Rochester Flood Management Plan

Final Study Report

June 2013

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PROJECT DETAILS

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Cover Photo: Rochester January 2011 flooding (http://www.burnewangnorth.com.au/flood-gallery.asp).

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GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage. The ARI definition is often poorly understood and misrepresented.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood damage	The tangible and intangible costs of flooding.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Flood mitigation	A series of works to prevent or reduce the impact of flooding. This includes structural options such as levees and non-structural options such as planning schemes and flood warning systems.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.

Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Freeboard	A factor of safety above design flood levels typically used in relation to the setting of floor levels or crest heights of flood levees. It is usually expressed as a height above the level of the design flood event.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
MIKE FLOOD	A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement.
Ortho-photography	Aerial photography which has been adjusted to account for topography. Distance measures on the ortho-photography are true distances on the ground.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequence and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

EXECUTIVE SUMMARY

Overview

Central Victoria was subject to a number of widespread heavy rainfall and flood events in late 2010 and early 2011. After a prolonged drought, the township of Rochester witnessed three separate flood events in November 2010, January 2011 and February 2011. The January flood event was the largest ever recorded for Rochester with approximately 80% of the township and up to 1,000 properties inundated.

The January 2011 flood event reached 115.4 metres Australian Height Datum (AHD) at the gauge within the town. This exceeded the previous largest flood on record in 1956 by 0.2 metres in flood height, as well as the previously mapped extent.

The Victorian Minister for Water, Peter Walsh, announced funding to undertake the Rochester Flood Management Plan on 6th September 2011. The North Central CMA, in conjunction with the Shire of Campaspe and the community, has developed the Rochester Flood Management Plan.

Community Consultation and Feedback

A key objective of the Plan was to ensure strong community engagement and to demonstrate strong community support for the final Plan. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and through more formal feedback methods such as surveys. Three public meetings held at various stages of the Plan development were all strongly attended. Feedback from these meetings guided the development of the Plan.

Key findings of the Draft Rochester Flood Management Plan were presented to the community in a public meeting held on 1st May 2013. A summary brochure outlining the mitigation packages and preferred option along with a feedback form was provided to all meeting attendees and distributed to all community members in the days following the meeting.

As a result of the extensive community consultation, and public feedback, it is clear that the implementation of the recommended flood warning system and construction of formal levees to replace decommissioned irrigation channels have strong community support. The community response to the proposed structural mitigation measures was mixed with approximately 40% of responders supportive of the measures, 40% unsupportive and 20% unsure. It is clear that further assessment of the structural mitigation measures is required so the full impact of these measures can be better understood.

Plan Recommendations

A detailed assessment of a range of mitigation options has been undertaken (Section 6). Mitigation options were assessed against a number of criteria including potential reduction in flood damage, cost of construction, feasibility of construction, environmental impact and community support.

After significant consultation with the community and stakeholders the Plan recommends:

- Further assessment of a package of works that will provide significant reduction in flood risk across a range of events up to and including the 0.5% AEP event at a total estimated cost of $1.8 million (note: excludes any land easement and compensation costs that may be associated with the recommended works).
- Staged implementation of a flood warning system for Rochester as described in Section 9.
- Detailed planning and design of a formal levee to replace irrigation channel 1/1 to the south of Rochester which is marked for decommissioning.
- Update of the planning scheme to incorporate updated flood overlays (LSIO and FO).

The proposed structural works need further investigation so their full impacts can be better understood and conveyed to the community. The structural works include:

- Excavation of land to the east of the Campaspe River railway bridge to allow additional flow northwards across the floodplain and through the railway culvert located 200 m north of the railway bridge
- Excavation of land between the Campaspe River and Bonn Street (near Jess Drive) to better engage the drainage line which flows eastwards from Rochester
- Construction of a strategic levee along the left bank of the Campaspe River between the water treatment plant on Campaspe St and the eastern end of Morton Street
- Construction of a small levee along Bonn Street which will protect properties from the increased engagement of the eastern drainage line
- Construction of an open drain in the existing drainage easement between the railway line and Ramsay Street from Elizabeth Street to the Campaspe River.
- Further investigation of irrigation channel 2/2 to the east of Rochester which is marked for decommissioning in consultation with affected landowners.

This project also provided the required flood intelligence for revised Appendices relating to Rochester for the Municipal Flood Emergency Plan.

Next Steps

The Rochester Flood Management Plan will seek endorsement from both the North Central Catchment Management Authority Board and the Campaspe Shire Council prior to sending to the Victorian Government for consideration for funding.

Upon endorsement, Campaspe Shire in conjunction with the North Central CMA will apply for funding for:

- Implementation of the recommended flood warning infrastructure
- Detailed planning and design of a formal levee to replace irrigation channel 1/1 to the south of Rochester which is marked for decommissioning
- Further assessment of the proposed structural mitigation measures

Other steps will include updating of the Municipal Flood Emergency Plan, implementation of updated planning scheme layers, and implementing recommendations regarding the flood warning system.

Acknowledgements

The Rochester Flood Management Plan was led by the Rochester Flood Management Plan Steering Committee and supported by the Technical Working Group.

The study team would like to thank the Steering Committee, Technical Working Group and all others concerned for their diligence in delivering a quality study in a timely manner.

It should be noted that this document does not represent policy of North Central CMA, Shire of Campaspe or Government. This is a technical report produced as part of the Rochester Flood Management Plan. There are many considerations that must be made following the completion of this study by all stakeholders and Government prior to implementing any of the recommendations of the Rochester Flood Management Plan.

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1. INTRODUCTION

Following the recent flood events in Rochester in November 2010, January 2011 and February 2011, Water Technology has been commissioned by the North Central CMA to undertake the Rochester Flood Management Plan study. This study will involve detailed hydrological and hydraulic modelling of the Campaspe River through Rochester, flood mapping of relevant areas and also provide recommendations for flood mitigation works.

As part of the initial scoping work, the data required for modelling and mapping was collated and reviewed. This report documents the data review findings and identifies gaps in the data. It also outlines the proposed hydrological and hydraulic modelling scope and methodology.

As part of the present study a detailed hydrologic analysis of the study area has been undertaken. The hydrology data will be used as the input boundaries to the hydraulic model. The hydrology can be split into two categories; flows from Campaspe River and rainfall data from the local catchment. The hydrology data was derived for a range of design events as well as the recent November 2010, and January 2011 events.

1.1 Study Area

Rochester is a township of 1,849 residents (2006 Census), located 180km north of Melbourne in Central Victoria. Rochester is principally an agricultural town and relies heavily on irrigated agriculture including vegetable and dairy. The flat landscape is traversed by irrigation channels managed by Goulburn Murray Water. The Catchment of the Campaspe River above Rochester is approximately 3,345km^2 (Figure 1-1) and extends to the south of Daylesford, Kyneton and Woodend. The steep gradient of the Great Dividing Range contrasts with the northern plains.

Rochester is located downstream of Lake Eppalock, a large storage (over 300 GL in volume) which is used to impound water for irrigation along the Campaspe River within the Campaspe Irrigation District located south of Rochester.

Rochester is situated on the Campaspe River floodplain. The area has little topographical relief, and the river channel at Rochester has a limited capacity, leaving the town susceptible to flooding. When the channel is exceeded, this results in widespread flooding adjacent to the river and along a number of other flood effluent paths.

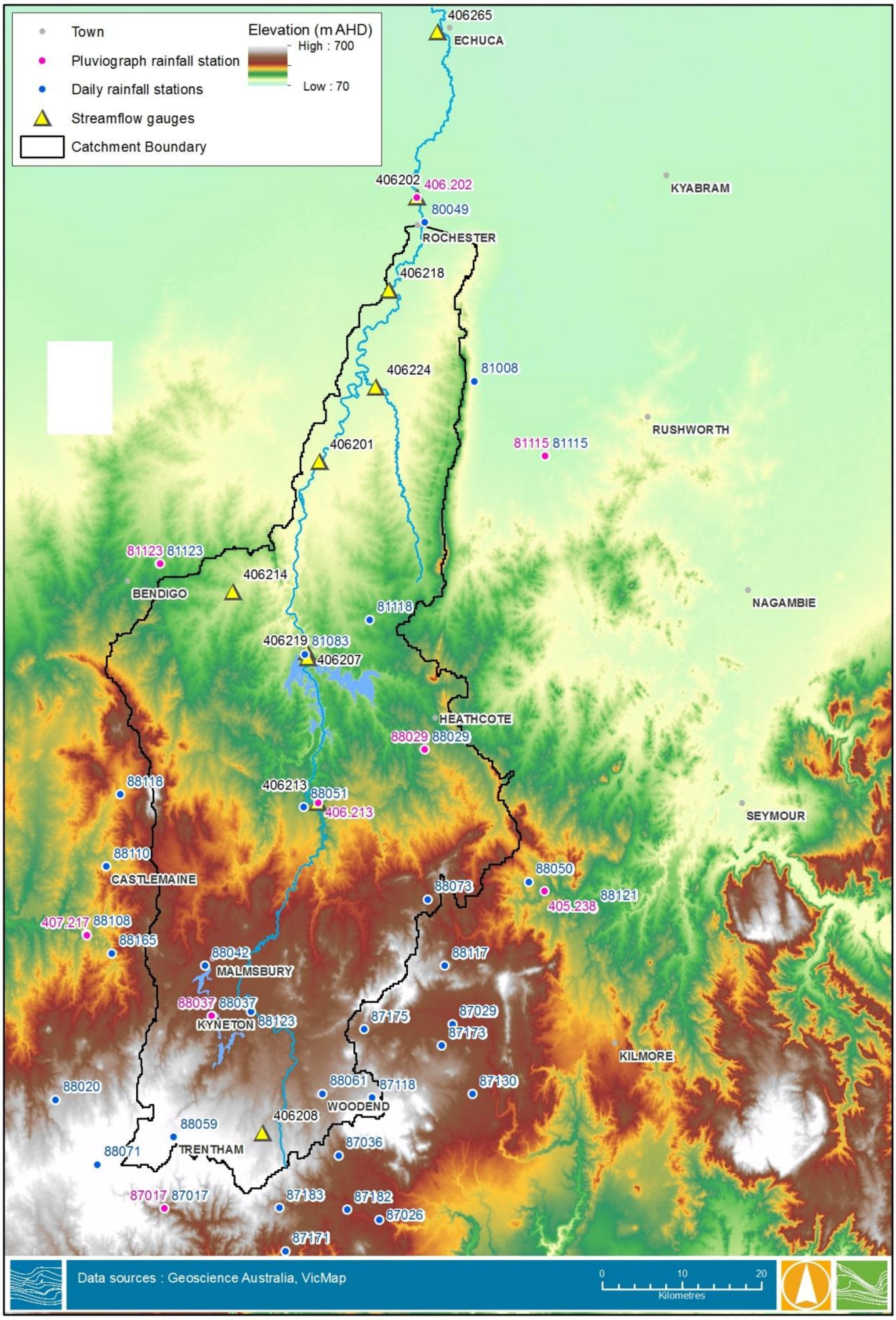


Figure 1-1 Campaspe River Catchment at Rochester (Geo-science Australia 20m contour data)

1.2 Flood Related Studies

The flood extent for Rochester is currently described by the existing Land Subject to Inundation Overlay for the town, show in Figure 1-2. No detailed flood studies or modelling have been carried out for Rochester to date and this extent is primarily based on data collected from flooding in 1956. The flood in January 2011 exceeded the mapped extent and has been recorded as the largest flood to affect the township to date.

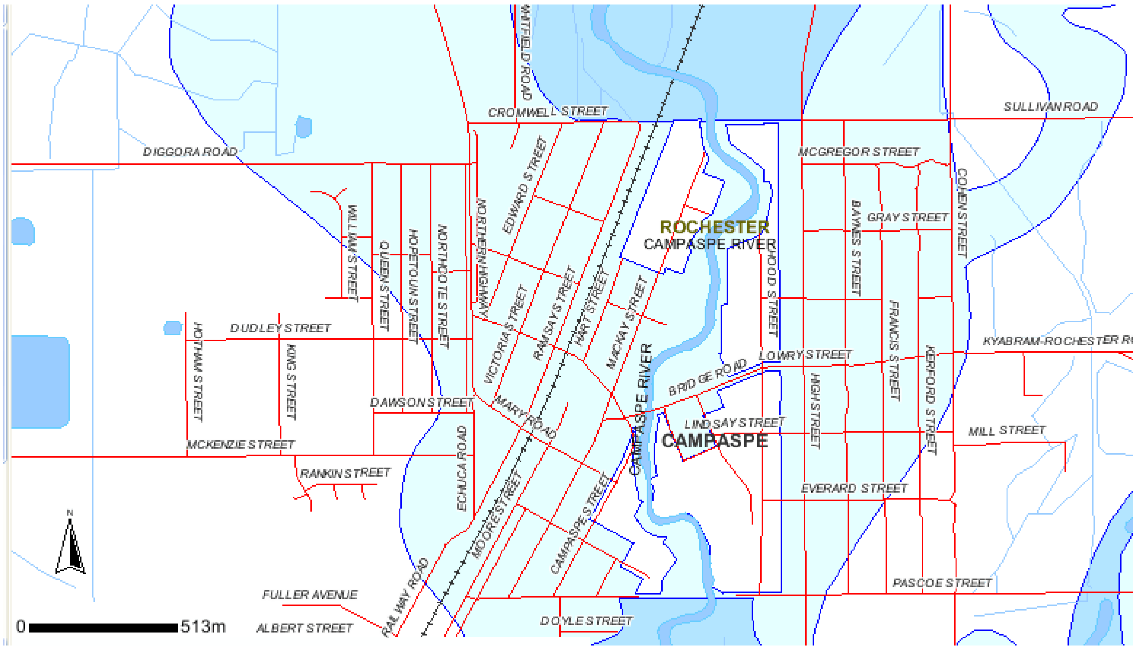


Figure 1-2 Land Subject To Inundation Overlay (LSIO) (DSE Planning Schemes Online, 2010)

1.3 Flood Records

1.3.1 Historical Flooding

Rochester sits within a natural floodplain and has a history of regular flooding. Anecdotal evidence and discussions with local residents indicate that the town in flooded quite often, with either multiple floods in one year or spaced by a decade or so. A historical overview of flood events and heavy rainfall events in Rochester shows that major flood events are:

- July 1916
- October 1916
- September 1917
- 1920
- August 1920
- September 1920
- September 1921
- July 1923
- August 1924
- August 1932
- June 1939
- June 1951
- July 1956
- August 1973
- September 1983
- November 2010,
- January 2011; and
- February 2011

The January 2011 flood event is thought to be the largest flood event to date. Records indicate that flooding historically occurs between the months of June and October, corresponding to periods of heavy rainfall as indicated by the Bureau of Meteorology (BOM) records (Figure 1-3). The flood record also indicates that when large floods occur, there are often two occurring within the same year (1916, 1920, 2010, 2011).

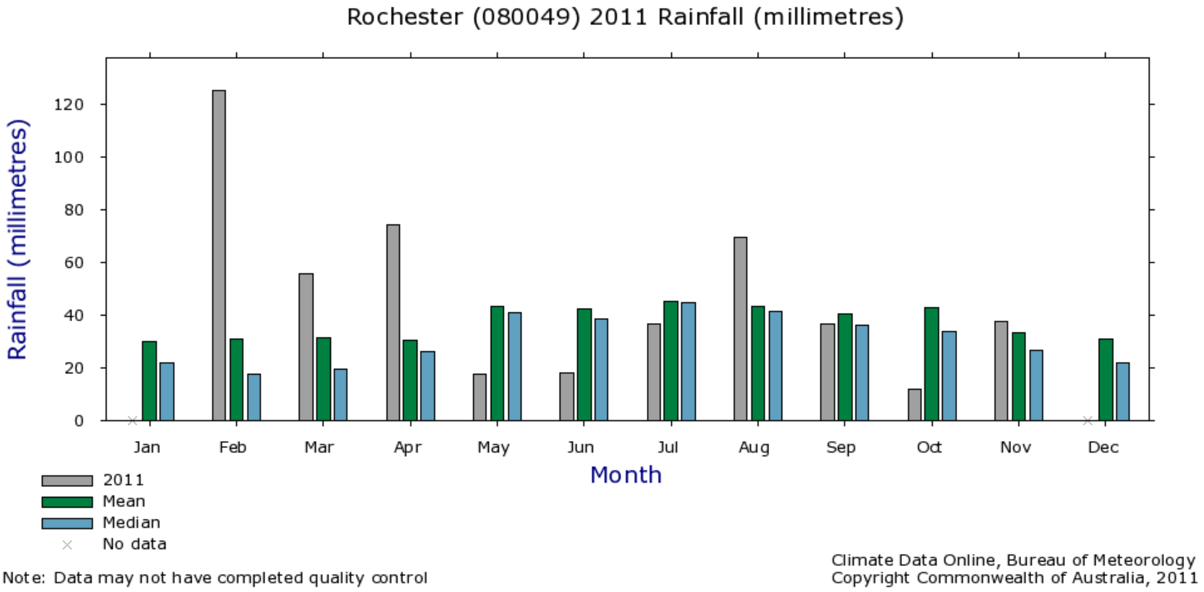


Figure 1-3 BOM historical rainfall records for Rochester (BOM, 2011). Data is missing for January 2011, however the monthly total is likely to be equivalent to or higher than February 2011.

1.3.2 Recent Flood Events

After a prolonged drought, the township of Rochester witnessed three separate flood events in November 2010, January 2011 and February 2011. The January flood event was the largest ever recorded for Rochester with approximately 80% of the township being inundated (up to 1,000 properties).

The January 2011 flood event reached 115.4 metres Australian Height Datum (AHD) at the gauge within the town. This exceeded the previous largest flood on record in 1956 by 0.2 metres in flood height, as well as the previously mapped extent.

The flood level predicted by the flood warning system was exceeded by up to 200 mm.

Lake Eppalock spilled in November 2010, for the first time since 1996, after heavy rainfall and flooding contributed to an already high water level in the Lake. During the January 2011 event both the primary and secondary spillways were activated, the first time the secondary spillway has done so since 1974.

January 2011

Reports from residents and local media detailed a rapid rise in the floodwater within the town and an evacuation warning being given at approximately 9am on Saturday 15th January. During this event, the top of the Campaspe River catchment received the highest monthly rainfall in 43 years of record with 201 mm recorded in eight days, the majority of which fell in the week beginning 10th

January 2011 (Weatherzone.com). There had been suggestions by some in the town that the irrigation infrastructure may have contributed to the extent of the flooding. A community meeting was held by Goulburn Murray Water after the flooding on Monday 24th January to allay these concerns.

Figure 1-4 below displays the three relevant gauges on the Campaspe River. The Rochester town flood level gauge is manually recorded and was not accessible during the peak of the January flood. The Barnadown gauge is upstream of Rochester at an irrigation off-take whilst the Syphon gauge is downstream where the Waranga Western Irrigation Channel passes under the Campaspe River.

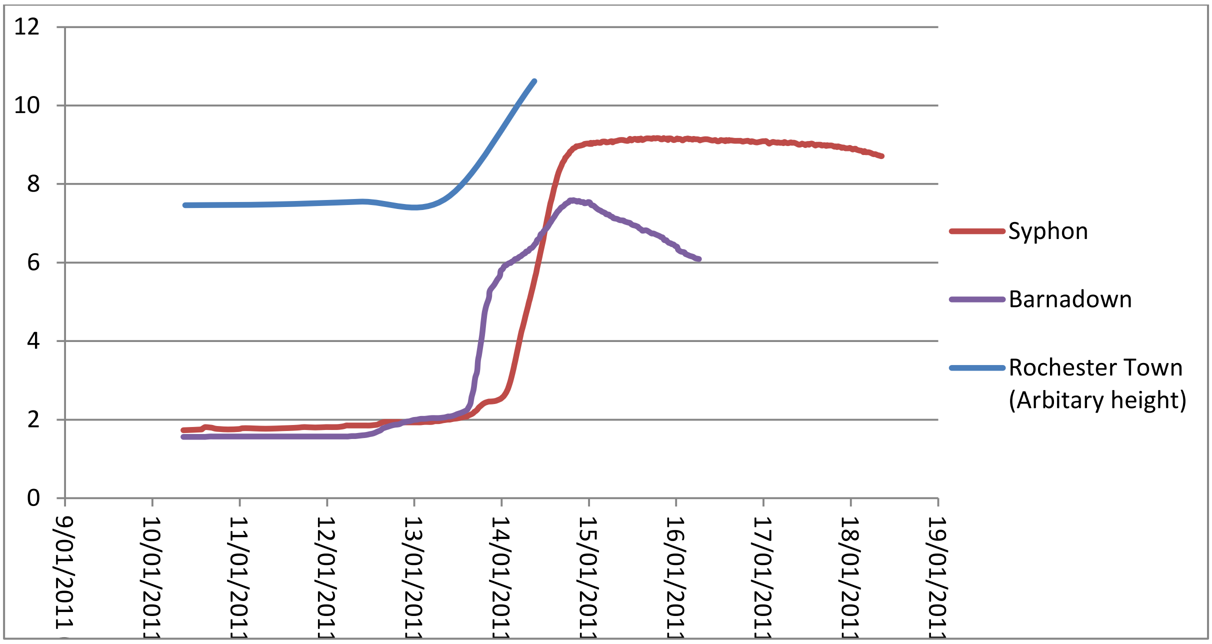


Figure 1-4 Campaspe flow height record in metres at Barnadown (36km upstream of Rochester); Rochester Town; and Campaspe Syphon (downstream of Rochester)

The flows in the Campaspe River at Rochester were estimated to equate to 55,000 ML/day. This compares to a peak flow into Lake Eppalock of 137,000 ML/day and a spillway peak flow out of the reservoir of 88,000 ML/Day. Therefore there was significant attenuation of the flows both within the reservoir and into the floodplain between Eppalock and Rochester.

2. SITE VISIT

A site visit was undertaken by Water Technology on 21st December 2011 with a representative from the North Central CMA, Sarah Stanaway. Also present at the site visit was Danny Moloney from the Campaspe Shire Council. The purpose of the site visit was to gain a better understanding of the flood issues in Rochester, identify key structures for the hydraulic modelling and investigate locations/options for future mitigation works. The site visit also provided an opportunity to request additional information from the council regarding flood markers from the January 2011 event, catchment conditions and ongoing flood mitigation works. Information gathered from the site visit has been documented in a separate report which is presented in Appendix A.

3. AVAILABLE INFORMATION

3.1 Topographic and Physical Survey

Two sources of topographic data have been obtained to prepare the hydrological and hydraulic models. These include:

- Light detection and ranging (LiDAR) data;
- Structure Survey

3.1.1 LiDAR Data

LiDAR data for the region was made available from two sources, the North Central CMA (referred to as Broken Creek data) and DSE (Index of Stream Condition, referred to as ISC). A comparison of both datasets was undertaken in ArcGIS. The datasets have resolutions of 5m and 1m respectively, and cover different extents: the ISC data set covers the channel and a narrow floodplain and the Broken Creek LiDAR covers a slightly larger extent into the wider floodplain.

The comparison showed an elevation difference where the two datasets overlap. The 1m DEM sits around 100 to 300mm above the 5m grid. The extents of the available LiDAR grids and their overlap are shown in Figure 3-2 below.

An average difference between the available datasets of 200mm reflects differences in processing of data and potentially some error. Therefore to investigate these differences and develop the composite final DEM a survey was undertaken for Water Technology by Shire of Campaspe. The survey comprised a 100m transect with elevation points measured every 10m which was compared with the LiDAR elevations.

A comparison of the elevation from the survey points and corresponding cells in the DEMs is shown in Figure 3-1. Also included is the Rochester West PM50 permanent mark. This mark was used as a reference point for correction during the survey. Note that this mark is located below the footpath, approximately 100mm below the surface.

It appears that the ISC 1m grid sits consistently above the survey measurements (~80mm), and the Broken Creek 5m grid is 100mm below on average (see Table 3-1). Comparison at the PM50 permanent mark is consistent with that observation. Unfortunately the survey has not confirmed the levels of either set of LiDAR rather that it lies in between both datasets. Therefore, rather than using either DEM as the basis, a composite dataset will be developed by correcting both datasets. This correction will apply the calculated mean difference between each DEM and the survey point elevations to both sets of LiDAR.

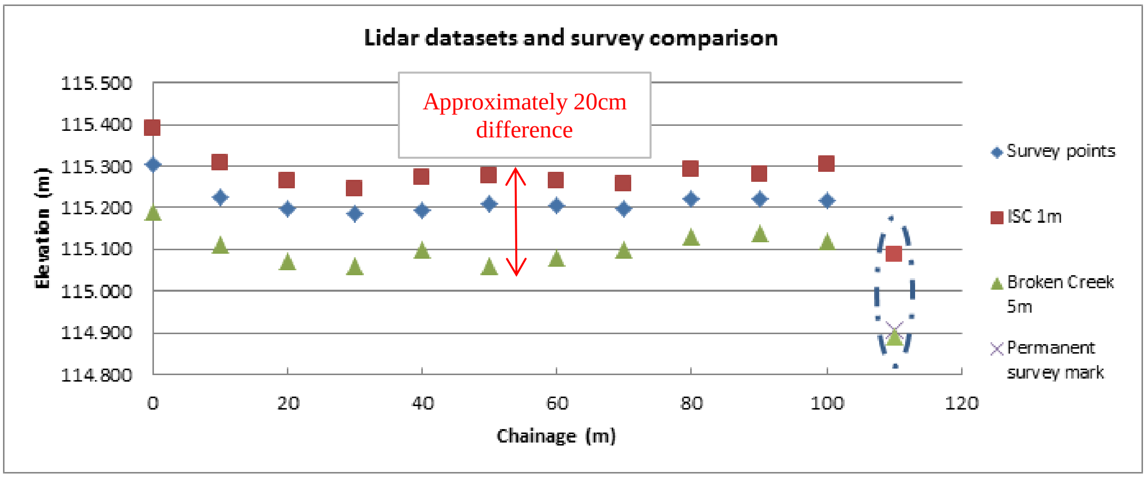


Figure 3-1 Survey points and LiDAR datasets elevation comparison

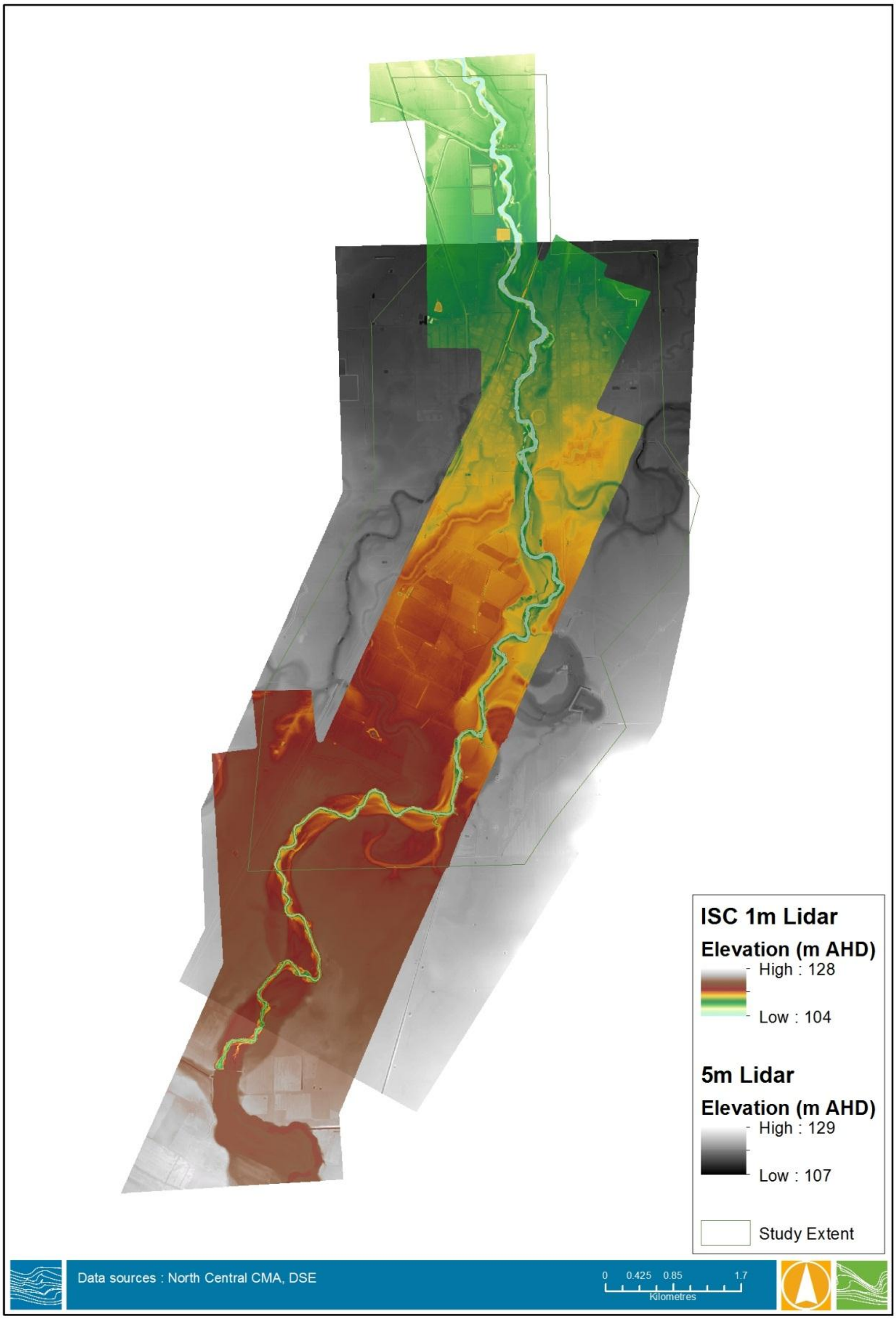


Figure 3-2 1m and 5m LiDAR extents for Rochester

Table 3-1 Survey and LiDAR elevation differences

Points	ISC 1m	Broken Creek 5m
Chainage	difference/survey (cm)	difference/survey (cm)
0	8.5	-11.5
10	8.3	-11.5
20	6.7	-12.8
30	5.6	-12.7
40	7.8	-9.5
50	6.7	-14.8
60	6.2	-12.4
70	5.8	-9.7
80	6.8	-9.3
90	5.9	-8.2
100	8.4	-9.8
West PM 50	18.2	-1.8
Mean =	7.9	-10.3

After adjustment to the grids through comparison with the survey points, Figure 3-3 shows that there are still some discrepancies between the two grids. The overall mean difference after correction is approximately 50 mm and the ISC data is consistently above the Broken Creek data.

It appears that on the western side of the channel there are still discrepancies that seem to be due to crops being at different levels during data acquisition. Also bands seem to appear along the DEM. It is important to note that aerial LiDAR was flown at different dates for the two datasets:

- Broken Creek: Acquisition start date 20/08/08, end date 26/08/08
- ISC: LiDAR data collection was performed according to several flight strips, flown at different dates. Figure 3-4 shows the different dates of data acquisition for the ISC LiDAR

Key differences include:

1. Crop / vegetation differences: There is a 2 year and 1 month interval between the two data sets. The information was collected in late August 2008 and late September 2010 for the Broken Creek and ISC data respectively.
2. Banding: clear bands through the data set seem to correspond to the different strips flown at different dates, with a 100mm step occurring at the boundary between two strips.

Based on the results of the comparison, the Broken Creek LiDAR (5 m grid) was used to model the floodplain. This was considered preferable to using a composite DEM for the following reasons:

- No banding is apparent in the Broken Creek dataset;
- Several corrections would be required to the ISC LiDAR in order for it to be used (i.e. to adjust for the crop and banding issue); and
- The Broken Creek dataset appears to be free of vegetation in the patches showing differences between the two DEMs and is therefore more representative of the ground surface elevation.

In order to accurately model the channel, cross sections were extracted from the ISC 1m grid at several locations along the Campaspe River and used in the hydraulic modelling. Figure 3-5 shows the locations of the extracted cross sections along the Campaspe River.

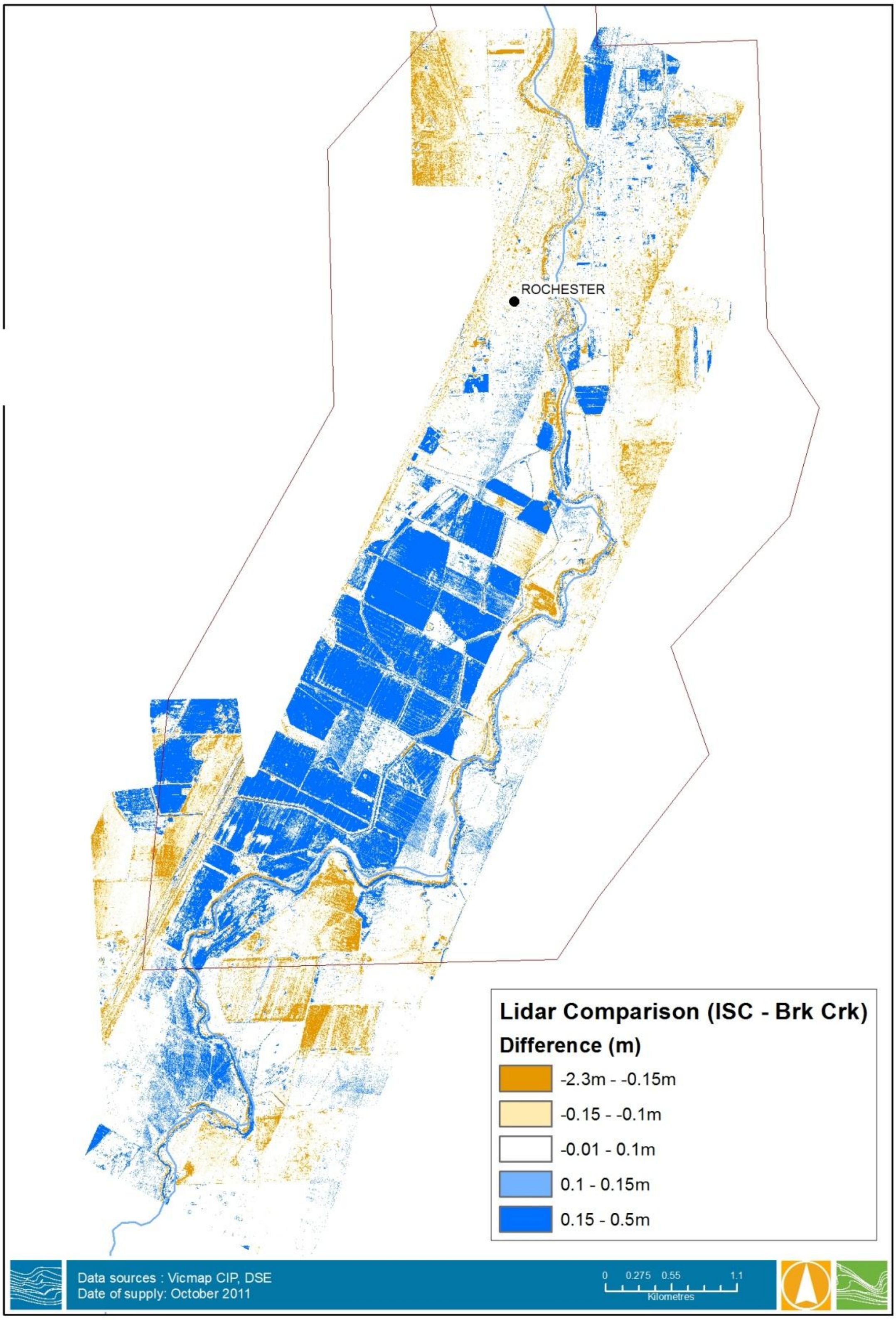


Figure 3-3 LiDAR comparison after correction

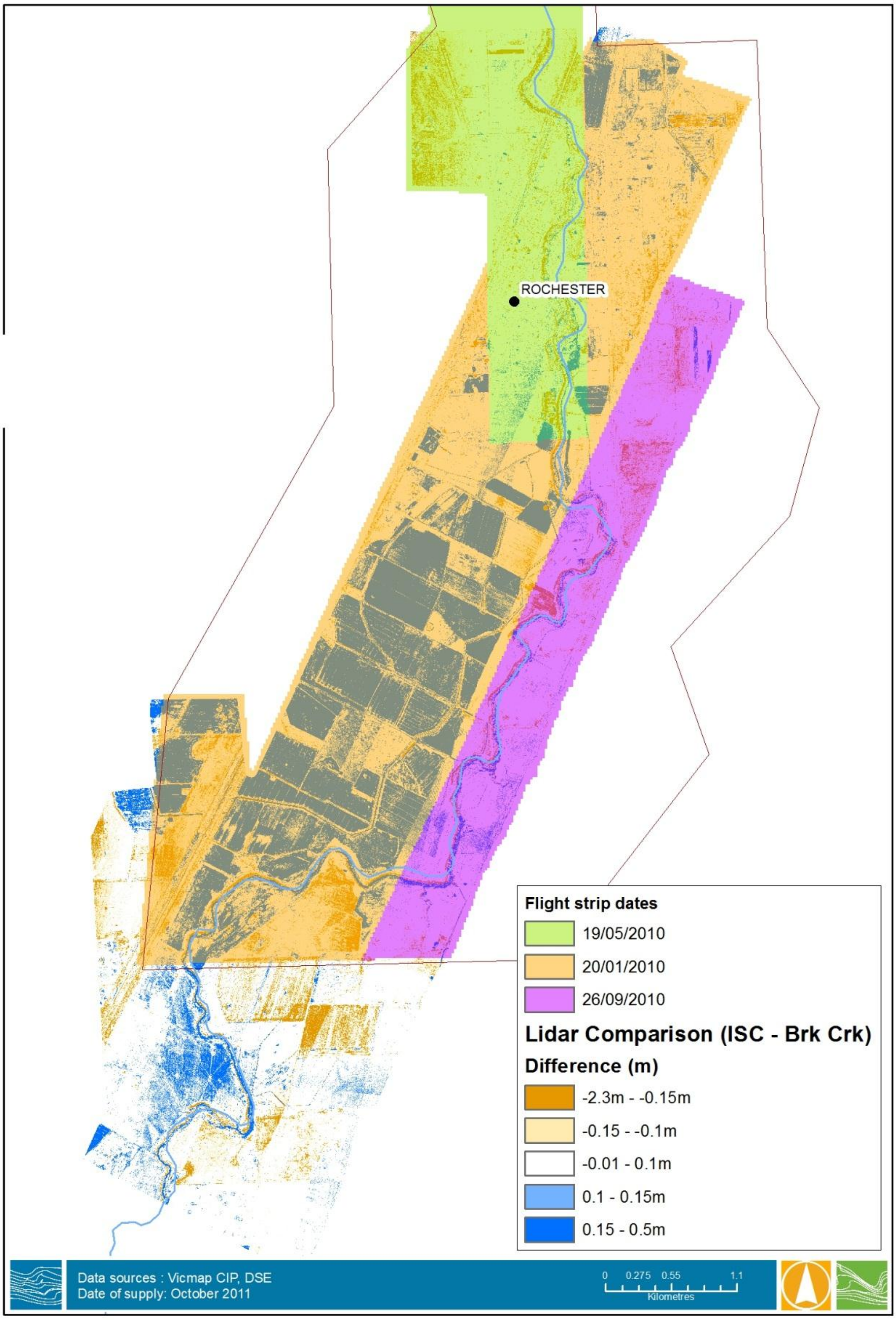


Figure 3-4 LiDAR Flight strips

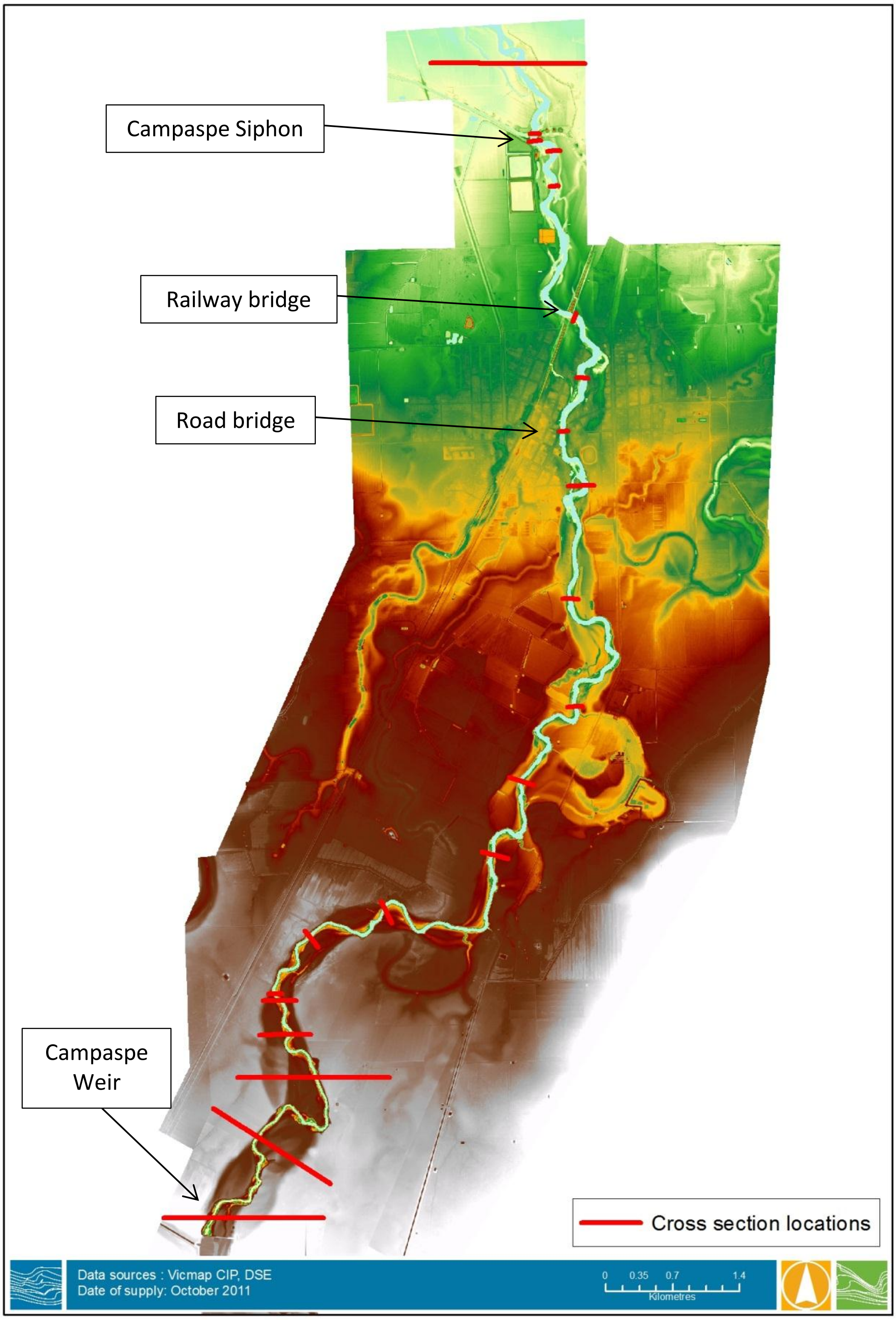


Figure 3-5 Location of cross sections along the Campaspe River

3.1.2 Structure Survey

Information about the key hydraulic structures along the Campaspe River including dimensions and inverts are required for input into the hydraulic model. The main structures in the catchment are considered to be:

- Road bridge over the Campaspe River;
- The railway crossing adjacent to Rochester-Strathallan Rd near Sullivan Street; and
- Culverts under the railway.

Plans of the road bridge were supplied by VicRoads. Cross section details, dimensions and obverts of the main hydraulic structures were estimated during the site visit. The pipe obvert was tied back into the LiDAR data to estimate the invert level. It is expected that this method of estimating the structure inverts will be accurate to +/-150mm and as such will not have a significant impact on the model accuracy. No additional structure survey was required for the model construction. Details of the various crossings are provided in Table 3-2 below and the locations shown in Figure 3-6.

