given flood along this reach of the river and further upstream near Hancocks Creek. Note that the north bank levees at Hancocks Creek have failed extensively in the September 1916, July 1981 and October 1993 floods.

(2) ***Waradgery Road*** The Waradgery Road levee realignment is recommended as it may also produce significant improvements in flood levels and the levee system conveyance capacity. The levee system through this section of the Goulburn River is only approximately 210 m wide at its narrowest point. While McCoys Bridge (approximately 900 m upstream) acts as the significant control on flood flows in this reach of the river, it is anticipated that the Waradgery Road levee realignment should still produce worthwhile improvements in the levee system conveyance capacity and in flood levels upstream.

(3) ***Goddards/Munro Road*** The Goddards/Munro Road levee realignments were proposed principally to provide additional floodplain storage to attenuate the effects of flooding before floodwaters passed through the constriction in the leveed floodway at McCoys Bridge. As the proposed scheme is to limit flows in the Goulburn to less than the capacity of McCoys Bridge (approximately 65,000 ML/d or 750 m^3/s), both the Goddards and Munro Roads levee realignments are unlikely to be justified purely

on the additional flood attenuation they will provide with the scheme in place. A review of the modelling undertaken to date however, shows that a constriction in the levee system in the reach of river encompassing the proposed Goddards Road levee realignment acts as a control on flood flows and produces locally raised levels within the levee system. This small re alignment is recommended as part of the scheme and is indicated in Figure 11-1 as 'Goddards Road alternative'.

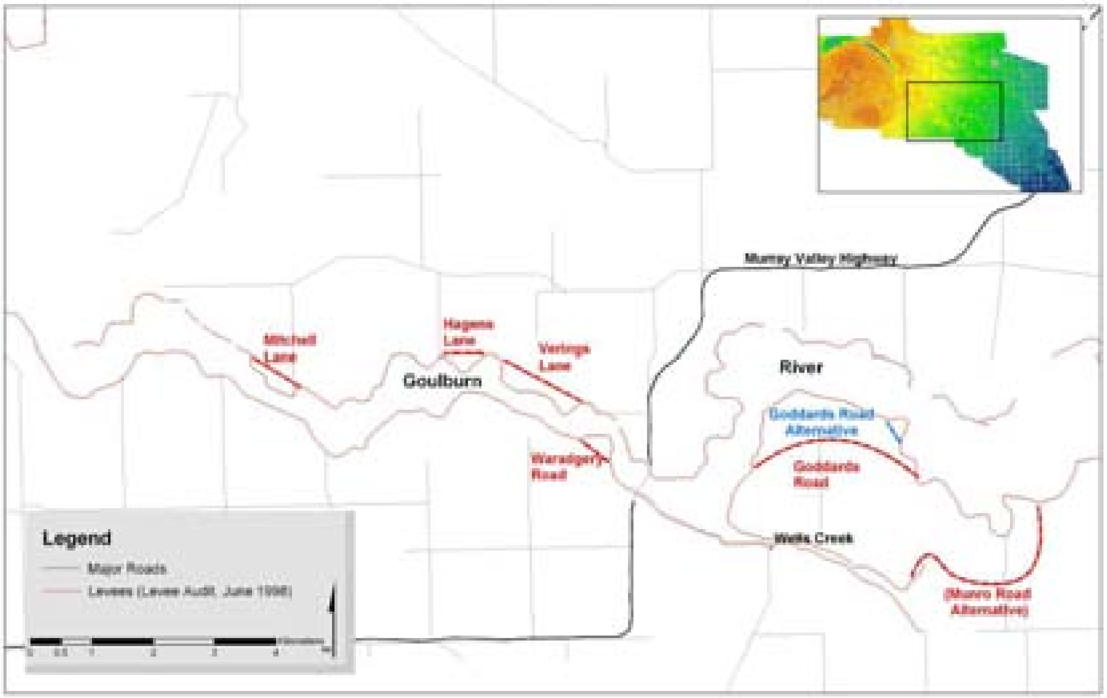


Figure 11-1 Proposed Existing Levee Realignments

11.4 Bund Alignment

The alignment of the proposed bund has been investigated as part of the optimisation of the scheme. The bund alignment should ideally minimise the area of land required for acquisition while maximising the conveyance capacity and storage within the floodway and recognising natural waterway features. In this respect it is noted that the results of the natural conditions model simulations undertaken have primarily been used to identify natural flow paths and the location of natural bunds within the northern floodplain. By identifying these areas in the floodplain, the proposed bund alignment can be optimised to incorporate important natural flow paths on the floodplain and eliminate elevated areas with little storage and conveyance capacity.

Figure 11-2 illustrates the natural condition 50-year ARI maximum depth and maximum conveyance (depth*velocity) results for the northern floodplain. The maximum discharge to the northern floodplain under natural conditions for a 50-year ARI has been modelled at approximately 78,000 ML/d (900 m^3/s). From Figure 11-2 it can be seen that the preliminary proposed bund alignment generally respects the major natural flow paths on the floodplain and the bund itself has been positioned generally along natural levees that already exist on the floodplain. There are however a number of areas the bund alignment could be modified to reduce the area required for acquisition and improve the conveyance capacity of the bunded floodway. Through consultation with GBCMA staff and a review of title boundaries on the floodplain, a number of modifications to the preliminary bund alignment have been recommended. The modifications to the bund alignment are also displayed in Figure 11-2.

An important finding during the modelling to optimise the bund alignment was that some elevated areas on the floodplain, with little conveyance capacity provided important floodplain storage at the flood peak. This storage, which only becomes active during floods with an ARI of greater than approximately 20-years provides attenuation to the flood waves within the floodway and reduces the impact of flood level increases further downstream at Lower Moira and Barmah. As a result, some elevated areas were included within the floodway to provide this important floodplain storage.

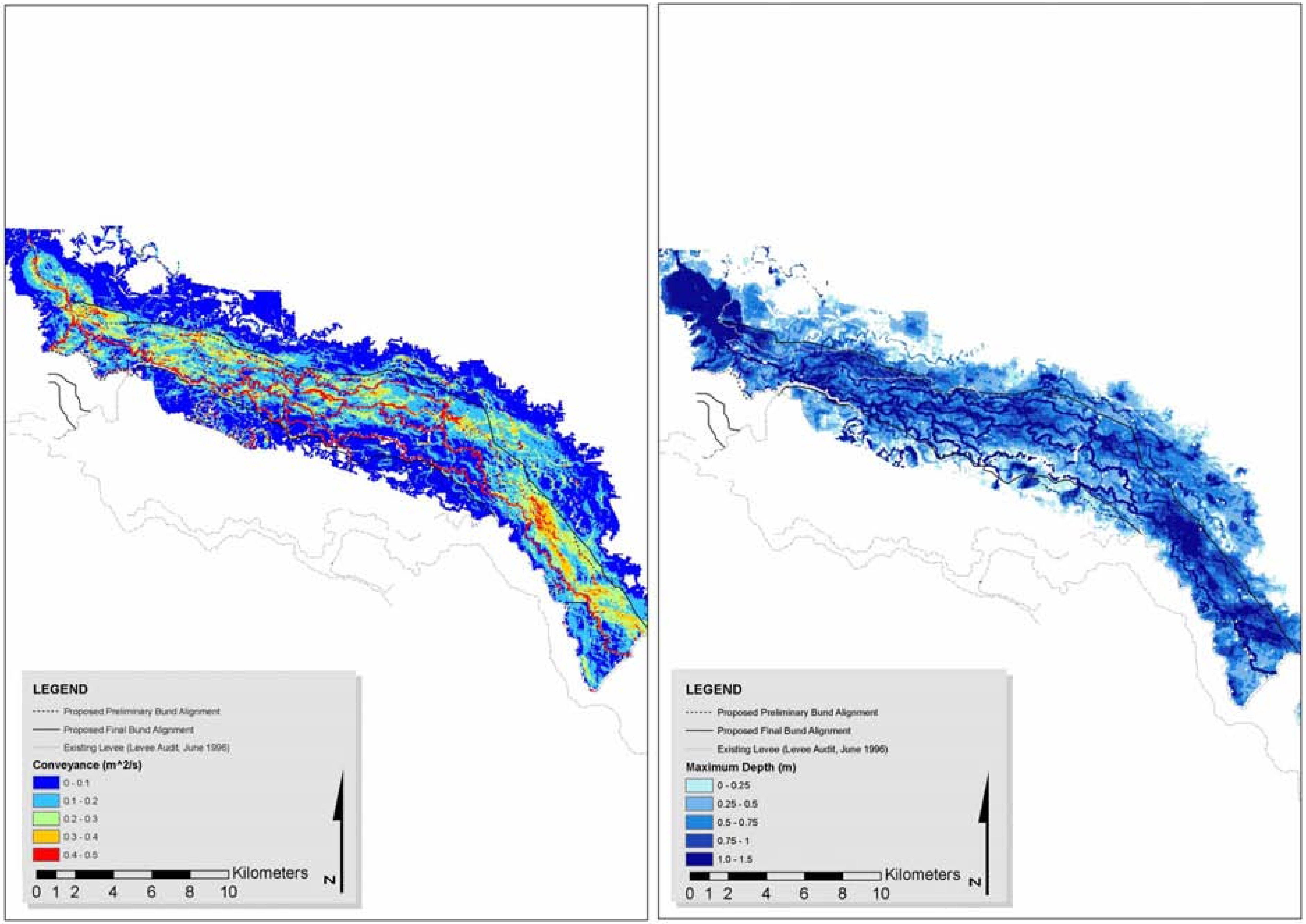


Figure 11-2 Proposed Bund Alignment Assessment

12 Proposed Scheme Design Modelling

The performance of the scheme adopted during the scheme design and optimisation process has been investigated over a large range of design floods. The scheme optimisation process included a significant number of simulations trialling many different scheme configurations to develop the most hydraulically sound configuration of spillways and bund alignment. The results of the scheme design modelling will help determine the final level of flood protection the scheme will provide to the study area.

12.1 Proposed Scheme Design Model Setup

To simulate the flooding behaviour of the floodplain with the proposed scheme in place, the physical features of the proposed scheme were incorporated into the model description. Table 12-1 outlines the proposed scheme elements that were incorporated into the hydraulic model.

Table 12-1 Proposed Scheme Model Elements

Item	Description	Approximate Design Level (m AHD)
1	1,510 m wide spillway at Loch Garry	105.5 – 106
2	240 m wide spillway at existing Deep Creek outlet	104.7 - 105
3	1,000 m wide spillway at Delma Lagoon and associated bunded floodway through to Madowla Lagoon	97.1
4	Replacement of Wakiti Creek outlet structure with single 0.3 m dia. culvert.	99.55
5	Replacement of Hancocks Creek outlet structure with single 0.3 m dia. culvert	94.87
6	Incorporation of the Mitchell Lane, Waradgery Road and alternative Goddards Road levee realignments as indicated in Figure 11-1.	NA
7	Upgrade of the existing levee system to provide a minimum of 300 mm freeboard during a 35-year ARI flood with the scheme in place.	See Appendix H
8	Incorporation of the proposed final bund alignment on the northern floodplain as displayed in Figure 11-2.	NA

Table 12-2 displays the design floods modelled with the scheme in place.

Table 12-2 Proposed Scheme Design Floods

ARI/Flood	Peak Discharge		Shepparton Gauge
yrs	m^3/s	ML/d	m
2	453	39,139	10.04
5	862	74,442	10.75
7/1981 Flood*	1009	87,178	11.00
10	1228	106,065	11.22
20	1567	135,423	11.56
27/1993 Flood*	1736	149,990	11.73
35	1820	157,248	11.75
50	2011	173,716	11.89
100	2333	201,571	12.13

A constant discharge of 30,240 ML/d (350m^3/s) was assumed in the Murray River for all simulations, except the 1993 and 1981 floods where the discharges adopted during the calibration process were employed. Initial conditions in both the Goulburn and Murray Rivers were determined by running the starting discharge of the flood hydrographs until steady state conditions had been achieved in a MIKE 11 model of the main river channels only. An average rating curve for the Echuca Wharf Gauge developed as part of the Moama-Echuca Flood Study (SKM, 1997) was utilised for the model's downstream boundary. The rating curve seeks to take into account the average backwater effect caused by Campaspe River flows entering the Murray River approximately four kilometres downstream of the Echuca Wharf Gauge.

12.2 Proposed Scheme Model Results

The processed model results from all design floods modeled have been included in the following appendices:

- Appendix F – Maximum flood depths and extents and peak flow splits;
- Appendix G – Maximum water surface profiles inside the levee system compared against north and south bank levees for design floods greater than the 5-year ARI flood.

Figure 12-1 displays the change in flooding extents compared to flood magnitude on the floodplain up to the 35-year ARI flood under the proposed scheme conditions.