Table 3-2 Details of key hydraulic structures in Rochester

Waterway	Crossings	Surveyed	Structure details	Approx. Invert Level (m AHD)
Campaspe River	Rochester road bridge	-	5 cast-in-place beams, 3 prestressed concrete beams	114.80 (road level on top of bridge)
	Cr5 - Railway bridge	-		112.99
	Cr10 - Syphon	-	Hydraulic behaviour Comparable to a weir across the Campaspe	107.30 (crest level)
Drainage	Cr1 - Northern Hwy B75	21/12/2011	Two box culverts 0.9m high * 1.2 m wide	116.69
	Cr2 – Railway bridge	-	Railway bridge 15/4.5m spans	116.20 (ground level)
	Cr4 – Railway bridge	21/12/2011	Clear span 6m wide, 1.1m high	113.60
	Cr3 – Path adjacent to railway	21/12/2011	Pipes adjacent to railway culvert Diameter : 800mm Length : 3.5m	113.60
	Cr6 – Cromwell St	21/12/2011	Two box culverts 1.2m wide * 0.45m high	113.04
	Cr7 – Victoria St	21/12/2011	Drainage pipe Diameter 1.1m	113.24
	Cr8 – Ramsay St	21/12/2011	Drainage pipe Diameter 1.1m	112.84
	Cr 9 – Waranga channel	21/12/2011	Culvert – width 1.1m	112.12

Figure 3-6 Location of key hydraulic structures within Rochester

Crossing 1 – Cr1

Crossing 2 – Cr2

Crossing 3 – Cr3

Crossing 4 – Cr4

Crossing 5 – Cr5

Crossing 6 – Cr6

Crossing 7 – Cr7

Crossing 8 – Cr8

Crossing 9 – Cr9

Crossing 10 – Cr10

3.1.3 Rochester Drainage Network

Details of the underground drainage network are important for the establishment of the hydraulic model and identification of flood related drainage issues. It should be noted however that this study is not to consider the entire stormwater system, and will be concentrating on larger flood events.

The North Central CMA supplied Water Technology with the Campaspe Shire Council drainage network layout for Rochester. The pipe network layout was received in hardcopy scan image files. The dates of these plans are 1975 and 1991.

After consideration of the benefits of modelling the drainage network, it was decided to only represent the major drainage pipes in the hydraulic modelling, that is the structures influencing the direction of large flows through the township. In other words, the structures within Rochester that were overflowing during the most recent flood events and/ or inundated surrounding areas which would not have otherwise been inundated.

Figure 3-7 Drainage pipe modelled in Mike11 (Cr7 and Cr8)

3.2 Other Background Data

Aerial images of Rochester were provided by the NCCMA. For flood mapping, the most recent aerial imagery was used as a background overlay.

Other background data available for the study included:

- Numerous photos of the recent flood events;
- Video footage of flood events and post flood flights;
- Flood mark levels, for the November 2010 and January 2011 events, at various locations in the township (survey undertaken by the North Central CMA);
- Floor level survey of a number of properties in town;
- Historical flood information and photos;
- Information on Coliban Reservoirs;
- Lake Eppalock historical records and previous studies (provided by GMW);
- Bridge hardcopy plans (VicTrack and VicRoads); and
- Rochester community survey

This data was useful for model set-up, calibration and results presentation.

3.3 Available hydrological data

3.3.1 Streamflow Data

Streamflow data was required for the calibration of the hydrological model. There are ten active streamflow gauges located within the study area; only seven of these are suitable for use in calibration of the hydrological model, as discussed in the report "*Rochester Flood Management Plan – Data Review, Model Scoping and Mitigation Prefeasibility*". Instantaneous streamflow data for the November 2010 and January 2011 flood events has been sourced from DSE and from the Victorian Water Resources Data Warehouse[1].

Table 3-3 Streamflow gauge details

Station Name	Station No.	Status	Data Type	Period of record
Campaspe River @ Ashbourne	406208	Active	Instantaneous Flow Station Level	April 1933 – June 2012
Campaspe River @ Barnadown	406201	Active	Instantaneous Flow Station Level	Oct 1977 – July 2012
Campaspe River @ Lake Eppalock	406207	Active	Instantaneous Flow Station Level	Oct 1976 – June 2012
Campaspe River @ Redesdale	406213	Active	Instantaneous Flow Station Level, Mean Daily Flow	Oct 1976 – June 2012
Campaspe River @ Rochester	406202	Active	Instantaneous Flow Station Level	Nov 1976 – July 2012
Mount Pleasant Creek @ Runnymede	406224	Active	Instantaneous Flow Station Level	June 1974 – July 2012
Axe Creek @ Longlea	406214	Active	Instantaneous Flow Station Level	March 1965 – June 2012

[1] http://www.vicwaterdata.net/vicwaterdata/data_warehouse_content.aspx?option=4

A review of the gauge data quality codes at the selected sites identified that the event data was typically of good quality, however it is noted that data was estimated through extrapolated rating curves for certain events on several gauges. This is due to the events exceeding the maximum rated flow for the streamflow gauge. Notably, a review of the streamflow gauge data quality codes at the Rochester site (406202) identified that both the flow and level data was to be used with caution for the high flows during the January 2011 event. Examination of the flood hydrograph for the January 2011 event shows unstable records around the peak of the flood event, with recorded data oscillating by approximately 10,000 ML/d (see Figure 3-8). The gauged streamflow data has most likely underestimated the peak, not reaching the flow that might be expected considering upstream gauging. It is likely that the oscillation is related to instrumentation error and underestimation of the peak is due to flows bypassing the gauging station due to breakouts from the main channel. Figure 3-10 shows a map of the possible locations where flow is bypassing the gauge (406202).

This data was reviewed by GMW within the Hydrology Report and it was suggested that the data was too low, namely for the outflow from lake Eppalock. After further investigation new, updated data, has been obtained for the gauges 406207 and 406202, from the Victorian Water Resources Data Warehouse.

Gauged streamflow data is shown in Figure 3-8 and Figure 3-9 for the January 2011 and November 2010 events.

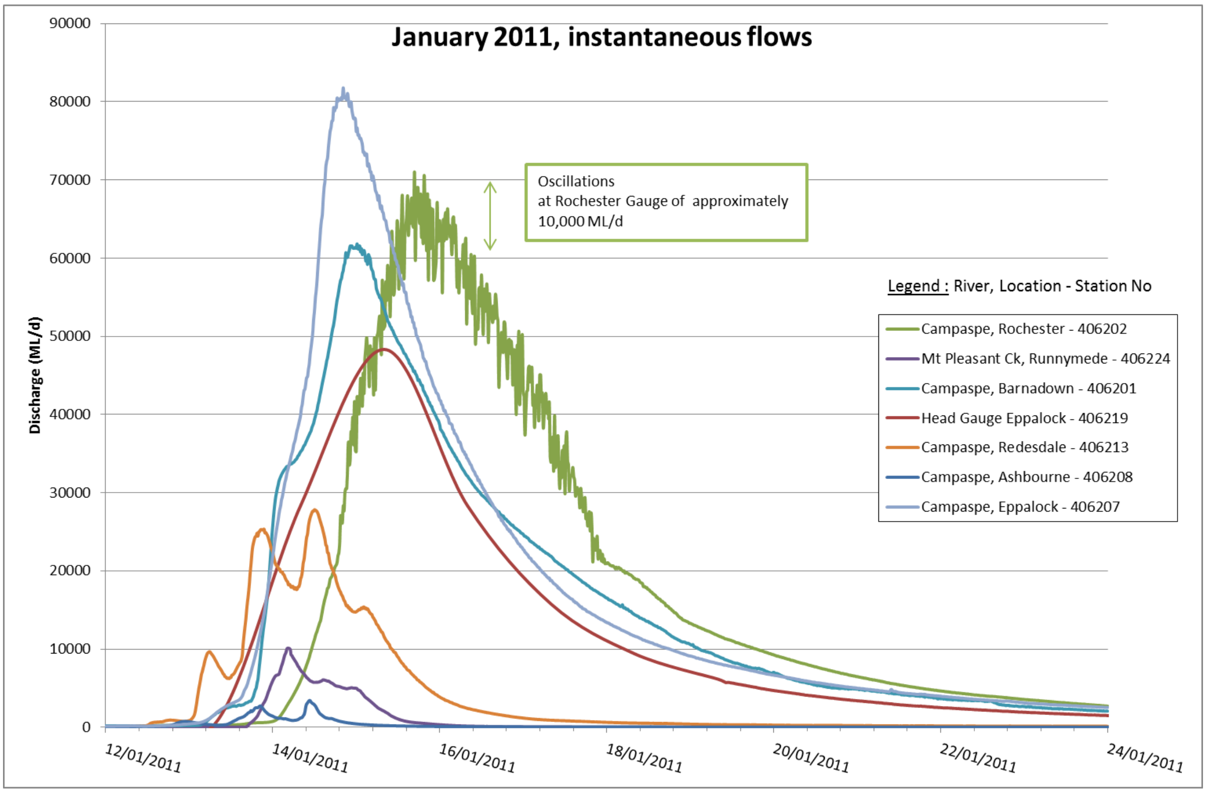


Figure 3-8 Recorded flood hydrographs for the January 2011 event

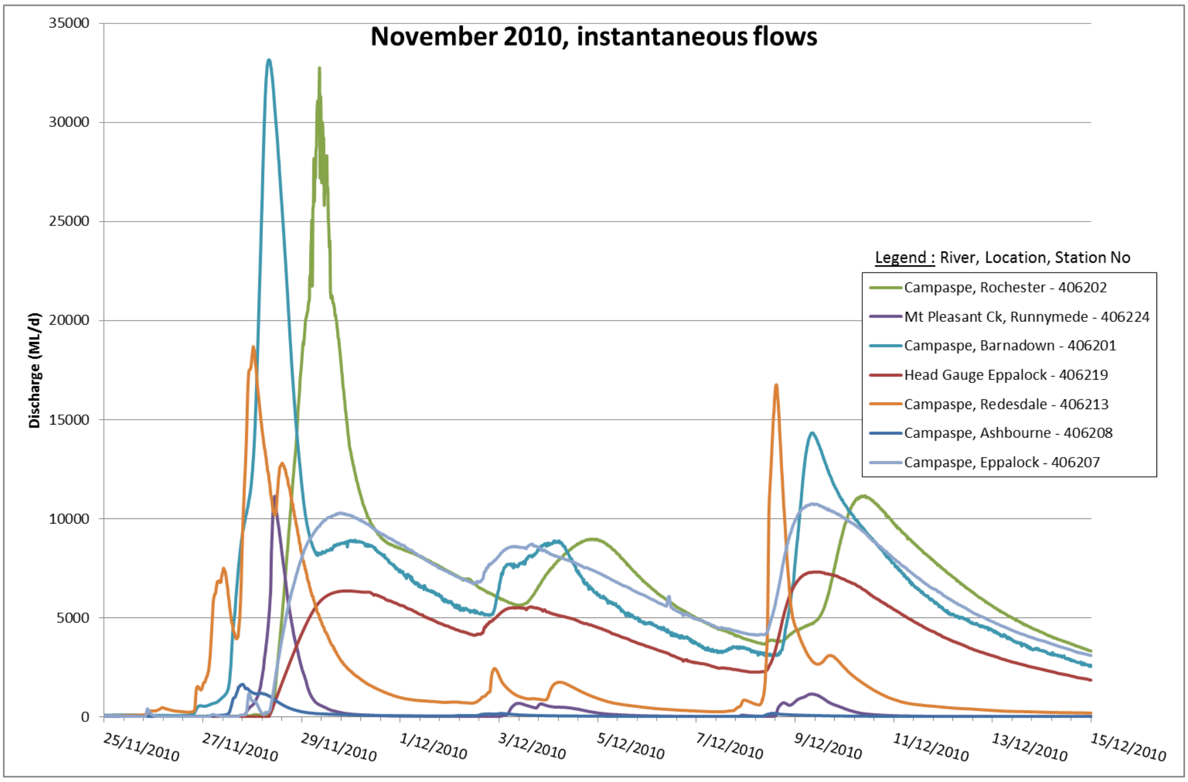


Figure 3-9 Recorded Flood hydrographs for the November 2010 event

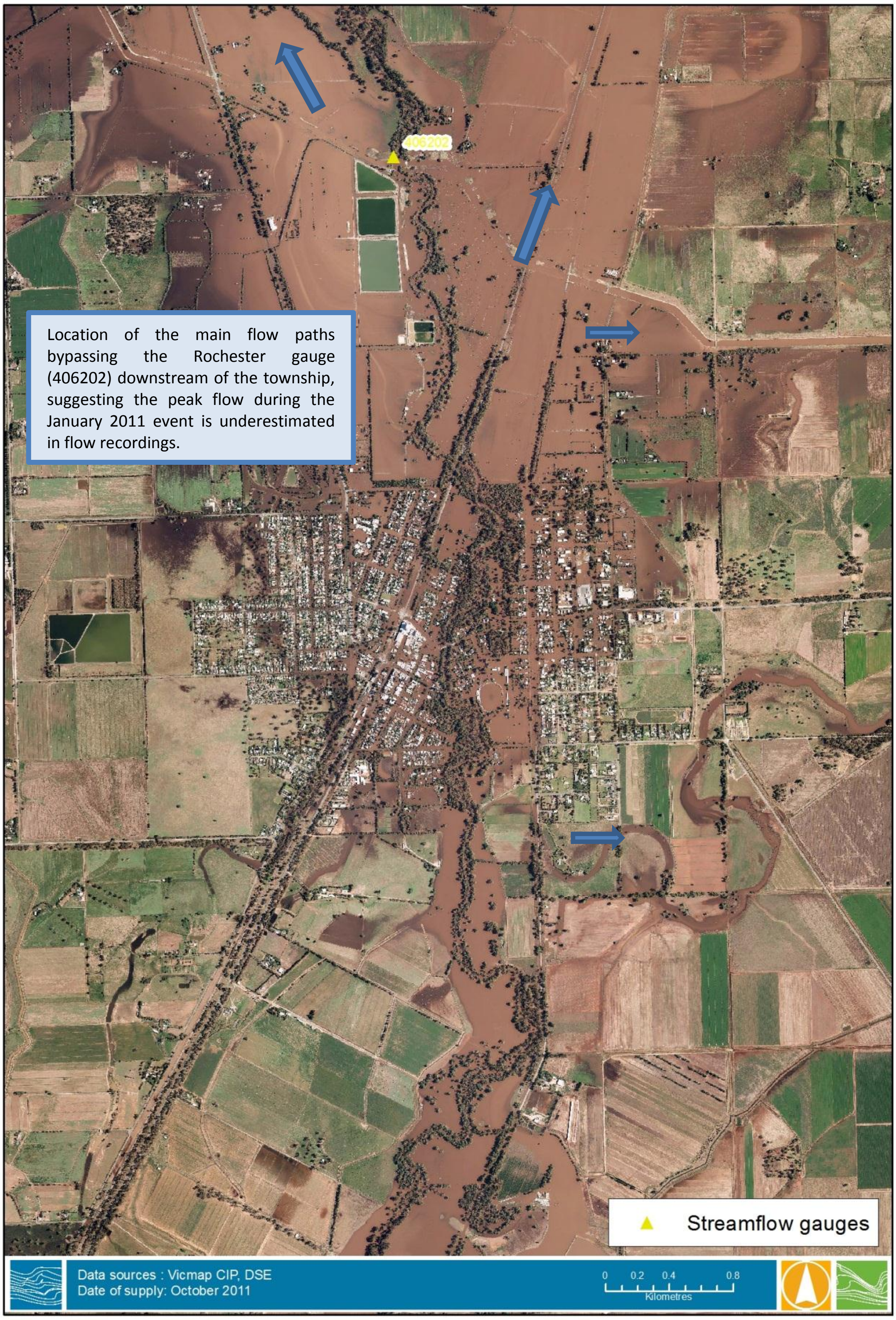


Figure 3-10 Aerial imagery depicting possible locations of flow bypassing the Rochester syphon gauge during the January 2011 event.

3.3.2 Rainfall Data

Both pluviograph and daily rainfall records were required for the calibration. Pluviograph rainfall data is used to understand the temporal distribution of rainfall during calibration events while daily rainfall data provides the spatial variation and rainfall depths for the specific calibration event. Figure 3-11 shows the locations of daily rainfall and pluviograph stations in the region. The number of gauges available is very valuable for the calibration process. Unfortunately the daily rainfall stations are concentrated at the upstream part of the catchment, and coverage is poorer further downstream which will limit the understanding of the spatial distribution of the modelled events.

Pluviograph records for the region were available at nine stations within or, in the vicinity of the catchment, detailed in Table 3-4. Daily rainfall records were obtained from thirty-six daily rainfall stations spread across and around the catchment, detailed in Table 3-5.

Table 3-4 Pluviograph station details

Station name	Station number	Period of Record
BENDIGO AIRPORT	081123	Sep-1992 to Jun-2012
BLACKWOOD (POST OFFICE)	087017	Feb-1974 to Jun-2012
HEATHCOTE	088029	Apr-1968 to Jun-2012
LAURISTON RESERVOIR	088037	Apr-1958 to Jun-2012
WANALTA DEAN STATION	081115	Jul-1974 to Jun-2012
ROCHESTER	406202	Jul-1992 to Jun-2012
PYALONG	405238	May-1966 to Jun-2012
REDESDALE	406213	Jun-1947 to Jun-2012
VAUGHN	407217	Nov-1953 to Jun2012

Table 3-5 Daily rainfall station details

Station Name	Station Number	Period of Record
BAYNTON	88073	Mar-1953 to present
BENLOCH	88117	Jan-1969 to present
BLACKWOOD	87017	Oct 1878 to present
BULLARTO SOUTH	88071	Jul-2001 to present
BULLENGAROOK (NORTH WEST)	87183	Oct-2010 to present
BULLENGAROOK SOUTH	87171	Mar-1992 to present
CASTLEMAINE PRISON	88110	Mar-1966 to present
COLBINABBIN	81008	Mar 1899 to present
DAYLESFORD	88020	Sep 1869 to present
ELMORE	81016	Jan 1882 to present

Station Name	Station Number	Period of Record
EPPALOCK RESERVOIR	81083	Mar-1965 to present
GISBORNE	87026	Jan 1887 to present
GISBOURNE (ROSSLYNNE RESERVOIR)	87182	Sep-2008 to present
GLENLUCE	88165	Aug-2010 to present
HARCOURT	88118	Dec-1968 to present
HEATHCOTE	88029	Jan 1882 to present
HESKET (STRAWS LANE)	87118	Dec-1968 to present
HIGH CAMP (LANNERMOOR)	88121	Jun-1969 to present
KNOWSLEY	81118	Jan-1984 to present
KYNETON	88123	Aug-1969 to present
LANCEFIELD	87029	Jan 1885 to present
LANCEFIELD (WINERY)	87173	Apr-1993 to present
LAURISTON RESERVOIR	88037	Jul-1948 to present
MACEDON FORESTRY	87036	Dec 1873 to present
MALMSBURY RESERVOIR	88042	Aug 1872 to present
MOLLISONS CK AT PYALONG	88064	Feb-2003 to present
NEWHAM (COBAW)	87175	Jan-1995 to present
PYALONG WEST (CAVAN PARK)	88050	May-2000 to present
REDESDALE	88051	Jan-2003 to present
ROCHESTER	80049	Feb-2004 to present
ROMSEY	87130	Feb-1970 to present
TRENTHAM (POST OFFICE)	88059	Jan 1878 to present
VAUGHAN	88108	Nov-1958 to present
WANALTA DAEN STATION	81115	Aug-1974 to present
WOODEND (CARLISLE STREET)	88061	Aug 1889 to present
BENDIGO AIRPORT	81123	Oct-1991 to present

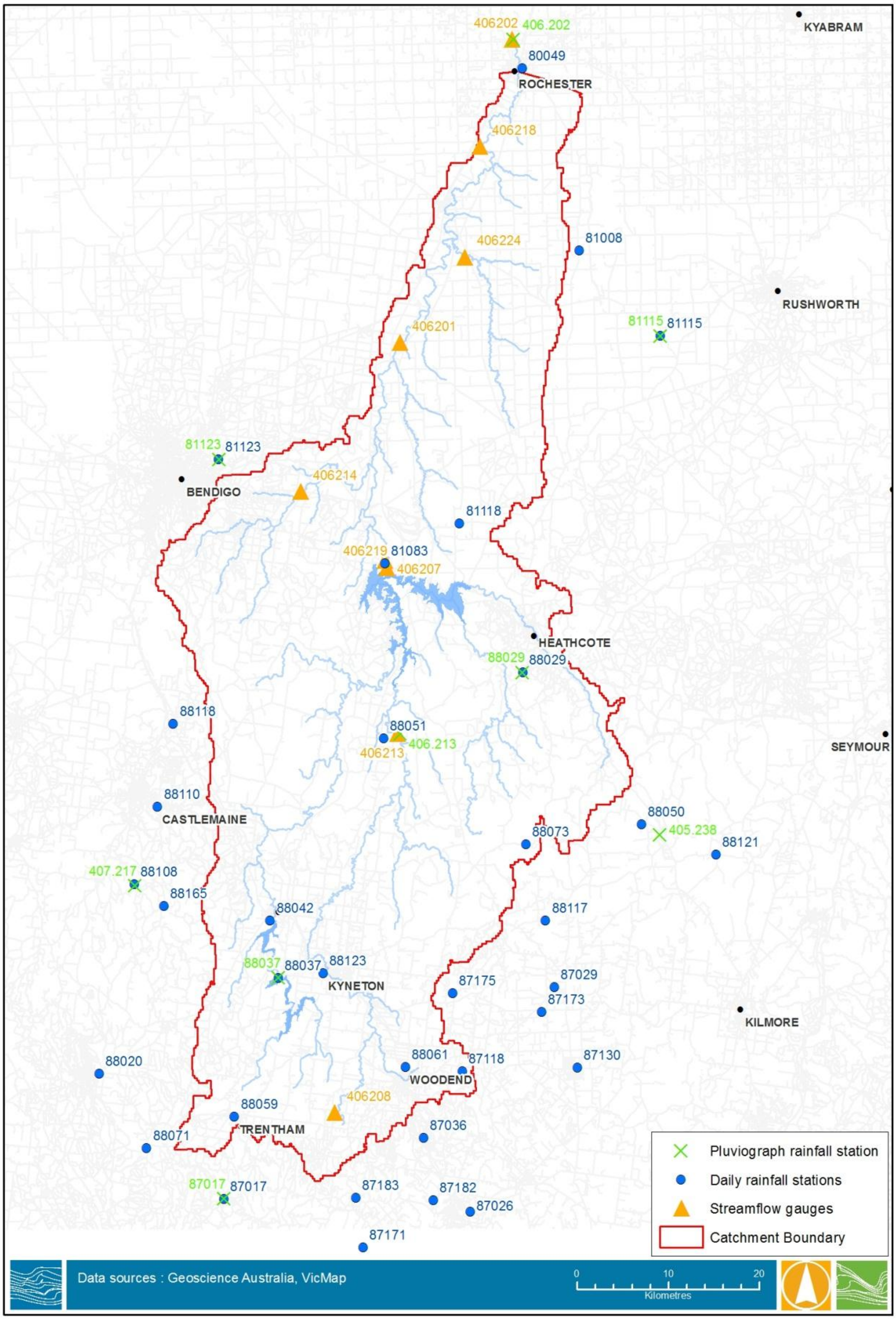


Figure 3-11 **Location of rainfall stations and streamflow gauges for this study**

3.3.3 Storage Data

The main water storages located along the Coliban and Campaspe Rivers, upstream of Rochester are Lake Eppalock, and the Upper Coliban, Lauriston and Malmsbury reservoirs, the last three known collectively as the Upper Coliban Storages (Figure 3-12). These water bodies provide storage for irrigation and water supply for nearby townships and their volumes and catchment areas are detailed in Table 3-6. Coliban Water manages the Upper Coliban Storages and Lake Eppalock is managed by Goulburn-Murray Water.

Table 3-6 Details of storages within the Rochester catchment

Storage name	Volume (ML)	Catchment Area (km2)
Upper Coliban Reservoir	37,770 ML	183
Lauriston Reservoir	19,790 ML	27
Malmsbury Reservoir	12,034 ML	65
Lake Eppalock	304,650 ML (Coliban Water's share is 54,837 ML)	2,028

It is important to include the main storages within the hydrological model as they can have a significant impact on the downstream hydrographs. This is particularly the case for Lake Eppalock. Stage-storage relationships, spillway rating curves and gauged water levels within the storages have been provided by GMW and Coliban Water for these storages.

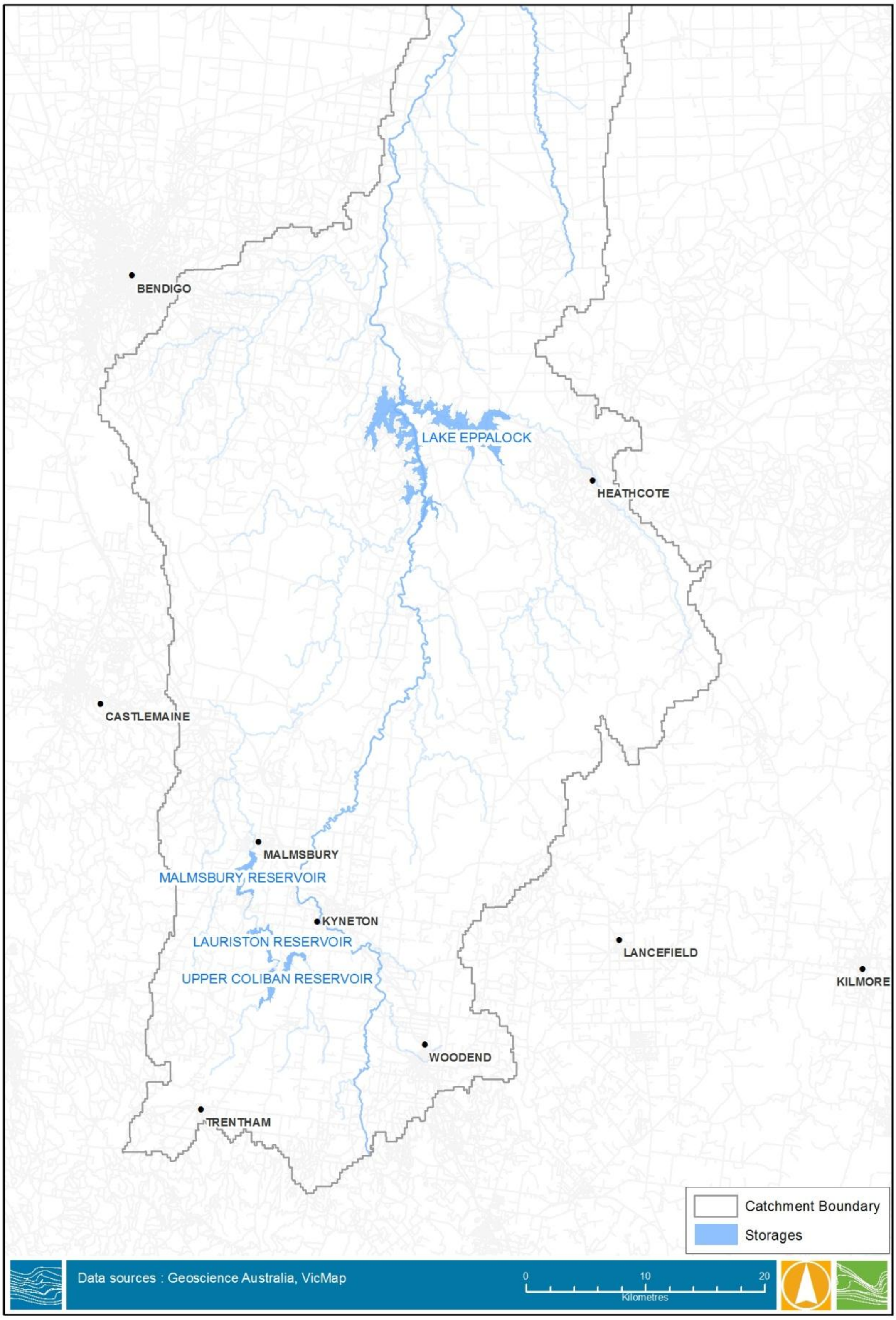


Figure 3-12 Location of Lake Eppalock, Upper Coliban, Lauriston and Malmsbury Reservoirs upstream of Rochester (DSE, 2011)

4. HYDROLOGIC ANALYSIS

A hydrologic model of the catchment was developed for the purpose of extracting flows to be used as boundary conditions in the hydraulic model. The rainfall-runoff program, RORB was utilised for this study.

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

The following methodology was applied for the RORB modelling:

- ArcHydro software was used to provide an initial delineation of the RORB model area (the Campaspe River catchment area upstream of the township of Rochester);
- The resultant delineated catchment was then inspected and manually adjusted based on the site's topography and required hydrograph print (result) locations;
- The RORB model was constructed, selecting reach types, slopes and subarea fraction impervious values;
- Storm files for the November 2010 and January 2011 events were constructed using pluviograph information and daily rainfall totals for the events;
- The RORB model parameter k_c was calibrated to the observed stream flow hydrographs for the November 2010 and January 2011 events, selecting appropriate losses;
- Flood frequency analysis was carried out at the streamflow gauges;
- The RORB model was run in design mode to determine flood quantiles for the 5, 10, 20 and 50 year ARI events. These were compared to flood frequency analysis at the streamflow gauges to determine design loss parameters;
- Flood quantiles, model parameters and losses were compared to regional estimates;
- Design flood events for the 5, 10, 20, 50, 100 and 200 year ARI events were run for multiple durations; and
- A Hydrograph was extracted from RORB for use as an inflow boundary to the hydraulic model;

4.1 RORB Model Construction

4.1.1 Subarea Delineation and Reach Types

The downstream outlet of the RORB model is at the 'Campaspe @ Rochester' gauge, and it covers the entire upstream catchment. The study area's catchment boundary is quite large, and covers an area of approximately 3,345 km^2.

The RORB model was constructed using MiRORB (MapInfo RORB tools), the RORB Graphical User Interface and RORBWin V6.0. Initially a catchment boundary was delineated from the available 10 m contours of the area. Sub-area boundaries were then delineated using ArcHydro GIS software and revised as necessary to allow flows to be extracted at the points of interest. There are 78 sub-areas within the RORB model. Figure 4-1 below shows the RORB sub area delineation for the study area.

Nodes were placed at areas of interest (including streamflow gauges) and the junction of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type. Reach slopes (where necessary) were calculated using a digital elevation model (DEM) created from the 10 m contours.

Reach types in the model were set to be consistent with the land use across the catchment. Five different reach types are available in RORB (1 = natural, 2= excavated & unlined, 3= lined channel or pipe, 4= drowned reach, 5= dummy reach). Drowned reaches were used within the storages. Reach types were determined from site visits and aerial photography and reaches were predominantly set to natural.

Interstation areas can be used in RORB to distinguish between different sub-catchments if necessary. This allows the use of a different routing parameter k_c between sub-catchments but should only be used where catchment characteristics indicate that there are differences in the storage between upper and lower sub-catchments and also where gauged flow information exists to perform calibration. The Rochester catchment is quite large (3,345 km^2) and there are differences in the catchment along the length of the Campaspe River. There are not considered to be significant differences in topography between the upper and lower parts of the Rochester catchment, nor in the density of vegetation cover, and therefore there is likely to be similar storage runoff behaviour through the catchment. The sensitivity of flows to the use of interstation areas and therefore varied routing parameters has been evaluated during calibration and is discussed in more detail in Section 4.2.

RORB requires the calibration of three model parameters (k_c, initial loss and continuing loss). The initial loss / continuing loss model was found to provide a better fit of observed and modelled flood hydrographs and was adopted for this study.

It is acknowledged and important to note that there are a large number of subareas within the model. The model has been designed for use with a hydraulic model and therefore inflows to the model may be required at several different points. Also the methods of subarea delineation have progressed from when RORB was first designed, and it is carried out using GIS programs which can quickly and accurately breakup a catchment using detailed terrain information. It is understood that the subarea size will affect the resulting kc and the ability to compare calibrated parameters to prediction equations. However, given that the model is calibrated to two events, the comparison to regional equations has only been provided to improve confidence in the parameter selection.

4.1.2 Fraction Impervious Data

The RORB model requires an input of fraction impervious values for the subareas. Fraction Impervious values were calculated using MiRORB. Default sub-area fraction impervious values were calculated based on the current planning scheme zones and then reviewed and modified as necessary based on recent aerial photos (from Google Maps and other aerial imagery). The total imperviousness of the catchment was calculated to be 0.054 reflecting the predominantly rural nature of the catchment. The spatial distribution of the fraction impervious data is shown in **Figure 4-2**, showing the Rochester township having a higher fraction impervious than the broader catchment.

Table 4-1 Land use and fraction impervious values

Land Use Zone	Description	Fraction Impervious
Residential Zone	Normal range of densities	0.45
Low Density Residential	0.4 ha min.	0.2
Rural Zone	Rural areas	0.0-0.1
Public Park and Recreation Zone	Open public space	0.01
Road Zone	Secondary and local roads	0.6

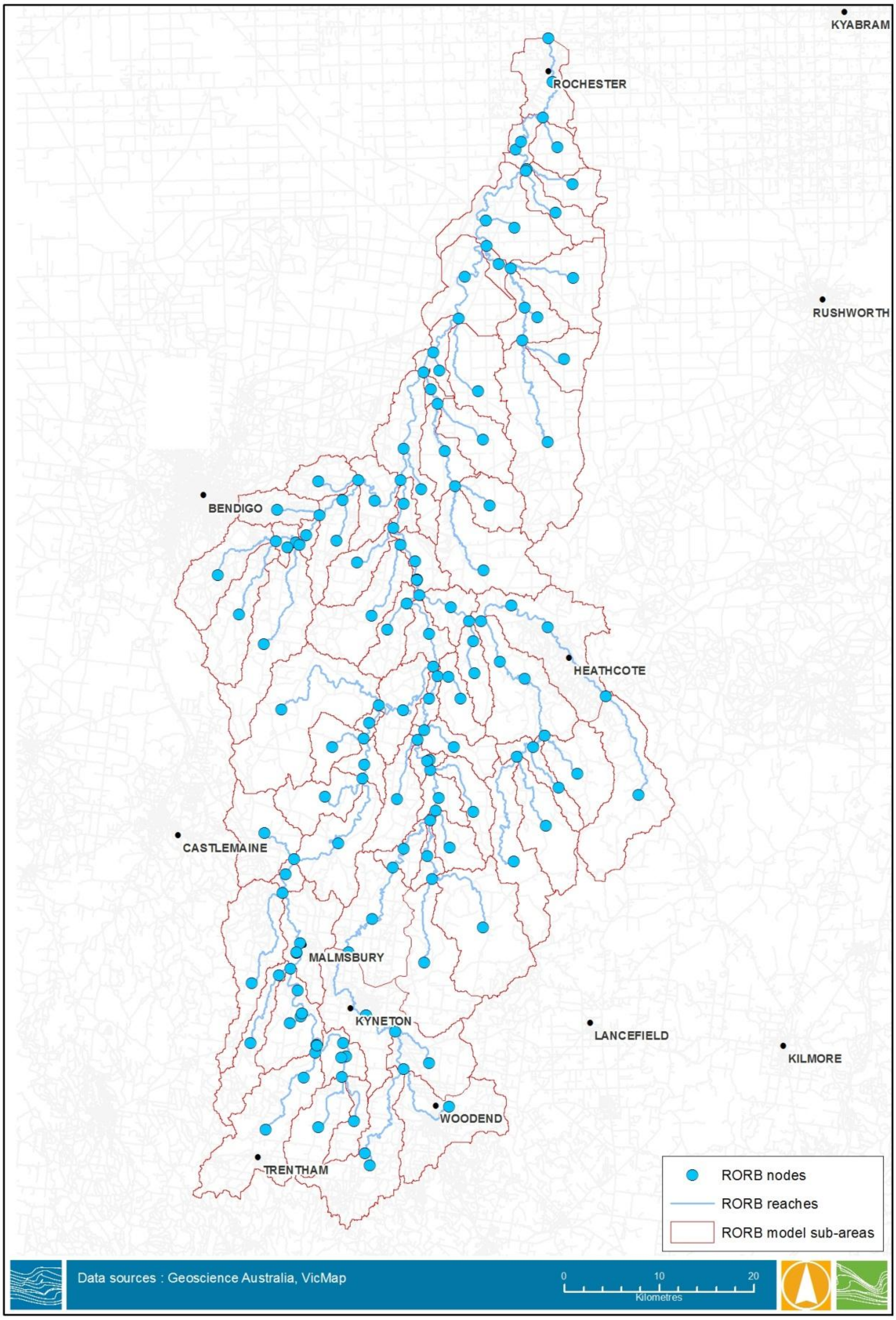


Figure 4-1 Graphical representation of the RORB Model

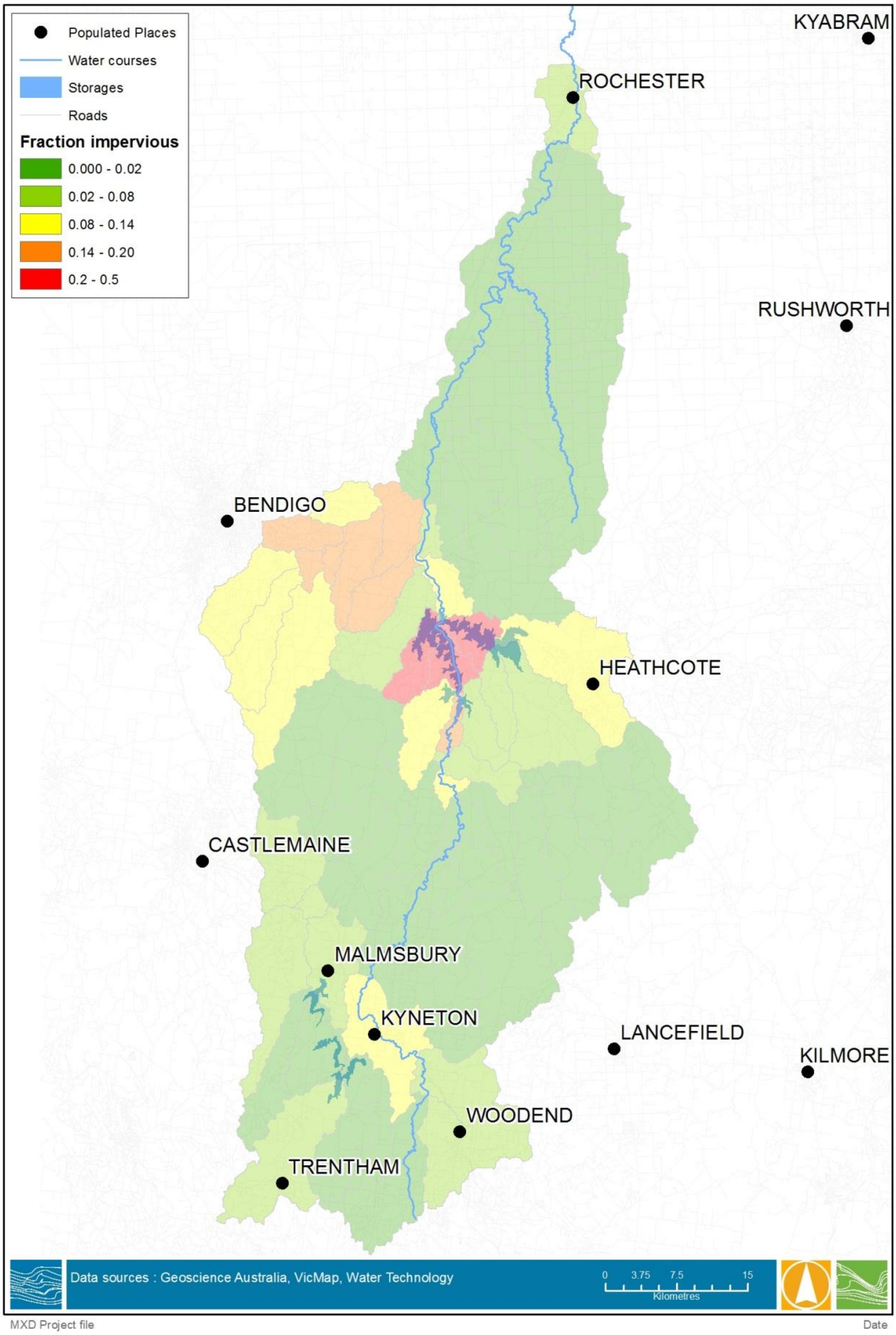


Figure 4-2 RORB Model Fraction Impervious Values

4.1.3 Storage Basins

It is important to incorporate online storages within the hydrological model as they may attenuate flows and can have a significant impact on downstream hydrographs. The initial starting level in Lake Eppalock will highly influence the flows through the Campaspe River. The Upper Coliban storages may have some impact, though this is likely to be overshadowed by Lake Eppalock. Details on the storages are summarised in Table 3-6.

Daily storage level information is available for each structure (supplied by Coliban Water and Goulburn Murray Water). This information was used to set the initial conditions during the calibration process for each event in the RORB model.

To understand the sensitivity of flows to the attenuation provided by Lake Eppalock the RORB model was run with initial storage conditions set to full and empty. The sensitivity analysis compared the peak flow at Rochester for the November and January calibration events and results are shown in Table 4-2 and Table 4-3. A comparison of the resulting hydrographs at Rochester for the November and January event are shown in Figure 4-3 and Figure 4-4.

Table 4-2 Sensitivity analysis of peak flow at Rochester for the November event

Initial Drawdown conditions at Lake Eppalock	Peak flow at Rochester (m^3/s)	% difference in peak flow to historic event
Historic level	321	0
FSL in Lake Eppalock	450	+ 40%
Lake Eppalock empty	321	0 %

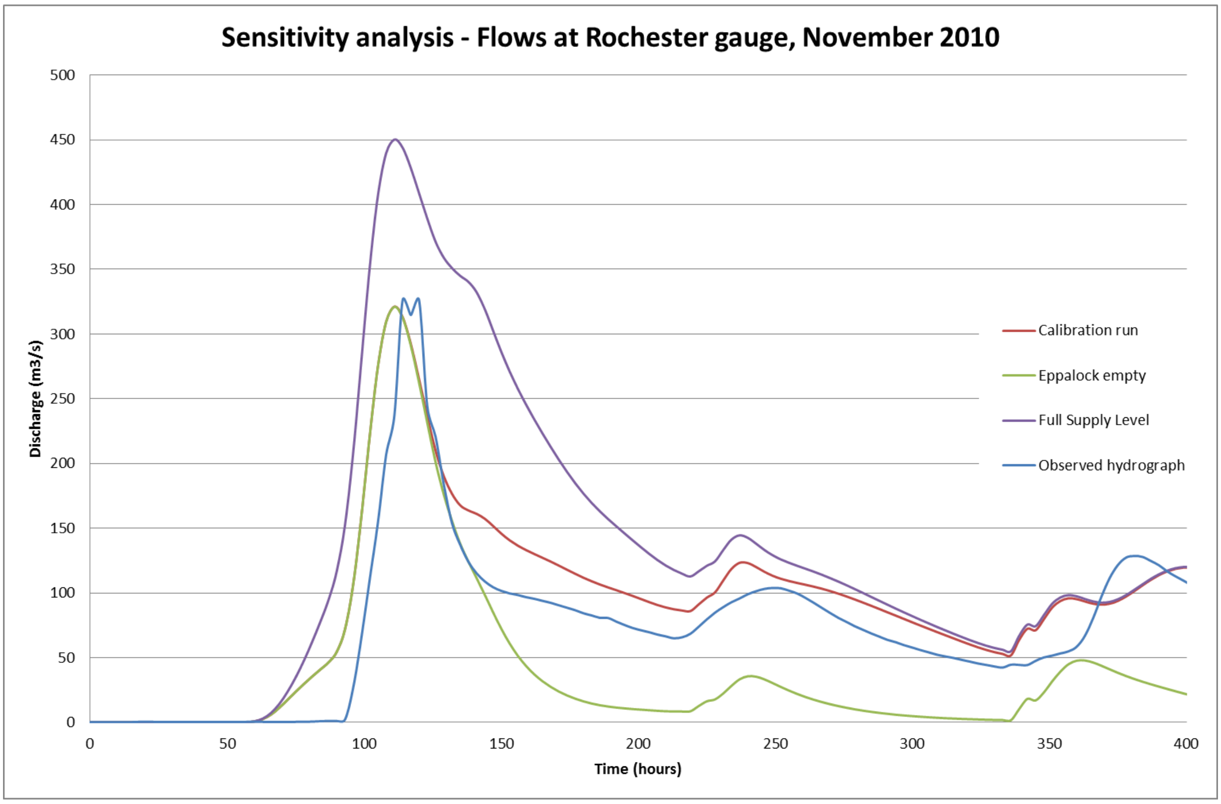


Figure 4-3 Sensitivity analysis on initial storage conditions for the November 2010 event.