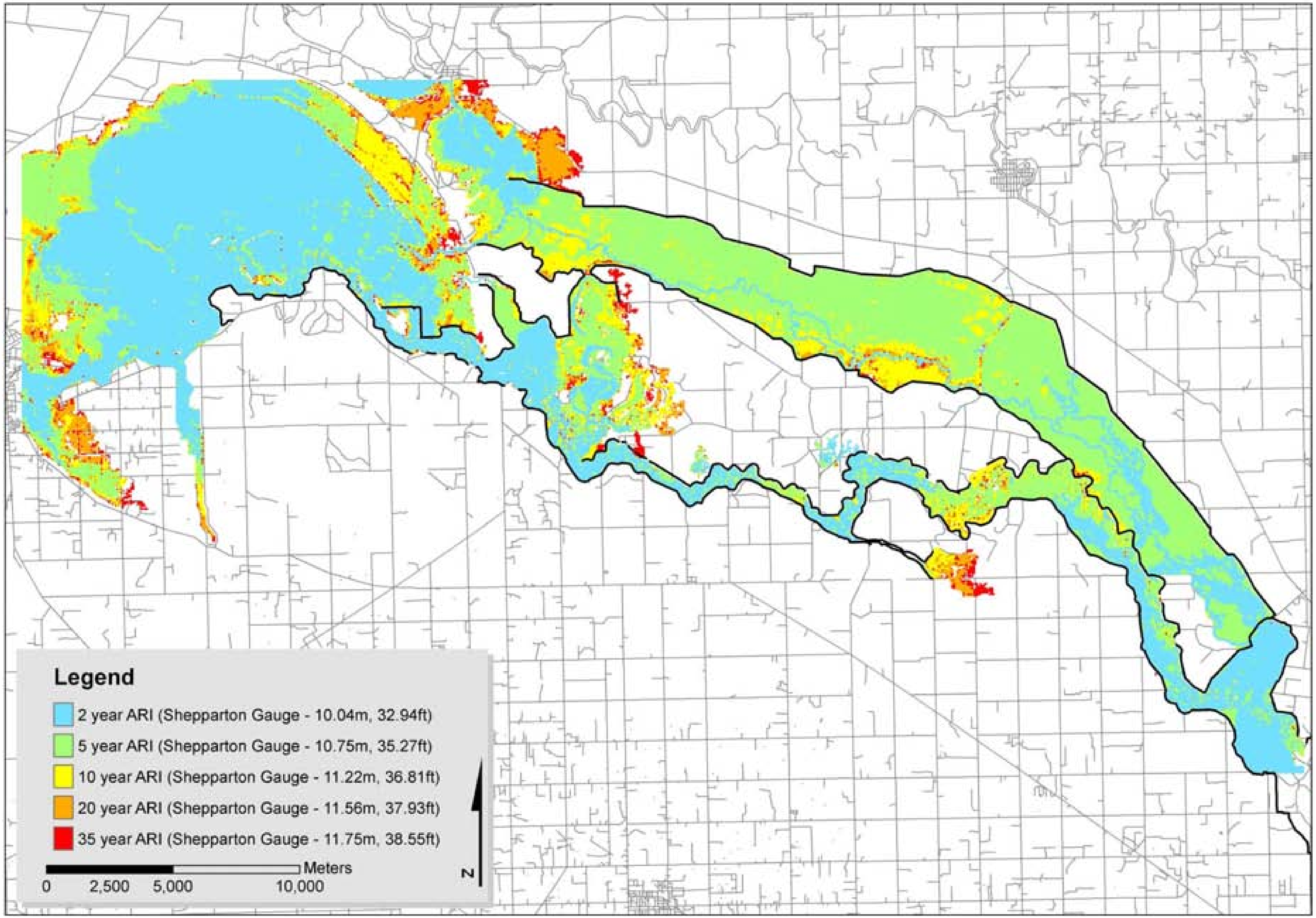


Figure 12-1 Difference in Flood Extent Compared to Flood Magnitude for Proposed Scheme

12.3 Proposed Scheme Flooding Behaviour

Comparisons between the October 1993 flood as observed and with the proposed scheme in place have been made to help quantify the impact of the proposed scheme on the flooding behaviour of the Lower Goulburn floodplain. It is considered the October 1993 flood provides an excellent case for comparing the impact of the proposed scheme as the flood occurred relatively recently, was well documented and was a moderate flood, close to the predicted capacity of the proposed scheme.

12.3.1 Flood Flow Distributions

The proposed scheme will result in significant changes to the distribution of flood flows on the Lower Goulburn floodplain. The differences will be greatest for the moderate sized floods (10 – 35-year ARI) and will reduce for floods greater than the 35-year ARI, as the levees are overwhelmed and the system reverts to more 'natural' conditions. Comparisons between the existing flow distributions that occurred during the October 1993 flood and those predicted to occur with the proposed scheme in place are presented below for the major Goulburn and Murray River gauges.

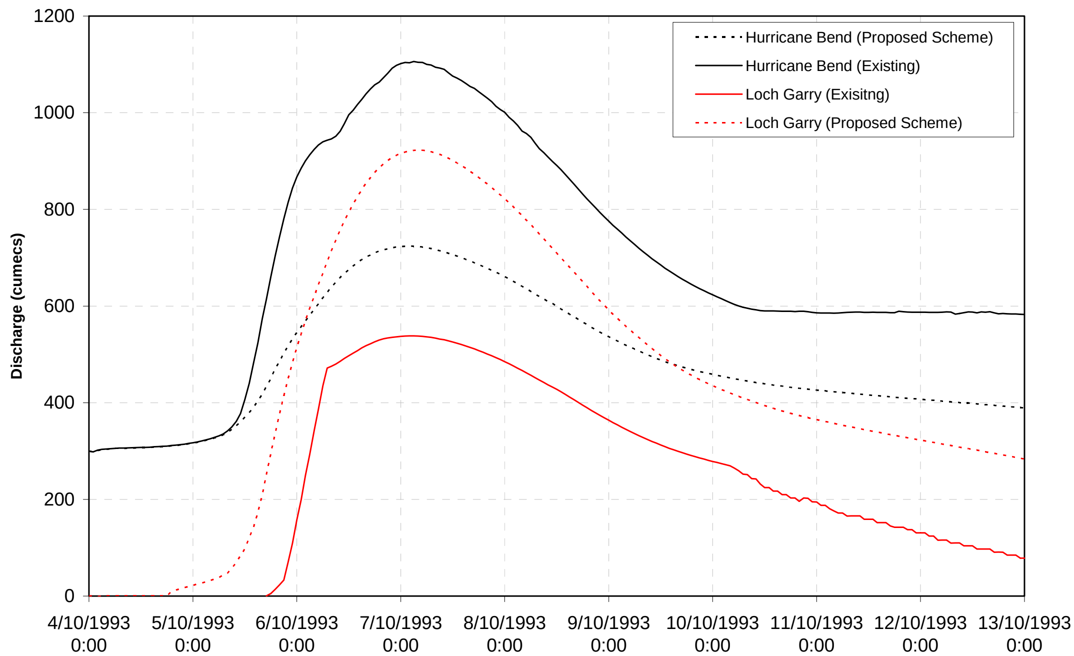


Figure 12-2 October 1993 Flood Comparison, Hurricane Bend (405276A)

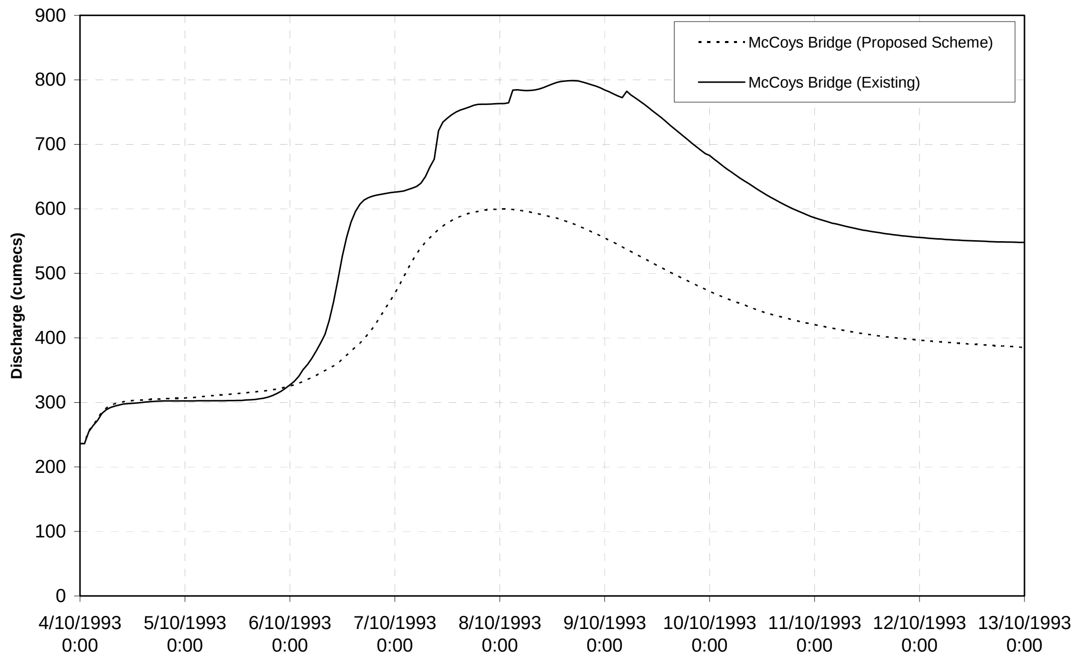


Figure 12-3 October 1993 Flood Comparison, McCoys Bridge (405232A)

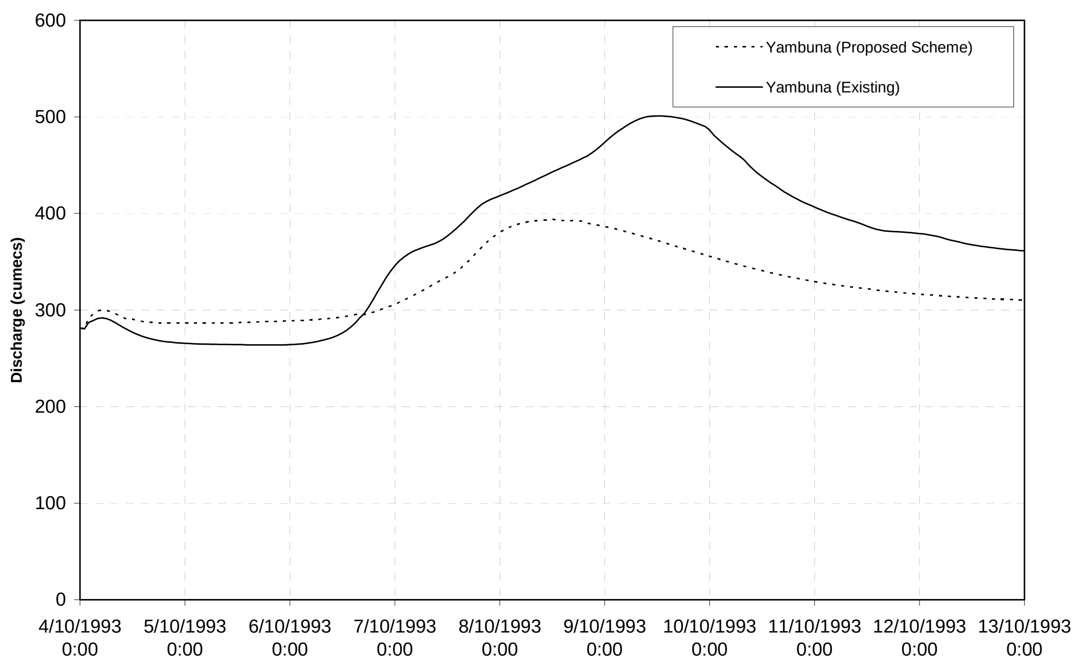


Figure 12-4 October 1993 Flood Comparison, D/S Yambuna Drain (405277A)