Table 4-3 Sensitivity analysis of peak flow at Rochester for the January event

Initial Drawdown conditions at Lake Eppalock	Peak flow at Rochester (m^3/s)	% difference in flow to historic event
Historic level	780	0%
FSL in Lake Eppalock	780	0%
Lake Eppalock empty	270	- 65%

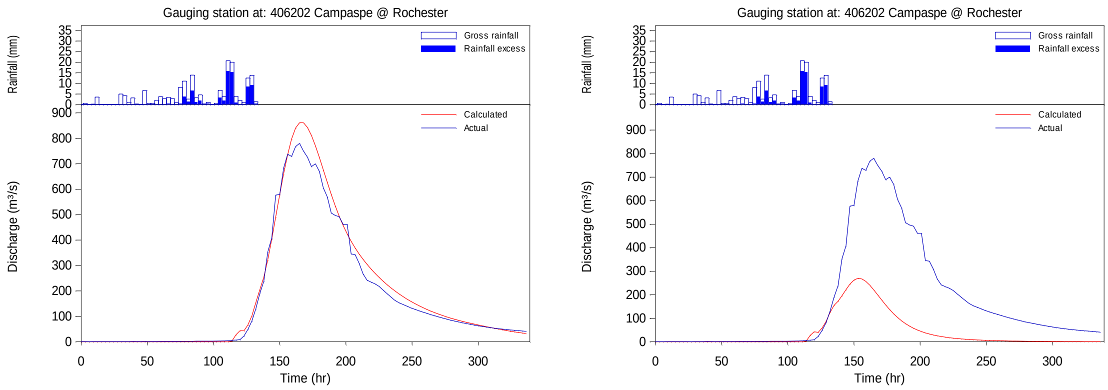


Figure 4-4 Sensitivity analysis on initial storage conditions. At the Rochester station for the January event, resulting hydrographs for full reservoir (left) and empty reservoir (right) as initial conditions.

The figures above clearly demonstrate that for the January event the initial level of Lake Eppalock greatly influences the peak discharge at Rochester. If the January event is modelled with the storage initially empty, the available storage in Lake Eppalock effectively more than halves the flow observed at Rochester when compared with starting the event at FSL. According to recorded flows, the discharge in Mount Pleasant Creek during the January event was 102 m^3/s, about 13% of the total flow into Rochester. This indicates that the majority of the flow arriving at Rochester during January was generated from runoff upstream of the dam.

Conversely, for the November event, the initial drawdown of Lake Eppalock has a smaller impact on the resulting downstream hydrograph. The discharge in Mount Pleasant Creek at Runnymede for this smaller event was similar to the January event - 118 m^3/s, about 36% of the total flow into Rochester. Therefore, the upstream catchment had less impact on the total flow at Rochester during the November 2010 event.

Therefore, in addition to the total volume of flows during an event, the impact of Lake Eppalock on flows at Rochester is driven by two characteristics of the events: (1) the initial drawdown in the reservoir; and (2) the spatial distribution of rainfall over the entire catchment.

Following this analysis and based on the available information, for the purposes of calibration the historic starting volumes were used. The reservoir starting level used in design is discussed in further detail in Section 4.4.3.

4.2 RORB Model Calibration

4.2.1 Overview

The purpose of calibration of the RORB model is the determination of model parameters for the entire catchment for use in design, principally the main parameter k_c. The process involves comparison of modelled flood hydrographs with the observed flood hydrographs at the selected stream flow gauges (see Table 3-3) and adjusting the value of k_c to reproduce both the peak and volume. The RORB model was calibrated to the November 2010 and January 2011 flood events. These events were selected for calibration due to the large size of the events and that they represent recent experiences of flooding.

Calibration of a RORB model requires the adjustment of both k_c and losses (initial and continuing loss). The initial loss / continuing loss model was found to provide a better fit of observed and modelled flood hydrographs and was therefore adopted for this study.

4.2.2 RORB Model calibration event data

Observed Stream Flow Data

Instantaneous streamflow data for the November 2010 and January 2011 flood events was sourced from DSE and Victorian Water Resources Data Warehouse (see Figure 3-8 and Figure 3-9). These streamflow gauges are summarised in Table 3-3.

A review of the gauge data quality codes at the selected sites identified that the event data was of good quality. However, it is noted that data was extrapolated for peak flood events at several of the streamflow gauges. Notably, a review of the streamflow gauge data quality codes at the Rochester site (406202) identified that both the flow and level data was to be used with caution for the high flows during the January event. Examination of the flood hydrograph for this event shows underestimated and unstable records at the peak, not reaching the flow that might be expected considering upstream gauging. That is, at the Eppalock gauge the peak flow recorded was 947 m^3/s, while further downstream the recorded peak flow at Rochester was 822m^3/s. This can be explained by flows bypassing the gauging station due to breakouts from the main channel. It is likely that the oscillation is related to instrumentation error due to very high flows. The hydrograph will still be considered when carrying out the calibration, however, as the volume of the hydrograph, as well as the shape of the rising and falling limbs will still be important in determining appropriate routing parameters.

Baseflow separation

The observed streamflow data consists of surface runoff resulting from the rainfall event and a groundwater component (baseflow). Runoff routing models, such as RORB, only model direct rainfall runoff and therefore it is necessary to understand the different components and, if necessary, separate the total streamflow into surface runoff and baseflow. The analysis of the baseflow contribution to flood hydrographs within the Campaspe River catchment upstream of Rochester showed that the contribution is quite small. The process used to analyse the baseflow contribution to the streamflow in the Campaspe River is described as follows:

- The recorded streamflow hydrograph on either side of the flood event was examined in order to provide an estimate of the general magnitude of the groundwater contribution in the absence of rainfall. The streamflow at the beginning of the hydrograph rise was assumed to be comprised solely of baseflow. A baseflow separation line was drawn by linearly extending the recession curve prior to the stream rise to a point under the peak of the hydrograph. The baseflow hydrograph was assumed to peak after the total hydrograph peak due to the storage-routing effect of the sub-storage stores. The falling limb of the baseflow recession curve was assumed to follow an exponential decay function so as to re-join the total hydrograph at the cessation of surface runoff. This was assumed to occur after the greatest curvature of the recorded streamflow recession curve.

- The calculated proportion of baseflow was removed from the hydrograph input to the hydrological model, even though it had little impact on the results obtained.
- The minimal baseflow contribution is confirmed by the information in "Soils and Land use in the Rochester and Echuca districts, Victoria" (Department of Agriculture, 1964):

"The Riverine Plain of south-eastern Australia is a huge depositional plain which extends over northern Victoria and southern New South Wales. The present-day streams which traverse the Plain are essentially "rivers of transit", i.e., they carry mainly water from the mountain catchments to the Murray River, and the Plain itself contributes but little to their flow. […]The Campaspe River is a well-defined stream with its channel deeply cut into the alluvium of the Plain. However, it has an extremely variable flow and barely flows at all for the greater part of the year, but periodically it floods its banks and causes serious inundation from Rochester to Echuca."

Following review of the data, based on the quality and quantity of available streamflow data, it was understood that sufficient data is available for calibration and that it was likely that events would be replicated with sufficient accuracy for hydraulic modelling purposes (i.e. using flows from the RORB model as boundary conditions and inflows to the hydraulic model).

Observed Rainfall Data

RORB has the option to distribute the rainfall data across separate rainfall bursts throughout an event. The purpose of using separate bursts is to allow the loss parameters to vary across each burst. A multiple burst approach was adopted for the November 2010 event only, as:

- The flooding events used for calibration result from rainfall events that ran over multiple days, resulting in daily variation of rainfall totals (from daily rainfall stations) across subareas;
- The pluviographs (Figure 4-5) show separate rainfall events during the November flood event. The events were separated by a minimum of 24 hour period of no rainfall; and
- The hydrographs recorded at the gauging stations also show multiple peaks. Multi-peaked hydrographs can be calibrated better if the event is treated as a multi burst event. The rainfall depth for each subarea was estimated using storm event rainfall isohyets. Five rainfall isohyets were created, one for the single bursts in January 2011, and three for November 2010, one for each of the three bursts.

The temporal rainfall distribution was determined using the rainfall pattern from the selected pluviographs. Figure 4-5 and Figure 4-6 display the continuous rainfall data recorded at the pluviographs for both events.

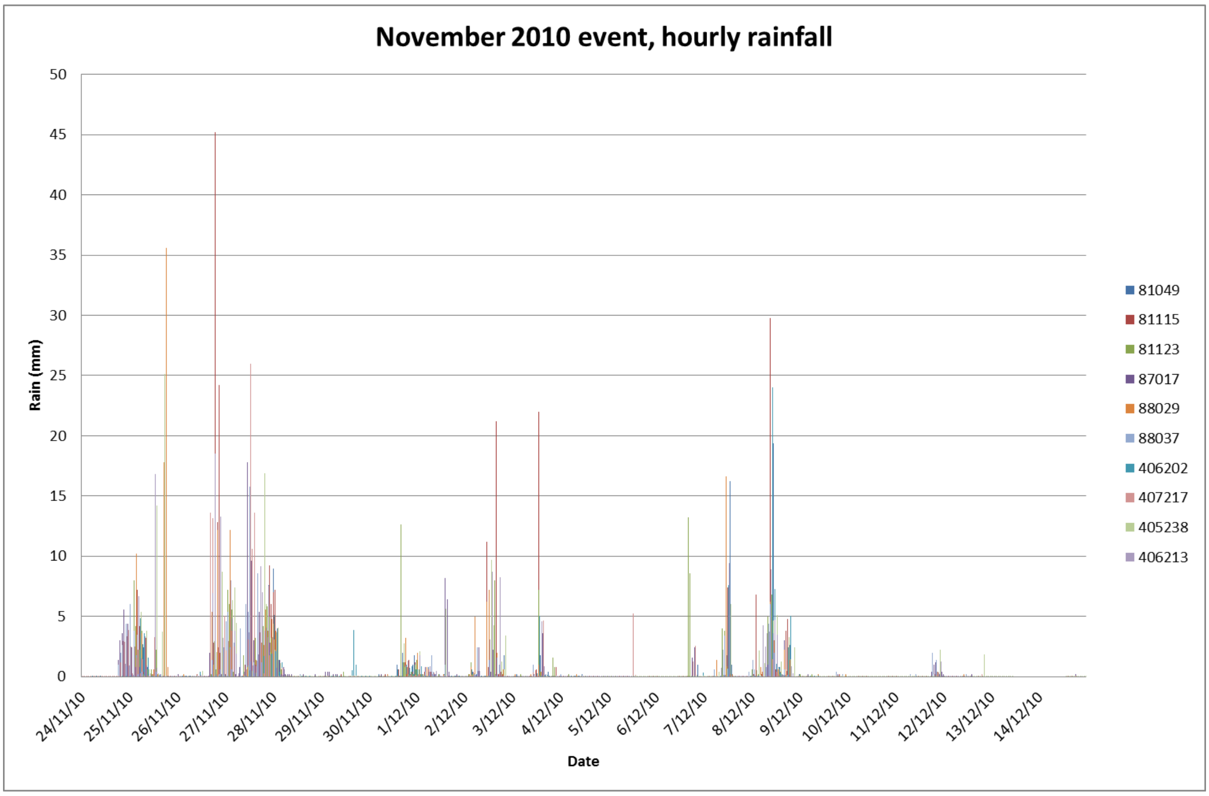


Figure 4-5 Pluviograph records - November 2010 Event

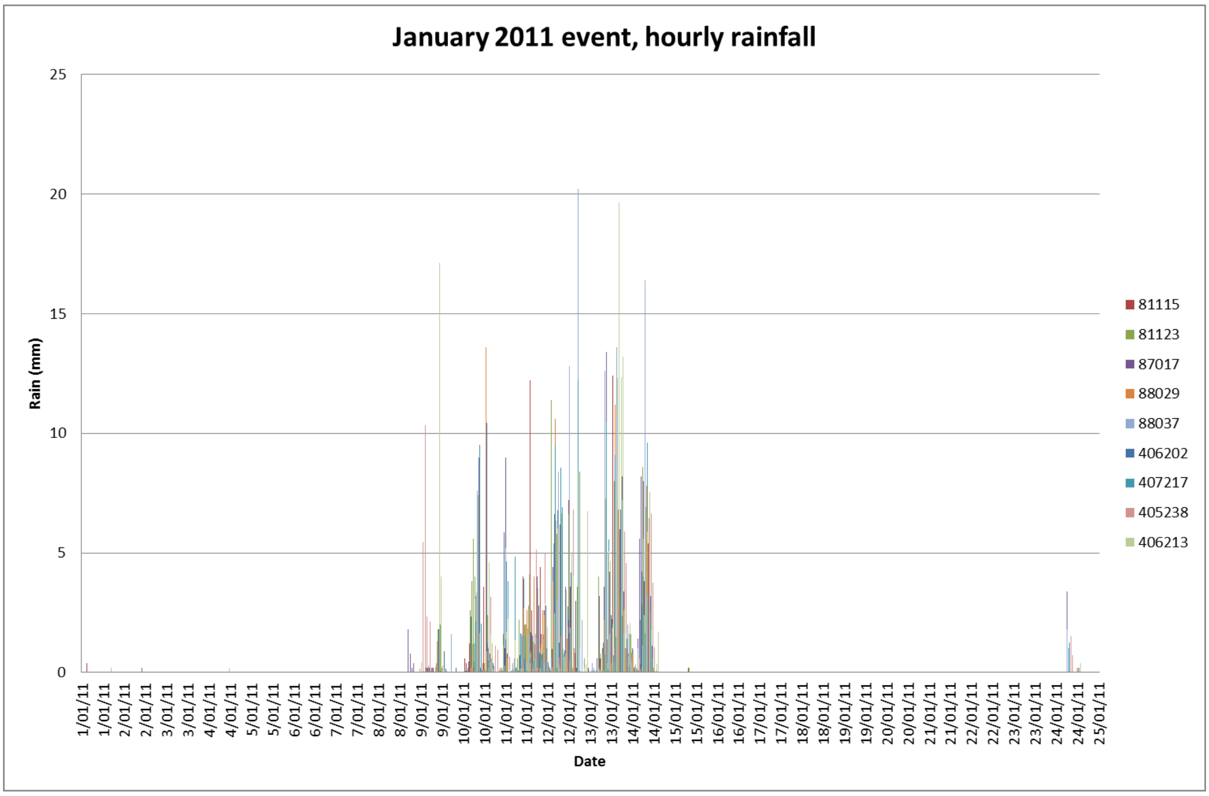


Figure 4-6 Pluviograph records – January 2011 Event

4.2.3 RORB Model Calibration Parameters

Within RORB, the model parameter k_c and losses (i.e. initial and continuous) are used to fit the calculated to the observed hydrograph. An initial loss/continuing loss model was found to provide a better fit of observed and modelled flood hydrographs and was therefore adopted for this study.

The calibration approach adopted for this study was as follows:

- The RORB m value is typically set at 0.80. This value is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987). There are methods for determining m values, one method is Weeks (1980) which uses multiple calibration event to select kc and m. However, given the extrapolation of selected parameters to larger events and the goodness of fit obtained using the recommended value of 0.80, there appears no significant reason to vary it for the Rochester catchment;
- The initial loss parameter (IL) was determined by finding a reasonable match between the modelled and observed rising limbs of the flood hydrograph;
- A continuing loss (CL) was selected to achieve a reasonable fit between the modelled and observed hydrograph volumes; and
- The RORB k_c parameter was initially calculated within RORB using a catchment area relationship (equation 2-5 in version 5 of RORB User Manual). This k_c value was then varied to achieve a reasonable fit of the peak flow and general hydrograph shape. The sensitivity of the calibration to the value of k_c and any improvement in the calibration through use of different parameters for different interstation areas was carried out. Results of this calibration are shown in Appendix A. The Rochester catchment is quite large (3,345 km^2) and there are differences in the catchment along the length of the Campaspe River. There are not considered to be significant differences in topography between the upper and lower parts of the Rochester catchment, nor in the density of vegetation cover, and therefore there is likely to be similar storage runoff behaviour through the catchment. Results of the calibration indicate that varying parameters by interstation area does not result in a greatly improved calibration and therefore a single parameter has been adopted.

Details of the selected calibration events are provided in Table 4-4 below.

Table 4-4: RORB Model Calibration Events

Event	November 2010	January 2011
Event Start & Finish Date	24/11/2010 12:00pm - 12/12/2010 0:00am	09/01/2011 0:00am - 23/01/2011 0:00am
Average Catchment Rainfall (mm)	53.9 mm (4 day period; burst1: 119.5mm, burst2: 26mm, burst3: 16mm)	176 mm (over a 5 day period)
Recorded Peak Flow at Redesdale Gauge (m3/s)	211.8	322.1
Recorded Peak Flow at Eppalock (m3/s)	124.4	931.3

Event	November 2010	January 2011
Recorded Peak Flow at Barnadown Gauge (m3/s)	379.5	706.2
Recorded Peak Flow at Longlea Gauge (m3/s)	92.22	111.8
Recorded Peak Flow at Runnymede Gauge (m3/s)	118	101.9
Recorded Peak Flow at Rochester Gauge (m3/s)	326.1	779.9

Note: Values reported here are values extracted from gauging records that have been interpolated to a 3 hour time step (RORB input), i.e. some minor differences with raw data can be found at peak values.

4.2.4 November 2010 Flood Event Calibration

Based on examination of daily rainfall, pluviograph and streamflow data, the November 2010 event was modelled from 12:00pm on 24th November 2010 to 00:00 am on 12th December 2010, with the first burst considered to be from 12:00pm on 24th November to 3:00pm on 30th November, the second burst from 3:00pm on 30th November to 3:00pm on 6th December and the third burst from 3:00pm on 6th December to 03:00 am on 9th December. Observed and calculated hydrographs at Campaspe at Redesdale (406213), Campaspe at Eppalock (406207), Axe Creek at Longlea (406214), Campaspe at Barnadown (406201), Mt Pleasant Creek at Runnymede (406224) and Campaspe at Rochester (406202) are compared in Figure 4-7 to Figure 4-12. The k_c and m values adopted are summarised in Table 4-5.

The RORB model calibration for the November 2010 flood event is considered good. The three peaks observed at the streamflow gauges are reproduced within satisfactory error bounds (given the uncertainty of several variables).

It is important to note that the difference in observed and estimated peak flow at Rochester is -1.1%, while the difference between estimated and observed flood volume is 24.5%. The fit of the calculated to observed rising and falling limbs is considered good for the first two peaks at the Rochester gauge. This reflects an accurate match between calculated and observed hydrographs.

Table 4-5 RORB Calibration Parameters and Results – November 2010

Location		Campaspe @ Redesdale	Campaspe @ Eppalock	Axe Creek @ Longlea	Campaspe @ Barnadown	Mt Pleasant Creek @ Runnymede	Campaspe @ Rochester
Model Parameters	k_c	161.5	161.5	161.5	161.5	161.5	161.5
	IL1	50	45	40	60	81	55
	CL1	2.4	1.5	2.8	0.2	0.1	0.8
	IL2	10	0	30	28	27	20
	CL2	1	0.4	2.5	2.5	0.7	1
	IL3	0	6	15	6	12	5
	CL3	0	0	0	0.5	0	0.2
Peak flow (m^3/s)	Observed	211.8	124.4	92.2	379.5	118.0	326.1
	Calculated	234.1	119.5	97.3	287.1	109.1	322.7
	Relative difference (%)	10.5	-4.0	5.5	-24.3	-7.5	-1.1
Volume (ML)	Observed	505,305	1,187,928	147,019	1,209,341	94,408	1,304,594
	Calculated	465,775	1,090,312	144,146	1,493,560	109,763	1,624,320
	Relative difference (%)	-7.8	-8.2	-2.0	23.5	16.3	24.5

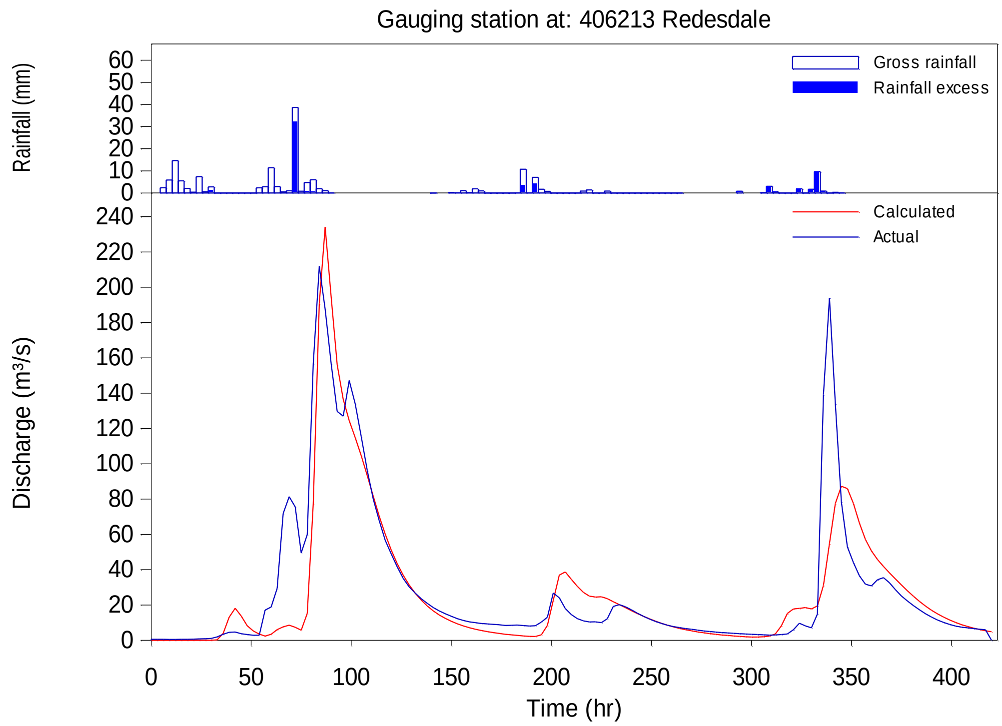


Figure 4-7 Comparison of modelled and observed surface runoff hydrographs for the November 2010 event on the Campaspe River at the Redesdale gauge (406213). The station is located upstream of Lake Eppalock.

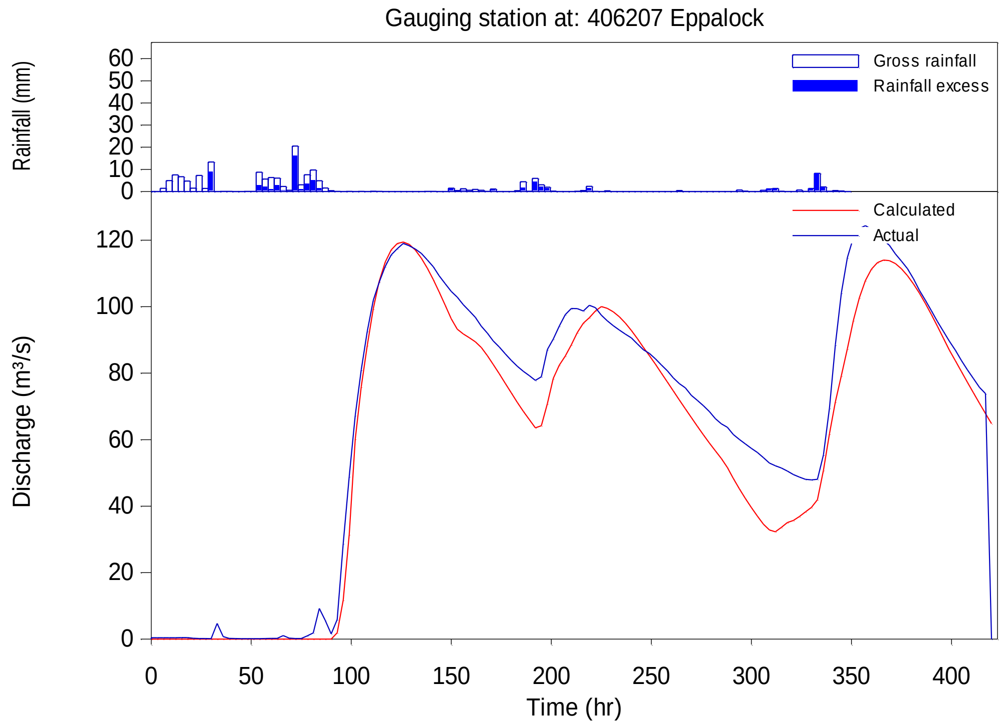


Figure 4-8 **Comparison of modelled and observed surface runoff hydrographs for the November 2010 Event on the Campaspe River at Lake Eppalock Head gauge (406207)**

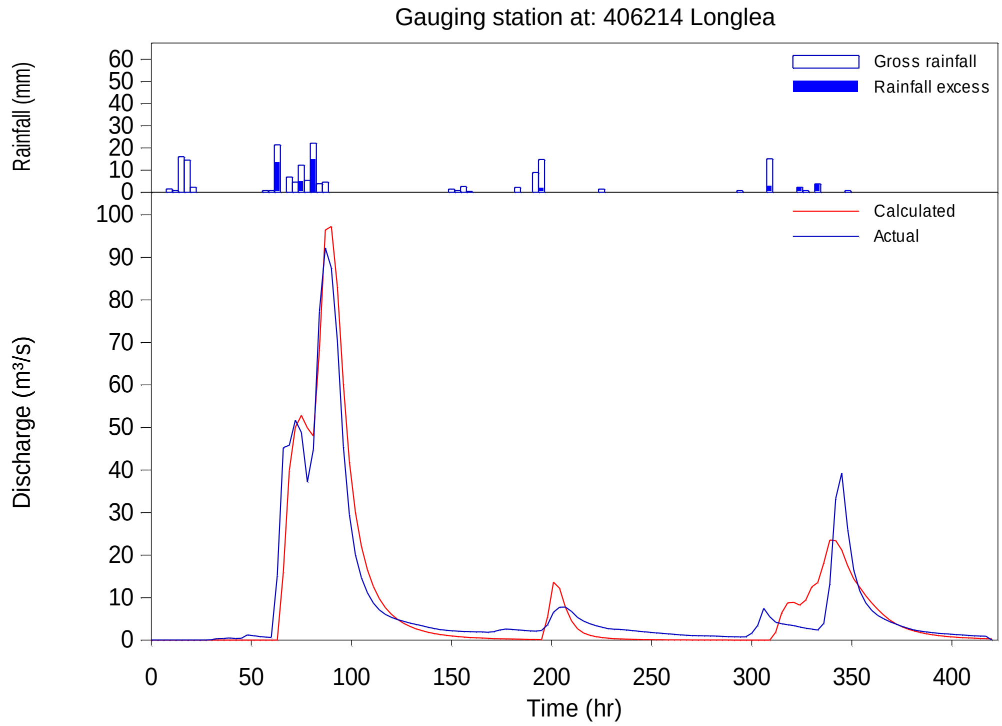


Figure 4-9 **Comparison of modelled and observed surface runoff hydrographs for the November 2010 Event on Axe Creek at the Longlea gauge (406214)**

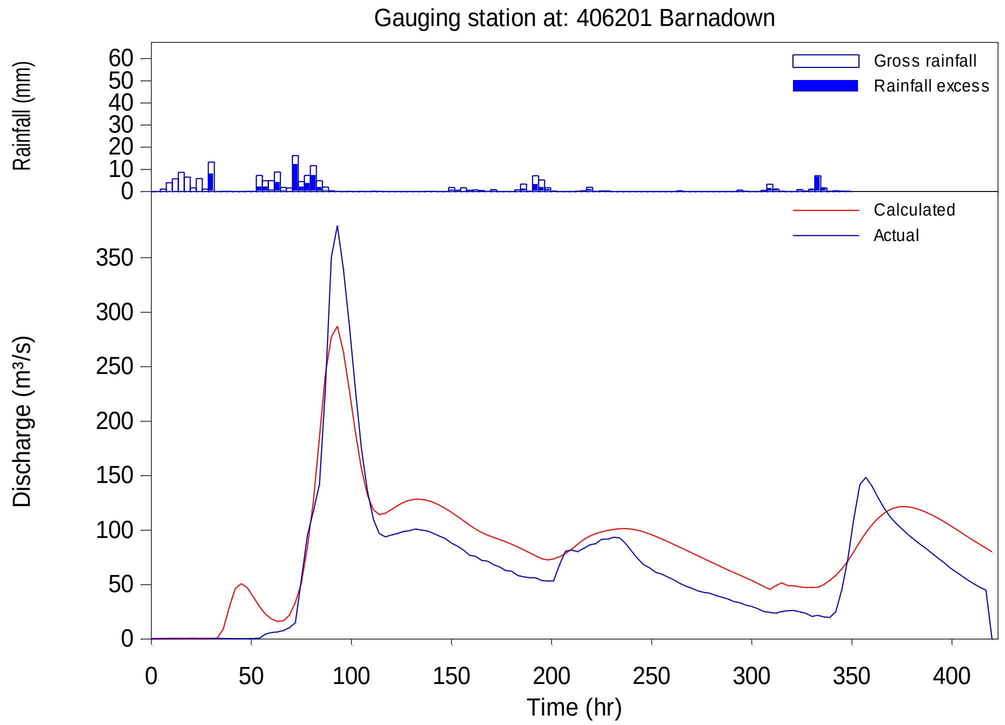


Figure 4-10 **Comparison of modelled and observed surface runoff hydrographs for the November 2010 event on the Campaspe River at the Barnadown gauge (406201), the station is located between Lake Eppalock and Rochester.**

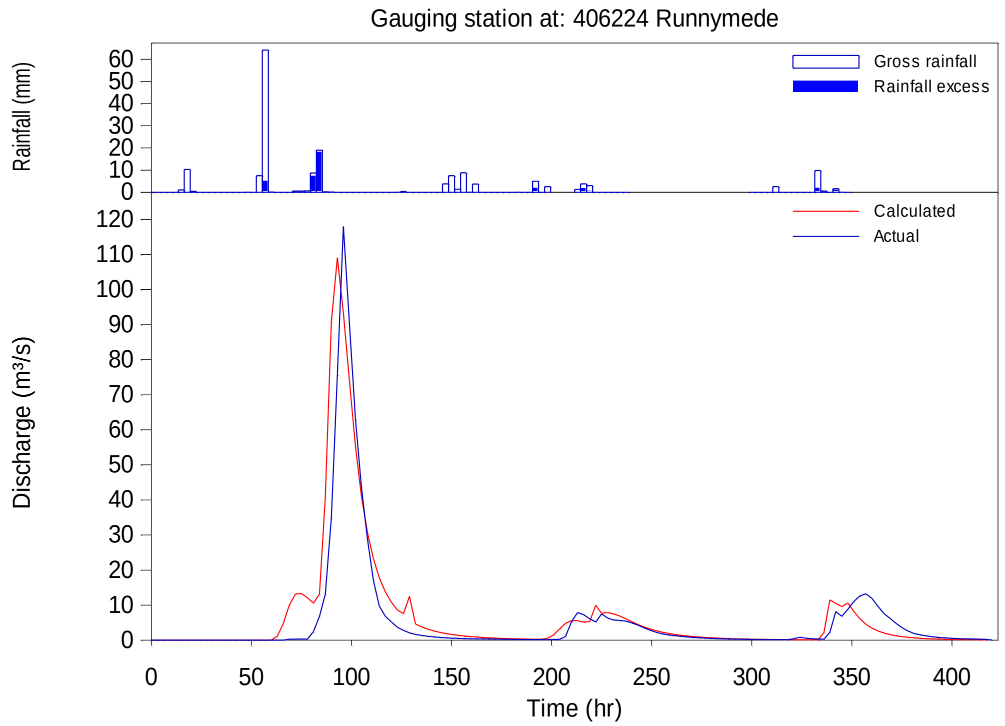


Figure 4-11 **Comparison of modelled and observed surface runoff hydrographs for the November 2010 Event on Mt Pleasant creek at the Runnymede gauge (406224).**

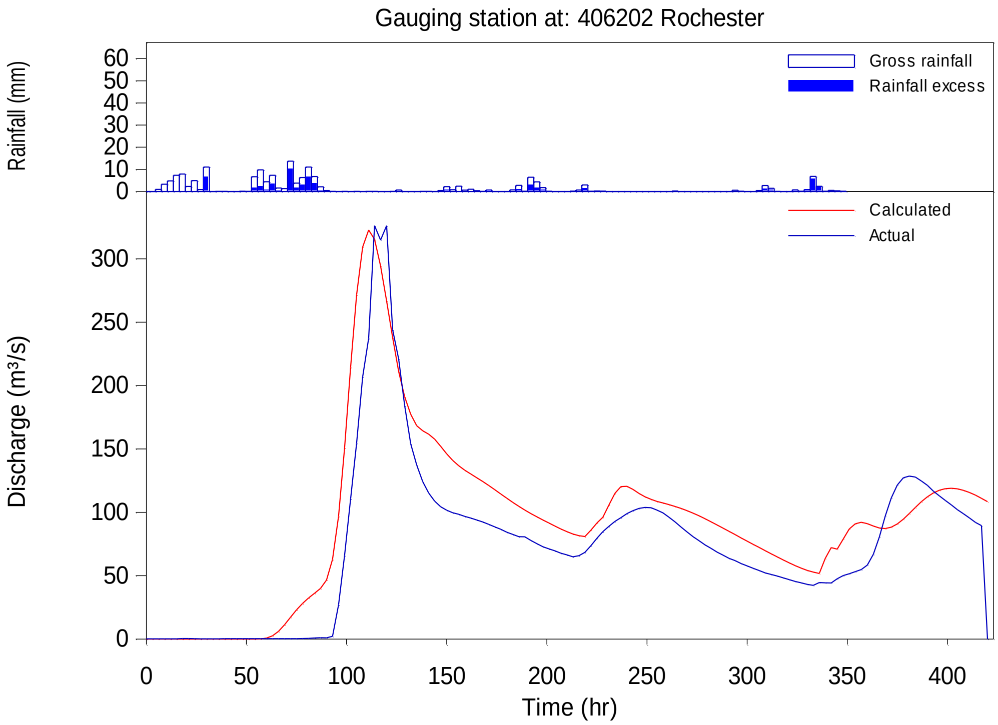


Figure 4-12 **Comparison of modelled and observed surface runoff hydrographs for the November 2010 event on the Campaspe River at the Rochester town gauge (406202).**

4.2.5 January 2011 Flood Event Calibration

Based on examination of daily rainfall, pluviograph and streamflow data, the January 2011 event was modelled from 12:00am on 9rd January 2011 to 12:00am on 23th January 2011, with a single burst. The initial storage level for this event, corresponding to 193.9 mAHD at Lake Eppalock, 479.46 mAHD at Lauriston reservoir, 447.58 mAHD at Malmsbury reservoir and 505.51 mAHD at Upper Coliban reservoir on the 9/01/2011 represent an initial drawdown of 325ML, 80ML, 394ML and 198ML respectively. Observed and calculated hydrographs at Campaspe at Redesdale (406213), Campaspe at Eppalock (406207), Axe Creek at Longlea (406214), Campaspe at Barnadown (406201), Mt Pleasant Creek at Runnymede (406224) and Campaspe at Rochester (406202) are compared in Figure 4-13 to Figure 4-18. The k_c and m values adopted are summarised in Table 4-6.

The RORB model calibration for the January 2011 flood event is considered good.

The observed and calculated results match well in terms of both the general hydrograph shape and in terms of timing. All modelled flows occur within a 5 hour interval of the observed data, especially with respect to peak flow and rising and falling limbs of the hydrographs. The results obtained at Lake Eppalock Head gauge appear to be particularly good, and fit to the observed data very well for both volume and rising and falling limbs, showing a relative difference -10.4% in flood volume and a very close match regarding the hydrograph's shape.

As described in previous sections, there are data quality issues at the streamflow gauge at Rochester and therefore this is reflected in the matching of the calculated to observed hydrographs. This is particularly the case for the January 2011 event which is the largest flood on record, and therefore discrepancies are to be expected. The difference in observed and estimated peak flow is 10.4% at Rochester, while the difference between estimated and observed flood volume is 8.4%. The fit of the calculated to observed hydrograph, including both the rising and falling limbs is considered to be acceptable at Rochester. The model is overestimating runoff in terms of both peak flow and volume; however this is expected given that the recorded flow is likely to be an underestimate. This is due to breakouts from the Campaspe River occurring just upstream of the township that are not able to be explicitly modelled, as well as some failure of the gauge during high flows.

Results of the calibration process are summarized in Table 4-6.

Table 4-6 RORB Calibration Parameters and results – January 2011

Location		Campaspe @ Redesdale	Campaspe @ Eppalock	Axe Creek @ Longlea	Campaspe @ Barnadown	Mt Pleasant Creek @ Runnymede	Campaspe @ Rochester
Model Parameters	k_c	161.5	161.5	161.5	161.5	161.5	161.5
	IL	82	60	90	60	65	60
	CL	2.6	0.8	2.4	2.5	1.5	2
Peak flow (m3/s)	Observed	322.1	931.3	111.8	706.2	101.9	779.9
	Calculated	336.8	781.3	115.3	879.0	102.6	861.4
	Relative difference (%)	4.6	-16.1	3.1	24.5	0.7	10.4
Volume (ML)	Observed	544,958	2,340,424	140,301	1,897,562	106,505	2,399,568
	Calculated	572,477	2,097,780	138,029	2,411,912	125,959	2,601,022
	Relative difference (%)	5.0	-10.4	-1.6	27.1	18.3	8.4

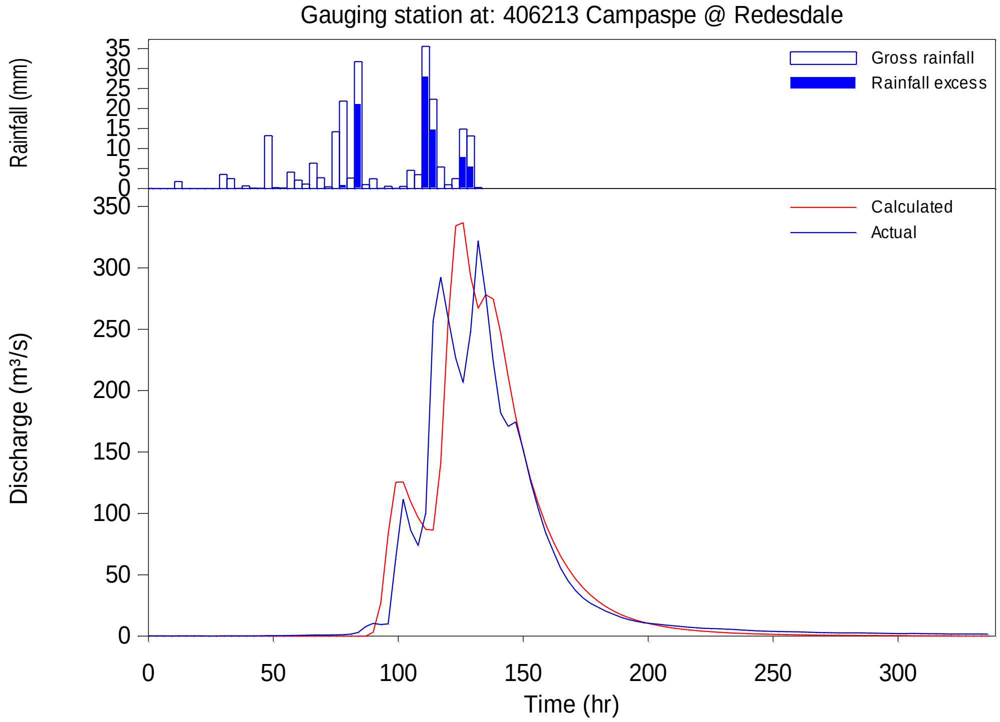


Figure 4-13 **Comparison of modelled and observed surface runoff hydrographs for the January 2011 event on the Campaspe River at the Redesdale gauge (406213), the station is located upstream of Lake Eppalock.**

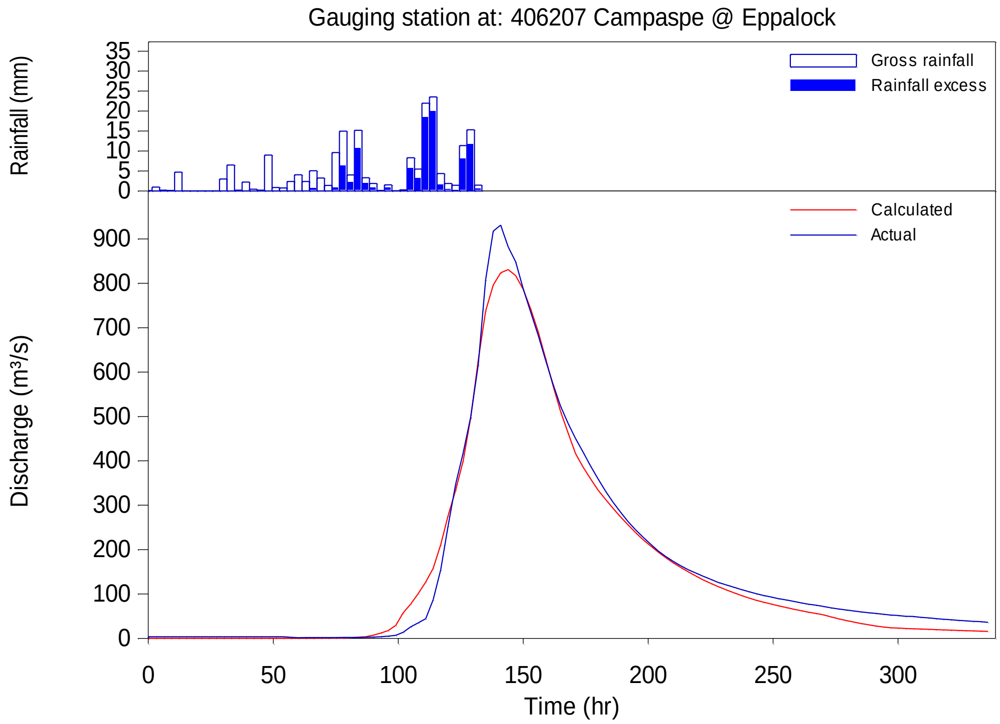


Figure 4-14 **Comparison of modelled and observed surface runoff hydrographs for the January 2011 Event on the Campaspe River at Lake Eppalock Head gauge (406207)**

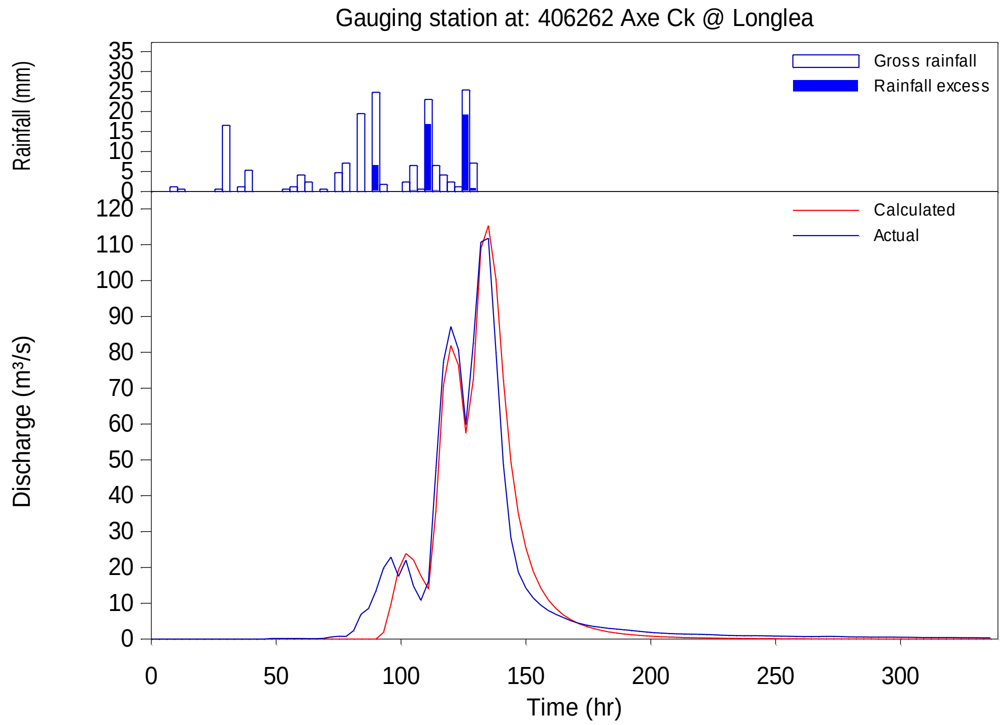


Figure 4-15 Comparison of modelled and observed surface runoff hydrographs for the January 2011 event on the Axe Creek at Longlea gauge (407214).