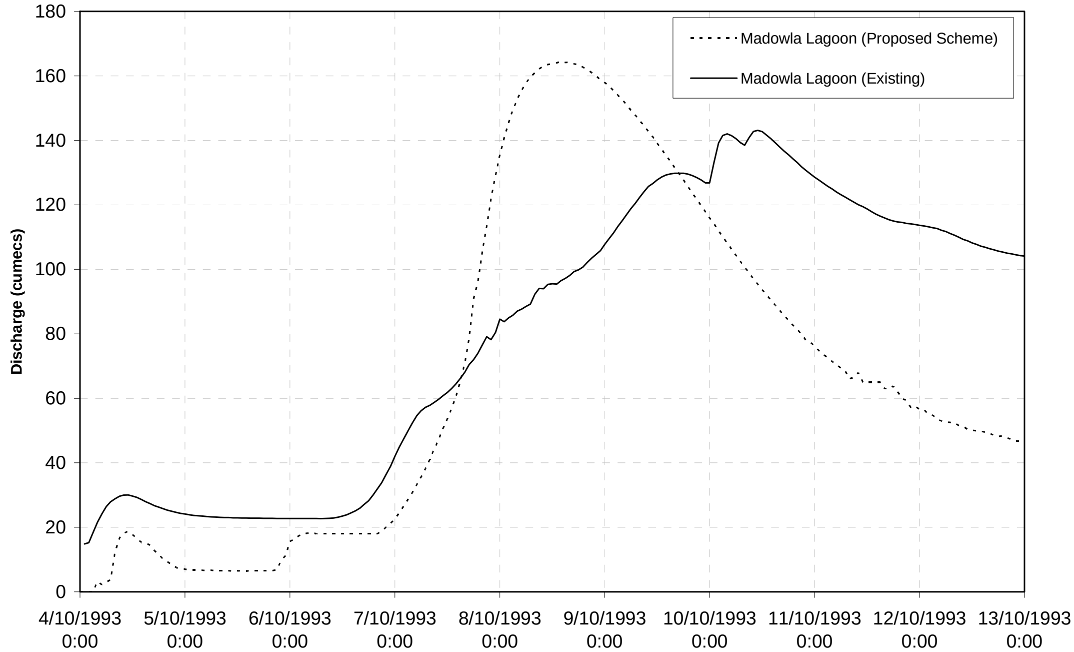


Figure 12-5 October 1993 Flood Comparison, Madowla Lagoon (405275A)

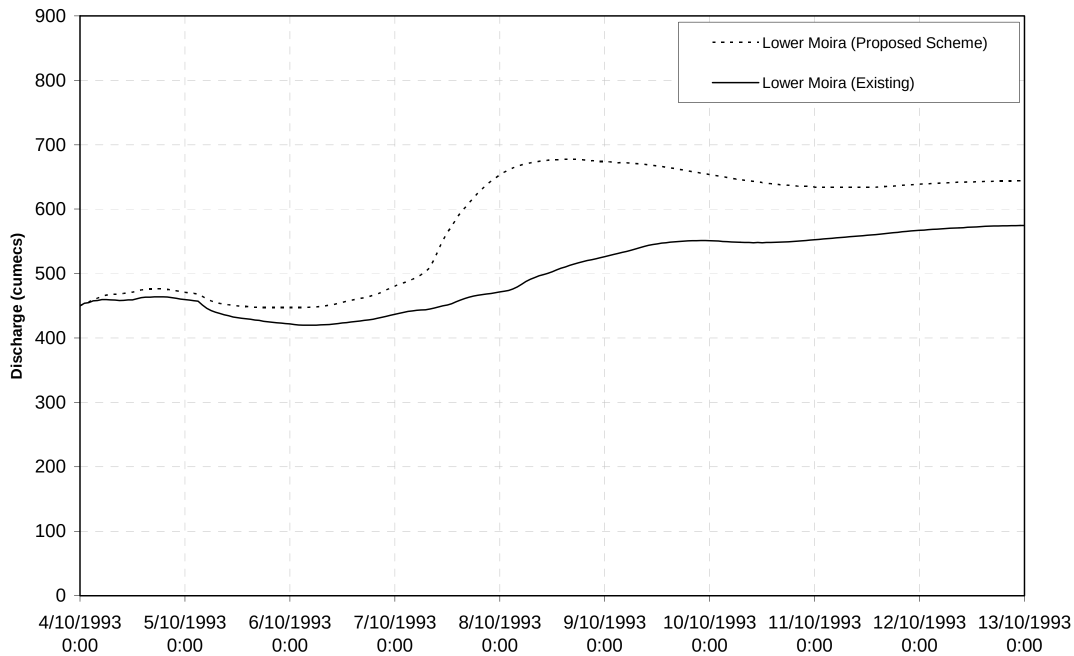


Figure 12-6 October 1993 Flood Comparison, Lower Moira (409221A)

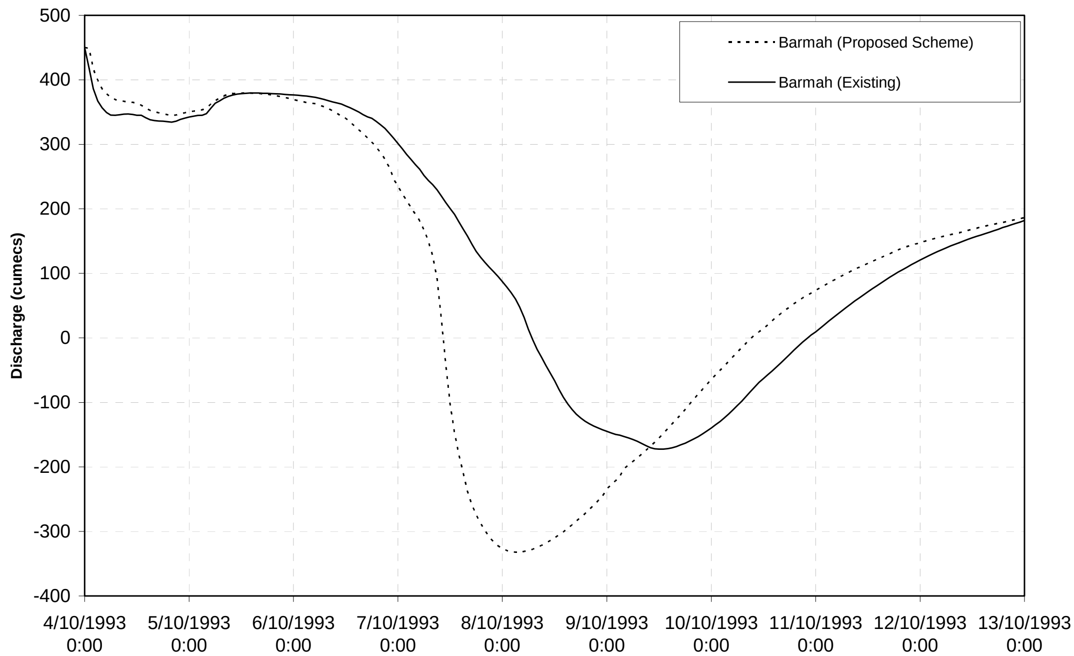


Figure 12-7 October 1993 Flood Comparison, Barmah (409215B)

As can be seen from the above figures, significant changes to flow distributions are predicted to occur with the proposed scheme in place. The replacement of the Loch Garry Regulator with a wide ground level spillway will allow floodwaters to enter the northern floodplain approximately 24 hours earlier during a repeat of the October 1993 flood. The peak flow through Loch Garry will also increase from approximately 46,650 ML/d (540 m^3/s) to 79490 ML/d (920 m^3/s). Flows to the northern floodplain through Loch Garry are also proposed to be supplemented by the secondary spillway near the existing Deep Creek Outlet. Compared to the existing Deep Creek Outlet, peak flows onto the northern floodplain will increase from approximately 3,020 ML/d (35 m^3/s) to 8,990 ML/dy (104 m^3/s) through the secondary spillway.