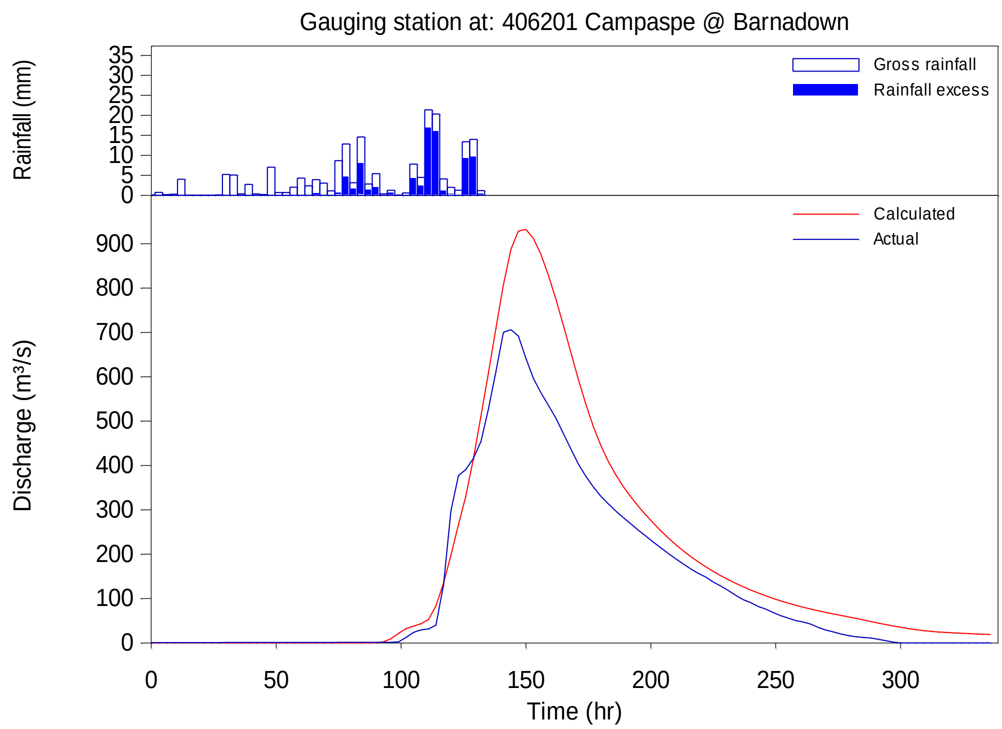


Figure 4-16 Comparison of modelled and observed surface runoff hydrographs for the January 2011 event on the Campaspe River at the Barnadown gauge (406201). The station is located between Lake Eppalock and Rochester.

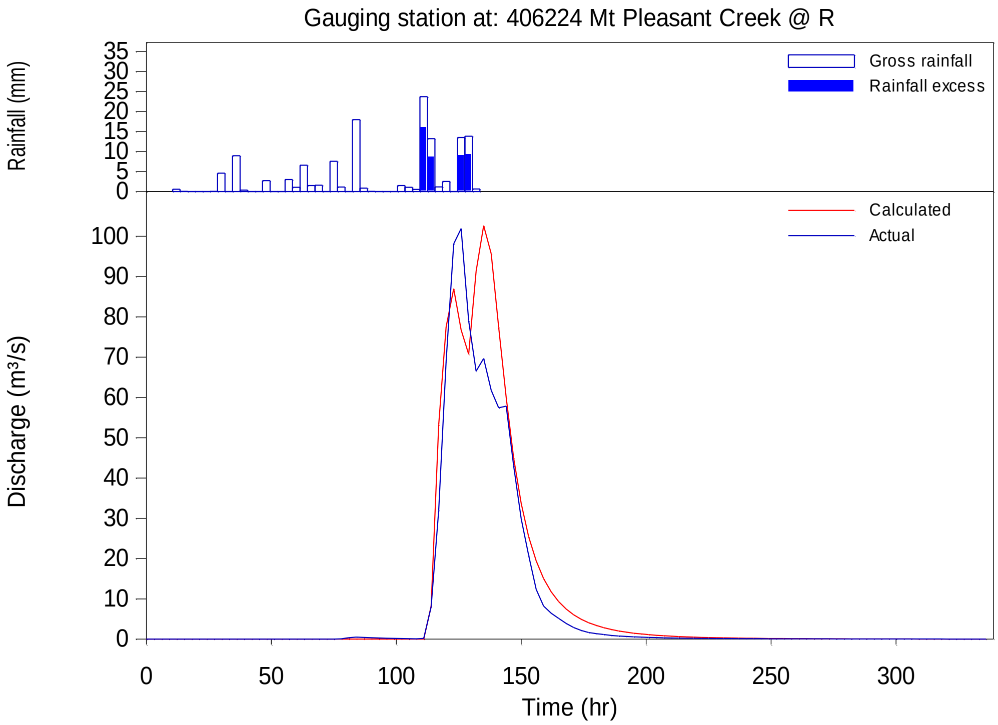


Figure 4-17 Comparison of modelled and observed surface runoff hydrographs for the January 2011 Event on Mt Pleasant Creek at the Runnymede gauge (406224).

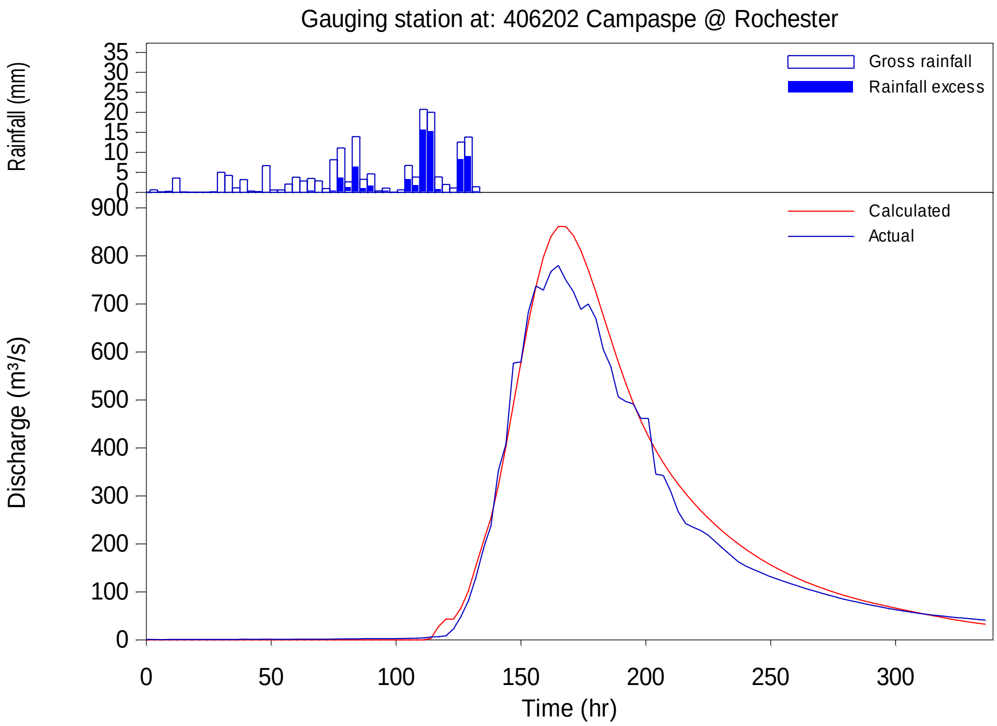


Figure 4-18 Comparison of modelled and observed surface runoff hydrographs for the January 2011 event on the Campaspe River at the Rochester town gauge (406202).

4.3 Discussion

4.3.1 Routing Parameters

All events were calibrated with m set to 0.8. Book VI of Australian Rainfall and Runoff recommends that in cases where there is insufficient data to examine the potential variation of non-linearity with event magnitude that a value of 0.8 is adopted for extreme flood estimation. Weeks (1980) provides an approach that allows selection of both k_c and m values if there are multiple historical events that can be used in calibration. Though this may potentially lead to a better fit between observed and calculated data, the RORB model of the Campaspe River to Rochester was calibrated to two large events with these parameters then extrapolated to the design runs. Calibration to two events is considered accurate for this purpose, however it is not considered sufficient to understand the variation in non-linearity. Therefore m was set to 0.8 for calibration events and then also adopted for design runs.

Estimation of design floods is typically based on the “design event” approach, as has been applied in this study. Using this approach, a single, fixed value is estimated for losses, rainfall temporal patterns, spatial patterns and reservoir drawdown. Considerable effort is made to ensure that the single values of the adopted parameters are appropriate for design flood estimation and are “AEP-neutral”. AEP-neutrality means that the resulting flood has the same AEP as its causative rainfall (that is a 1 in 100 rainfall results in a 1 in 100 flood).

For each of the calibration events, a unique value of the routing parameters was obtained for the whole catchment, and the calibrated k_c values are as shown in Table 4-7. An indication of the travel distance to the outlet is given by d_{av}. This is the weighted average flow distance from all nodes to the catchment outlet and is shown in the following table for the whole catchment. The results indicate that the average k_c / d_{av} is reasonably consistent across the two flood events to which the RORB model was calibrated.

Table 4-7 RORB model routing parameters

Area	dav	November 2010		January 2011	
		k_c	k_c / da_v	k_c	k_c / da_v
406213 - Redesdale	45.45	161.5	3.55	161.5	3.55
406207 - Eppalock	54.36	161.5	2.97	161.5	2.97
406214 - Longlea	18.95	161.5	8.52	161.5	8.52
406201 - Barnadown	26.60	161.5	6.07	161.5	4.46
406224 - Runnymede	22.47	161.5	7.19	161.5	7.19
406202 - Rochester	37.07	161.5	4.36	161.5	4.36
Average:		**161.5**	**5.18**	**161.5**	**5.18**

Based on the results in Table 4-7, the initial decision was to set K_c to 161.5 for the modelled catchment upstream of Rochester.

Due to a large amount of data available for calibration, the achieved fit of calculated to observed data is considered good. Given that the value of routing parameters obtained through calibration is extrapolated to design events and used to estimate flows for a range of ARIs, the calibrated value was compared to recommended parameters from prediction equations and regional equations. The resulting k_c values are shown in Table 4-8.

Table 4-8 Additional regional prediction equation estimates of routing parameter

Method	Applicable Region	Equation	Predicted k_c
RORB default equation	Australia wide	$k_c = 2.2* A^{0.5}*(Qp/2)^{0.8-m}$	127.2
Regional Equation	For Areas where Annual Rainfall <800mm	$k_c = 0.49*A^{0.65}$	95.7
Regional Equation	For Areas where Annual Rainfall >800mm	$k_c = 2.57*A^{0.45}$	99.1
Pearse et al. (2002) after Dyer (1994)	Australia wide	$k_c = 1.14 \times d_{av}$	147.3
Pearse et al. (2002) after Yu (1989)	Australia wide	$k_c = 0.96 \times d_{av}$	124.0

A review of the k_c values determined from alternative methods suggested that the parameters determined from calibration were reasonable. It was deemed that the k_c values determined from calibration were appropriate and adopted for use in design runs.

Table 4-9 Adopted RORB model parameters

k_c	m
161.5	0.8

4.3.2 Losses

To achieve a reasonable fit between the observed and design hydrographs significant losses were required, as shown in Table 4-10.

Table 4-10 RORB model loss parameters (Calibration runs)

Area	November 2010						January 2011	
	IL1	CL1	IL2	CL2	IL3	CL3	IL	CL
406213 - Redesdale	50.0	2.4	10.0	1.0	0.0	0.0	50.0	2.4
406207 - Eppalock	45.0	1.5	0.0	0.4	0.0	0.0	45.0	1.5
406214 - Longlea	40.0	2.8	30.0	2.5	15.0	0.0	40.0	2.8
406201 - Barnadown	60.0	0.2	28.0	2.5	6.0	0.5	60.0	0.2
406224 - Runnymede	81.0	0.1	27.0	0.7	12.0	0.0	81.0	0.1
406202 - Rochester	55.0	0.8	20.0	1.0	5.0	0.2	55.0	0.8

The losses applied to design runs will not be based on the losses adopted in the calibration events. Losses applied for the November 2010 and January 2011 are highly dependent on antecedent catchment conditions and are not suitable for design flood estimation.

Therefore, regional design losses as described in Hill, Mein and Siriwardene (1998) were calculated to use as a first estimate of design losses. These losses are show in Table 4-11 and indicate that in this region significant initial and continuing losses are likely.

Initial loss equation:

$$ILs = -25.8 * BFI + 33.8 \quad (1)$$

Burst initial loss:

$$ILb = ILs * \left\{1 - \frac{1}{1 + 142 * \frac{\sqrt{duration}}{MAR}}\right\} \quad (2)$$

Continuing loss:

$$CL = (7.97 * BFI) + (0.00659 * PET) - 6 \quad (3)$$

Where;

BFI = the baseflow index is defined as the volume of the baseflow divided by the total stream flow volume. It is a fixed value for a given catchment, determined as an average ratio over a long period of time.

PET = the mean annual potential evapotranspiration (mm), estimated from climate or pan evaporation data.

duration = the burst duration (hours)

MAR = the mean annual rainfall for the catchment

The resulting losses are shown in Table 4-11 and indicate that in this region significant initial and continuing losses are likely. The calculated initial loss in this method is entirely a function of baseflow and calculations on streamflow data yield a low base flow of approximately 8%. This correlates with the gauge results which show that Campaspe River has quite a low flow the rest of the year.

Verification of design flows to flood frequency analysis of gauged streamflows is used to determine design losses, as discussed in Section 4.4.4 below.

Table 4-11 RORB losses from Hill et al (1998)

Loss Type	Loss (mm)
Storm Initial Loss	30.93
Continuing Loss	3.33

In Book II section 3 of the AR&R guide book the following values to represent design losses are recommended for the area, values are listed in Table 4-12.

Table 4-12 Design loss rates for Victoria (AR&R)

Location	Loss Model and Design Parameters		References
South and East of the Great Dividing Range	Initial loss - continuing loss		
	Median continuing loss = 2.5mm/h		Cordery & Pilgrim (1983)
	Initial loss = 25-35mm		MMBW
	Initial loss = 15-20mm		Rural Water Commission
North and West of the Great Dividing Range	Probably as for similar areas of NSW		
	Initial loss	Initial loss 10 to 35mm, varying with catchment size and mean annual rainfall.	Cordery (1970a), Cordery and Webb (1974) and
	Continuing loss	Continuing loss 2.5mm/h	Avery (1986)

4.4 Design Event Modelling

The aim of the RORB model design runs is to provide design flow hydrographs over a range of ARIs for input into the hydraulic model. For this study the 5, 10, 20, 50, 100 and 200 year ARI events were run. The inputs for the design flood estimation are described below.

4.4.1 Design Rainfall

Design rainfall depths

Design rainfall depths were determined using the IFD methodology outlined in AR&R Volume 2, 1987. IFD parameters were generated from the Bureau of Meteorology's online IFD tool. Table 4-13 below shows preliminary values extracted from the BOM online IFD extraction tool for several locations in the Rochester catchment (see Figure 4-19 below).

The variation in IFD parameters and resulting design rainfalls was explored. Table 4-14 shows the variation in the 1:100 year rainfall intensity across the catchment and that rainfall intensities are higher in the upper catchment. Therefore, two locations will be used for extracting design rainfalls – upstream and downstream of Lake Eppalock.

Table 4-13 Catchment IFD Parameters

Location	$2I_1$ (mm/hr)	$2I_{12}$ (mm/hr)	$2I_{72}$ (mm/hr)	$50I_1$ (mm/hr)	$50I_{12}$ (mm/hr)	$50I_{72}$ (mm/hr)	G	F2	F50	Zone
Rochester	18.4	3.21	0.86	39.5	7.00	1.84	0.12	4.34	15.03	2
Lake Eppalock	19.7	3.67	0.93	42.1	7.21	1.96	0.2	4.33	14.98	2
Redesdale	20	3.94	1.01	42.5	7.43	2.05	0.23	4.33	14.97	2
Ashbourne	19.9	4.3	1.26	43	8.68	2.58	0.31	4.32	14.93	2

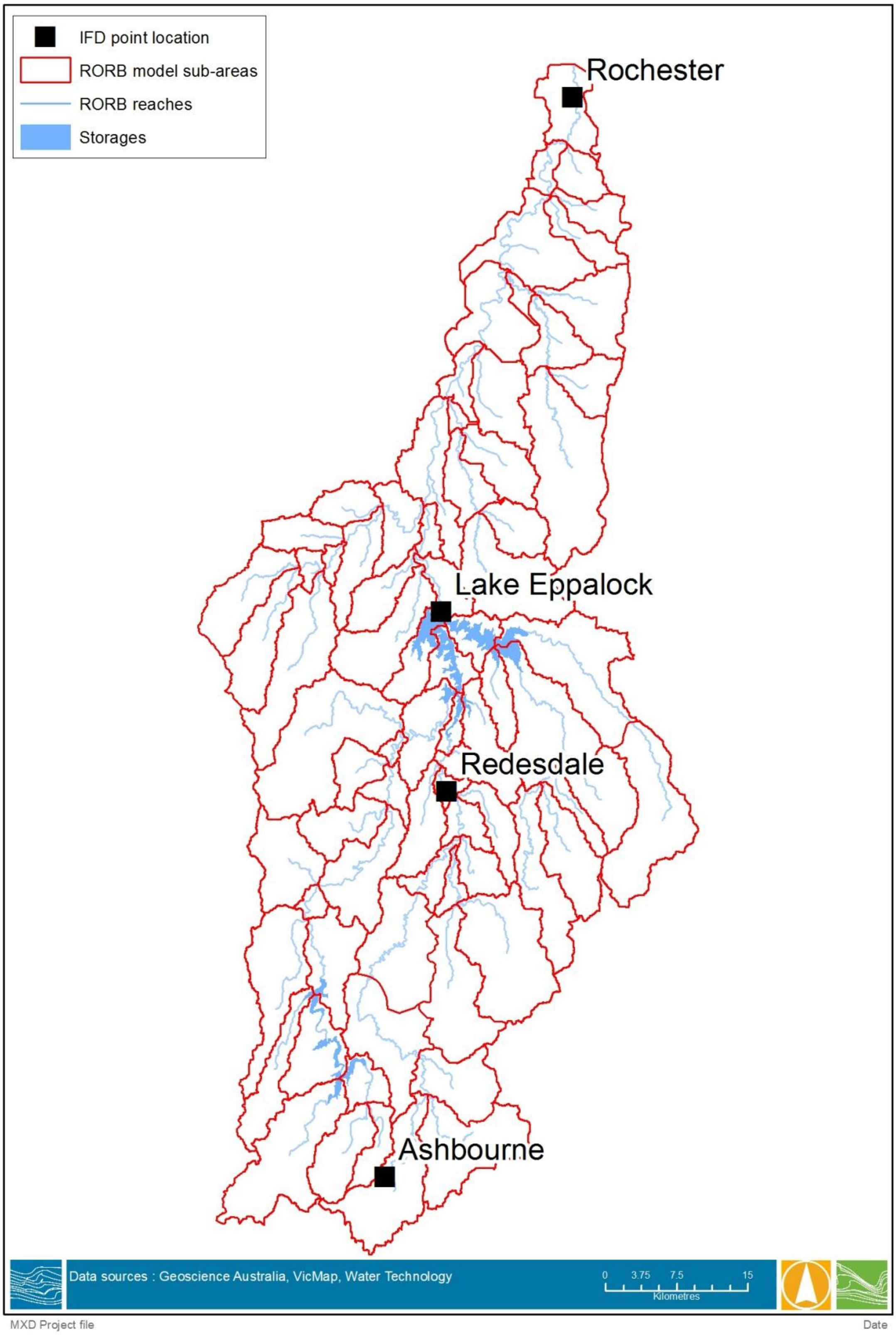


Figure 4-19 Location of calculated IFD points

Table 4-14 Variation in 1 in 100 year ARI rainfall intensity across the catchment

Duration	Intensity (mm/hr) for 1 in 100 year ARI rainfall						
	Rochester	Lake Eppalock	% diff.	Redesdale	% diff.	Ashbourne	% diff.
5Mins	170	178	5%	179	5%	182	7%
6Mins	158	165	4%	167	6%	169	7%
10Mins	126	132	5%	133	6%	135	7%
20Mins	87.8	93	6%	93.9	7%	94.4	8%
30Mins	69.4	73.8	6%	74.6	7%	74.9	8%
1Hr	44.7	47.7	7%	48.3	8%	49	10%
2Hrs	27.9	29.5	6%	29.9	7%	31.4	13%
3Hrs	21	22	5%	22.4	7%	24.1	15%
6Hrs	12.9	13.3	3%	13.5	5%	15.3	19%
12Hrs	7.94	8.09	2%	8.28	4%	9.81	24%
24Hrs	4.87	5.02	3%	5.17	6%	6.29	29%
48Hrs	2.9	3.07	6%	3.19	10%	3.95	36%
72Hrs	2.08	2.22	7%	2.31	11%	2.92	40%

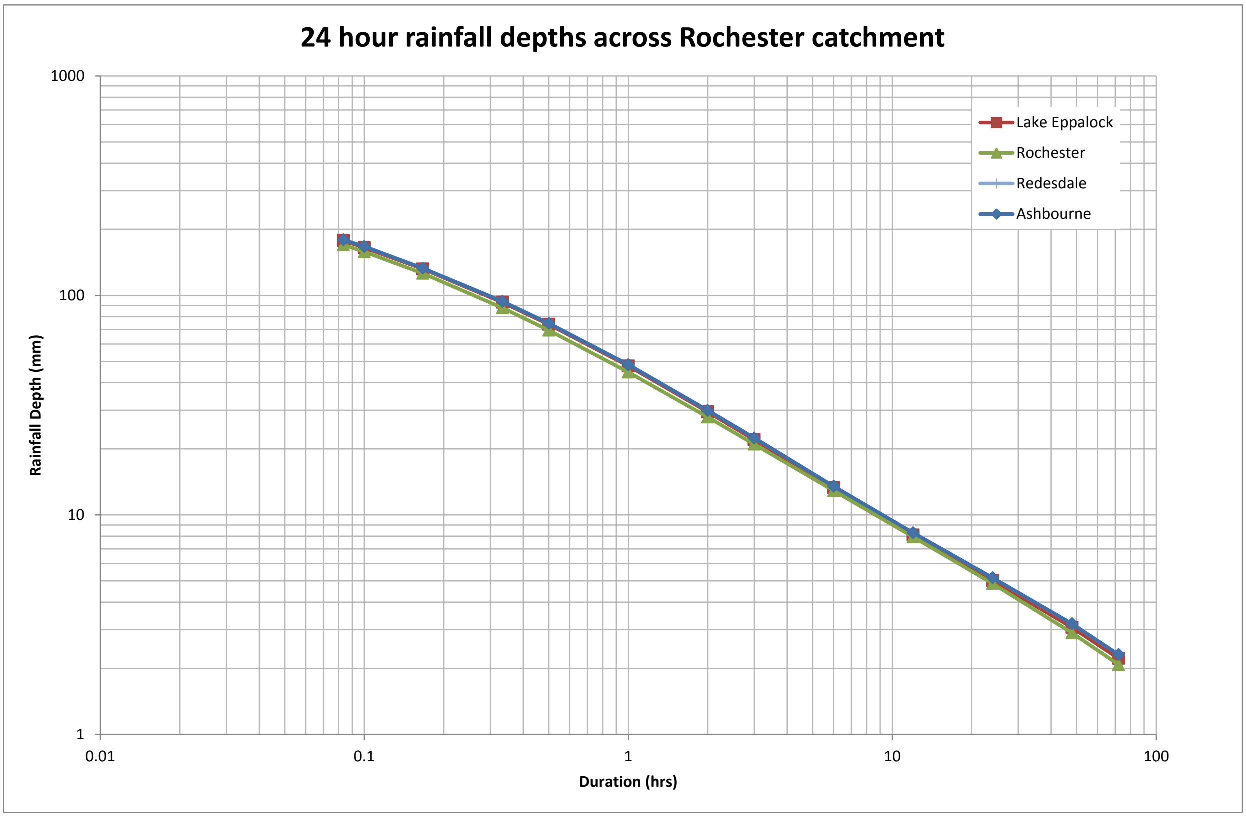


Figure 4-20 Variation in design rainfall depths by varying the IFD location

Design temporal pattern

Design temporal patterns were taken from the Generalised Short Duration Method and Generalised South East Australian Method as well as ARR 1987 in order to understand the sensitivity of the flood estimates to temporal pattern. GSDM patterns were used for durations up to and including 12 hours and GSAM patterns for durations greater than 12 hours.

The Campaspe River catchment is located within Zone 2 of the temporal pattern map as defined in AR&R 1987.

Design spatial pattern

Typically, a uniform spatial rainfall pattern (i.e. same rainfall depths applied to the entire catchment) would be adopted for the generation of design flood hydrographs. However given that the catchment is quite large, and that we are also extracting 200 year ARI flows, the possible spatial variation in rainfall was accounted for by using the GSAM spatial pattern for the catchment of the Campaspe River upstream of Rochester. The pattern was obtained using the method outlined by the Bureau of Meteorology[2].

Areal reduction factor

Areal reduction factors convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. Siriwardena and Weinmann (1996) [3] reduction factors were applied.

Table 4-15 Summary of design inputs

Design Consideration	AEP	
	Large (to 1 in 100 AEP)	Rare (beyond 1 in 100 AEP)
Point rainfall depths	IFD information	
Areal reduction factors	Siriwardena and Weinmann (1996)	
Temporal patterns	Short duration: ARR (1987) Long duration: unsmoothed GSDM	Short duration: GSDM Long duration: unsmoothed GSAM
Spatial patterns	GSAM	GSAM

Climate change scenarios

An understanding of the impact of climate change will be determined for the 1 in 50, 100 and 200 AEP events. Rainfall intensities will be increased by 32% to produce revised peak flows and hydrographs for these events. This increase is consistent with recommendations from the CSIRO publication Climate Change in Australia (CSIRO, 2007)[4].

[2] Bureau of Meteorology (2006). Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method

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

[4] CSIRO (2007). Climate change in Australia: Technical Report (http://www.climatechangeinaustralia.gov.au/technical_report.php)

4.4.2 Design Model Parameters

The design model parameters (k_c and losses) have been determined from calibration and comparison to flood frequency analysis.

Routing parameters

Various regional k_c estimation equations were trialled for the calibration process and a value of 161.5 was found to provide a good fit of the observed and modelled hydrographs. This value of k_c is proposed for the design flood estimation.

Table 4-16 Adopted RORB model parameters

k_c	m
161.5	0.8

Design losses

Prior to verification of flows to flood frequency analysis, this study adopted an initial loss of 30.93 mm and a continuing loss of 3.33 mm/hr as the design loss parameters based on the prediction equation from Hill, Mein and Siriwardene (1998) as described in Section 4.3.2.

Design losses were set through validation of design flows against a flood frequency analysis as described below. The loss parameters were applied across all ARI events and durations.

The design losses were not based on the losses adopted in the calibration events. Losses applied for the November 2010 and January 2011 events are highly dependent on antecedent catchment conditions and are not suitable for design flood estimation.

Table 4-17 Adopted Design losses

Il (mm)	Cl (mm/hr)
20	0.6

4.4.3 Reservoir Drawdown

Reservoir drawdown, particularly for Lake Eppalock, has been shown to have a large impact on resulting flows at Rochester (see Section 4.1.3). A study assessing the hydrologic risk posed by Eppalock Dam was carried out by GMW in 1998 (SKM, 1998), using historic storage levels to 1998 in a joint probability analysis to account for the impact of reservoir levels on outflows from Lake Eppalock.

SKM used a joint probability analysis based on the stochastic deterministic method of Laurenson (1974). In undertaking a joint probability analysis, the probability distribution of storage levels was considered. This distribution is shown in Figure 4-21 and the resulting inflow and outflow frequency curves are shown in Figure 4-22.

Given the high impact of flooding on the town of Rochester and the importance of the initial starting level in Lake Eppalock to the magnitude of flows downstream, Lake Eppalock is assumed to be full at the start of the modelled flood events. This is considered to be a conservative approach, particularly given that the reservoir has historically been full only approximately 10-15% of the time. This approach was recommended by North Central CMA and approved by the Steering Committee.

In future if the approach is considered to be too conservative, it may be possible to undertake a seasonal analysis of reservoir drawdown, or indeed to update the inflow and outflow frequency curves for Lake Eppalock using a Monte Carlo analysis of drawdown.

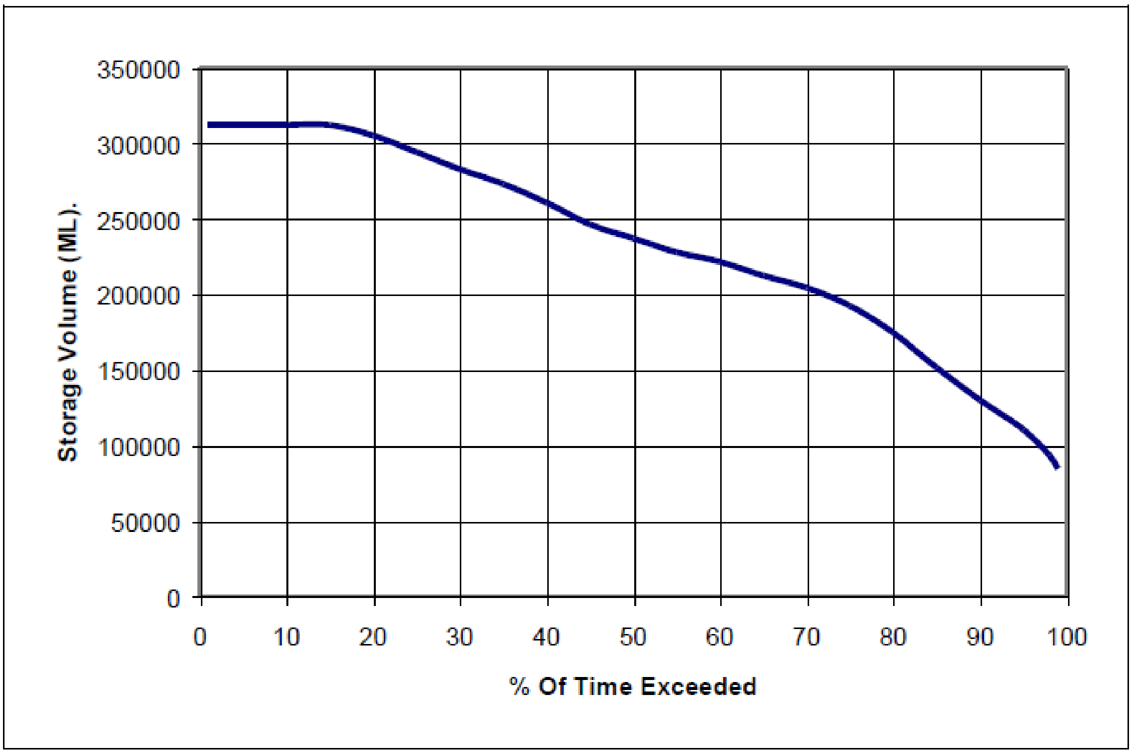


Figure 4-21 Storage exceedance curve for Lake Eppalock (SKM, 1998)

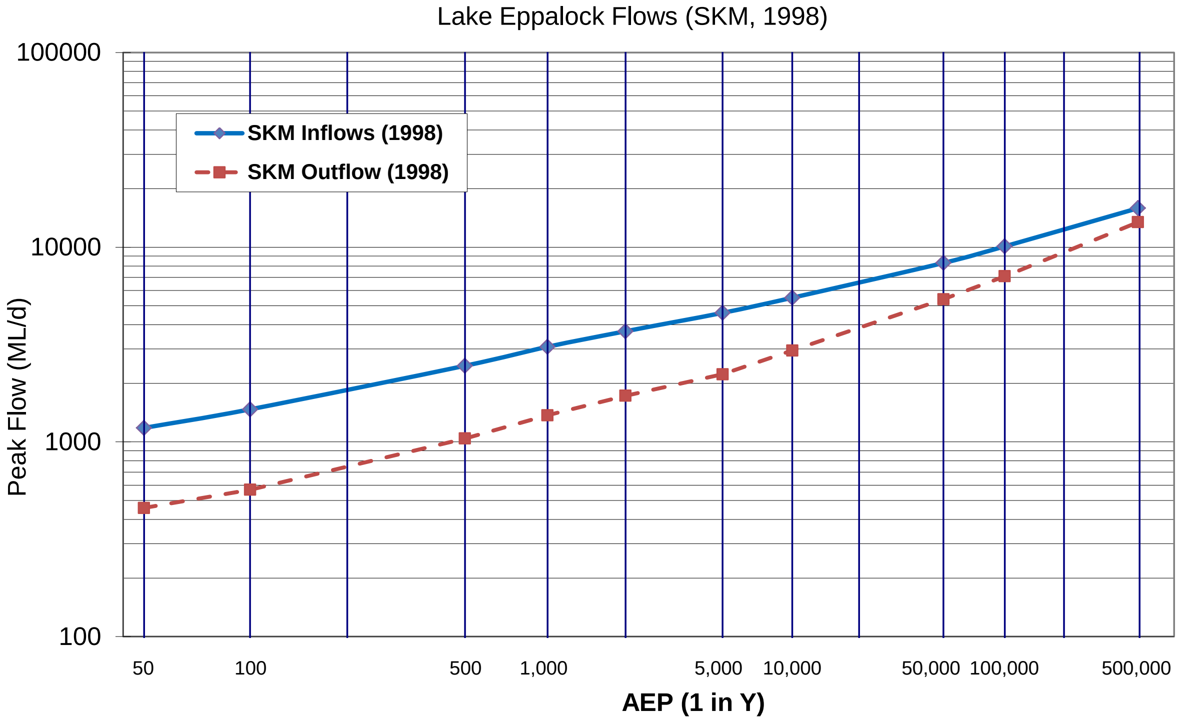


Figure 4-22 Modelled inflows and outflows Lake Eppalock (SKM, 1998)

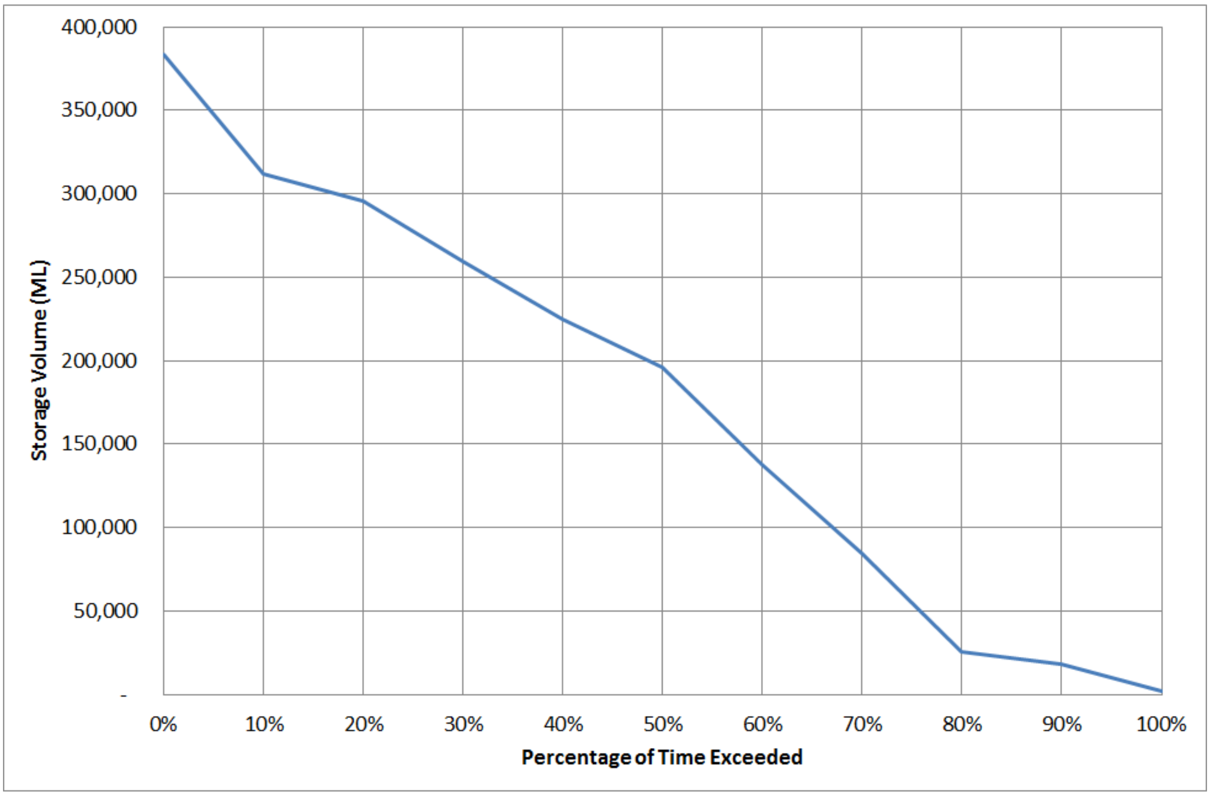


Figure 4-23 Storage exceedance curve for Lake Eppalock (1962-2011)

4.4.4 Design Flow Verification

The design flows are largely dependent on the adopted RORB model design parameters. Loss parameters used in design are verified through comparison with flood frequency analysis at a number of locations in the catchment.

4.4.5 Flood Frequency Analysis

A flood frequency analysis (FFA) allows the estimation of peak selected ARI flows based on a statistical analysis. FFA was undertaken for three Campaspe River gauges: Redesdale; Barnadown and Rochester; as well as the station at Runnymede on Mt Pleasant Creek. The aim of the FFA was to produce an estimate of a range of ARI flow events at these locations. An annual flood series was extracted from the available 44 years of instantaneous streamflow data, from 1967 to 2011.

There are a number of probability distributions which can be used to best describe the historic streamflow peak data, however the 'Log Pearson III' distribution provided the best fit to recorded data. The peak flow estimates based on this distribution for a range of ARIs is summarised in Table 4-18.

Table 4-18 FFA Peak ARI flood estimates (Log Pearson III)

ARI (Years)	Peak Design flow (m^3/s)			
	Campaspe River at Redesdale	Campaspe River at Barnadown	Mt Pleasant Creek at Runnymede	Campaspe River at Rochester
2	57	98	36	101
5	136	229	84	244
10	189	321	114	344
20	260	445	155	484
50	346	629	205	676
100	423	846	248	857
200	506	1111	293	1109

The FFA at Rochester indicates, after comparison with measured flows that the November 2010 and January 2011 flood events were approximately 10 and 100 year ARI events respectively.

The design losses were determined by adjusting them to obtain the best fit with the probability distribution of peak flows. The design losses selected were: 20 mm for the initial loss and 0.6 mm/hr for the continuing loss.

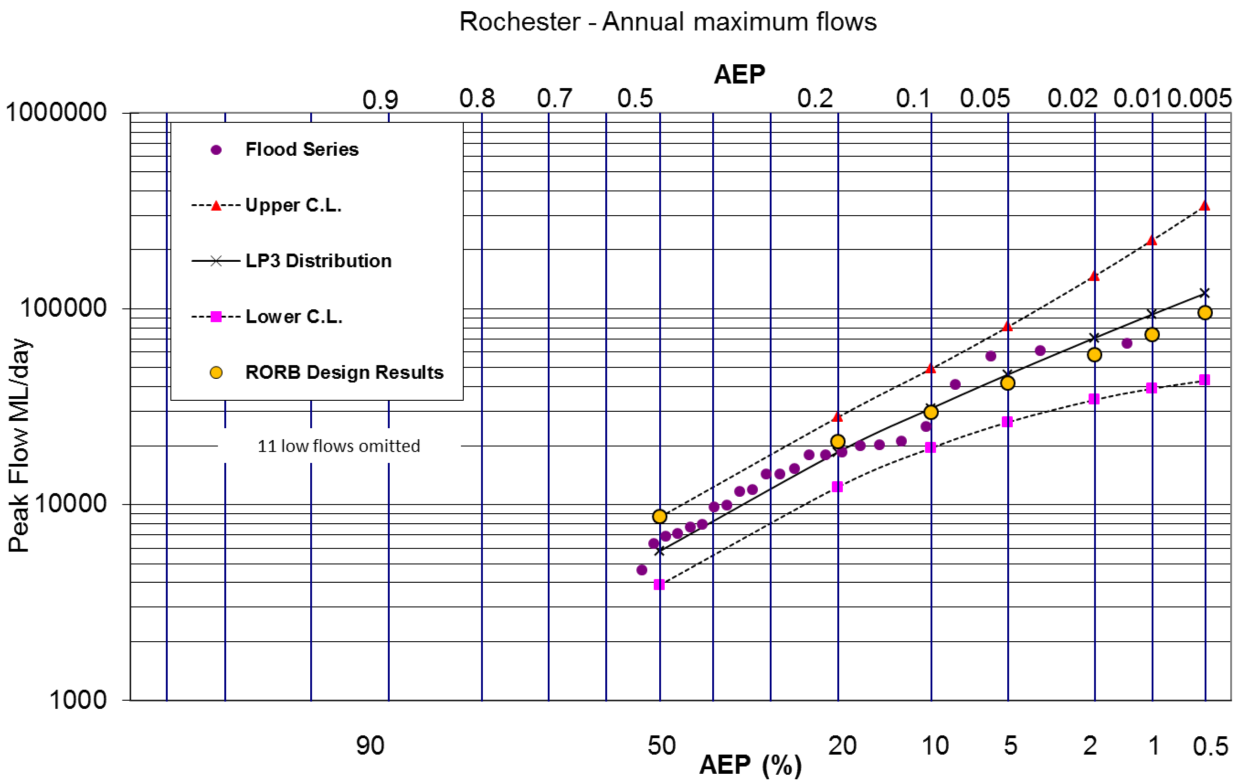


Figure 4-24 Log Pearson III Flood Frequency Analysis – Campaspe River at Rochester

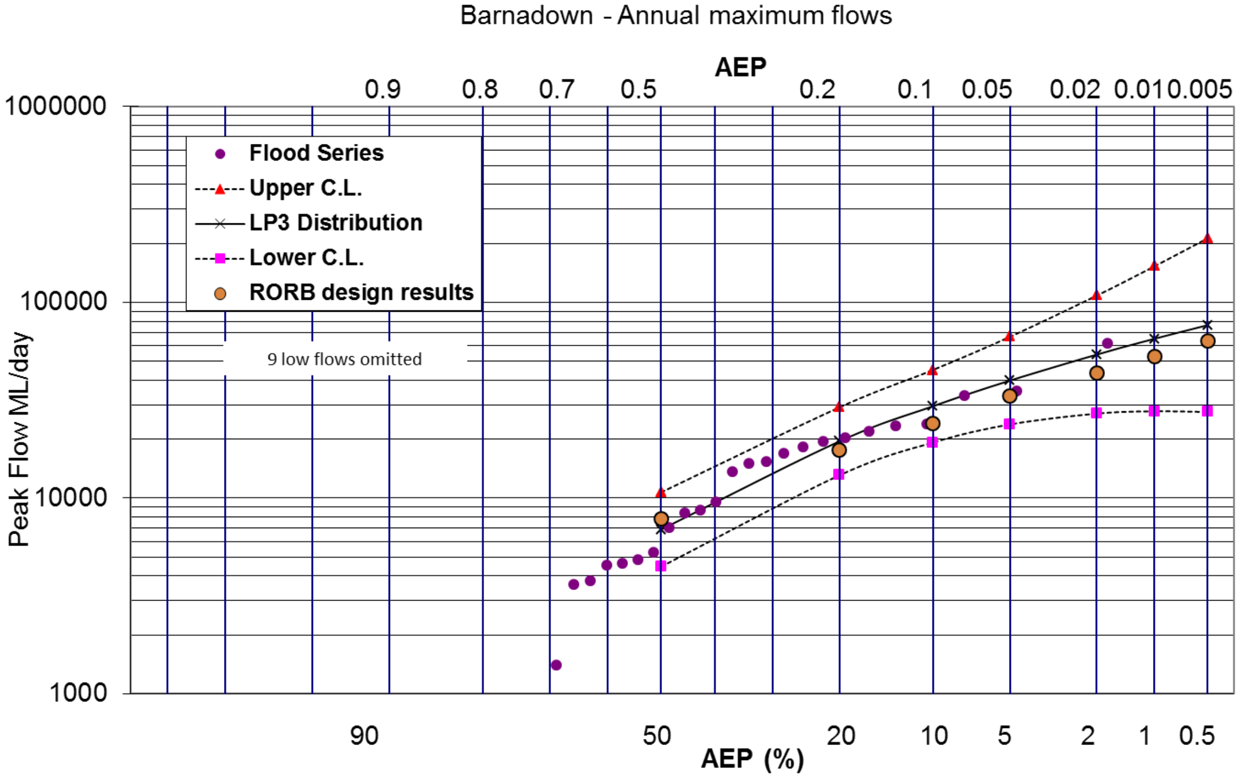


Figure 4-25 Log Pearson III Flood Frequency Analysis – Campaspe River at Barnadown

4.4.6 Adopted Hydrology Parameters

Based on the hydrological analysis undertaken the following parameters have been adopted for design purposes:

- Design rainfall depths for Rochester
- Zone 2 design temporal patterns
- Areal Reduction Factors for an area upstream of 3,345 km^2
- GSAM isohyet based spatial rainfall pattern across the catchment
- Design losses; an initial loss of 20 mm and a continuing loss of 0.6 mm/hr

4.4.7 Design Flood Hydrographs

Design flood hydrographs were determined at 8 locations for input into the hydraulic 'spine' model. A range of storm durations were run (10min – 72hrs) to ensure the critical storm durations of the large branches and smaller tributaries were determined. Table **4-19** displays the calculated design peak flows and critical storm durations for various ARI events.