During a 35-year ARI flood, flows through Loch Garry will increase to 86,750 ML/d (1,004 m^3/s) and flows through the secondary spillway will increase to 9,940 ML/d (115 m^3/s). For floods greater than the 35year ARI flood, the levee system will be compromised and flows through the spillways will be affected by levee failures.

With the proposed scheme in place, flows at McCoys Bridge during a repeat of the October 1993 flood will be reduced from approximately 69,120 ML/d (800 m^3/s) to 51,840 ML/d (600 m^3/s). Flows at McCoys Bridge during a 35-year ARI flood, are predicted by the model to be approximately 54,864 ML/d (635 m^3/s). For floods greater than the 35-year ARI flood, flows above 56,160 ML/d (650 m^3/s) are predicted at McCoys Bridge, compromising the freeboard of the levee system and resulting in levee failures.

The proposed scheme will also affect the distribution of flood flows through the Bama Sandhills compared with existing conditions. As expected with the proposed scheme, the larger Murray River opening will convey a greater proportion of the flood flows through the sandhills as a result of the redistribution of flows via the Deep Creek system. The extent of the flow reversal of the Murray River at Barmah is also expected to increase for the same reason. Due to the reduced flows in the leveed section of the Goulburn River under the proposed scheme, a smaller proportion of flood flows will pass through the Goulburn River opening in the Bama Sandhills compared with existing conditions. The magnitudes of the flows that can be achieved through Madowla Lagoon are dependent on the flood levels within the Yambuna Forest providing a hydraulic gradient through the opening. As the scheme will reduce flood levels in the Yambuna Forest, the large spillway at Delma Lagoon is expected to produce a moderate (15%) increase in flows through Madowla Lagoon compared with the flows modeled under existing conditions. The optimization of the proposed scheme aimed to produce flood flow distributions through the Bama Sandhills closer to those predicted under natural conditions. However, due to the impact of the existing levee system on the hydraulic behaviour of the floodplain, the flow spits through the Bama Sandhills are not expected to entirely achieve those predicted by the hydraulic model under natural conditions. However, the flow splits predicted by the model with the proposed scheme are considered to provide a more balanced distribution of flows compared to those that occur under existing conditions.

A comparison of the peak flow splits through the three major openings of the Bama sandhills during a repeat of the October 1993 flood are presented inin Table 12-3.

Table 12-3 Comparison of the Bama Sandhill Peak Flow Splits During a Repeat of the October 1993 Flood.

Location	Existing Conditions m^3/s	Proposed Scheme m^3/s
Murray River	575	677
Madowla Lagoon	143	164
Goulburn River	501	394

12.3.2 Peak Flood Levels and Extents

The proposed scheme will produce changes to the peak flood levels and extents experienced previously on the Lower Goulburn floodplain, particularly for the moderate sized floods (10 – 35-year ARI). Figure 12-8 shows a comparison of the predicted net decrease and increase in flood extents during a repeat of the October 1993 flood with the proposed scheme in place. As can be seen from Figure 12-8 the scheme will reduce the extent of flooding on the Lower Goulburn floodplain during a repeat of the October 1993 flood. In comparison, only small increases in flood extents on the northern floodplain are predicted by the hydraulic model as a result of the implementation of the scheme. In particular, it is noted that flood extents around Lower Moira and Barmah are not predicted to increase significantly as the floodplain is reasonably confined in these areas.

Figure 12-9 shows the predicted impact of the proposed scheme on peak flood levels on the Lower Goulburn floodplain during a repeat of the October 1993 flood. As can be seen from Figure 12-9, flood levels between the existing levee system will be generally reduced from between 0.2 and 0.5 metres. The reduction in flood levels between the existing levee system combined with works to improve poorly constructed and low sections of the levee system are aimed at providing protection against destructive flooding caused by levee failures up to the 35-year ARI flood. Flood levels between the bund system on the northern floodplain will generally increase by between 0.1 and 0.5 metres.

12.3.3 Impact on Flood Levels at Barmah

The hydrology and hydraulics associated with flood flows and flood levels on the Murray River at Barmah are extremely complicated. The Barmah Flood Mitigation Study (GHD

1994) identified three mechanisms by which flooding of the River Murray at Barmah can occur:

1. Murray River flooding at Barmah caused by widespread floods in the Murray catchment.
2. "Backdoor Flooding" at Barmah caused by floodwaters arising principally from the Ovens River and others flowing from the Great Dividing Range to the Murray downstream of the Hume. In these cases floodwaters spill from the Murray proper at around Cobram and flow over the floodplain towards Barmah. This mechanism was evident in the 1870 and October 1993 floods.
3. Goulburn River flooding from the Deep Creek system, where floodwaters back up through Barmah.

Barmah is currently affected by flooding when levels in the Murray River rise to approximately 96.0 m AHD, corresponding to a 5-year ARI flood. As part of the Barmah Flood Mitigation Study, a flood frequency analysis was carried out on historical peak levels at Barmah to determine the 100-year ARI flood level. This level was subsequently determined as 96.9 m AHD.

The township is currently afforded some flood protection by a collection of earthen levees which have been built over a period of time and to no particular standards. During the October 1993 flood, estimated to be a 30-year ARI flood at Barmah (GHD 1994), the levee system was overtopped and it was only through emergency sand bagging and pumping that flood damage to Barmah was prevented. The October 1993 flood peak at Barmah was 96.51 m AHD.

The Barmah Flood Mitigation Study highlighted the degree to which the town is presently flood prone and recommended the Nathalia Shire apply for funding of a levee system with a crest level at 97.5 m AHD to protect the town from the 100-year ARI flood.

The complex interaction of rivers systems and flooding behaviour at Barmah has not been investigated in great detail as part of this study. Flood levels for any given flood at Barmah depend on a number of conditions in the Murray and Goulburn Rivers. Therefore for this study conservative initial conditions and flows were assumed in the Murray River and are therefore considered to produce conservative flood levels when investigating the impact of the proposed scheme at Barmah.

The increased discharges to the northern floodplain as a result of the proposed scheme are however likely to increase the frequency and magnitude of elevated flood levels due to backwater flooding of the Murray River. During a repeat of the October 1993 flood with the proposed scheme in place, the peak flood level at Barmah is predicted to increase by 90 mm. NB. More recent hydraulic modelling of the Barmah-Millewa Forest has predicted an increase of approximately 40mm during a repeat of the October 1993 flood with the scheme in place (Water Technology, 2005)

To put this increase in perspective, however, it is noted that if extensive levee failures occurred on the north bank of the Goulburn River during the October 1993 flood, rather than the south bank, or if the levees surrounding Loch Garry failed (they were slightly overtopped), the resulting discharges to the northern floodplain may have produced flood level increases similar to those predicted with the proposed scheme.

Assuming conservative initial conditions in the Murray River, the 100-year ARI flood level with the proposed scheme in place at Barmah is predicted as 96.9 m AHD (i.e., the existing 100-year flood level). It is considered unlikely that the scheme itself will result in flood levels above the existing 100-year ARI flood level at Barmah.

It is important to recognise the existing flood risks when attempting to weigh the impacts of the proposed scheme at Barmah. Ideally Barmah would currently be protected with a formal levee system from a 100-year ARI flood. The construction of a formal levee system would result in the proposed scheme having no significant flooding impact on Barmah.

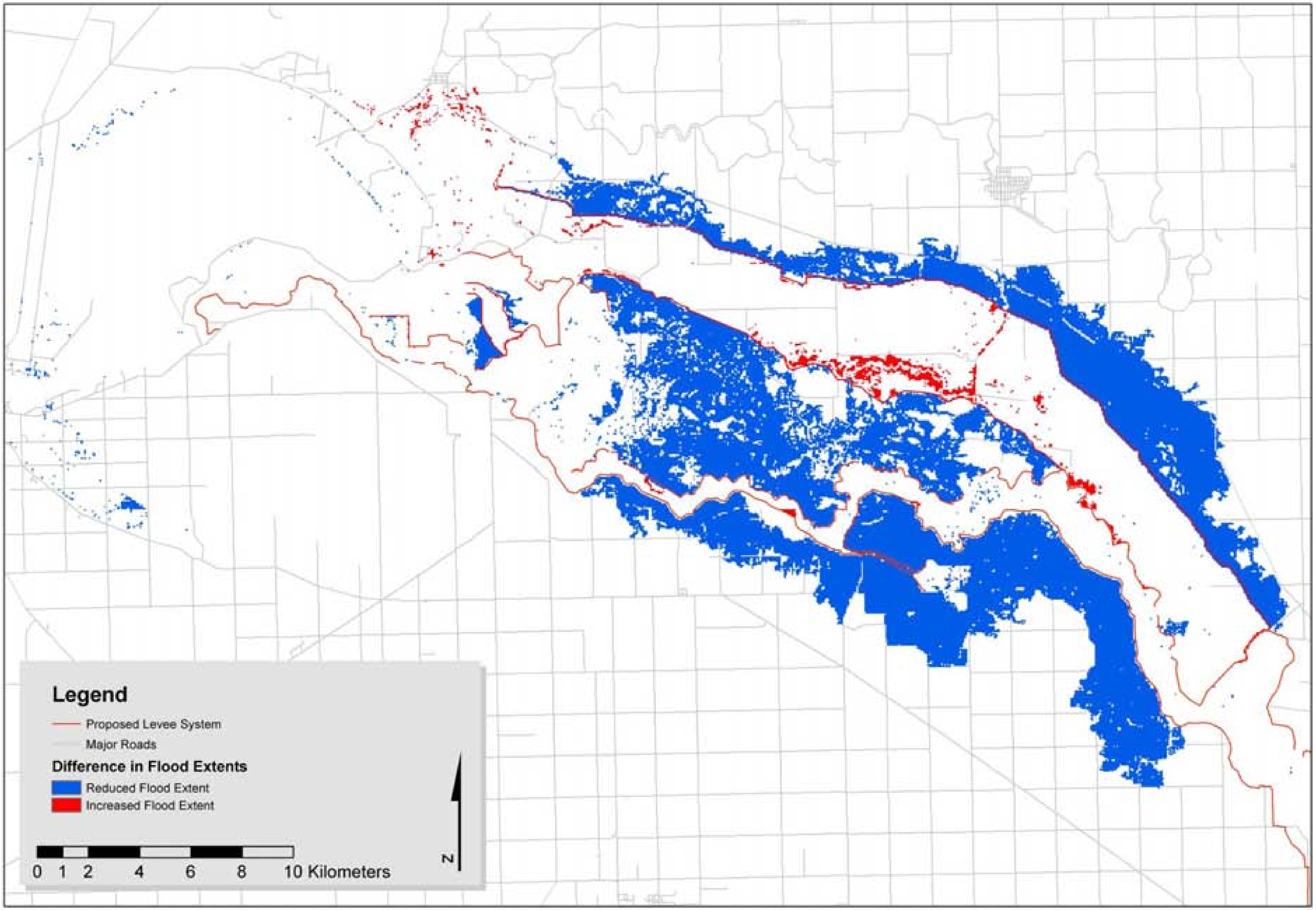


Figure 12-8 Predicted Net Decrease and Increase in Flood Extents During a Repeat of the October 1993 Flood