Table 4-19 RORB model design peak flows and critical storm durations at Campaspe Weir

ARI	Campaspe River at Campaspe Weir	
	Peak flow (m^3/s)	Duration (hrs)
5	248	30
10	350	30
20	492	30
50	684	30
100	860	30
200	1116	30

4.5 Summary

A RORB hydrological model was used to generate design flows for the study. The RORB model developed for the catchment was calibrated to the November 2010 and January 2011 flow hydrographs at five gauges located at Campaspe at Redesdale, Campaspe at Eppalock Head gauge, Campaspe at Barnadown, Mt Pleasant Creek at Runnymede and Campaspe at Rochester. The model was then used to generate design flows for the 5, 10, 20, 50, 100 and 200 year ARI events. The choice of hydrological model parameters used to generate design flows was comprehensively checked using sensitivity testing and recommended for adoption in this study. The design flows indicated that the November 2010 and January 2011 flood events were approximately 10 and 100 year ARI events respectively in the Campaspe River at Rochester.

5. HYDRAULIC ANALYSIS

5.1 Approach

A detailed combined 1D-2D hydraulic model of the township was developed for the determination of flood levels and extents over a range of flood events and for testing various mitigation options. The calibrated hydraulic model simulates flood flow behaviour of the Campaspe River as well as the overbank flow throughout the floodplain. The hydraulic modelling approach consisted of the following components:

- One dimensional (1D) hydraulic model of key hydraulic structures;
- Two dimensional (2D) hydraulic model of key waterways and the broader floodplain; and
- Links between the 1D and 2D hydraulic models to integrate hydraulic structures with the broader floodplain flow.

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

The initial hydraulic analysis was carried out for the November 2010 and January 2011 flood events, with the model calibrated to reproduce the observed flood heights and extents.

A number of design events were then modelled.

5.2 Information Used

The key information used to develop and run the hydraulic model is discussed below.

5.2.1 LiDAR data

LiDAR data for the region was made available from two sources, the North Central CMA (referred to as Broken Creek data) and DSE (Index of Stream Condition, referred to as ISC). A comparison of both datasets was undertaken in ARCGIS. The datasets have resolutions of 5 m and 1 m respectively, with the Broken Creek LiDAR covering a slightly larger extent. During this analysis an elevation difference was observed where the two datasets overlap. The 1m ISC DEM was approximately 100 to 300 mm above the 5 m Broken Creek DEM. The available LiDAR grids are shown in Section 3.1.

After careful analysis it was decided to use the Broken Creek LiDAR 5 m DEM to model the floodplain rather than using a composite DEM resulting from applying several corrections to the ISC LiDAR (i.e. to address the crop and banding issue). This approach was discussed with the Steering Committee and approved.

5.2.2 Field Survey

Key survey data collected for the study included:

- Culvert crossings and bridge structure survey;
- Floor level survey of affected properties;
- Survey of key local drainage assets; and
- Flood marks for the November 2010 and January 2011 events.

5.2.3 Hydrological Data

As part of the current study a detailed hydrologic analysis of the study area was undertaken and is detailed in Section 4.

The hydrology data was used as the input boundaries to the hydraulic model at Campaspe Weir. The hydrology of the Campaspe River was derived for a range of design events as well as the recent November 2010, and January 2011 events.

5.3 Hydraulic Model Development

5.3.1 Topography

The model covers a section of the Campaspe River from the Campaspe Weir, approximately 7.5 km upstream of the township, extending to 1 km downstream of the Campaspe Syphon. Rochester is located within the floodplain of the Campaspe River, with heights ranging across the area from 129 m AHD near Hanrahan Road to around 105 m AHD at the river bed downstream of the Syphon. Across the floodplain there are a number of small ephemeral watercourses, structures and roadways which all influence flood behaviour.

In order to best represent the region, while allowing for reasonable run times, the model topography was based on a 5 m grid resolution. A 5 m grid size was found to have sufficient accuracy to pick up the minor overland flow paths along the table drains in Rochester. The extent of the hydraulic model boundary is shown in Figure 5-1 below.

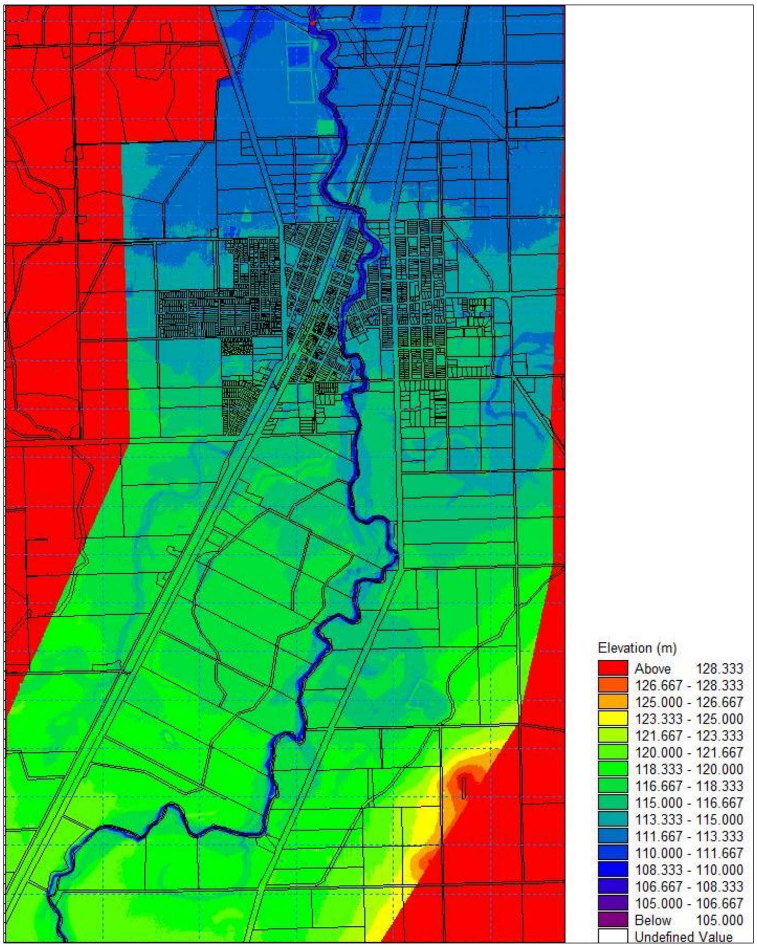


Figure 5-1 Rochester Hydraulic Model Schematisation

5.3.2 Key Structures

Information about the key hydraulic structures along the Campaspe River including dimensions and inverts were required for input into the hydraulic model. The main structures within the study area were:

- Kyabram-Rochester Road Bridge over the Campaspe River;
- The railway bridge over the Campaspe River;
- The railway crossing adjacent to Rochester-Strathallan Rd near Sullivan Street;
- The Waranga Channel and the Campaspe Syphon; and
- Drainage structures at various locations in the floodplain, such as culverts under the railway and roads.

Plans of the road bridge have been supplied by the Shire of Campaspe. Cross section details, dimensions and obverts of the main hydraulic structures were estimated during the site visit. The pipe obvert was tied back into the LiDAR data to estimate the invert level. It is expected that this method of estimating the structure inverts will be accurate to +/-150 mm and as such will not have a significant impact on the model accuracy. The structures were modelled as one-dimensional elements coupled to the two-dimensional model domain, with flow over the top of the culverts and bridges simulated in the two-dimensional model domain.

5.3.3 Hydraulic Roughness

The variation in hydraulic roughness within the study area was schematised as a hydraulic roughness grid, representing various hydraulic roughness values (e.g. roads, floodplain, channels, vegetation, buildings and land). Areas with different roughness types were identified using aerial photographs and Vicmap data layers. The roughness grid is shown in Figure 5-2 below with the values adopted for the two-dimensional hydraulic model are summarised in Table 5-1 below. These values were based on standard industry roughness values and were modified during the calibration process.

The values adopted are reasonable estimates of hydraulic roughness given the floodplain condition.

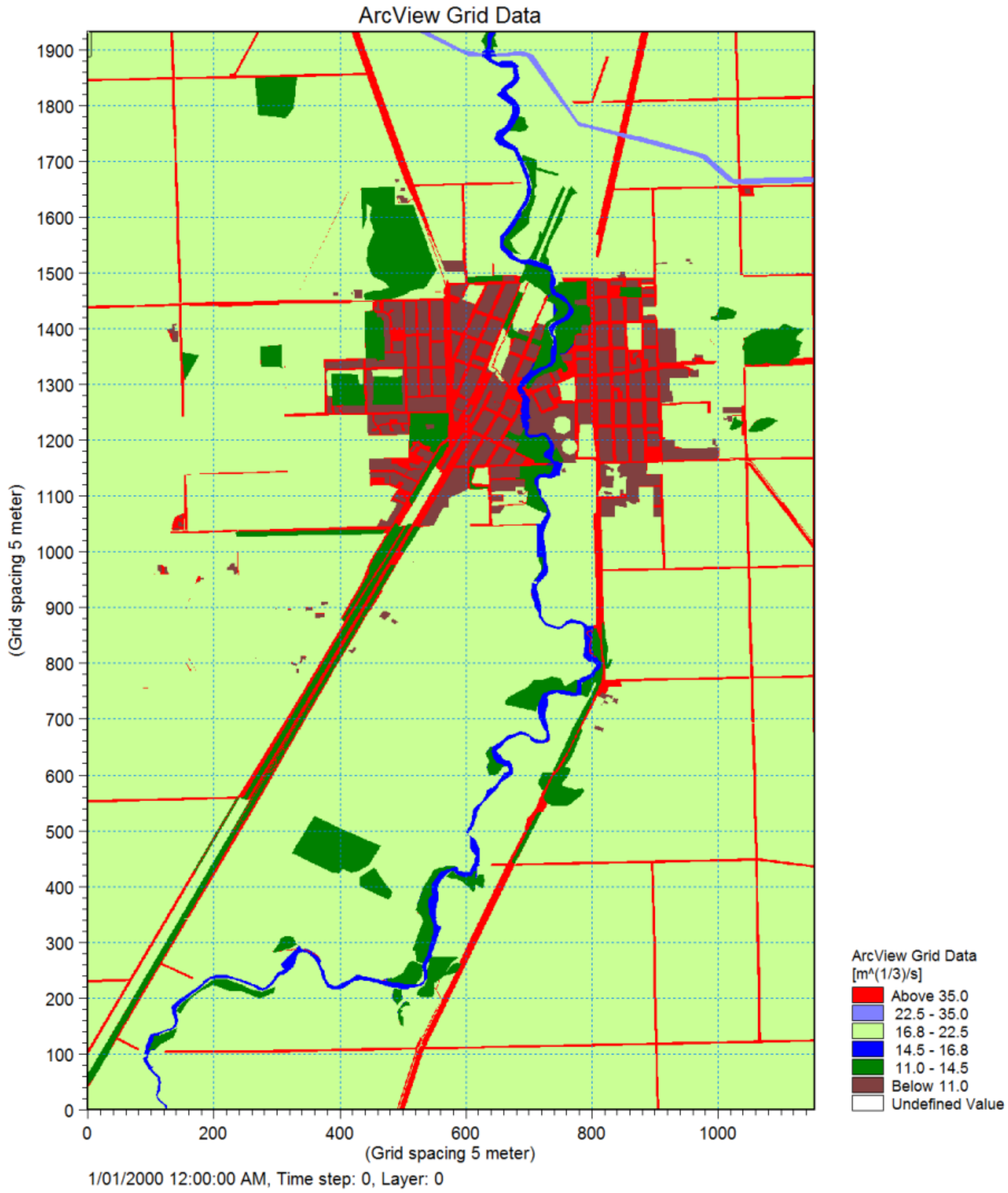


Figure 5-2 2D hydraulic model roughness grid (values are given in Strickler's "M", M=1/n)

Table 5-1 Hydraulic Roughness Parameters

Land Type	Roughness (Manning's "n")
Roads	0.02
Floodplain	0.045
Channels	0.06
Vegetation	0.07
Buildings	0.1

5.3.4 Boundary Conditions

The model was developed with a single inflow boundary for the Campaspe River at Campaspe Weir, located 7.5 km upstream of the Rochester Bridge.

The downstream boundary was located 700 m downstream of the Campaspe Syphon. Downstream of the Campaspe Syphon flows from the two-dimensional model domain were transitioned into a one-dimensional branch of the entire floodplain. This allowed the use of a Q-H relationship to be used to define the downstream boundary.

A Q-H relationship allows a much more accurate representation of the flood levels at the downstream boundary rather than setting a constant water level representative of the water level expected at the peak of the flood. A constant water level is not representative of all flows or all points in time across a single event. With a Q-H relationship the boundary level is determined by a hydraulic relationship and requires no estimation of an appropriate water level for each event. It also allows the downstream area to fill and drain as it should during a flood rather than being constantly inundated by the backwater of the downstream boundary. This ensures the boundary condition does not have undue effect on the water levels further upstream.

5.4 Hydraulic Model Calibration

5.4.1 Overview

This section discusses the fine-tuning of the hydraulic model parameters through calibration against observed flood data. The model was calibrated to two large flood events in November 2010 and January 2011. Surveyed flood marks (provided by the North Central CMA), general observations and aerial photographs of the floods formed the basis of which to calibrate the modelled results to.

A number of sensitivity runs were undertaken with minor changes to the model parameters to get a better match to surveyed flood levels and observations, namely:

- Raising the crest elevation of both the railway and Northern Highway in the model topography. In some locations the 5 m DEM had not accurately picked up the crest elevation as determined from the 1 m LiDAR, the 1 m LiDAR levels were stamped onto the 5 m DEM.
- Adjusting the crest level of the Waranga channel in the model topography to the plans provided by the Campaspe Shire.
- Increased the waterway roughness from 0.05 to 0.06 (reasonable given the dense vegetation and woody debris along the channel).
- Reduced the open agricultural area roughness from 0.057 to 0.045 to better simulate flood depths around the town and along the major waterways (reasonable for pasture and long grass).
- Modelling the flow under the railway and through road culverts in 1D as opposed to 2D to better represent the conveyance through these structures. Addition of more detailed modelling approach of the Rochester south drain and the floodway along Railway Road.

The final roughness parameters determined from the calibration process are shown in Table 5-1.

It should be noted that while flood mark survey is available for the calibration events there is inherent inaccuracies in the collection of those levels. The levels are primarily based on flood debris marks which may be significantly higher or lower than the true peak due to a number of reasons such as debris piling up on the upstream side of an obstruction or debris collecting on the recession of a flood, and obstructions causing a bow wave effect (with higher levels on the upstream face and lower on the downstream face).

A certain degree of judgement is required in the collection of this data and inaccuracies in the data at some locations are likely.

5.4.2 November 2010 Calibration

15 flood marks from the November 2010 flood event were collected by the North Central CMA. A list of flood affected properties, community feedback regarding the flood events and aerial imagery provided by the North Central CMA were also used to check the modelled flood extent. Calibration plots for the November 2010 flood event are shown in Figure 5-4 Hydraulic model calibration plot – November 2010Figure 5-4 below.

The 15 survey flood marks located within the study area were compared to the modelled flood levels:

- 10 points were within +/- 200 mm;
- 3 points had modelled water levels with a difference greater than 200 mm;
- The remaining 2 points were slightly outside the modelled flood extent;
- On average the model levels were 150 mm higher than the observed flood marks.

The overall trend showed that the modelled flood levels were slightly higher than the surveyed flood levels.

Figure 5-3 below shows a plot of the water level at the Rochester town gauge comparing the model results to those manually read by Shire of Campaspe Staff and rang through to the VICSES Incident Control Centre in Bendigo. The graphs show that the rising limb of the modelled hydrograph arrives slightly earlier than the manually read data, nevertheless the peak elevation is well represented in the model.

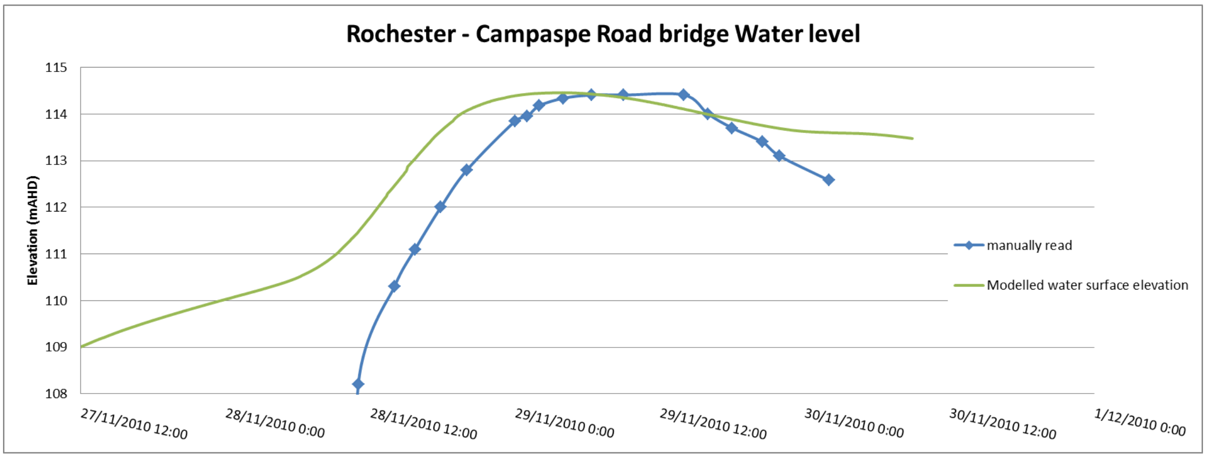


Figure 5-3 Comparison between modelled and manually read water levels at the Campaspe Road bridge during the November 2010 event.

The modelled flood extent matched very well with observations, community feedback and aerial photographs, and was deemed an acceptable calibration result.

Flood Behaviour

Following up to 76 mm of rain in the Campaspe River catchment from 9.00am Saturday 27th through to early Sunday 28th November 2010, the Campaspe River rose quickly to peak in Rochester on Monday 29th November at 8am at 114.4 m AHD at the bridge (or 9.001 at the syphon at 9.30am). In addition, Axe Creek, Sweenies Creek, Forrest Creek and Mt Pleasant Creek, which are tributaries of the Campaspe River, all flooded. For the November 2010 event the flood was largely contained within low lying areas adjacent to the river, with the floodplain inundated approximately 200 m on either side of the Campaspe River.

Within the township of Rochester, flood waters broke out on the eastern side of the railway, with the western side of the railway largely unaffected through town. A number of streets were inundated and closed to traffic including the main VICROADS bridge over the Campaspe River on the Kyabram Rochester Road which was closed for a number of hours. Modelling suggests that the bridge itself was not overtopped (flood waters reaching within 200 mm of the road deck) but the approach road to the east was inundated. The modelling indicates that the river began to overtop its banks around 6 pm on the 28th November, however given the comparison to the observed water level at the road bridge gauge, the actual time that water began to break out of the channel may have been 6 hours later. The main breakout observed in the simulation was located north-east of the "red bridge" (railway bridge over the Campaspe River), flowing towards the Waranga Channel.

Sand bagging of houses was carried out by the VICSES at some low lying properties and although some were inundated there was no above floor inundation as stated in the report from the Shire of Campaspe "*Shire of Campaspe – Inquiry into Flood Mitigation Infrastructure in Victoria - July 2011*".

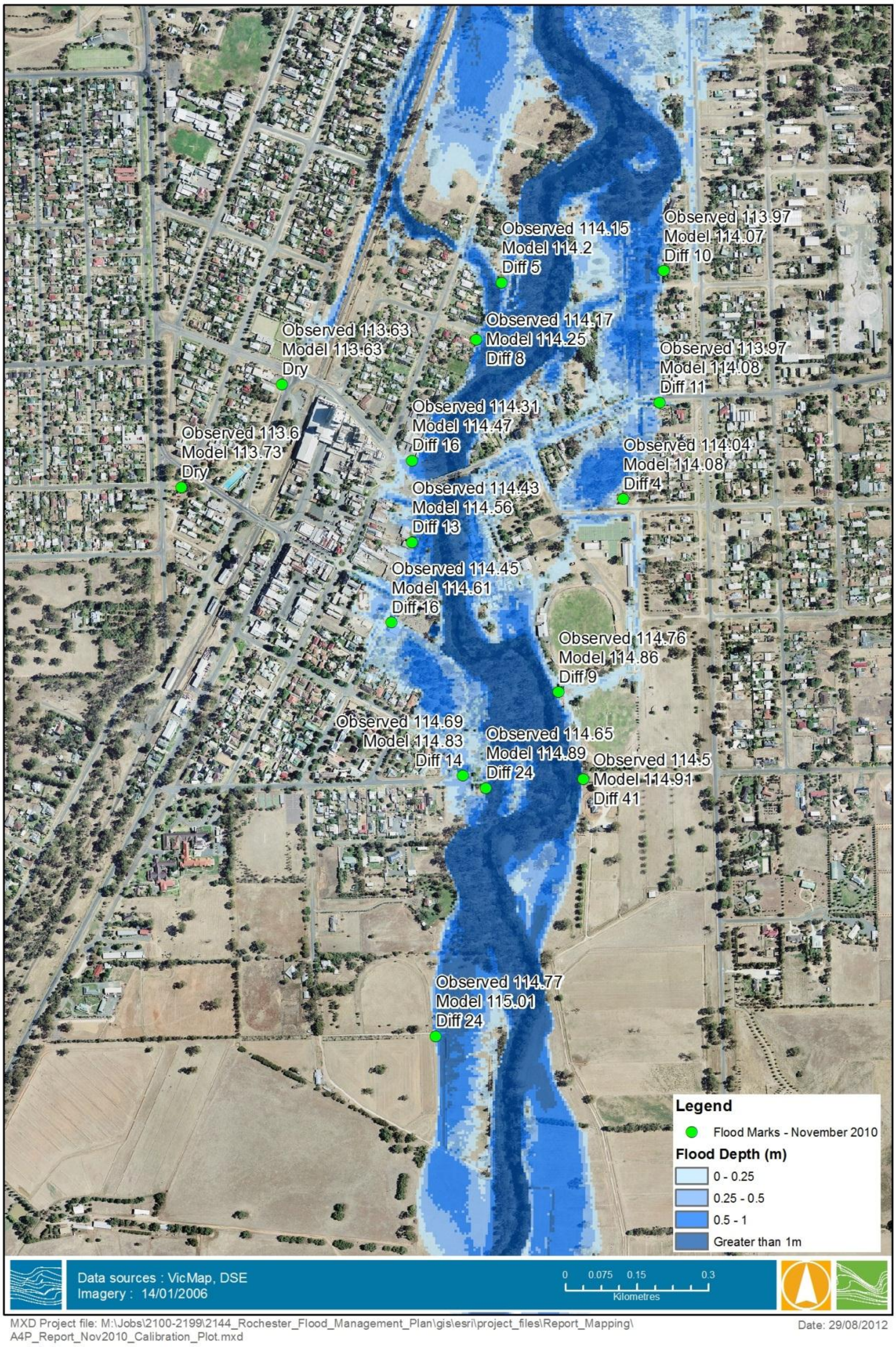


Figure 5-4 Hydraulic model calibration plot – November 2010

5.4.3 January 2011 Calibration

A large number of survey flood marks were collected for the January 2011 flood event. In total there were 188 survey points to which the model results were calibrated, giving confidence in the reliability of the reproduced flood behaviour. Calibration plots of the January 2011 flood event are shown in Figure 5-5. Of the 188 survey flood marks located within the study area:

- 115 (61%) points were within +/- 100 mm.
- 54 (29%) points were within +/- 200 mm.
- Approximately 90% of the modelled calibration points were within 200 mm.
- 11 (6%) points were within +/- 300 mm.
- 4 (2%) points were below 300mm but may also be a result of an error in survey.
- 4 (2%) points were slightly outside the modelled flood extent.
- On average the modelled water levels were 25 mm below the surveyed flood marks, with a standard deviation of 130 mm.

The overall trend showed that the modelled flood levels were very slightly lower than the surveyed flood levels but well within the satisfactory error interval expected for flood modelling scenarios.

The modelling results matched very well with observations, community feedback and aerial photographs.

Flood Behaviour

The flood in January was the largest on record for Rochester, exceeding the height of the previous record flood (1956) by 200 mm.

In Rochester the river level peaked at around 115.4 m AHD at the bridge gauge or 9.17 m at the syphon at 5.45pm on Saturday 15th January 2011. The flooding resulted in roughly 80% of the town being inundated and more than 250 properties being inundated above floor level.

The January 2011 flood was considerably larger than the November 2010 event (see Figure 5-6). Water levels in the Campaspe River were about 1.4 m higher at the Syphon gauge and about 0.8 m upstream of the road bridge. Once the January 2011 event reached the November 2010 peak level, it took approximately another 24 hours to reach the January 2011 peak flood level.

The high Campaspe River flow resulted in large breakouts throughout the floodplain and high water levels in the township. The Waranga Western Channel, north of Rochester, was overtopped. This is visible in the aerial imagery of the site on the 16th January and is also reproduced in the modelling.

The floodway located upstream of the town, on the right bank of the Campaspe River near Aitken Road was inundated. In the model, the maximum flow through the floodway reached 61 m^3/s on the 15th January around 10pm at the eastern boundary of the model (5km from the river).

Flood waters flowed to the western side of the railway line through the crossings located either side of the Campaspe railway bridge (600 m south at Ramsey and Charles St, and 200m north). These crossings passed 40 and 25 m^3/s during the peak of the flood, occurring at 6.05pm in the model simulation (anecdotal observations estimate the peak to have occurred at 5.45pm). The railway line was overtopped between Elizabeth Street and south of the railway station.

Detailed modelling of the South-East drainage structures was also implemented. Several culverts from Ramsey St down to Railway road form a floodway that was designed to drain local runoff from the catchment to the west back to the river. During the January 2011 event, due to the scale of the flood, the floodway was flowing in the opposite direction. The water began to flow through the culverts in the early hours of the 15th of January. This observation was verified by a Steering Committee member and local resident who lives nearby.

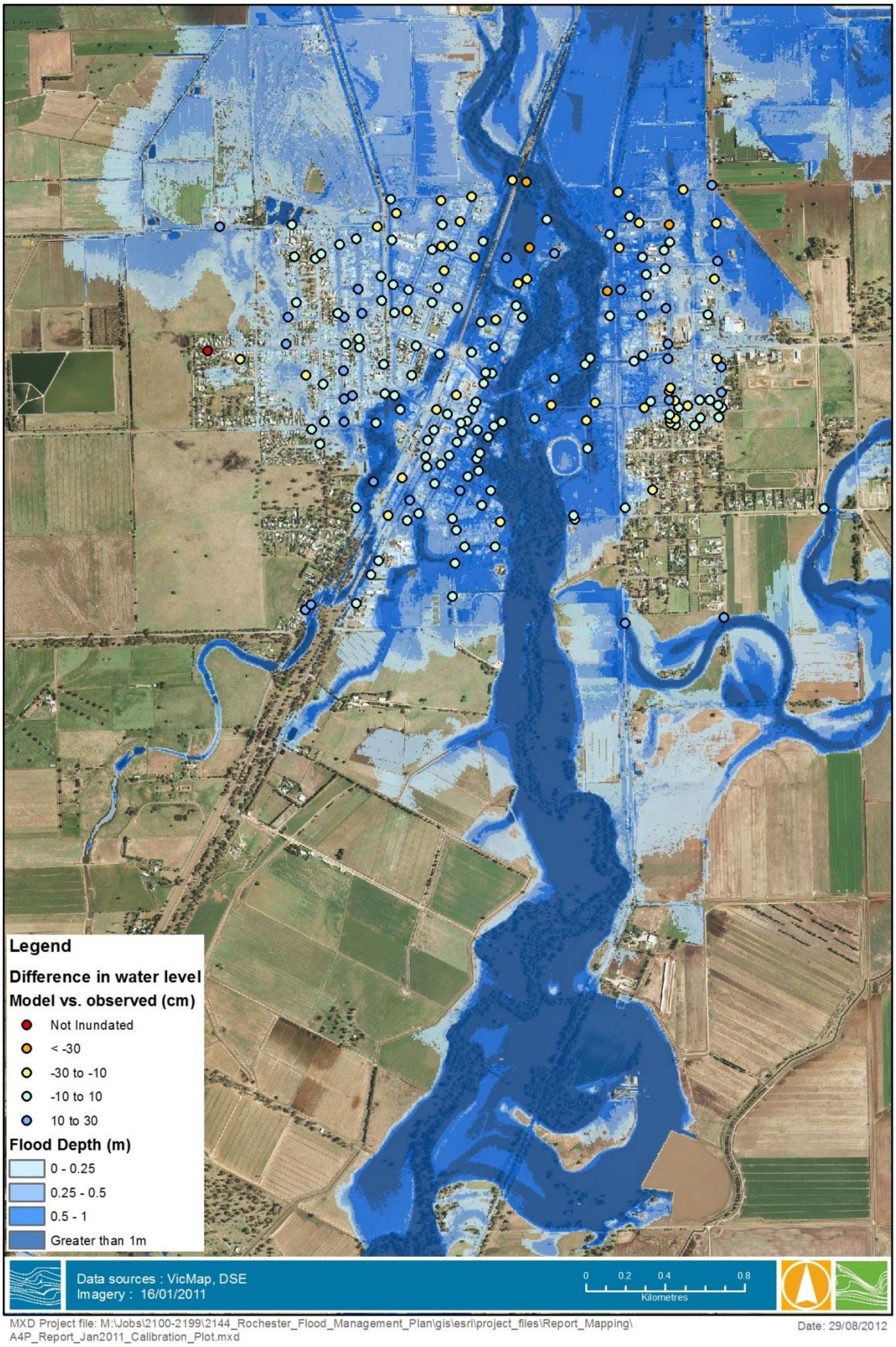


Figure 5-5 Hydraulic model calibration plot – January 2011 event

5.4.4 Hydraulic Model Calibration Summary

The hydraulic model calibration results demonstrated the ability of the model to represent the flood behaviour within Rochester for the January 2011 and November 2010 flood events. The modelling demonstrates that the events were quite different in nature with January 2011 being a much larger and more damaging event. The January 2011 event inundated approximately 250 residential and commercial buildings above floor as a result of large breakouts from the Campaspe River. The November 2010 event resulted in inundation of some properties but none above floor level.

Modelling has identified that the peak flow in the Campaspe River for the January 2011 and November 2010 events was approximately 867 and 318 m^3/s respectively. These flow estimates represent the flow in the Campaspe River upstream of town, prior to any breakaway flows.

It was observed from the January 2011 modelling that widespread inundation through the township occurred once the flow reached approximately 550 m^3/s upstream of Rochester.

The model results for the January 2011 and November 2010 floods replicated the observed flood behaviour through the town quite accurately; this was confirmed by a comparison to observed flood marks, aerial images as well as community feedback during public consultation. The model was considered appropriate for use for design event modelling and mitigation options investigation.

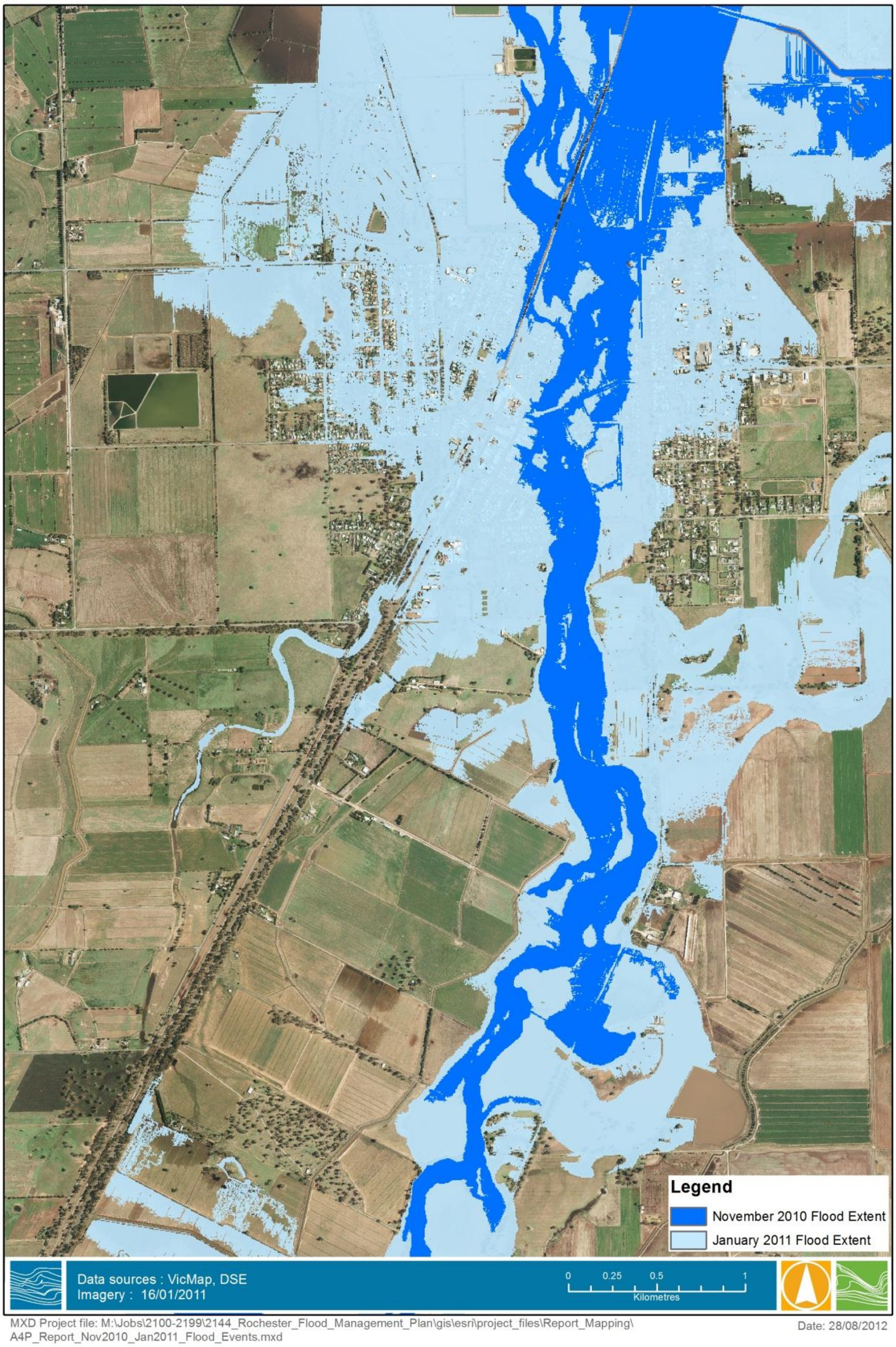


Figure 5-6 November 2010 and January 2011 Flood Extent Comparison

5.5 Design Flood Modelling

The hydraulic model used for calibration and as described earlier in this report was also used to run the 5, 10, 20, 50, 100 and 200 year ARI design events.

Each design event was run for the 30 hour critical duration. A suite of flood maps was developed across the range of flood magnitudes as shown in Appendix B. Figure 5-7 shows the 100 year ARI design flood extent overlayed with the January 2011 event modelled extent and shows that both extents are very similar. This was to be expected given the similarity between peak flows for these two events.

Figure 5-8 shows all design flood extents overlayed on the one figure for comparison.

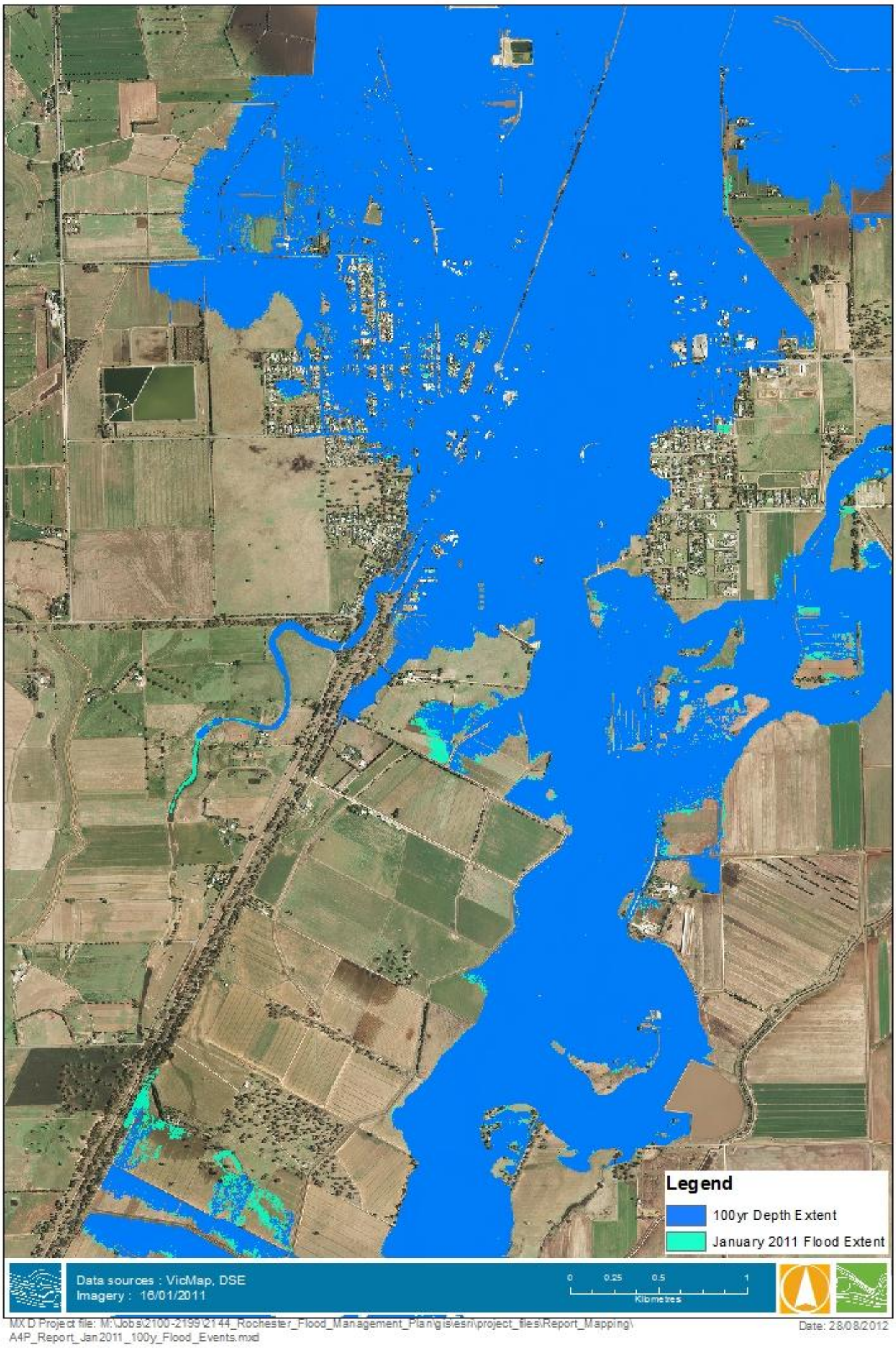


Figure 5-7 Hydraulic Modelling January 2011 event and 100 year design event flood extents

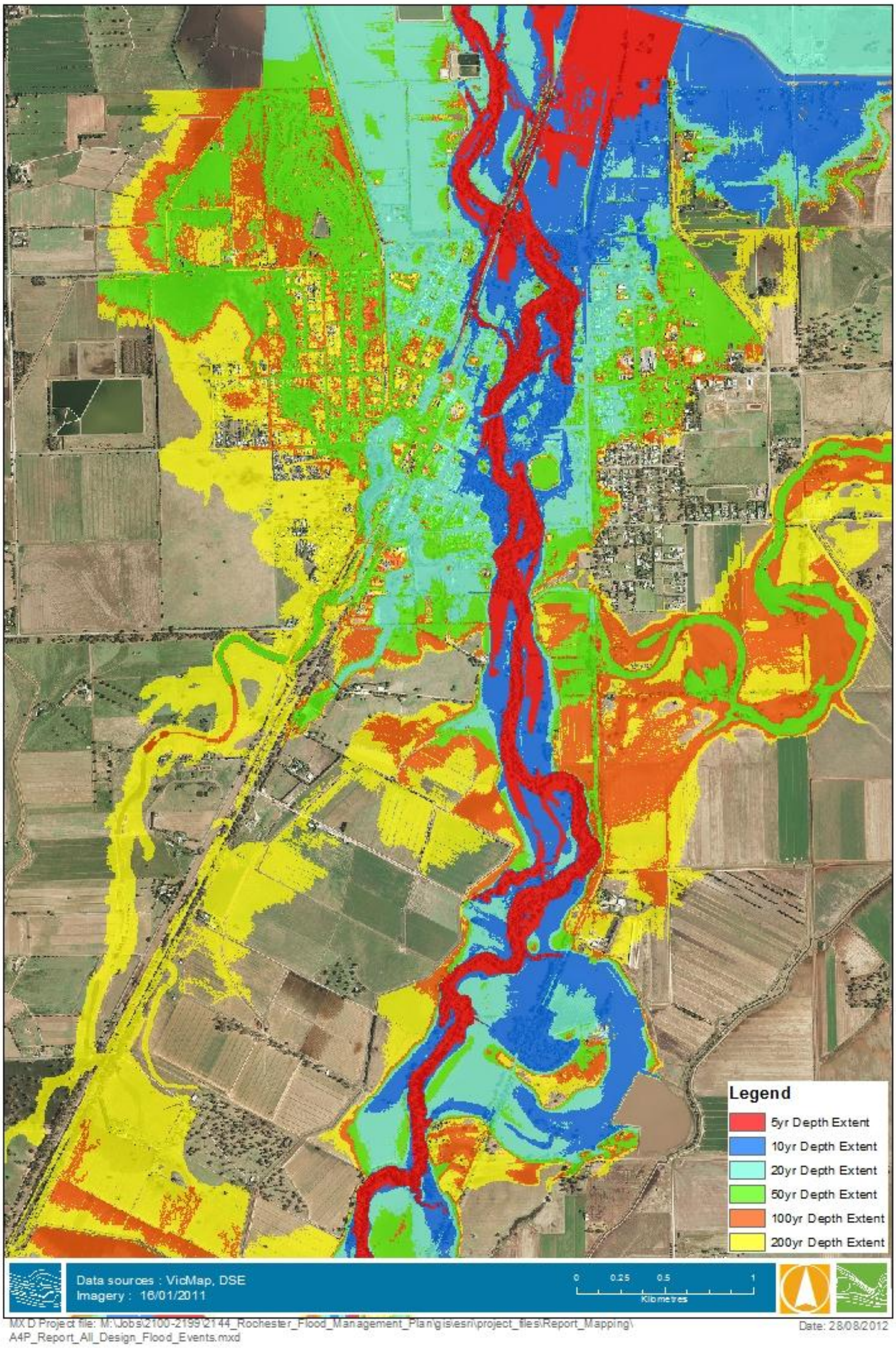


Figure 5-8 Hydraulic modelling design flood extents

5.6 Design Flood Behaviour

The design flood mapping shows that during relatively small events such as the 5 year ARI flood event, the Campaspe River inundates low lying areas of the floodplain. As the flow in the river increases the water levels rise and the extent of inundation widens.

The 10, 20 and 50 year ARI floods produce similar inundation extents upstream of Rochester, with each design flood producing incrementally larger flood extents through town. The 10 year ARI event shows relatively little inundation on the western side of the railway line, with the 20 year ARI extent inundating the area between the railway line and the Northern Highway.

The 50 year ARI event inundates to the west of the Northern Highway with shallow inundation on a large proportion of the township. During the 50 year ARI event floodways on either side of the river begin to flow upstream of town.

The 100 year ARI extent is similar to the 50 year ARI extent with increases in depth through the township. The flow and flood extent along the eastern floodway is increased.

The 200 year ARI event causes widespread flooding across Rochester, with almost all properties impacted other than a small pocket of houses unaffected in east Rochester.

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

5 Year ARI Event

- Flood well-confined along the Campaspe River.
- Wetlands, lagoons and low depressions adjacent to the river are inundated by backwater from the river.
- Some shallow inundation north of the township east of the railway line through to the Waranga Channel.
- Floodways under the railway line north and south of the river flowing.
- No buildings flooded above floor and 30 flooded below floor.

10 Year ARI Event

- Similar in extent and depth to the November 2010 flood event.
- Flooding largely contained to the eastern side of the railway line.
- Breakout flow to the east of the river near sporting ground, may inundate the club rooms, the Rochester Caravan and Camping Park and properties along Church St, Reserve St, Hood St and the Kyabram-Rochester Rd (between the river and Hood St).
- Breakout flow to the west of the river inundates some properties on Pascoe St, Fraser St and Campaspe St, threatening the water treatment plant (although it is understood that this will be protected by a levee).
- Breakout flow to the west of the river inundates properties along Mackay St and Hart St, flowing under railway line floodway, and flowing along the railway line to the north along Ramsay St.
- Major breakout upstream of the railway bridge flowing north toward the Waranga Channel, inundating the area between the railway line and Cohen Rd, including the Rochester-Strathallen Rd.
- Minor breakouts observed adjacent to the river upstream of Rochester.
- 3 buildings flooded above floor and 114 flooded below floor.

20 Year ARI Event

- Flooding upstream of Rochester similar to that of the 10 year ARI event.
- Widespread flooding east of the railway line, with most properties inundated between the river and High St.

- East of High St, a block of properties bounded by High St, Bayness St and Kyabram-Rochester Rd are inundated, along with a significant proportion of properties north of the Kyabram-Rochester Road between the river and Cohen Rd.
- The hospital grounds and a number of care facilities around the hospital may witness shallow inundation on the property, and may have some access difficulties with Pascoe St and the Northern Highway inundated.
- To the west of the railway line, between the railway line and the Northern Highway a significant proportion of properties are inundated north of George St.
- Water begins to accumulate in the Rochester south drainage line west of the railway line along Ramsay St, Echuca Rd, Railway Rd, threatening low level properties situated adjacent to the drainage course.
- 32 building flooded above floor and 456 flooded below floor.

50 Year ARI Event

- Flooding upstream of Rochester is very similar to the 20 year ARI event.
- Almost entire area east of the river and north of the Kyabram-Rochester Rd is inundated.
- East of the railway line there is only a small pocket of houses bounded by Lindsay St, High St and Aitken Rd that are not inundated.
- The floodway to the east of town begins to flow, largely staying within the floodway.
- Further inundation at the hospital and care facilities could be expected, increased access issues, with flood waters completely surrounding the hospital.
- Floodwaters rise between the Northern Highway and the railway line and also breakout west of the Northern Highway, inundating the golf course and a number of properties between Diggora Rd and McKenzie St.
- Low lying properties along the Rochester South drainage line under threat.
- 157 building flooded above floor and 826 flooded below floor.

100 Year ARI Event

- Further breakouts upstream of Rochester in cropping areas, with the channel embankment restricting floodplain flows.
- Widespread flooding along the eastern floodway upstream of town, no known impacts on any buildings.
- Flooding to the east and west of the railway line is very similar to that of the 50 year ARI event, with increased depths and slightly wider extents.
- The hospital grounds and care facilities are completely inundated.
- 266 building flooded above floor and 878 flooded below floor.

200 Year ARI Event

- The breakout upstream of town to the east in the rural cropping area is increased, flowing under the railway line floodway, flowing into town along the Rochester South drainage line.
- The area inundated along eastern floodway upstream of town is increased, with still no known buildings impacted.
- The flooding to the east of the railway line through town and on to the Waranga Channel is very similar to that of the 100 year and 50 year ARI events with increased depth.
- The flooding to the west of the Northern Highway is significantly increased in extent, with only small pockets of houses not inundated.
- 440 building flooded above floor and 819 flooded below floor.

6. FLOOD MITIGATION OPTIONS

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

6.1 Suggested Structural Mitigation Options

This section provides a preliminary assessment of potential structural flood mitigation measures for the township of Rochester. These are made up of community suggested options as well as options suggested by North Central CMA, Campaspe Shire, Steering Committee members and Water Technology.

Each option was assessed to determine its feasibility. The prefeasibility assessment considered the options likely cost, effectiveness in reducing flood risk, environmental impact and feasibility of construction.

The full list of suggested mitigation measures is shown below in Table 6-1.

Table 6-1 Suggested mitigation options

Option No.	Detail
1	Improve gauges and flood warnings
2	Change management of Lake Eppalock
3	Increase railway bridge capacity
4	Additional culverts under railway
5	Additional culverts under highway
6	Levee from Pascot Street to the bridge
7	Development restrictions on floodplain
8	Remove or lower existing channels and levees
9	Clear debris in river
10	Lower roundabout at western end of road bridge
11	Improve local stormwater drainage, add flap valves
12	Divert flow around town using bypass channels
13	Construction of additional strategic levees

6.2 Preliminary Modelling of Commonly Suggested Options

Preliminary modelling was conducted to assess the impact of some smaller mitigation measures which had been put forward by a number of stakeholders and to help guide the choice of options for detailed modelling. The options and results are discussed below.

6.2.1 Clearing of debris along Campaspe River

Clearing of debris along the Campaspe River channel was suggested to improve the flow of water through the township. This option was modelled by reducing the roughness substantially along the Campaspe River channel from a Manning's 'n' value of 0.06 to 0.03. In reality this represents substantial clearing and smoothing works along the channel. The impact on flood levels is shown below in Table 6-2.

Table 6-2 Impact on water levels through reduction of vegetation

Location	Change in Flood Level (mm)	
	10 year ARI event	100 year ARI event
Upstream of Rail Bridge	-230 mm	-30 mm
Upstream of Road Bridge	-280 mm	-30 mm
Upstream of township (level with Spencer Rd)	-320 mm	-100 mm

The results indicate that a reduction in roughness along the Campaspe channel has a moderate impact on upstream flood levels in a 10 year ARI event but a minimal impact in a 100 year ARI event. The difference in flood level in central Rochester is less than 50 mm in a 100 year ARI event despite the substantial changes that were modelled. In a large flood the impact of vegetation along the river is negligible as the majority of the floodplain is inundated, with most of the flow travelling outside of the channel. The density of understorey is low through the reach with vegetation dominated by mature River Red Gum. Furthermore debris in the channel is likely to be submerged to some depth, so the achievable reduction in roughness is likely to be much lower than that modelled.

This option does not change the flood risk in a large event, with the true impact of vegetation thinning likely to be much lower than that modelled. This option is not recommended for further consideration.

6.2.2 Removal of Siphon

Lowering or removal of the siphon was suggested to stop flood water backing up behind the siphon and to assist flood water to flow out of the town more readily. This option was modelled by removing the siphon completely. The impact on flood levels is shown below in Table 6-3.

The results indicate that this option has a minor local impact on flood levels immediately upstream of the siphon in a 100 year ARI event but has no impact on levels further upstream closer to the township. This is due to the slope of the water surface profile. In a 100 year ARI event there is a drop of approximately 1 m in the water surface elevation between the highway bridge and the railway bridge, with another 1 m drop in level between the railway bridge and the siphon. This confirms that the siphon is not a major constriction on floodplain flow.

Table 6-3 Impact on water levels through lowering of siphon level

Location	Change in Flood Level (mm)	
	10 year ARI event	100 year ARI event
Upstream of Rail Bridge	Negligible (less than 10 mm)	Negligible (less than 10 mm)
Upstream of Road Bridge	Negligible (less than 10 mm)	Negligible (less than 10 mm)
Upstream of siphon	Negligible (less than 10 mm)	-80 mm

6.2.3 Increased capacity of road and bridge

Increasing the flow capacity of the road and railway bridges was suggested to stop water backing up behind these structures and allow water to flow through Rochester more easily. This option was modelled by increasing the flow capacity of both the railway and road bridges by 25%. The impact on flood levels is shown below in Table 6-4.

Table 6-4 Impact on water levels through increasing road and rail bridge capacity

Location	Change in Flood Level (mm)	
	10 year event	100 year event
Upstream of Road Bridge	Negligible (less than 10 mm)	-10 mm
Upstream of Rail Bridge	Negligible (less than 10 mm)	-10 mm

The results indicate that a significant increase in the capacity of both the rail and road bridges has a minimal impact on flood levels and extents around Rochester.

6.2.4 Summary of preliminary modelling

The preliminary modelling has indicated that lowering of the siphon and increasing the capacity of the road and rail bridges has a minimal impact on flood levels in Rochester. Clearing of vegetation along the Campaspe River channel has had a greater impact with flood levels lowering by approximately 30 mm in central Rochester in a 100 year ARI event and by approximately 200-300 mm in a 10 year ARI event.

The preliminary modelling indicates that much larger mitigation measures would be needed in Rochester to achieve a significant reduction in water levels and flood extents in large flood events.

6.3 Mitigation Option Prefeasibility Assessment

6.3.1 Assessment Criteria

Each suggested mitigation option was assessed against a number of criteria; potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 6-5 below. The reduction in flood damage was of course the most heavily weighted criteria as this is really the main objective for all flood mitigation. Table 6-6 reviews and scores each mitigation option against the four criteria and calculates a total score for each option. The options with the higher scores indicate the most appropriate mitigation solutions for Rochester from the prefeasibility assessment. While these options were reviewed and recorded individually it is important to consider a combination of options when developing a complete flood mitigation scheme.

Table 6-5 Prefeasibility assessment criteria

Score	Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact
Weighting	**2**	**1**	**0.5**	**0.5**
5	Major reduction in flood damage	Less than $50,000	Excellent (Ease of construction and/or highly feasible option)	None
4	Moderate reduction in flood damage	$50,000 – $100,000	Good	Minor
3	Minor reduction in flood damage	$100,000 – $500,000	Average	Some
2	No reduction in flood damage	$500,000 – $1,000,000	Below Average	Major
1	Increase in flood damage	Greater than $1,000,000	Poor (No access to site and/or highly unfeasible option)	Extreme

6.3.2 Assessment

Each of the suggested mitigation options was assessed using the outlined assessment criteria as shown below in Table 6-6.

Table 6-6 Prefeasibility assessment scoring

No.	Works Location	Mitigation Option	Criteria					Score
			Reduction in Flood Damages	Cost ($)	Feasibility/ Constructability	Environmental Impact	Comments	
1	Rochester and upstream gauges	Improve gauges and flood warnings	3	5	5	5	Improvements in flood warnings and gauges will form part of the ongoing management of flood risk at Rochester. This option does not necessitate detailed modelling as it already forms part of the Rochester Flood and Drainage Plan.	16
2	Lake Eppalock	Change management of Lake Eppalock	5	1	2	4	The use of Lake Eppalock for flood mitigation is likely to be prohibitively expensive and no storages in Victoria are currently used for flood mitigation purposes. Data records show that even when at full capacity Lake Eppalock is very effective at attenuating flows. This option does not require detailed modelling, because changes to the reservoir itself do not impact the hydraulic behaviour of Rochester, it just reduces the flow in the Campaspe and reduces the likelihood and magnitude of flooding (i.e. a 100 year ARI event at Rochester may be reduced to a lower probability if the reservoir begins at a lower starting level).	14
3	Railway bridge over Campaspe River	Increase railway bridge capacity	2	2	3	3	Preliminary modelling has indicated that increased flow capacity under the Campaspe River railway bridge has a minimal impact on flood levels and extents.	9

							This would also be a relatively costly option, causing closure or partial closure of the railway line.	
4	Railway Line	Additional culverts under railway (reducing impact of railway line)	2	2	3	4	Additional culverts under the railway line may reduce flood levels at some locations and reduce the railway line acting as a levee, however may increase water levels downstream of the railway line. Further assessment of this option would be required using the hydraulic model to determine the overall change in flood levels and where additional culverts would be best located, however preliminary modelling looking at a 25% increase in the bridge capacity revealed minor benefits in reduction of flood levels.	9.5
5	Northern Highway	Additional culverts under highway (reducing impact of highway acting as a levee)	2	3	3	4	Additional culverts under the highway may reduce flood levels at some locations and reduce the highway acting as a levee. Engaging existing culverts which aren't being fully utilised may also be effective. This option may also work in conjunction with other options to divert flow out of the Campaspe River and around the township. An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels.	10.5
6	Land adjacent to river between Pascoe Street and road bridge	Levee from Pascoe Street to the bridge	2	3	3	3	A levee at this location may offer some protection in mid-range ARI events however in larger events it is likely water would flow around the levee due to the volume of flood water involved. The levee may also negatively impact flood levels at other locations in the township. An assessment of this option would be required using the hydraulic model to determine the overall change in flood	10

							levels.	
7	Various locations	Development restrictions on floodplain	2	5	3	4	Restricting development on the floodplain may reduce future inundation of new structures however flood risk on the large number of existing homes and businesses is unchanged.	12.5
8	Various locations	Lowering or removing existing channel banks and levees	3	3	4	5	Removing, modifying or lowering existing irrigation and levees may allow better use of the floodplain and provide increased floodplain storage. This option may be expensive and has the potential to dramatically change the flood distribution. This option may work in conjunction with a bypass channel and strategic levees. An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels.	13.5
9	Campaspe River	Clear debris in river, reduce roughness along channel	2	3	2	1	Clearing the Campaspe River of debris is likely to cause some negative environmental impact, decrease the amenity and aesthetics of the township and has the potential for ongoing erosion issues. Preliminary modelling has indicated that a moderate reduction in flood levels in lower ARI events can be achieved. The impact in larger ARI events is negligible.	8.5
10	Various Locations	Lower roundabout at west end of bridge	2	3	3	4	Lowering the roundabout at the western end of the road bridge is likely to have a minimal impact on flood levels in large flood event. The option may be effective in lower ARI events if combined with other options. An assessment of this option would be required using the	10.5

							hydraulic model to determine the overall change in flood levels.	
11	Various Locations	Improve local stormwater drainage, add flap valves	2	3	3	4	Improving local stormwater drainage is likely to have minimal impact on inundation from large flood events but may reduce flood levels in low ARI events where flooding is a result of local stormwater. Installation of flap valves may be effective at reducing the transmission of floodwater in large riverine flood events in conjunction with other mitigation measures.	10.5
12	Existing channels to west of township, other locations to be determined	Divert flow around town using bypass channels	4	2	3	3	Diversion of local flows around the western side of the township is likely to reduce flood levels through the township. The costs associated with this option may be prohibitive and result in additional inundation of private land to the west of Rochester. This option would most likely require the purchase of flood easements. An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels.	13
13	Various locations	Construction of additional strategic levees	4	2	3	3	Additional strategic levees may offer some protection in large ARI events. This option may also be effective when combined with other options such as diversion channels. An assessment of this option would be required using the hydraulic model to determine the location and height of the required levees and the overall change in flood levels.	13

Using the prefeasibility assessment above, the 19 mitigation options were ranked by weighted score. Their ranking is shown below in Table 6-7.

Table 6-7 Weighted prefeasibility mitigation Scores

Rank	Option No.	Mitigation Option	Weighted Score
1	**1**	Improve gauges and flood warnings	16
2	**2**	Change management of Lake Eppalock to include flood mitigation objectives	14
3	**8**	Reduce impact of channels and levees including Waranga Western Channel	13.5
4	**12**	Divert flow around town using bypass channels	13
5	**13**	Construction of additional strategic levees	13
6	**7**	Development restrictions on floodplain	12.5
7	**5**	Additional culverts under highway (reducing impact of highway acting as a levee)	10.5
8	**10**	Lower roundabout at west end of bridge	10.5
9	**11**	Improve local stormwater drainage, add flap valves	10.5
10	**6**	Levee from Pascoe Street to the bridge	10
11	**4**	Additional culverts under railway (reducing impact of railway line acting as a levee)	9.5
12	**3**	Increase railway bridge capacity	9
13	**9**	Clear debris in river, reduce roughness along channel	8.5

The prefeasibility assessment identified a number of works as unfeasible on the basis of low associated damage reduction, high costs and other constructability or environmental issues or unsuitable for detailed modelling due to the nature of the options.

It was clear that improved gauging and flood warnings, and changed operation of Lake Eppalock should be discussed further in this study but both do not require detailed modelling as they are not changing the physical flow characteristics of Rochester itself.

Besides the management of Lake Eppalock, the structural options that appear to have the best chance at reducing flood risk at Rochester include bypass channels, combined with strategic levees, removing/lowering existing channel banks and levees. It was suggested that further detailed modelling be carried out on these themes.

6.4 Structural Mitigation Options

The three packages of mitigation options that were modelled were:

Mitigation Option 1: Removal of all decommissioned irrigation channels from the landscape. This was to gain an understanding of what impacts on flooding the proposed removal of these channels will have on Rochester.

Mitigation Option 2: This option was aimed at diverting significant flow to the west of Rochester using the eastern bank of the decommissioned Campaspe Number 1 channel as a levee. This option would also require a significant off-take structure at the Campaspe Weir.

Mitigation Option 3: This option involved testing a number of structural measures within Rochester aimed at protecting from more frequent flood events, not large flood events like the January 2011 event. This included strategic levees, new drains and earthen excavation to better engage the floodplain.

The three mitigation options are described in more detail below.

6.4.1 Mitigation Option 1

A number of Goulburn-Murray Water irrigation channels have been decommission in recent months, with further decommission to follow. These channels are to be filled in and levelled. The impact of this removal on flooding in Rochester is not yet known and so Option 1 involved removal of all decommissioned irrigation channels from the landscape to gain a better understanding of these impacts. This option was run for the 1% AEP event only.

The channels removed from the model were:

- Campaspe Channel No. 1 located to the west of Rochester
- Channel 2/2 located to the east; and
- Channel 1/1 located to the south

The locations of these channels are shown in Figure 6-1.

Results

The results of the Option 1 modelling indicate the following:

- Increased engagement of the floodplain to the north-east of Rochester with the removal of Channel 2/2 which has resulted in lowering of water levels to the north of Rochester on the east side of the railway line.
- Engagement of the drainage line on the west side of the railway line to the south-west of Rochester which remains dry under existing conditions. This is due to a break out to the south of Rochester resulting in flow through the highway culverts adjacent to Black Culvert Road. This flood water than flows along the drainage line to the west of the railway line and into the south-west of Rochester township
- Increased water levels in the west and south-western parts of the township of between 2 and 10 cm as a result of the additional flow down the railway drainage line as described above.
- No difference in water levels in central Rochester on the eastern side of the railway line

A difference plot comparing the modelled results to existing conditions is shown in Figure 6-2.

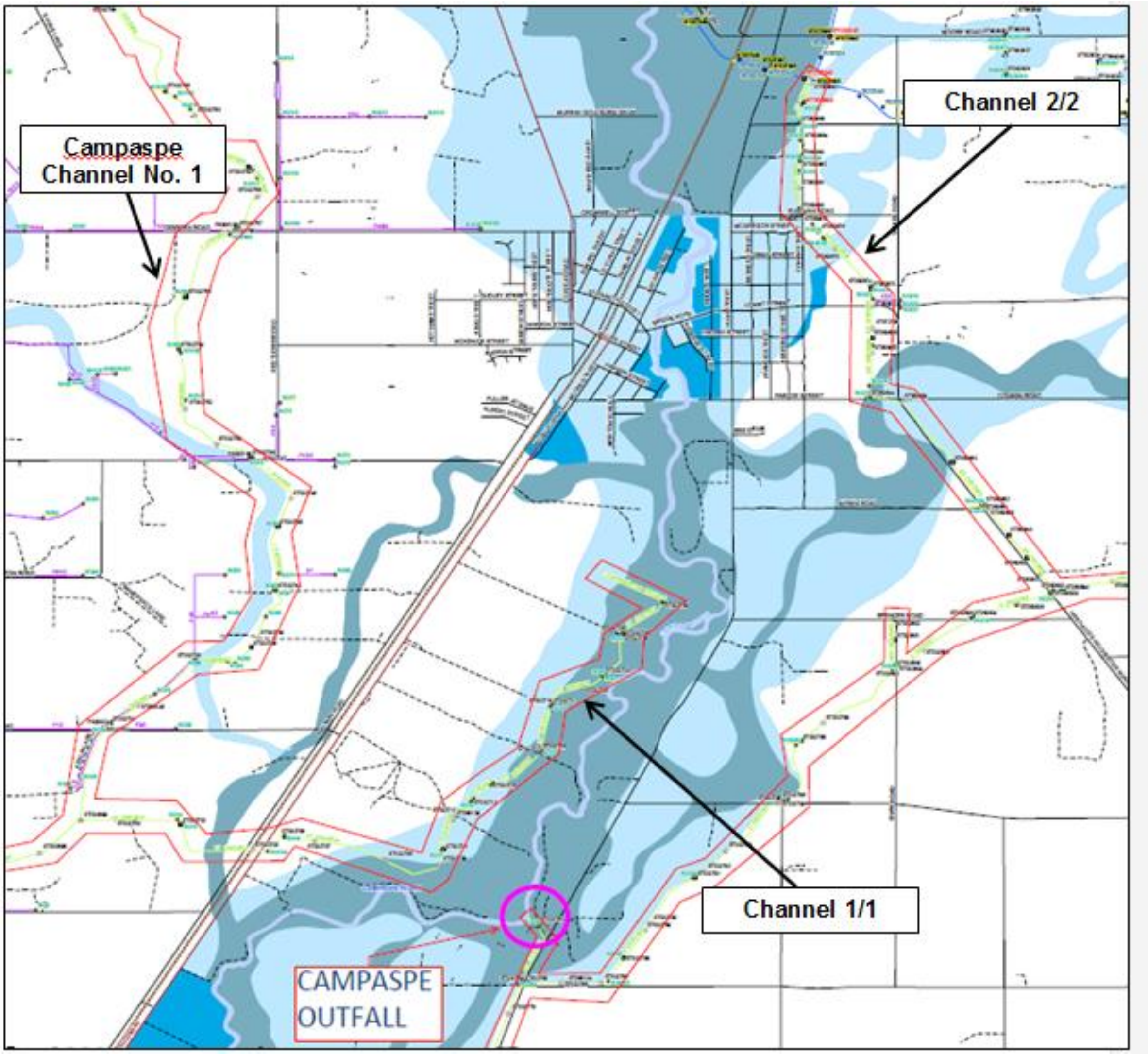


Figure 6-1 Location of decommissioned channels removed from Mitigation Option 1 model (source: Goulburn Murray Water)

Summary

The result of Mitigation Option 1 indicates that the decommissioned channels have a significant impact on flood behaviour around Rochester in a 1% AEP event. In particular Channel 1/1 has an important role in preventing flood water breaking out from the Campaspe River and flowing under the railway and into south-western Rochester. Channel 2/2 to the north-east of Rochester also has a significant impact on flood levels, when removed it reduces the level between the river and the channel, and increases the water level and extent to the west of the channel.

It is recommended that that a small section of the Channel 1/1 be maintained or a traditional levee constructed to prevent the breakout under the highway and railway line. It is recommended that the impact of decommissioning Channel 2/2 be considered carefully prior to any works.

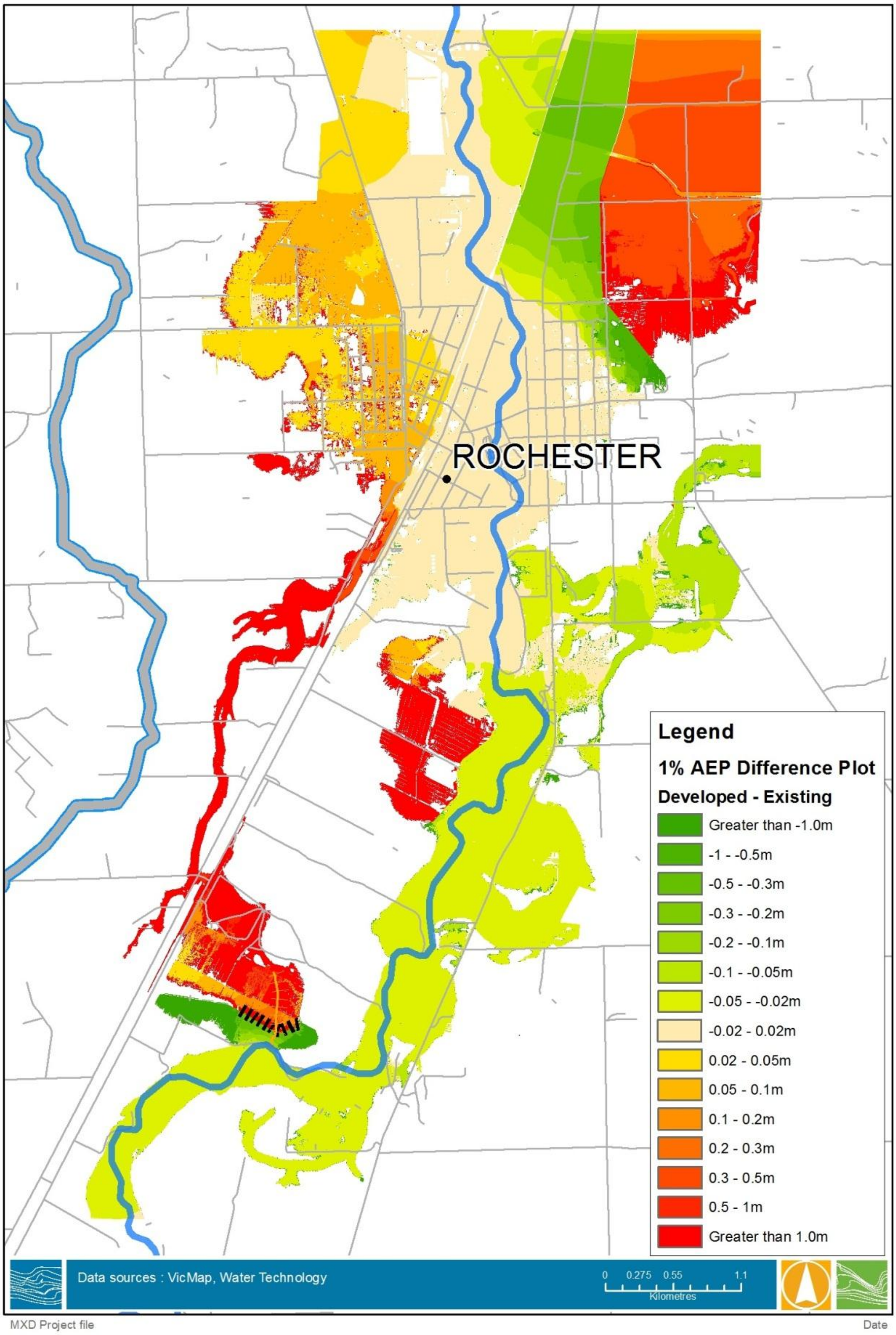


Figure 6-2 Mitigation Option 1 - 1% AEP difference plot

6.4.2 Mitigation Option 2

Mitigation Option 2 was aimed at protecting the township from river flows by diverting significant flows to the west of Rochester using the raised banks of Campaspe Channel No 1 as a levee. Flows would be diverted from the Campaspe River at the channel off-take at Campaspe Weir. Depending on the volume of water diverted this has the potential to significantly reduce flood levels within the township of Rochester. Campaspe Channel No 1 runs in a north-south direction to the west of Rochester.

Campaspe Channel No. 1 is not sufficiently large to transmit a significant volume of flow so instead of using the channel to convey the flood water a floodway would need to be created to the west of the channel with the raised banks of the channel used as a form of levee. This would require raising the height of the right-hand bank of the channel in some areas.

6.4.3 Flow Scenarios

Three flow diversion scenarios were considered for the 1% AEP design event along the Campaspe River. Scenario 1 involved diverting all flow above the Campaspe 10% AEP flow (30,200 ML/d) to the west of the Campaspe Channel No 1. Whilst the peak flow through Rochester would be restricted to that of the current 10% AEP event, flooding within the township would be expected to be greater than the 10% AEP event because the total volume of water flowing through the town will be greater. It would be expected that flooding throughout the township of Rochester under Scenario 1 would be the equivalent of a 10-20 year ARI event.

Figure 6-3 below depicts the hydrographs for Scenario 1 along with the 10% AEP event hydrograph through Rochester for comparison.

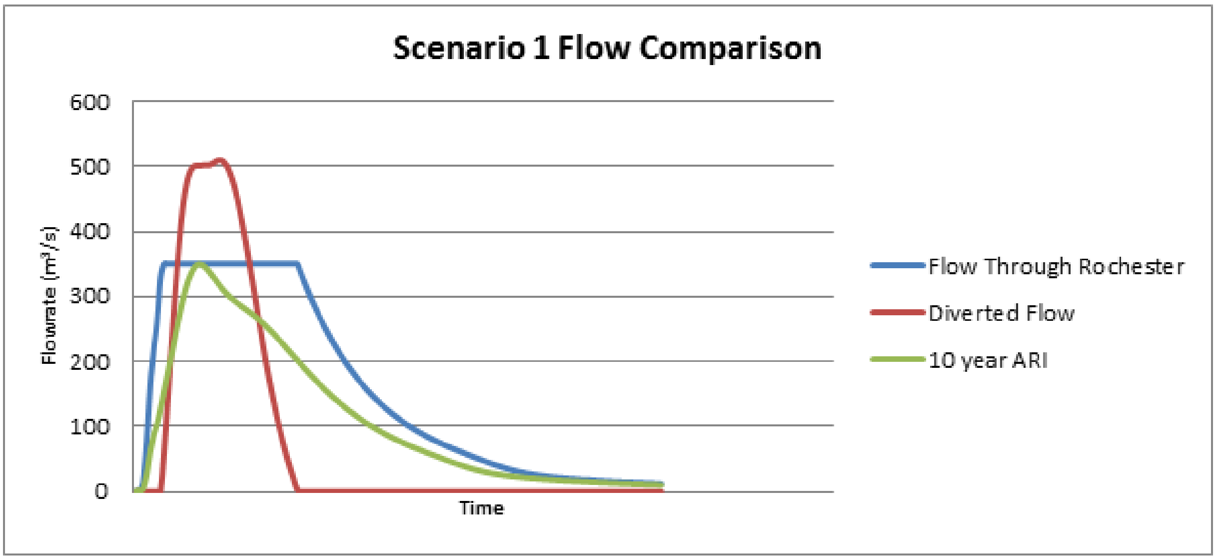


Figure 6-3 Scenario 1 Flow Comparison

Scenarios 2 and 3 diverted all flows above the 20 and 50 year ARI peak flows respectively. Table 6-8 provides a summary of the peak flows for each scenario.

Table 6-8 Mitigation Option 2 scenario flow details

	Peak flow diverted around Campaspe Channel No. 1 (ML/d)	Peak flow through Rochester (ML/d)	Equivalent design event through Rochester
Scenario 1	44,000	30,200	10-20 year ARI
Scenario 2	31,800	42,500	20-40 year ARI
Scenario 3	15,200	59,100	50-70 year ARI

6.4.4 Additional Strategic Levee

The initial model runs indicated that the diverted flows inundate a large overland area to the north and north-west of Rochester. In order to reduce the area of inundation and create a more defined floodway an additional strategic levee to the west of Campaspe Channel No 1 was tested. This was referred to as the Western Levee.

This levee was represented in the topography of the hydraulic model to restrict flows passing to the west and north-west. The location can be seen in the Figure 6-4. A more detailed assessment of the levee design and alignment would be required if this mitigation option had progressed further.

6.4.5 Indicative Costs

A preliminary cost estimate was developed for the construction of the Western Levee which did not include land easement and compensation costs. The estimated cost of constructing the levee (including administration, engineering and contingencies) is approximately $800,000 to $1,000,000. This is based on a freeboard of 0.3m and a crest width of 1 to 3 m along the entirety of the levee. This cost estimate may differ somewhat following a more detailed analysis of the levee design and alignment with better topography available. Note that this cost does not include the offtake regulator, road crossings, floodway earthworks between the river and east of the railway line or any topping up of the Campaspe Channel banks. The total structural cost of the option is likely to be in the order of $5 million.

Following completion of the modelling the North Central CMA made some preliminary estimates of land easement and landholder compensation costs for this option based on the area of inundation. Preliminary estimates were in the region of $85 million indicating this option is cost prohibitive.

6.4.6 Model Results

The model results for each scenario were mapped and are shown in Figure 6-4 and Figure 6-5. In each scenario flows are initially confined to a floodway between the Campaspe Channel No.1 and the Western Levee. Downstream of the Western Levee and Campaspe Channel No 1 the area of inundation widens significantly throughout the natural floodplain. The majority of flood water flows overland northwards before entering the Murray River whilst a portion of the flows return to the lower Campaspe upstream of Echuca. A review of the existing LSIO layers indicate that this option is utilising existing drainage lines and re-engaging areas of the floodplain which historically would have flowed in a large flood event.

The incorporation of the Western Levee into the model topography eliminates most of the overland flow to the north-west and is effective at directing the flow northwards and back towards the Murray and Campaspe. The total area of overland inundation for Scenario 1 is approximately 237 km^2. The majority of the inundated area consists of farmland and rural properties, and would inundate a significant length of rural roads. Summary statistics of the model results can be seen in the table below.

Table 6-9 Summary of Mitigation Option 2 Results

	Inundated Area (km^2)	Average Depth (m)
Scenario 1	237	0.487
Scenario 2	178	0.421
Scenario 3	128	0.345

6.4.7 Summary

The results indicate that significant flow can be diverted around Rochester however the costs to achieve this are likely to be prohibitively high. Preliminary estimates of compensation costs were as high as $85, million due to the large area that would be inundated by this option in large flood events, that is on top of a possible $5 million in capital costs.

The results of this option were presented to the steering committee on 30th January 2013 and discussed. It was agreed in that meeting that this option is not feasible and cost prohibitive.

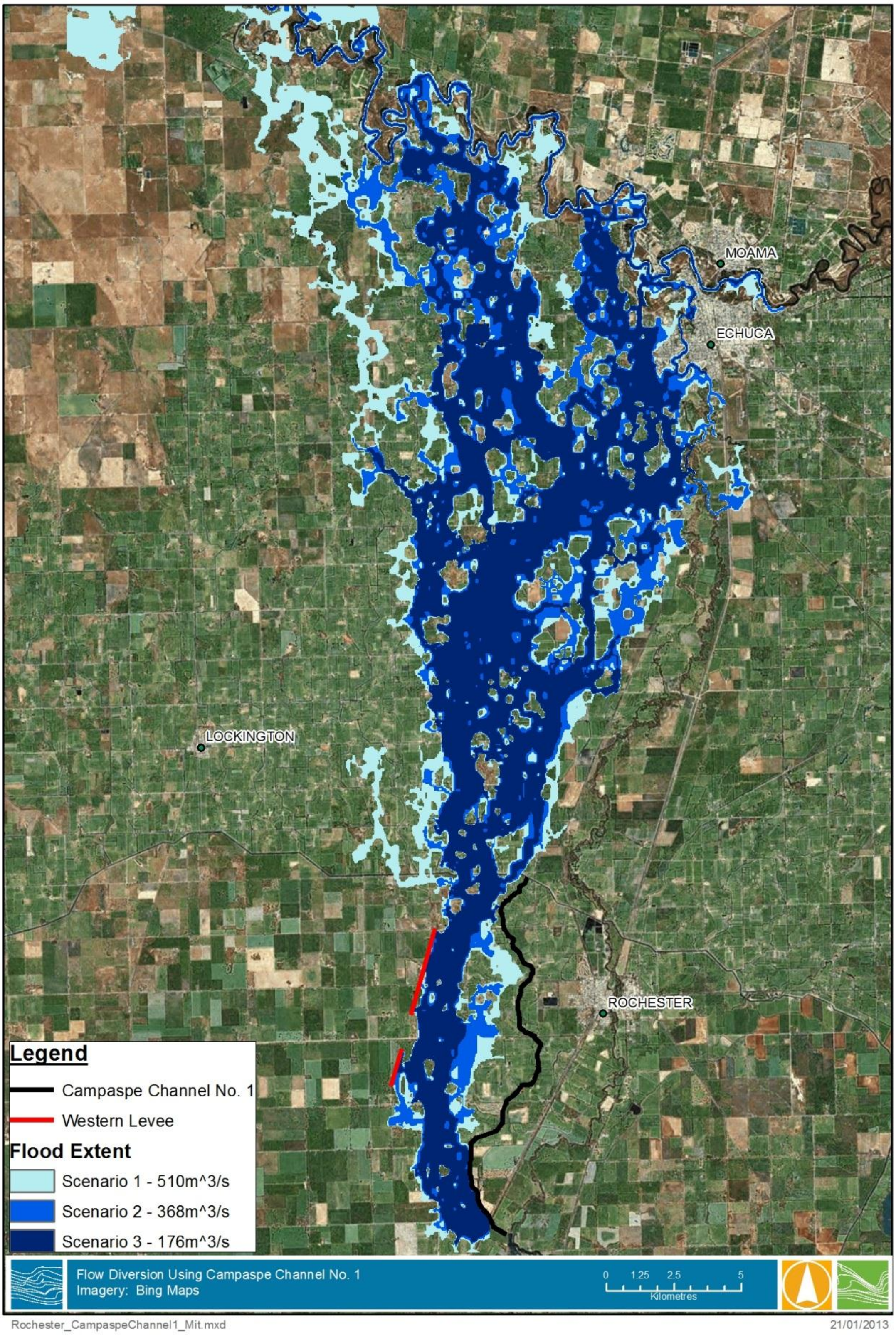


Figure 6-4 Mitigation Option 2 results (1% AEP event)

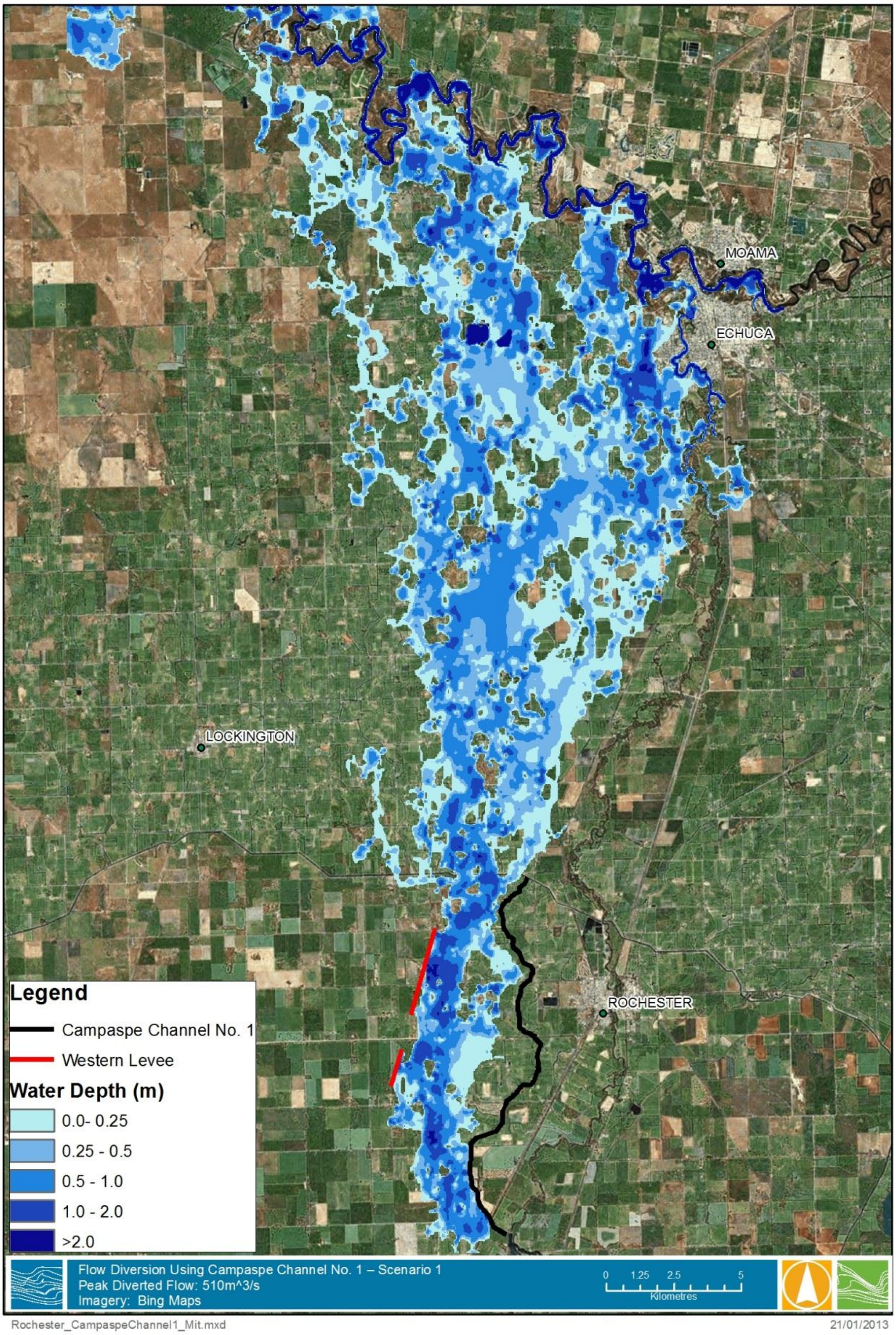


Figure 6-5 Mitigation Option 2 – Scenario 1 results (1% AEP)

6.4.8 Mitigation Option 3

Previous modelling had indicated that protecting Rochester from a 1% AEP event was likely to be unachievable so this option looked at structural options which could provide some protection from more frequent events. The 5% AEP flood extent was used as a starting point with a number of works tested to reduce the damage of this event.

The Package 3 model consisted of the following:

- Excavation of land to the east of the railway bridge to allow additional flow northwards across the floodplain and through the railway culvert located 200 m north of the railway bridge. Approximately 10,800 m^3 of earth would need to be excavated.
- Excavation of land between the Campaspe River and Boon Street (near Jess Drive) to better engage the watercourse which flows eastwards from Rochester. Under existing conditions this drainage line is well utilised in a 1% AEP event but not in a 5% AEP event and lower. Approximately 5,800 m^3 of soil would need to be excavated.
- Construction of a strategic levee along the left bank of the Campaspe River between the water treatment plant on Campaspe St and the eastern end of Morton Street. The levee aims to protect from a large breakout which flows north-west through this area in the 5% AEP event and greater. The levee would be approximately 1,100 m long and have an average height of 1.1 m.
- Construction of a smaller levee along Bonn Street which will protect properties from the increased engagement of the eastern drainage line. The levee would be approximately 280 m long and have an average height of 0.7 m.
- Construction of an open drain in the existing drainage easement between the railway line and Ramsay Street from Elizabeth Street to the Campaspe River. This option is aiming to assist drainage of flood water and local runoff in that area. Approximately 3,900 m^3 of soil would need to be excavated to construct the drain.