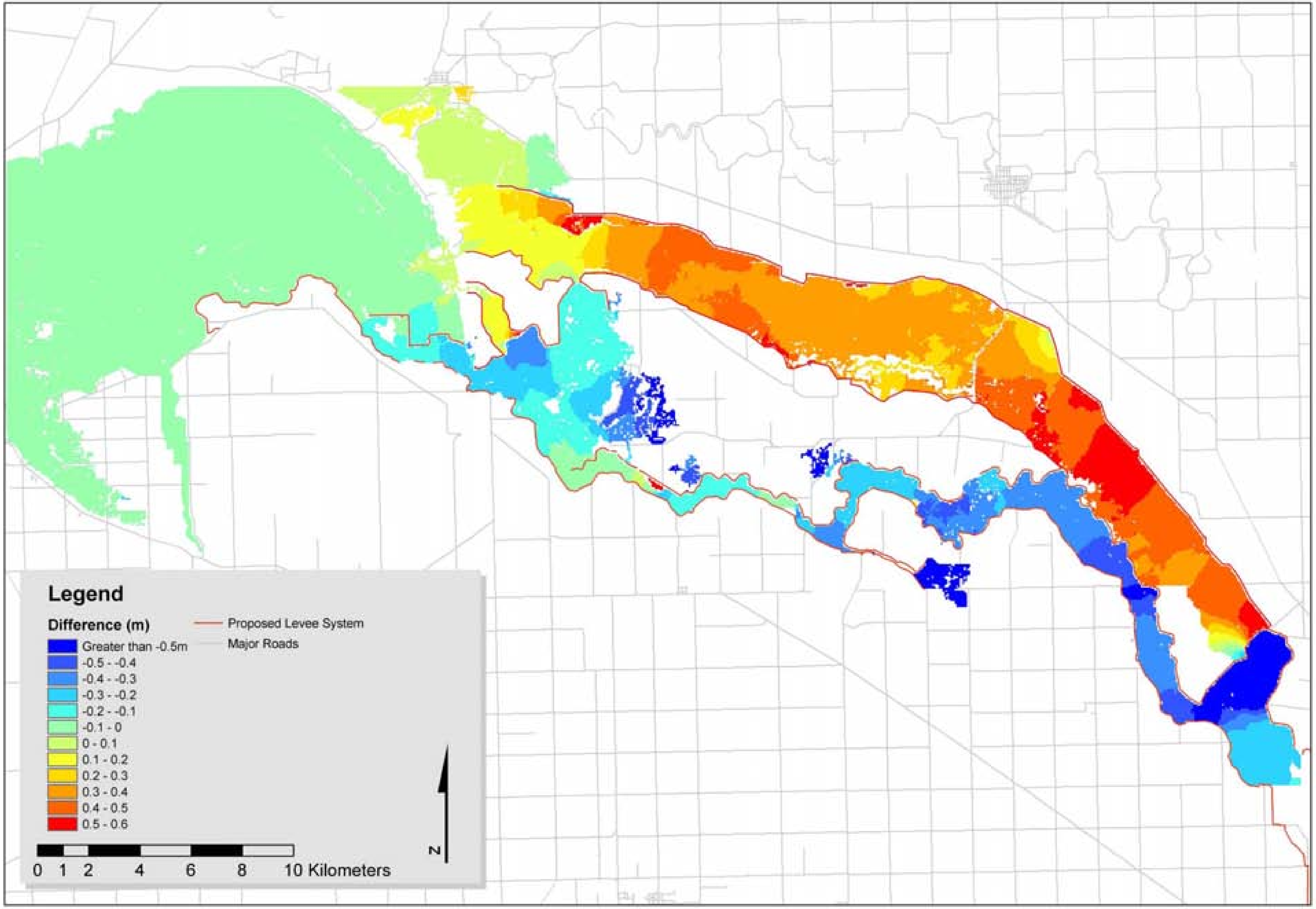


Figure 12-9 Predicted Impact on Peak Flood Levels During a Repeat of the October 1993 Flood

13 Conclusion

The Lower Goulburn Floodplain is significantly flood prone. Under natural conditions, sections of the floodplain would have experienced inundation in as frequent as a 2-year ARI flood. The construction of the existing levee system has, however, provided parts of the floodplain with a modest amount of protection from more frequent floods. However, for larger floods the capacity of the levee system is progressively exceeded and levee failures occur. These levee failures result in destructive flooding and cause significant damage to agriculture, infrastructure and the levees themselves.

The creation of the Loch Garry Minor Flood Protection Scheme was far sighted in that it recognised, from early on, that the levee system does not have the capacity to convey moderate to large floods. Therefore, floodwaters in excess of the levee system capacity would have to be released onto the floodplain. Despite the good intentions, the capacity of Loch Garry Regulator was under designed and experience from the October 1993 flood showed that the regulator is unable to redistribute flows onto the floodplain for even moderate sized floods.

The establishment and calibration of a state of the art hydraulic model of the Lower Goulburn floodplain has allowed the flooding behaviour of the Lower Goulburn floodplain to be simulated in great detail. This has made it possible to carry out detailed investigations into the relative effects of a range of scheme configurations. The scheme configuration finally adopted seeks to find a balance between providing flood protection for small to moderate floods, while allowing a more even distribution of floodwaters to both floodplains during large floods. In this respect it considered that the proposed scheme, hydraulically, does not differ significantly from the intent of the original Loch Garry Minor Flood Protection Scheme.

There remains no easy solution to the flooding problems on the Lower Goulburn and the floodplain will always remain prone to flooding from large floods. The situation at present however provides little certainty as to the level of protection that sections of the floodplain are provided for all but the most frequent floods. The continued decline in the standard of the levee system and the rate of channel change and other environmental impacts also raises questions about the sustainability of the present situation.

The scheme proposed in this study will provide flood protection for moderate floods up to a 35-year ARI flood in the Lower Goulburn floodplain. The scheme aims to provide a more balanced system that will minimise the damages associated with frequent and extensive levee failures and reduce the rate of channel change and erosion on the floodplain.

14 Assumptions and Qualifications

1. This report has been prepared in accordance with SKM's proposal and GBCMA's study brief (Lower Goulburn Floodplain Rehabilitation Project, June 2001).
2. The findings of this study are only as accurate as the accuracy of the topographic, hydrologic and hydraulic data used.
3. The design and sizing of the proposed spillways are only considered preliminary at this stage and are not suitable for construction purposes. More localised detailed modelling should be undertaken to determine more precisely the size of the structures required to meet their respective design discharges. More detailed modelling of the spillways will also provide improved understanding of low flows through the structures from more frequent floods. This information is considered important from an ecological and environmental perspective.
4. For minor floods, less than approximately a 1 in 5 ARI flood, the ability of the model to accurately describe the minor flow paths that initiate flow into lagoon systems and down minor creek systems on the floodplain is restricted by the resolution of the topographic grid and the extent of the coupling between the 1D channel model and the 2D floodplain model. While the model should be able to provide good estimates of flow distributions and levels in the Goulburn and Murray Rivers for minor floods, flooding extents produced by the model should be viewed with some caution.
5. It should be noted that the hydraulic model has been developed to model flood flows originating from the Goulburn and Murray Rivers. The model has not been developed to describe flooding caused by local rainfall events or the inundation of land from overflows from irrigation channels in the study area.
6. The hydraulic model description of the Murray River in the Moira and Barmah State Forest area has been only broadly schematised. To simulate the flooding behaviour of this area more accurately, the model would need to be extended further upstream in the Murray River and include the Tuppal Bulatale Creek systems.

15 References

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