The options described above are shown in Figure 6-6.

Results

The results indicate that this package provides significant benefit in both the 1% and 5% AEP events. In the 5% event the large breakout in the vicinity of Fraser and Pascoe Streets has been prevented resulting in a number of properties in that area being protected. The package has also resulted in lower flood levels at many properties in central and northern Rochester as a result of the additional flow into the eastern drainage line and floodplain to the north. Inundation and access around the hospital has also been improved.

While not the main goal of this package significant benefits were also observed in the 1% AEP event results. Water levels in central Rochester and on the western side of the railway line are significantly improved with reductions of up to 400 mm in those areas. The eastern drainage line is significantly better engaged with increases in water level of up to 500 mm through that area. There are also large areas of southern and western Rochester which are now protected with this option including approximately 60 properties around Northcote, Hopetoun and Queen Streets. These improvements are largely a result of the strategic levee preventing water from breaking out through the central township and over the railway line. On the eastern side of the Campaspe River water levels are also generally lower however the difference is smaller and in the order of 30-50 mm. Water levels are marginally higher in a small area near the southern end of High Street. Water levels in this area are approximately 10-20 mm higher.

The only property to be significantly negatively impacted by this option within the model area is at 512 Bonn Road. Planning maps demonstrate that this property lies within the floodway of the eastern drainage line. In the 5% AEP event additional flow occurs across the property however buildings are not impacted. In the 1% AEP event water levels at the house would increase by 250 mm. Floor level survey is not available for this property however it is suspected that the new water surface elevation in the 1% AEP event would be just above floor level. This is based on an assumption in the damages assessment that the floor level is 200 mm above natural surface level. A ring levee would therefore likely be required at this location to mitigate these impacts. Prior to this option going further it is recommended that the site be surveyed for existing floor levels, both the dwelling and any other significant storage sheds.

The additional flow occurring down the eastern drainage line with this option was measured. It was found that in the 1% AEP peak flows increased from just under 5,000 ML/d to just under 11,800 ML/d. The impacts on properties and infrastructure further to the east, which lie outside of the model boundary, are not known at this point. It is recommended that further analysis be undertaken so that the full impact of these measures can be better understood and conveyed to the community.

The 5% AEP depth results for Option 3 are shown in Figure 6-6 and a difference plot is shown in Figure 6-7. The 1% AEP depth results for Option 3 are shown in Figure 6-8 and a difference plot is shown in Figure 6-9.

Summary

The Mitigation Option 3 modelling has demonstrated a significant improvement in flood risk for many parts of Rochester in the full range of AEP events. The option has achieved its aim of providing protection to a number of properties in a 5% AEP event but has also resulted in significant benefits in larger events up to and including the 0.5% AEP event.

The option has had a significant negative impact on one property within the model area and additional structural mitigation measures will likely be required to mitigate from these impacts. These impacts are due to more flow occurring down the eastern drainage line in 5% AEP events and greater. The impacts on properties and infrastructure further to the east, outside of the model area, are not known at this point. It is recommended that further analysis be undertaken so that the full impact of these measures can be better understood and conveyed to the community.

A flood damages and benefit-cost analysis was completed for this option which is described in Section 8 below. The min

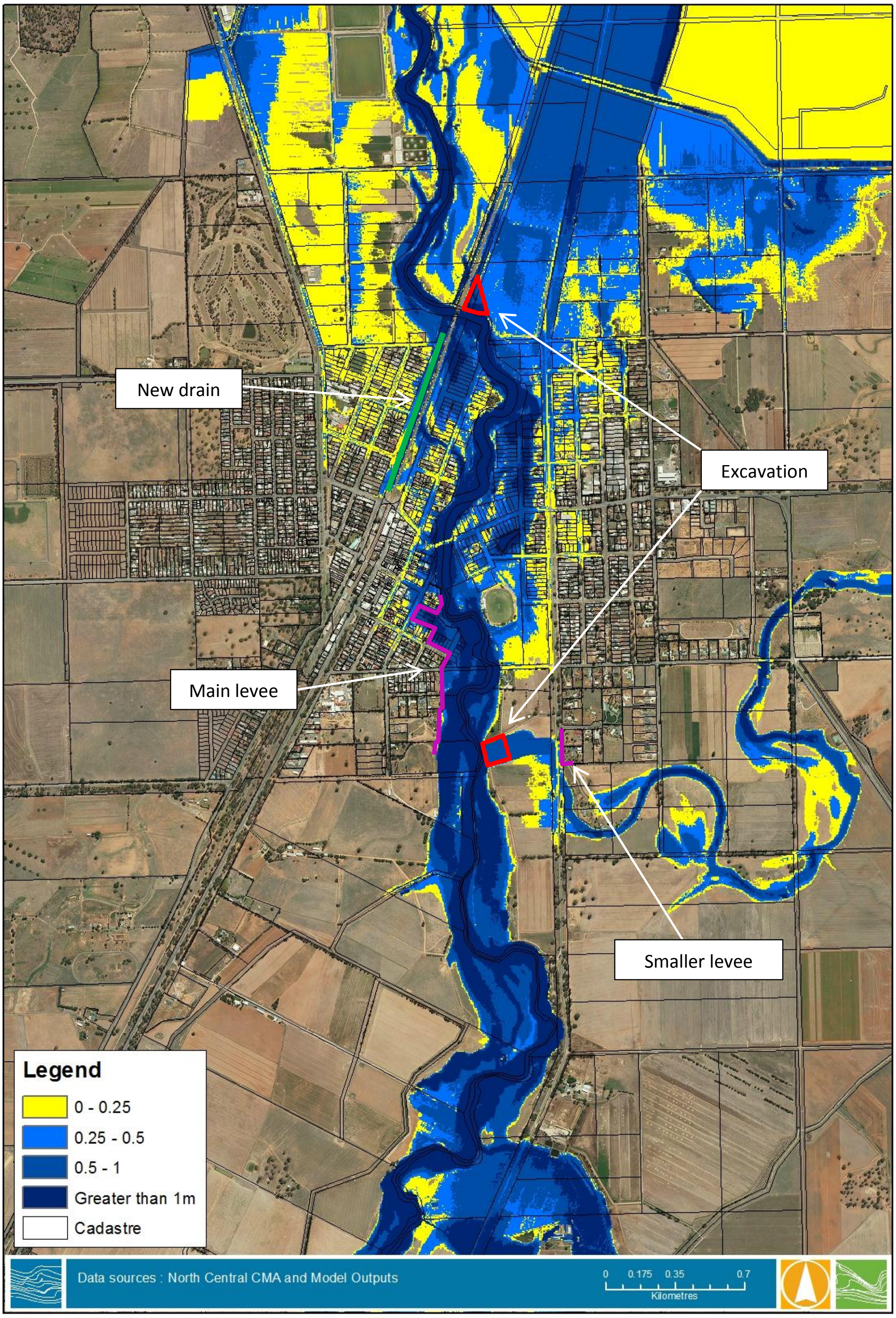


Figure 6-6 Mitigation Option 3 results - 5% AEP event

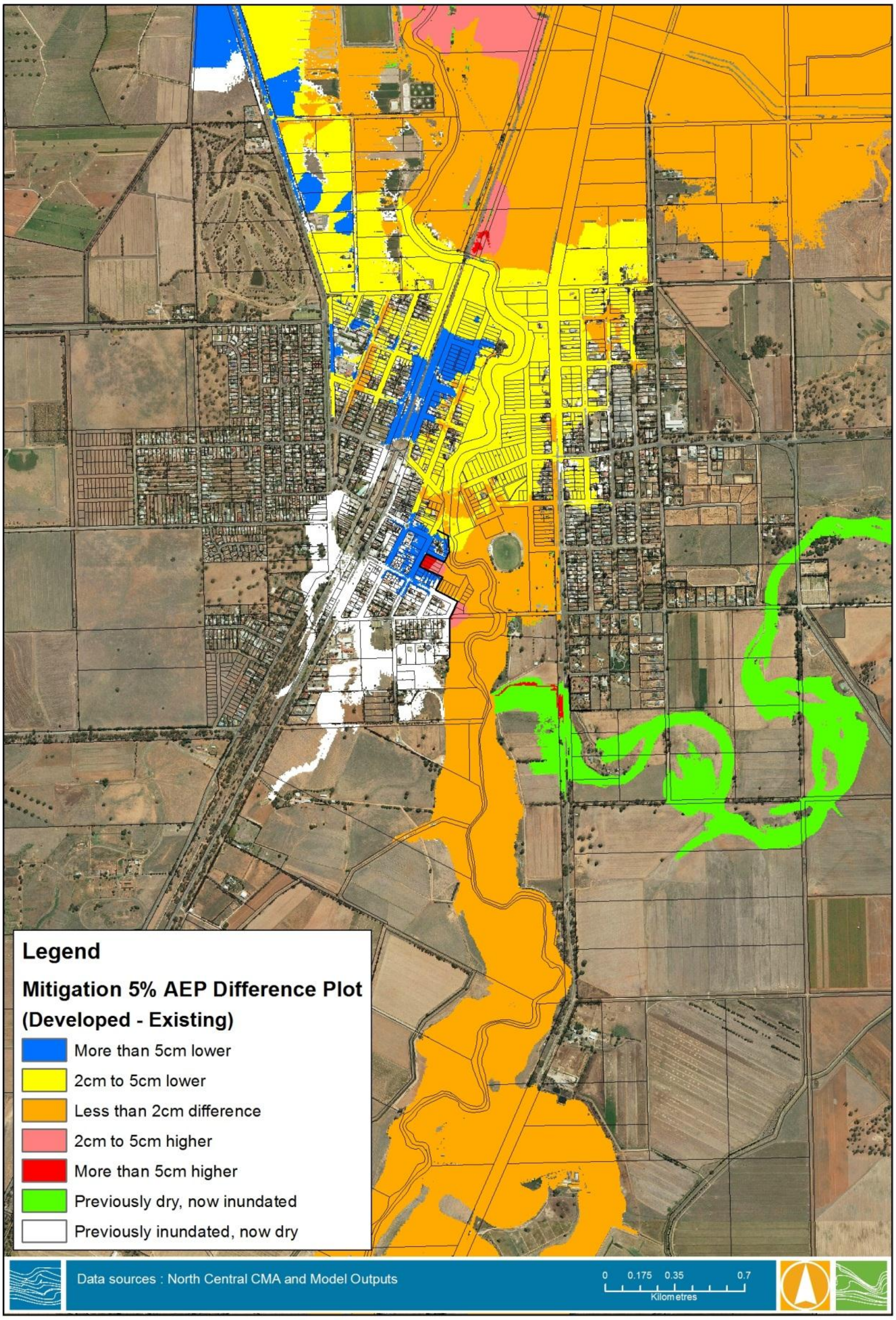


Figure 6-7 Mitigation Option 3 Difference Plot - 5% AEP event

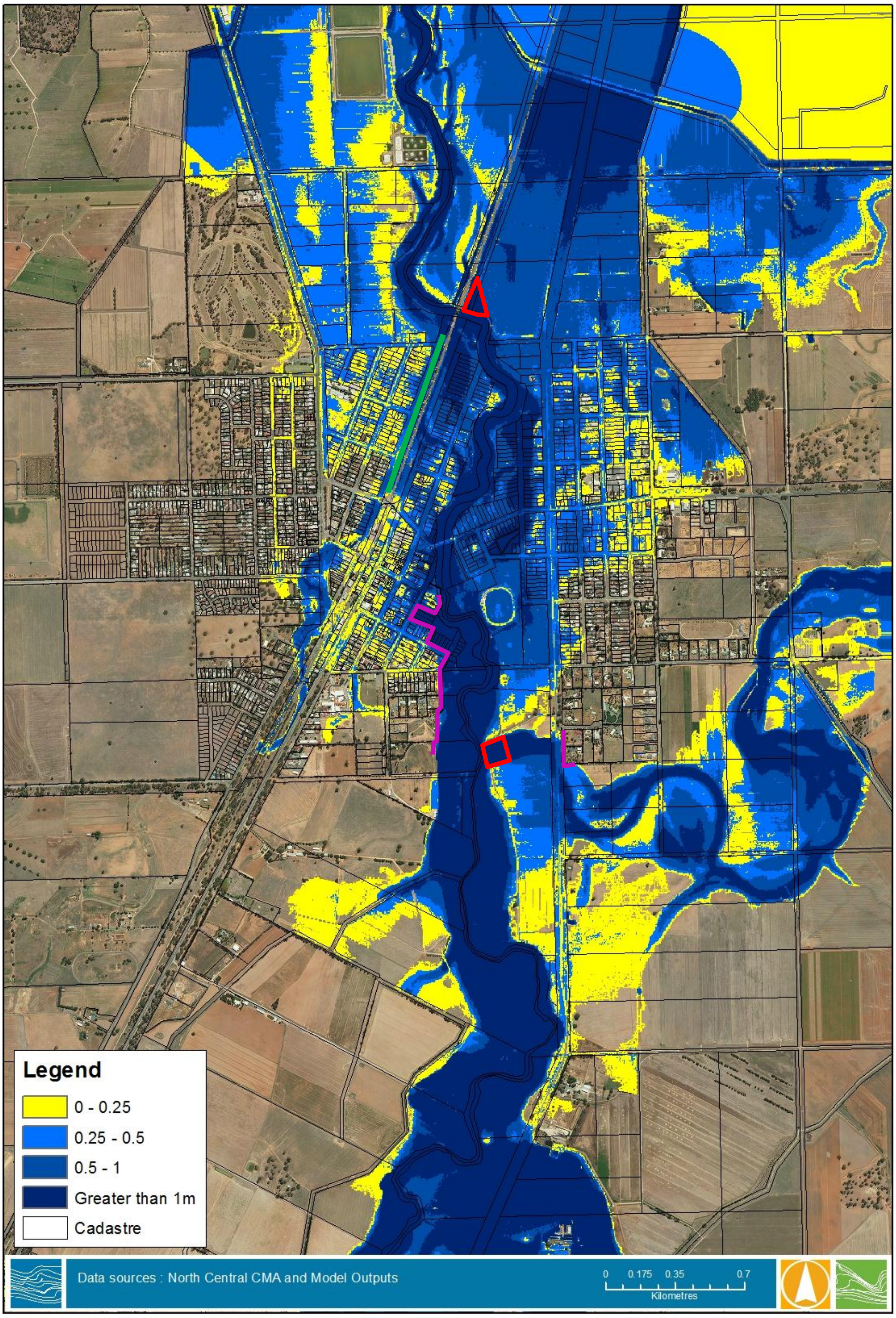


Figure 6-8 Mitigation Option 3 results - 1% AEP event

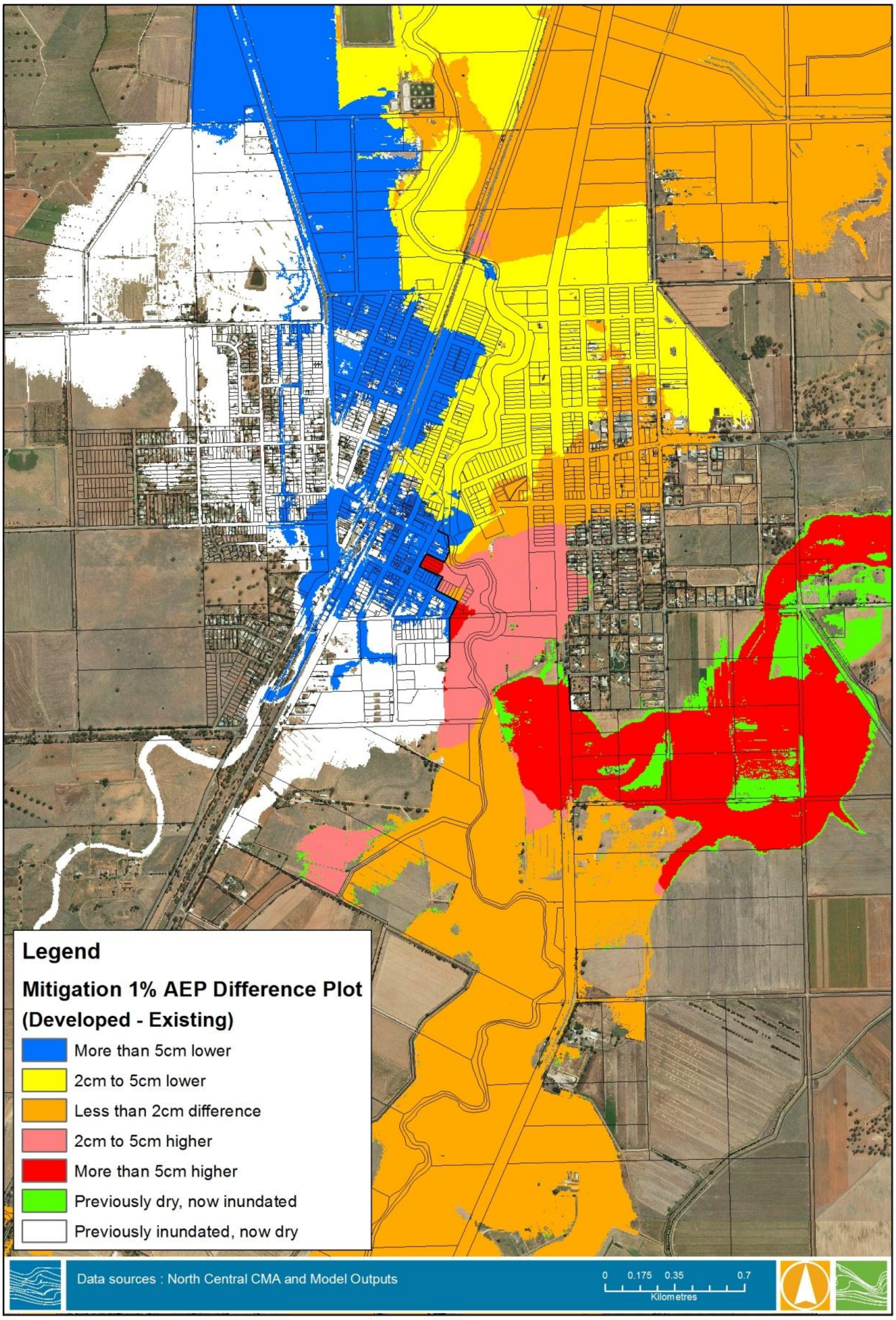


Figure 6-9 Mitigation Option 3 Difference Plot - 1% AEP event

6.5 Non Structural Mitigation Options

There are a range of non-structural mitigation options that can be implemented including land use planning, flood warning, flood response and flood awareness. This section discusses Land Use Planning while the Flood Warning System for Rochester is discussed in Section 12.

6.5.1 Land Use Planning

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

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

Guidance for applying flood controls to Planning Schemes is available from the Department of Planning and Community Development's (DPCD) Practice Note on Applying Flood Controls in Planning Schemes.

Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. It is recommended that the planning scheme for Rochester is amended to reflect the flood risk identified by this project. Figure 6-11 shows proposed FO and LSIO for consideration into such an amendment. The draft planning scheme map is based on the 'Advisory Notes for Delineating Floodways' (NRE, 1998), with three approaches considered.

Flood frequency - Appendix A1 of the advisory notes suggest areas which flood frequently and for which the consequences of flooding are moderate or high, should generally be regarded as floodway. The 10 year ARI flood extent was considered an appropriate floodway delineation option for Rochester.

Flood hazard - Combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 6-10 for delineating the floodway based on flood hazard. The flood hazard for the 100 year ARI event was considered for this study.

Flood depth - Regions with a flood depth in the 100 year ARI event greater than 0.5 m were considered as FO based on the flood depth delineation option.

All three of the above flood frequency, hazard and depth maps were enveloped to provide the final proposed FO maps as shown below.

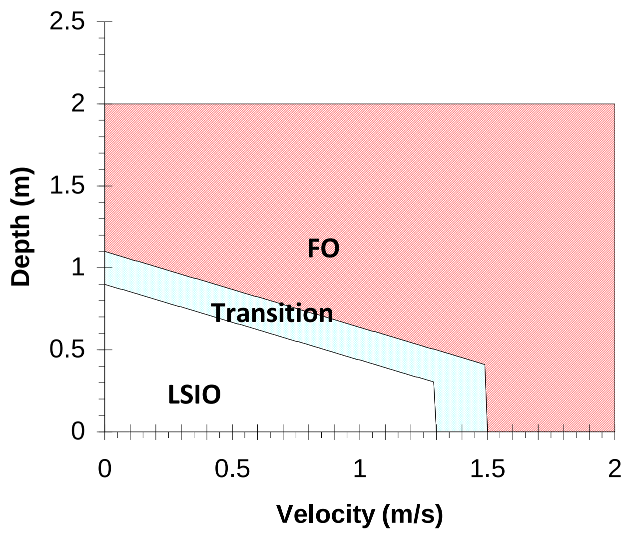


Figure 6-10 Flood Hazard Delineation of FO

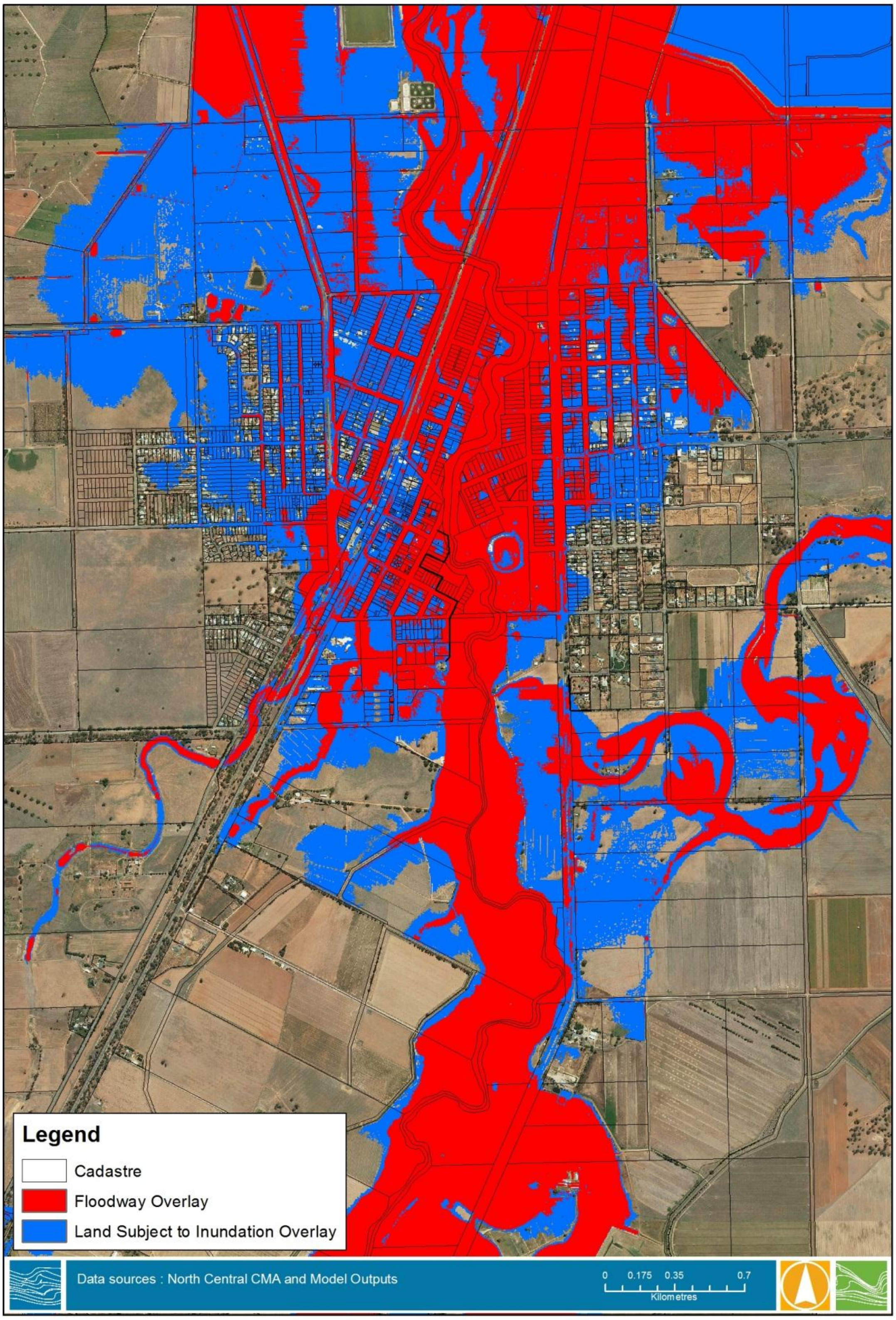


Figure 6-11 Draft LSIO and FO Map for Existing Conditions

7. FLOOD DAMAGE ASSESSMENT

7.1 Overview

A flood damages assessment was undertaken for the study area under existing conditions. The flood damage assessment determined the monetary flood damages for design floods (5, 10, 20, 50, 100 and 200 year ARI events). The flood damage assessment was also undertaken for the third mitigation option.

Water Technology has developed an industry best practice damage assessment methodology that has been utilised for a number of studies in Victoria, combining aspects of the Rapid Appraisal Method, ANUFLOOD and other relevant flood damage literature. The model results for all mapped flood events were processed to calculate the numbers and locations of properties affected. This included properties with buildings inundated above floor, properties with buildings inundated below floor and properties where the building was not impacted but the grounds of the property were. In addition to the flood affected properties, lengths of flood affected roads for each event were also calculated. Details of the flood damage assessment methodology are provided in Appendix D.

7.2 Existing conditions

The 100 year ARI flood damage estimate for existing conditions was calculated to be over $11.5 million. A total of 1,144 properties are flooded in a 100 year ARI event, with 266 of those properties flooded above floor level. The January 2011 event is estimated at very close to a 100 year ARI event. The total number of properties flooded is consistent with that reported in VICSES rapid impact assessments. The Average Annual Damages (AAD) was determined as part of the flood damage assessment. The AAD is a measure of the flood damage per year averaged over an extended period. The AAD for existing conditions for the study area is estimated at approximately **$431,573**. This is effectively a measure of the amount of money that must be put aside each year in readiness for the event that a flood may happen in the future.

Table 7-1 Flood damage assessment for existing conditions

ARI (years) AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	440	266	157	32	3	0
Properties Flooded Below Floor	819	878	826	456	114	30
Total Properties Flooded	**1259**	**1144**	**983**	**488**	**117**	**30**
Direct Potential External Damage Cost	$4,941,649	$4,158,074	$3,354,352	$1,551,736	$317,192	$63,529
Direct Potential Residential Damage Cost	$10,333,562	$5,376,879	$2,603,843	$366,638	$58,644	$0
Direct Potential Commercial Damage Cost	$2,334,642	$1,786,764	$1,246,081	$297,154	$39,654	$0
Total Direct Potential Damage Cost	**$17,609,854**	**$11,321,716**	**$7,204,275**	**$2,215,529**	**$415,490**	**$63,529**
Total Actual Damage Cost *(80% potential)*	**$14,087,883**	**$9,057,373**	**$5,763,420**	**$1,772,423**	**$332,392**	**$50,823**
Infrastructure Damage Cost	**$1,526,076**	**$1,224,992**	**$952,217**	**$430,873**	**$147,615**	**$15,348**
Indirect Clean Up Cost	$2,289,871	$1,326,794	$743,713	$142,565	$15,390	$0
Indirect Residential Relocation Cost	$243,047	$126,636	$61,352	$9,439	$1,573	$0
Indirect Emergency Response Cost	$30,420	$25,350	$20,280	$15,210	$10,140	$5,070
Total Indirect Cost	**$2,563,338**	**$1,478,780**	**$825,344**	**$167,214**	**$27,103**	**$5,070**
Total Cost	**$18,177,297**	**$11,761,145**	**$7,540,981**	**$2,370,510**	**$507,110**	**$71,241**

Average Annual Damage (AAD)	$431,573

7.3 Mitigation Option 3

The AAD for mitigation option 3 was calculated to be approximately **$269,971**. During a 100 year ARI event, mitigation option 3 reduces the total number of properties inundated above floor level from 266 properties to 141 properties. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$161,602** per year by implementing mitigation option 3.

Table 7-2 Flood damage assessment for mitigation option 3

ARI (years) AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	257	141	84	13	3	0
Properties Flooded Below Floor	956	560	462	324	96	31
Total Properties Flooded	**1213**	**701**	**546**	**337**	**99**	**31**
Direct Potential External Damage Cost	$4,361,788	$2,724,918	$2,138,085	$1,044,235	$282,824	$66,085
Direct Potential Residential Damage Cost	$5,188,584	$2,380,496	$1,152,725	$181,631	$63,002	$0
Direct Potential Commercial Damage Cost	$1,560,588	$1,036,420	$580,698	$99,327	$29,542	$0
Total Direct Potential Damage Cost	**$11,110,959**	**$6,141,834**	**$3,871,509**	**$1,325,193**	**$375,368**	**$66,085**
Total Actual Damage Cost *(80% potential)*	**$8,888,768**	**$4,913,467**	**$3,097,207**	**$1,060,154**	**$300,294**	**$52,868**
Infrastructure Damage Cost	**$1,377,900**	**$835,004**	**$547,551**	**$345,861**	**$141,089**	**$21,929**
Indirect Clean Up Cost	$1,294,507	$674,744	$380,019	$58,206	$15,390	$0
Indirect Residential Relocation Cost	$126,636	$57,419	$26,743	$3,933	$1,573	$0
Indirect Emergency Response Cost	$30,420	$25,350	$20,280	$15,210	$10,140	$5,070
Total Indirect Cost	**$1,451,563**	**$757,513**	**$427,042**	**$77,349**	**$27,103**	**$5,070**
Total Cost	**$11,718,230**	**$6,505,984**	**$4,071,800**	**$1,483,365**	**$468,487**	**$79,867**

Average Annual Damage (AAD)	$269,971

7.4 Average Annual Damage Summary

The damage assessment shows that Mitigation Option 3 has a significant impact on reducing the AAD in Rochester as shown in the summary table in Table 7-3.

Table 7-3 Average Annual Damage Summary for Rochester

Options	**Average Annual Damage**
Existing Conditions	$431,573
Mitigation Option 1	$269,971

7.5 Non-Economic Flood Damages

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

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

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

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

There is no doubt that the Rochester community has suffered greatly as a result of the recent floods and will continue to do so with potential future floods. The intangible non-monetary flood related damage in Rochester is very high. The benefit-cost analysis presented later in this report (section 8.3) has not considered this cost. Any decisions made that are based on the benefit-cost ratios need to understand that the true cost of floods in Rochester is far higher than the economic damages alone. This would have the effect of increasing the benefit cost ratio, improving the argument for approving a mitigation scheme at Rochester.

8. BENEFIT COST ANALYSIS

8.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the third mitigation option. Indicative benefit-cost ratios were based on the construction cost estimates and average annual damages. For the analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life.

8.2 Mitigation Option Costs

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

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

A summary of the cost estimates for the third mitigation option are shown in Table 8-1 below. A detailed breakdown of the costing for each mitigation option is included in Appendix C The cost for the proposed levees and earthworks was calculated based on unit costs of the estimated volume of material required to construct the structure.

A 30% contingency cost was added along with engineering and administration costs. An annual maintenance cost of 1.5% of the construction cost was also factored in for the works.

Table 8-1 Mitigation Option Cost Breakdown

Option	Total Construction Cost	Annual Maintenance
Mitigation Option 3	$1,802,957	$17,409

8.3 Benefit Cost Analysis

The results of the benefit cost analysis are shown below in Table 8-2. Mitigation Options 1 and 2 did not require a benefit cost analysis due to the reasons described above. The analysis for Option 3 demonstrated a high benefit cost ratio of 1.1 This relatively high ratio is due to a high annual saving in damages due to the large number of properties protected from above floor flooding in the full range of events.

Table 8-2 Benefit Cost Analysis

	Existing Conditions	Mitigation Option 1
Average Annual Damage	$431,573	$269,971
Annual Maintenance Cost		$17,409
Annual Cost Saving		$144,193
Net Present Value		$2,027,701
Capital Cost of Mitigation		$1,902,957
Benefit – Cost Ratio		1.1

9. FINAL PREFERRED STRUCTURAL MITIGATION OPTION

Based on the study results, steering committee discussions and the community consultation feedback the final preferred structural mitigation option of the steering committee was:

- Further assessment of the proposed structural mitigation measures described below so that the full impacts of the works can be better understood and conveyed to the community.
- Detailed planning and design of a formal levee to replace irrigation channel 1/1 to the south of Rochester which is marked for decommissioning
- Further investigation of irrigation channel 2/2 to the east of Rochester which is marked for decommissioning in consultation with affected landowners.

The structural works proposed for further assessment and detailed design include:

- Excavation of land to the east of the Campaspe River railway bridge to allow additional flow northwards across the floodplain and through the railway culvert located 200m north of the railway bridge
- Excavation of land between the Campaspe River and Bonn Street (near Jess Drive) to better engage the drainage line which flows eastwards from Rochester
- Construction of a strategic levee along the left bank of the Campaspe River between the water treatment plant on Campaspe St and the eastern end of Morton Street
- Construction of a small levee along Bonn Street which will protect properties from the increased engagement of the eastern drainage line
- Construction of an open drain in the existing drainage easement between the railway line and Ramsay Street from Elizabeth Street to the Campaspe River.

10. FLOOD WARNING SYSTEM

The full flood warning assessment and recommendations report is available in Appendix C. The key recommendations from that report are provided below.

10.1 Aim and Function

Flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[5].

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

10.2 Flood Warning Recommendations

A staged approach to the refinement of the flood warning system for Rochester is proposed. The stages have been ordered and the tasks within each stage grouped to facilitate incremental growth of the TFWS elements in a balanced manner and with full regard for community feedback received as part of this study. Early work is directed at addressing deficiencies in the existing data collection network and forecasting capability. The availability of a flood forecast centred on Rochester is fundamental to the use of deliverables from this study to inform future flood response and awareness activities. Following resolution of the forecasting issue, other activities can occur in the knowledge that required data is / will be available and that arrangements are in place that will enable maximum benefit to be derived from any information or programs delivered to the community. A timetable and priorities have not been attached to the suggested actions other than for establishing BoM access to Rochester town gauge data and the development of a capability to deliver flood forecasts for the town gauge rather than the Syphon.

Stage 1A

1. Acknowledging that there is a high need to change the flood forecast location from the Rochester Syphon to the town gauge, Council, DSE and BoM to determine the responsible entity/ies in relation to "ownership" of an upgraded and telemetered river monitoring station at Rochester. Ownership is considered to denote responsibility for funding and site functionality and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with associated payments. VFWCC[6] provides guidance on this matter although recommendation 1 from the Comrie Review Report[7] suggests that some clarifications may be required.

[5] More generally, the objective of early warning is to empower individuals and communities, threatened by natural or similar hazards, to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and damage to property, or nearby and fragile environments (UN, 1997).

[6] Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria.* February 2001.

[7] Comrie, N. (2011): *Review of the 2010-11 Flood Warnings and Response: Final Report.* 1 December 2011.

The estimated capital cost of this installation, comprising concrete instrument housing on concrete pad, HS dry bubbler and pressure transducer, Campbell logger, modem, solar panel, antenna and cabling, is likely to be of order $25,000 + GST. This cost could be reduced by ~$2,000 if a less robust instrument housing was used. Cost includes estimated allowances for cultural heritage assessment and service checks and marking at site. Based on current rates, on-going costs are likely to be order $3,000 + GST per year without gaugings.

2. As part of the above, consider relocating the rain gauge at the Syphon to the town gauge site. This would increase the estimated capital cost by around $2,500 + GST and on-going costs by around $1,000 + GST per year using current rates.
3. Council with the support of VICSES, NCCMA, DSE and the Rochester community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for activities listed below and aimed at upgrading the TFWS for Rochester.

Stage 1B

1. If responsibilities for funding and operation of the upgraded gauge at Rochester cannot be resolved quickly (i.e. unlikely to be resolved before the end of June 2013), it is suggested that interim arrangements are initiated whereby the BoM establishes a formal agreement with either a local resident, the Shire or another entity to obtain manual gauge readings routinely but particularly in the lead up to and during flood events.
2. Following establishment of gauge reading arrangements, BoM to add the site to river level bulletins, data tables and other related products accessible via the BoM website as appropriate.

Stage 2

1. BoM to rework the Campaspe River flood forecast model so that predictions can be provided for Rochester town rather than for the Syphon. Without this change, the TFWS for Rochester is compromised and the benefits expected from this study will not be realised. The rating developed for the town gauge as part of this study may be of interest to the BoM and assist the change. In view of the critical nature of this activity in relation to flood preparedness and response at Rochester, it is suggested that a very high priority is allocated to this work with a planned completion date of end July 2013 (i.e. before possible spring flooding).
2. VICSES in conjunction with Council to advise BoM of critical levels and impacts at Rochester. This is aimed at BoM delivery of flood forecasts that include information on when these critical levels will be exceeded (on both the rise and the fall) along with the peak level and time.
3. Following BoM resolution of the AHD gauge zero conversion issue at Campaspe Weir and availability of data once again via the BoM website, VICSES in conjunction with Council to review these flood class levels. As the river is well confined at the Weir even under very high flow conditions, flows / levels / trends at the site provide a good indication of likely impacts at Rochester. Thus deliverables from the Rochester Flood Investigation will facilitate and inform the review. It is suggested that this review should be completed by the end of July 2013 (i.e. before possible spring flooding).

Stage 3

1. Following resolution of gauge “ownership” responsibilities and Surface Water Monitoring Partnership arrangements, the responsible entity (or as agreed between involved parties), to initiate actions to purchase, install and commission the required equipment at Rochester.
2. Following achievement of full operational status at the upgraded Rochester river monitoring site and if not already done, BoM to add the site to river level bulletins, data tables and other related products accessible via the BoM website as appropriate.

Stage 4

1. VICSES in conjunction with Council to establish and document in the MFEP arrangements for:
   - Determining whether weatherboard buildings should be sandbagged / protected or emptied of items susceptible to damage from floodwater and evacuated prior to flooding;
   - Initiating the pick-up and relocation of items susceptible to damage from floodwater from buildings likely to be flooded but not amenable to sandbagging;
   - Supply of sandbags and sand within Rochester with sufficient lead time to enable non-weatherboard buildings and / or buildings at risk of minimal over-floor flooding (see list in MFEP) to be sandbagged / protected.

Stage 5

1. Council and VICSES with input from others as required, to populate the "required actions" column of the Rochester Flood Intelligence Card for the various flooding depths listed.
2. Council, VICSES and VICPOL to complete the documentation / planning of evacuation arrangements for Rochester (Appendix E of the MFEP).
3. VICSES to initiate a community engagement program at Rochester aimed at communicating changes to the flood warning system along with evacuation arrangements. This may need to be repeated as the TFWS continues to mature.

Stage 6

1. Following formal adoption of the MFEP, VICSES to make the flood inundation and depth maps and relevant Appendices of the MFEP available on their website in order to assist community members and stakeholder agencies determine the likely effects of a potential flood and inform their development of individual flood response plans. Where possible, Council should also have these documents publicly available (Council offices, library, website)
2. Council to consider including flood related information in (say) Council welcome packages for new residents and business owners and with annual rate notices.
3. Council to consider loading and maintaining other flood related material on its website with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp).

Stage 7

1. VICSES in conjunction with Council to develop, review and update protocols with input from NCCMA and other stakeholders as required. This should include who does what when and process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP and personal / business flood action plans. This should include the capture of information contained in Rapid Impact Assessment reports.

Stage 8

1. Council to consider installing flood markers indicating the heights of previous floods (e.g. on power poles, street signs, public buildings, sides of bridges, etc.).
2. Council to consider the preparation and distribution of property specific flood depth charts and / or meter box flood level stickers for each property within Rochester subject to over-ground flooding up to and including the 200-year ARI event. The data to inform the charts can be extracted from the hydraulic model developed for the Rochester Flood Investigation.
3. Council in conjunction with VICSES, to periodically provide feature articles to local media on previous flood events and their effects on the community. This could extend to establishing photo displays of past flood events in local venues (these could be permanent).

Stage 9

1. VICSES in conjunction with Council to encourage and assist residents and businesses to develop individual flood response plans following (or perhaps in concert with) formal adoption of the updated MFEP.

Stage 10

1. VICSES in consultation with Council to establish protocols for routinely reviewing, updating and repeating distribution of flood awareness material.
2. Council to decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at key locations within Rochester and where there is appreciable danger to human life due to flood depth and / or velocity (e.g. as indicated by the flood hazard maps delivered by the Rochester Flood Investigation).

11. FLOOD WARNING BENEFIT COST ANALYSIS

To undertake a benefit cost analysis of flood warning for Rochester, firstly the costs were estimated. As part of the flood warning recommendations a number of items were costed. The recommendations included items that are considered essential through to items that are considered a luxury. For the purposes of the benefit cost analysis we have chosen from all items recommended and formed three packages, essential, standard and complete packages. Table 11-1 below summarises the packages. Note that for the costing, items that require agency in-kind support have not been included as a cost to the project.

Table 11-1 Flood Warning Packages for Benefit Cost Analysis – Key Items

Package	Essential	Standard	Complete
Items	Change flood forecast location to town gauge and upgrade of site to telemetered gauge BOM to rework flood forecast model to predict to town gauge Flood class levels to Campaspe Weir gauge to be reviewed See Appendix E for full package details	Change flood forecast location to town gauge and upgrade of site to telemetered gauge BOM to rework flood forecast model to predict to town gauge Flood class levels to Campaspe Weir gauge to be reviewed Relocate rain gauge from Syphon to town gauge VICSES and Council to make flood maps publicly available (Council office, library, website) VICSES to initiate community engagement program See Appendix E for full package details	Change flood forecast location to town gauge and upgrade of site to telemetered gauge BOM to rework flood forecast model to predict to town gauge Flood class levels to Campaspe Weir gauge to be reviewed Relocate rain gauge from Syphon to town gauge VICSES and Council to make flood maps publicly available (Council office, library, website) VICSES to initiate community engagement program Installation of flood markers indicating heights of previous floods Council to prepare and distribute property specific flood depth charts See Appendix E for full package details
Capital Cost	$38,000	$44,500	$75,500
Maintenance Cost	$4,500	$7,000	$18,500

The benefits of flood warning through reduced flood damages have long been recognised, however the benefit delivered by providing flood warning is very difficult to quantify. A number of papers and previous studies were reviewed to determine an appropriate methodology to quantify the flood warning benefit for Rochester[8,9,10,11]. A number of different approaches to assessing the benefit of flood warning have been suggested in the literature, the most simple, common and accepted of which are versions on the Day curve[12]. The Day curve relates warning time to percentage reduction in tangible damages. The Day curve can be further complicated by combining the effect of flood depth, as there is some data that suggested that flood warning provides a larger benefit in cases where the eventual flood depth is high rather than low[13]. This analysis has not considered such an effect. Carsell et. al.[11] suggest that the effectiveness of the warning time must be factored in, providing a range of factors that could be applied to adjust the effectiveness of the damage reduction due to response rate from the community. This analysis has applied an 80% effectiveness factor to the reduced tangible damages from the Day curve. Figure 11-1 below shows the modified Day curve adopted in this analysis.

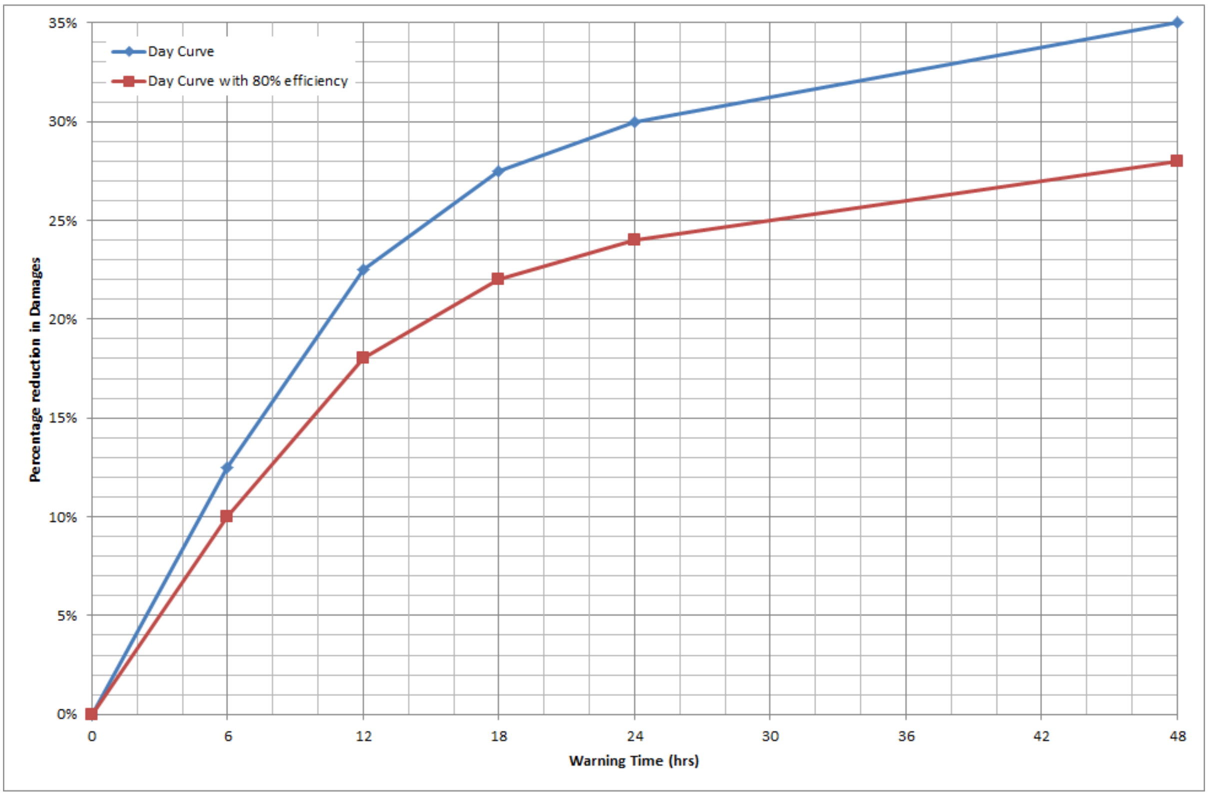


Figure 11-1 Modified Day Curve for Evaluating Flood Warning Benefit

Based on previous experience from the recent 2010/11 floods and a knowledge of the current flood response arrangements, it was estimated that Rochester would receive approximately 12 hours of

[8] Department of Natural Resources and Environment (2000), Rapid Appraisal Method (RAM) for Floodplain Management, *Section 5.4*.

[9] Foundation for Water Research (2006), Assessing the Benefits of Flood Warning: A Scoping Study.

[10] Carsell, K. M. et. al. (2004), Quantifying the Benefit of a Flood Warning System, *Natural Hazards Review, American Society of Civil Engineers*.

[11] Ball, T. et. al (2012), Assessing the Benefits of Flood Warning, *Journal of Flood risk Management*.

[12] Day, H.J. (1970), Flood Waring Benefit Evaluation – Susquehanna River Basin, *ESSA Technical Memo WBTM Hydro-10*.

[13] Chatterton, J.B. and Farrell, S.J. (1977), Nottingham Flood Warning Scheme: Benefit Assessment, *Severn-Trent Water Authority*.

warning time under the current arrangements. It is anticipated that provided with flood warning the warning time may be increased to 24 hours if the Complete system is implemented, an increase of 12 hours from the current arrangements. It is estimated that the Standard system could increase the warning time by 10 hours while the Essential system could increase the warning time by 8 hours.

Reading off the Day curve an increase in warning time from 12 to 24 hours at Rochester for the Complete system may result in a reduction in tangible flood damages of 6%. This percentage reduction in tangible damages translates to a monetary reduction of average annual damages of $20,715 which equates to an annual saving of $2,215 after maintenance costs of $18,500 are accounted for.

An increase in warning time from 12 to 20 hours at Rochester for the Standard system may result in a reduction in tangible flood damages of 5%. This percentage reduction in tangible damages translates to a monetary reduction of $20,215 which equates to an annual saving of $13,275 after maintenance costs of $7,500 are accounted for.

An increase in warning time from 12 to 16 hours at Rochester for the Essential system may result in a reduction in tangible flood damages of 2.5%. This percentage reduction in tangible damages translates to a monetary reduction of $10,137 which equates to an annual saving of $5,637 after maintenance costs of $4,500 are accounted for.

The flood warning packages were subject to a benefit cost analysis following the same approach as that adopted for the structural mitigation options. The benefit-cost ratio was calculated as 2.1, 4.2 and 0.4 for the essential, standard and complete packages respectively. The benefit cost ratios are particularly high for the essential and standard packages as the likely reduction in the flood damages is significantly greater than the annual maintenance costs.

This analysis has demonstrated that flood warning has a very strong benefit cost ratio at Rochester, particularly the Standard and Essential packages. It is clear that there is a strong case for the implementation of these options.

12. COMMUNITY CONSULTATION

A key objective of the Plan was to ensure strong community engagement and to demonstrate strong community support for the final Plan. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and through more formal feedback methods. Three public meetings held at various stages of the Plan development were all strongly attended. Feedback from these meetings guided the development of the Plan.

Key findings of the Draft Rochester Flood Management Plan were presented to the community in a public meeting held on 1st May 2013. A summary brochure outlining the mitigation packages and preferred option along with a feedback form was provided to all meeting attendees and a two week consultation period then ensued. The brochure was also distributed to community members who could not attend the meeting.

As a result of the extensive community consultation, and public feedback, it is evident that the implementation of the recommended flood warning system has very strong support while construction of formal levees to replace decommissioned irrigation channels has moderate community support. Approximately 90% of respondents were supportive of the improved flood warning system while 46% were supportive and 21% unsure of the formal levees to replace the decommissioned channels. Only 17% were unsupportive of the formal levees to replace the decommissioned channels.

The community response to the proposed structural mitigation measures was mixed with approximately 40% of responders supportive of the measures, 40% unsupportive and 20% unsure. The main reason provided for the objections were around the uncertainty of the impacts to properties in the east of the town and around Nanneella. These responses are not unexpected as the impacts to these areas are not fully understood at this point. There were also some concerns around the visual amenity of the proposed levees.

These responses highlight that further assessment of the structural mitigation measures is required so the full impact of these options can be better understood and conveyed to the community. Further information will enable the Rochester and Nanneella communities and Campaspe Shire to make an informed decision about the proposed structural mitigation options.

13. CONCLUSIONS AND RECOMMENDATIONS

The Rochester Flood Management Plan successfully provides improved understanding of flood behaviour around Rochester and identifies a number of mitigation measures which can improve the town's protection from riverine flooding.

The November 2010 and January 2011 flood events were successfully modelled, replicating the observed behaviour, with a detailed description of the flood behaviour from these recent historic events described in the Plan. The November 2010 event was estimated as a 10 year ARI (10% AEP) event, while January 2011 was estimated to be a 100 year ARI (1% AEP) event.

A series of design flood events were modelled, providing critical intelligence regarding potential future flood events, from small in-channel events to large events even bigger than the January 2011 event.

A detailed assessment of a range of mitigation options was undertaken. It was determined that it is not feasible to completely protect Rochester from large flood events. The final mitigation option targeted smaller more frequent events such as the 5% AEP event, which resulted in significant benefits to much of the township in a range of AEP events. All options were assessed against a number of criteria including potential reduction in flood damage, cost of construction, feasibility of construction, environmental impact and community support.

After significant consultation with the community and stakeholders the steering committee recommends further assessment of a package of works that will provide a significant reduction in flood risk across a range of events up to and including the 0.5% AEP event at a total estimated cost of $1.8 million (note: excludes any land easement and compensation costs that may be associated with the recommended works). The structural works aim to better protect Rochester from flooding and reengage the floodplain to the east of the township.

The proposed structural works which require further assessment and detailed design include:

- Excavation of land to the east of the Campaspe River railway bridge to allow additional flow northwards across the floodplain and through the railway culvert located 200m north of the railway bridge
- Excavation of land between the Campaspe River and Bonn Street (near Jess Drive) to better engage the drainage line which flows eastwards from Rochester
- Construction of a strategic levee along the left bank of the Campaspe River between the water treatment plant on Campaspe St and the eastern end of Morton Street
- Construction of a small levee along Bonn Street which will protect properties from the increased engagement of the eastern drainage line
- Construction of an open drain in the existing drainage easement between the railway line and Ramsay Street from Elizabeth Street to the Campaspe River.
- Detailed planning and design of a formal levee to replace irrigation channel 1/1 to the south of Rochester which is marked for decommissioning
- Further investigation of irrigation channel 2/2 to the east of Rochester which is marked for decommissioning in consultation with affected landowners.
- Detailed planning and design of a formal levee to replace irrigation channel 1/1 to the south of Rochester which is marked for decommissioning

The following actions are also recommended:

- The staged implementation of a flood warning system for Rochester which will include changing the flood forecast gauge to the Rochester town gauge (with associated gauge

upgrade), reworking of the BOM flood forecast model and a review of the Campaspe Weir gauge flood class levels.
- The flood warning system should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system.
- It is recommended that the revised Municipal Flood Emergency Plan Appendices relating to Rochester be adopted and the community is engaged along with the responsible agencies (BoM, SES, Shire of Campaspe, North Central CMA etc.) in developing appropriate actions.
- It is recommended that the planning scheme for Rochester be updated with the proposed Land Subject to Inundation and Floodway Overlays.

The Rochester Flood Management Plan will seek endorsement from both the North Central Catchment Management Authority Board and the Campaspe Shire Council prior to sending to the Victorian Government for consideration for funding.

Upon endorsement of the plan, Campaspe Shire in conjunction with the North Central CMA will apply for funding for:

- Implementation of the recommended flood warning infrastructure
- Detailed planning and design of a formal levee to replace irrigation channel 1/1 to the south of Rochester which is marked for decommissioning
- Further assessment of the proposed structural mitigation measures described above specifically in relation to the impact along the eastern drainage line.

14. REFERENCES

BOM weather and climate data, http://www.bom.gov.au/climate/data/, accessed December 2011

Ball, T. et. al (2012), Assessing the Benefits of Flood Warning, *Journal of Flood risk Management*.

Carsell, K. M. et. al. (2004), Quantifying the Benefit of a Flood Warning System, *Natural Hazards Review, American Society of Civil Engineers*.

Chatterton, J.B. and Farrell, S.J. (1977), Nottingham Flood Warning Scheme: Benefit Assessment, *Severn-Trent Water Authority*.

Comrie, N. (2011): *Review of the 2010-11 Flood Warnings and Response: Final Report.* 1 December 2011.

Day, H.J. (1970), Flood Warning Benefit Evaluation – Susquehanna River Basin, *ESSA Technical Memo WBTM Hydro-10*.

Department of Natural Resources and Environment (2000), Rapid Appraisal Method (RAM) for Floodplain Management, *Section 5.4*.

DSE Victorian Water Resource Website, http://www.vicwaterdata.net/vicwaterdata/home.aspx, accessed December 2011

Foundation for Water Research (2006), Assessing the Benefits of Flood Warning: A Scoping Study.

Hill, P.I., Mein, R.G. and Weinmann, P.E. (1998) *How Much Rainfall becomes Runoff? Loss Modelling for Flood Estimation.* Cooperative Research Centre for Catchment Hydrology Report 98/5, June 1996

Institution of Engineers, Australia (1987) *Australian Rainfall and Runoff, Vol. 1&2*. (Ed: Pilgrim, D.H.) Institution of Engineers, Australia.

Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria.* February 2001.

APPENDIX A ROCHESTER SITE VISIT REPORT

Rochester Site Visit

Date:	Wednesday, 21th December 2011
Time:	1:30pm – 3.30pm
Location:	Rochester

Draft

Attendees:	Ben Tate	Sarah Stanaway	Danny Moloney
	Lauren Mittiga		
	Sebastien Barriere		
Via Phone:			
Apologies:			

A site visit was undertaken by Water Technology on 21st December 2011 with a representative from the North Central CMA, Sarah Stanaway. Also present at the site visit was Danny Moloney from the Campaspe Shire Council. The purpose of the site visit was to gain a better understanding of the flood issues in Rochester, identify key structures for the hydraulic modelling and investigate locations/options for future mitigation works. The site visit also provided an opportunity to request additional information from the council regarding flood markers from the January 2011 event, catchment conditions and ongoing flood mitigation works. Information gathered from the site visit is documented below.

Notes of Conversations with Steering Committee Members

- It was reported that as part of the revised irrigation scheme, led by the Northern Victoria Irrigation Renewal Project (NVIRP), the channels Campaspe 1 and Campaspe 2 will be decommissioned. It appears crucial to take into account the channel interactions with the floods and subsequently adapt the mitigation measures to the irrigation upgrade.
- It was felt by the community that Lake Eppalock played a great role in the flood events. A number of concerns have been raised and the present study will aim to alleviate the latter and give as many answers as possible to those questions.
- It was reported by Goulburn-Murray Water (GMW) that a number of hydrology studies have been performed; GMW advised the latter will be made available for the present study.
- It was advised that the local community had been consulted by means of public sessions after the recent flood events. The Campaspe Shire Council reported that comments and concerns were saved in a database.
- It was reported by the Campaspe Shire Council that numerous flood levels have been marked around the township after the recent events.
- During the inception meeting, the different members of the steering comity expressed their expectations of the study and the future flood management plan.
    - SES : Whilst working closely with the community it is expected to produce valuable data used for community education programs.

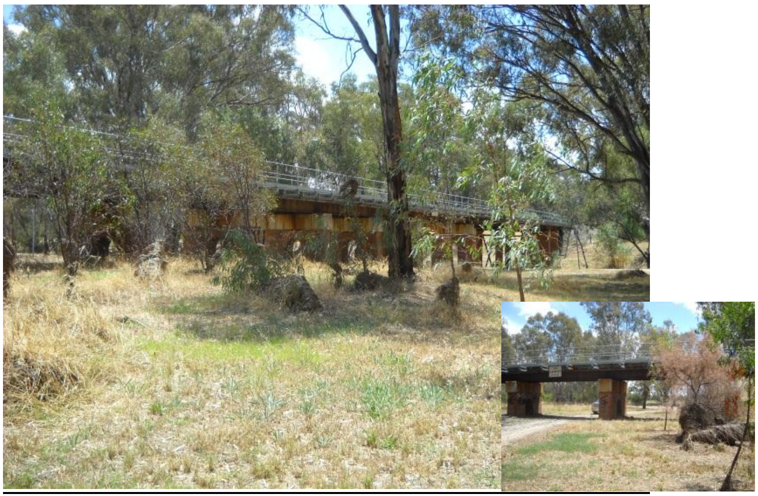
- Campaspe Shire Council: A high level of communication with the community during the study, furthermore providing answers to the questions and alleviating concerns raised by local residents.
- James Williams (NCCMA Board member): Improved accuracy of future flood warnings and processes.
- Johan Veldema (BoM): Review of flood class levels, better understanding of the local hydrology (travel times, time to peak…)
- Frank Oliver (Campaspe Shire Council): Community empowerment. Faith in future predictions
- Wayne Park (Rochester Resident): Good communication, allow the community to move on past this difficult situation. Better understanding of the influence of Lake Eppalock.
- Tom Wilkinson (DSE Floodplain Management): Review of gauging stations and improved telemetry. More gauging stations for rainfall and river data and consistency in levels. Improved models and flood warning.
- GMW: Production of good hydrology data. Better understanding of the impact of Lake Eppalock and other contributions, and of the channel interactions with flood waters.
- NCCMA: Improvement of flood warning and predictions. Production of a study adopted by the community.
- Tim Giffin (Coliban Water): Precise information on flood levels and more efficient management.
- VIC Roads: A map based system on VIC Roads website, clear classification of danger levels regarding velocity/depth couples.
- Water Technology: Best possible study. Plan to be delivered on time and on budget.

Prior to a visit to the Campaspe siphon 3km north of Rochester, with members of the steering committee Water Technology visited a number of sites around town to gain a better understanding of the town's drainage system and key hydraulic structures. A number of culverts were measured and are detailed below:

Survey of Structures

Below is a list of the structures that were roughly surveyed to the road crest levels. These can then be tied into AHD using the available LiDAR. Note this is a rough approximation, but will be sufficient.

<table>
<tr><td>Structure Details</td><td>Measurements</td></tr>
<tr><td>Box culverts under Northern Hwy B75/Black Culvert Road
</td><td>Two box culverts
2 * 0.9m high * 1.2 m wide
Length = 20m
Survey to be provided</td></tr>
<tr><td>Railway Bridge, Northern Hwy B75/Black culvert Road
</td><td>Survey to be provided (VIC tracks)</td></tr>
<tr><td>Railway culvert – 100m south of Northern Hwy/Pascoe St</td><td>Clear span
Survey to be provided</td></tr>
</table>

	6m wide 1.1m high
Pipes adjacent to railway culvert 	Survey to be provided Diameter : 800mm Length : 3.5m
Railway bridge over Campaspe River, north of township 	Debris on tree near bridge (railway) crossing the Campaspe. The debris was approximately as high as the top of the arches. Survey to be provided
Culvert under Northern Hwy/Cromwell St	Two box culverts 2 * 1.2m wide * 0.45m high

	
Park – Victoria St/Northern Hwy - Drainage pipe behind bar screen 	Diameter : 1.1m
Outlet of park drainage pipe, Ramsay St (behind municipal swimming pool)	Diameter : 1.1m

	
Waranga channel, north of township 	Width at the base : 1.1m
Campaspe siphon – 3km north of the township	Takes the Waranga-Mallee Channel under the Campaspe River through three 4 metre diameter, 90 metre long concrete pipes.

Sebastien Barriere

Water Technology Pty Ltd

sebastien.barriere@watech.com.au

<u>Culvert Measurements:</u>

Box culverts under Northern Hwy B75/Black Culvert Road: Two box culverts: 2 * 0.9m high * 1.2 m wide, Length = 20m approximately

Railway culvert – 100m south of Northern Hwy/Pascoe St: Clear span, 6m wide * 1.1m high

Pipes adjacent to railway culvert: Diameter : 800mm, Length : 3.5m

Culvert under Northern Hwy/Cromwell St: Two box culverts, 2 * 1.2m wide * 0.45m high

Park – Victoria St/Northern Hwy - Drainage pipe behind bar screen: Diameter : 1.1m

Waranga channel culvert, north of township: Width at the base : 1.1m

APPENDIX B DESIGN FLOOD EXTENTS (20% TO 0.5% AEP EVENTS)

Figure 14-1 20% AEP design event map

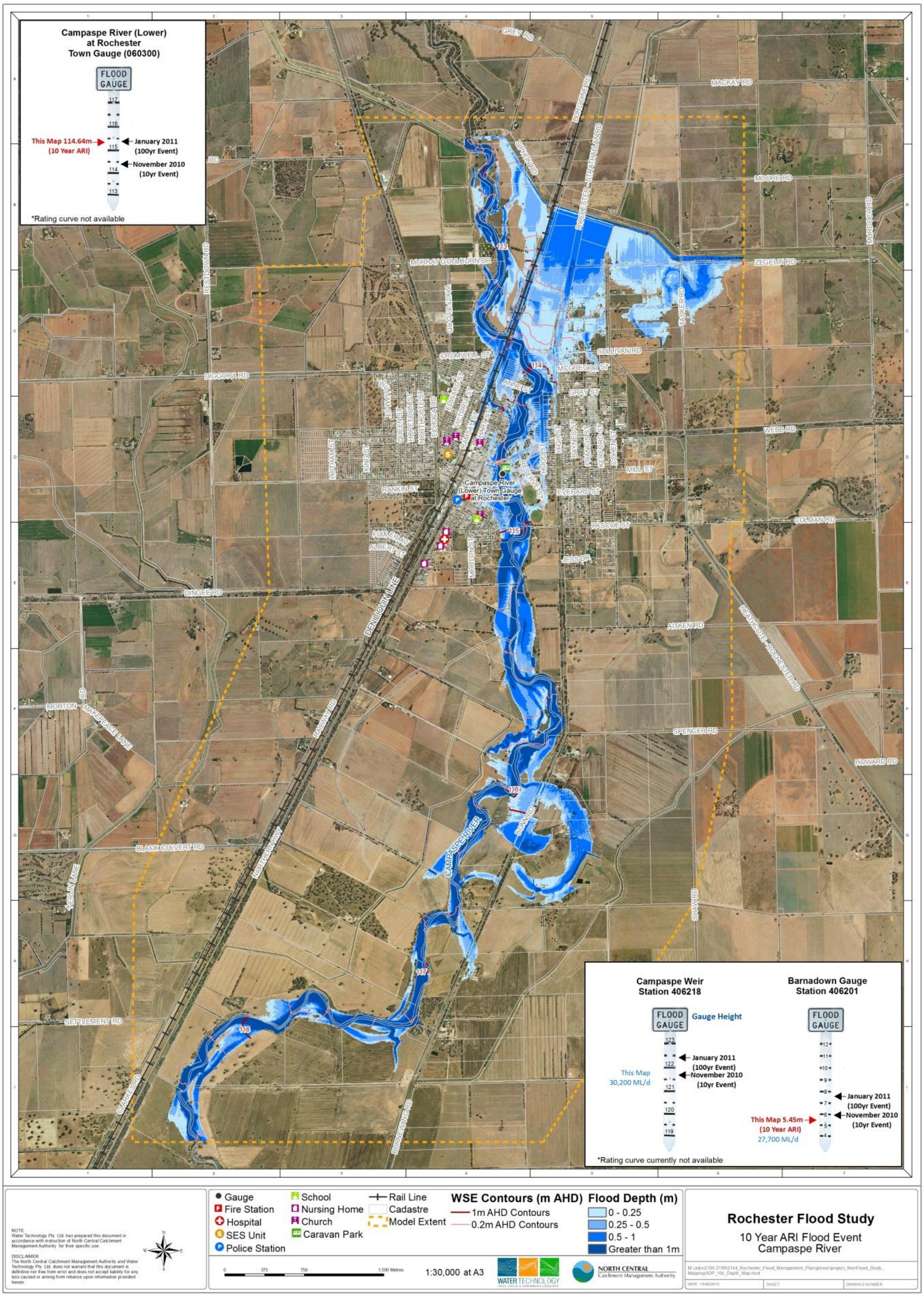


Figure 14-2 10% AEP design event map

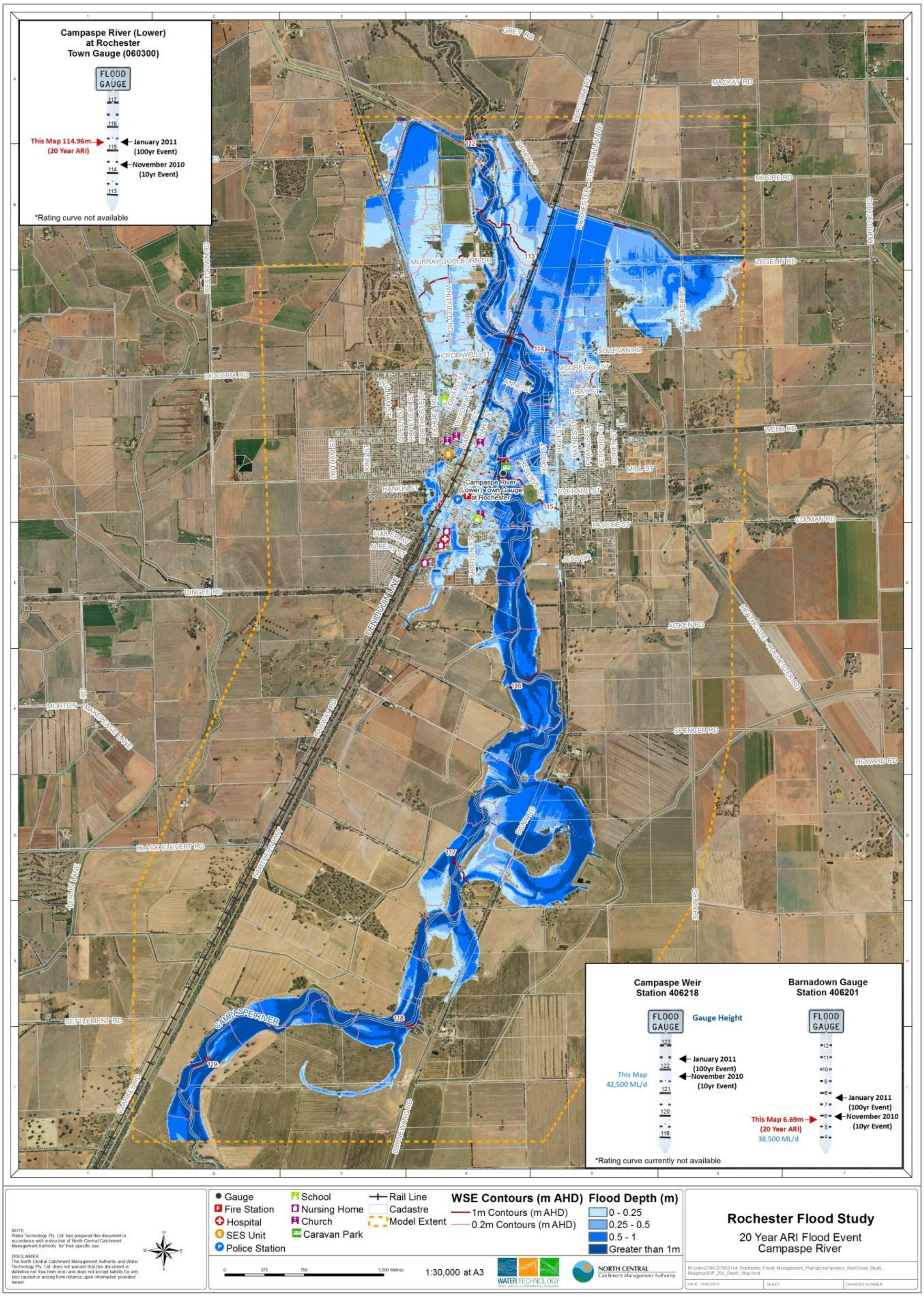


Figure 14-3 5% AEP design event map

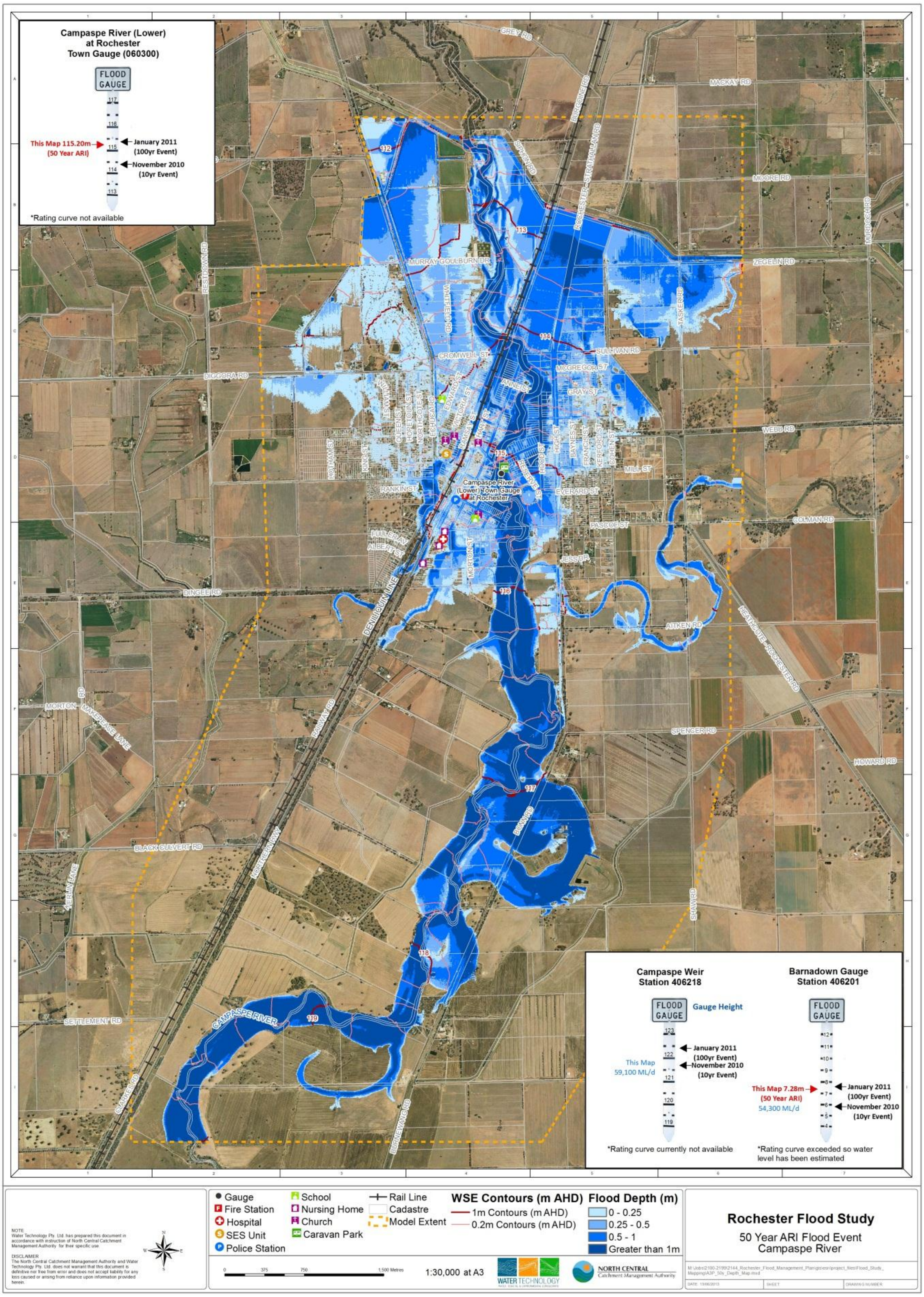


Figure 14-4 2% AEP design event map

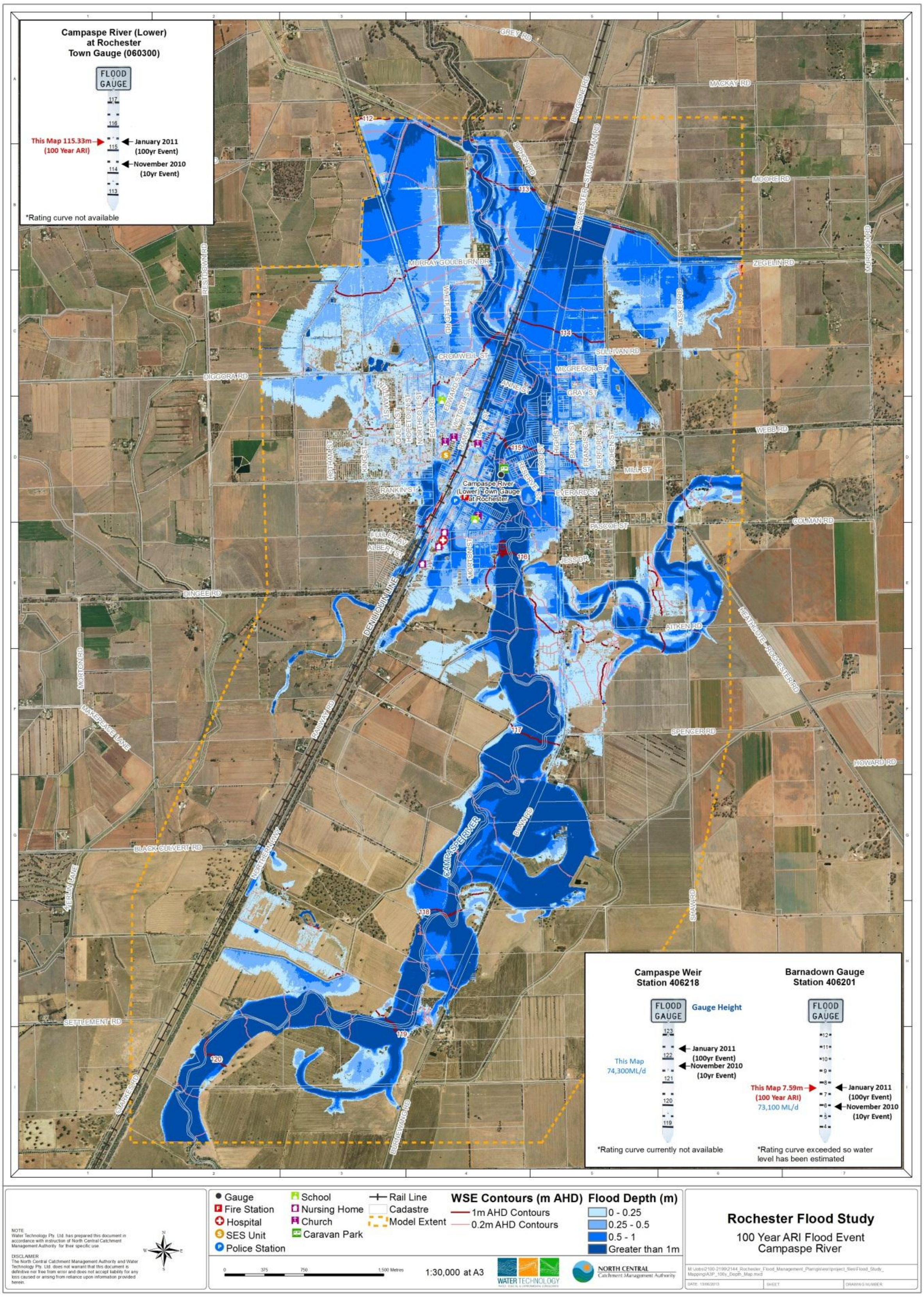


Figure 14-5 1% AEP design event map

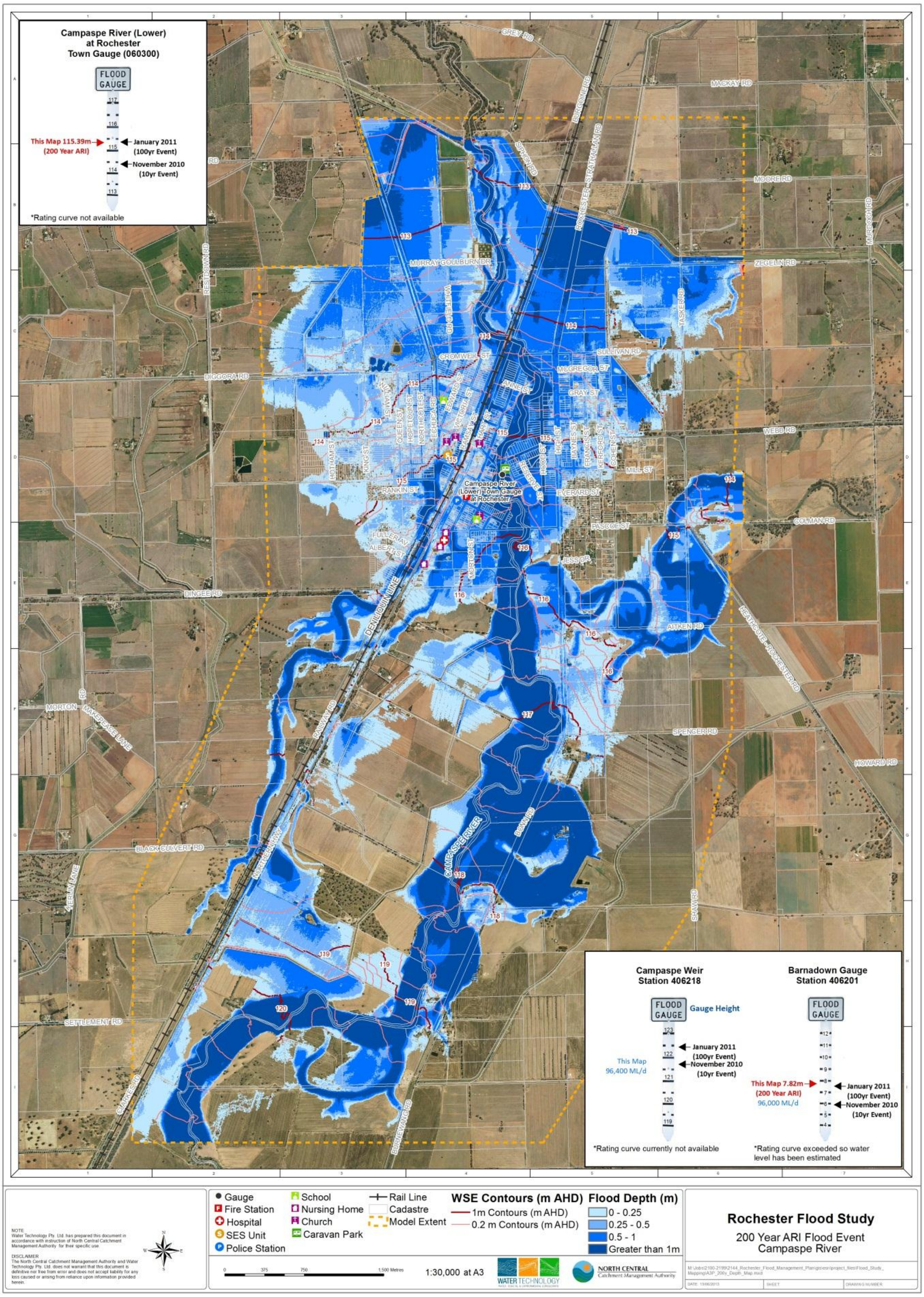


Figure 14-6 0.5% AEP design event map

APPENDIX C DETAILED COSTING OF MITIGATION OPTION 3

Table 14-1 Mitigation Option 3 Costs

Status	Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Mitigation Option 3	Main Levee	$247,535	$3,713
	Eastern Drainage Line Levee	$30,124	$452
	Northern floodway excavation	$249,536	$3,743
	Eastern drainage excavation	$465,954	$6,989
	Drain upgrade between Ramsey Street & Railway Line	$167,428	$2,511
	Compensation/Land Easement Costs*		
	Sub-total 'A'	$1,160,578	
	'A' x Engineering Fee @ 15%	$174,087	
	Sub-total 'B'	$1,334,664	
	'B' x Administration Fee @ 9%	$120,120	
	(Land Acq only) 'B' x Administration Fee @ 1%	-	
	Sub-total 'C'	$1,454,784	
	'A' x Contingencies @ 30%	$348,173	
	FORECAST EXPENDITURE	**$1,802,957**	**$17,409**

*** Requirements further assessment**

APPENDIX D DAMAGE ASSESSMENT METHODOLOGY

Two primary sources for flood damage calculations were used, the original ANUFLOOD cost curves (CRES 1992) and the RAM methodology (Reed Sturgess and Associates (RSA) 2000). Further details on the ANUFLOOD methodology are provided in a guidance report produced by DNR (2002). ANUFLOOD cost curves cover residential and commercial direct costs applicable for townships. The RAM methodology incorporates the ANUFLOOD approach and extends it to include indirect and intangible costs resulting from flooding and provides guidance on costs for agricultural enterprises. A major study of the Economics of Natural Disasters in Australia by the Bureau of Transport Economics (BTE 2001) provides some further information on indirect costs and a recent study by Geoscience Australia (Middelmann-Fernandes 2010) provides information for accounting for the impact of velocity in flood damage assessments. These key references are described below.

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

Before any stage damage curves from the literature were applied in the Rochester flood damage assessment they were adjusted to today's value by scaling using a ratio of today's CPI and the CPI at the time of development of the stage-damage curve. A number of stage damage curves are included below, representing the value at the time of development (i.e. no CPI adjustment).

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

Table C1 Above floor level stage damage relationships for residential properties (from ANUFLOOD 1992; reproduced from DNR 2002)

		Small house (< 80 m2)	Medium house (80 – 140m2)	Large house (> 140m2)
Depth over flood level	0 m	$905	$2 557	$5 873
	0.1 m	$1 881	$5 115	$11 743
	0.6 m	$7 370	$13 979	$25 351
	1.5 m	$17 379	$18 585	$32 276
	1.8 m	$17 643	$18 868	$32 768

Table C2 Size categories for commercial properties (from ANUFLOOD 1992; reproduced from DNR 2002)

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

Table C3 ANUFLOOD Commercial properties cost curve (reproduced from DNR 2002)

	Small commercial properties (<186m²)					Medium commercial properties (186-650m²)					Large commercial properties (>650m²)*				
Value class	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.25	$2 202	$4 405	$8 809	$17 618	$35 237	$6 975	$13 948	$27 896	$55 791	$111 583	$7	$15	$32	$61	$122
0.75	$5 506	$11 011	$22 023	$44 046	$88 092	$16 884	$33 768	$67 537	$135 074	$270 147	$39	$78	$154	$308	$619
1.25	$8 258	$16 518	$33 034	$66 069	$132 137	$25 693	$51 387	$102 773	$205 574	$411 094	$81	$162	$326	$649	$1297Ł
1.75	$9 176	$18 352	$36 705	$73 410	$146 819	$28 445	$56 893	$113 785	$227 570	$455 140	$132	$267	$533	$1065	$2129
2	$9 726	$19 454	$38 907	$77 814	$155 628	$30 281	$60 564	$121 126	$242 252	$484 504	$159	$318	$636	$1 272	$2 545

* units of $/m²

Table C4 External / below floor damage per building (from DPIE Floodplain Management in Australia (1992))

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

Table C5 Unit damages for roads and bridges (per kilometre of road inundated) (From DNR 2002)

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

Table C6 Actual to Potential Damages Ratio from RAM (RSA 2002)

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

Table C7 Indirect costs following BTE (1999)

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

APPENDIX E FLOOD WARNING REPORT

FLOOD WARNING SYSTEMS

Aim and Function

Put simply, flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[14]. Effective flood warning systems maximise the opportunity for the implementation of public and private response strategies aimed at enhancing the safety of life and property and reducing avoidable flood damage.

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

Limitations of Flood Warning Systems

No single floodplain management measure is guaranteed to give complete protection against flooding. For example, levees can be overtopped (when a flood exceeds design height, as happened at Nyngan in 1990) or fail (when construction standards are poor or maintenance is inadequate). Likewise, flood response plans can be poorly formulated or applied ineffectually.

Flood warning systems are, by their very nature, complex. They are a combination of technical, organisational and social arrangements. To function effectively they must be able to forecast coming floods and their severity (using data inputs that may include rainfall and upstream river heights and / or flows along with modelling techniques) and the forecast must be transmitted to those who will be affected (the at-risk communities) in ways that they understand and which result in appropriate behaviours on their part (for example, to protect assets or to evacuate out of the path of the floodwaters).

It is not surprising, given the above, that flood warning systems often work imperfectly and have, on occasions, failed. Indeed, as Handmer[15] points out, "*flood warnings often don't work well and too frequently fail completely – and this despite great effort by the responsible authorities*." While in some cases the problem is the result of a physical mechanical or technical failure (for example of gauges or telemetry or of communications equipment during a flood event), or perhaps in defining what constitutes success (or failure), the more common reason is that the systems have not been properly conceptualised at the design stage and in terms of their operation, despite the considerable and conscientious efforts of those involved. All too often, too little attention has been paid to issues of risk communication. In particular:

- To building a local awareness of flood risk along with knowledge of what can be done to minimise that risk;
- Determining what information is required by the at-risk community and with what lead times;
- How warnings and required information will be distributed to and within the target communities;

---

[14] More generally, the objective of early warning is to empower individuals and communities, threatened by natural or similar hazards, to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and damage to property, or nearby and fragile environments (UN, 1997).

[15] Handmer, J.W. (2000): *Are Flood Warnings Futile? Risk Communication in Emergencies*. The Australasian Journal of Disaster and Trauma Studies. Volume: 2000-2.

- Ensuring that recipients of warning messages understand what the message is telling them and what it means for their property and individual circumstances in terms of the damage reducing actions they need to take.

The outcome of the above is that many flood warning systems have an inbuilt likelihood of failing.

In numerous cases where flood warning systems have been developed, the bulk of the effort has been devoted to creating and strengthening data collection networks, devising and upgrading forecasting tools and facilities and utilising new dissemination technologies to distribute the forecast to at-risk communities. While all these things are important, they are never sufficient by themselves to ensure that flood warnings are heeded by those who receive them. Other equally vital elements of the system such as risk communication and the comprehension that people have of the flood problems they may face (and the value that warnings can offer) need at least as much attention at the design stage and in system operation. The lesson from many studies of flood warning systems (e.g. Smith and Handmer (1986)[16]; Phillips (1998)[17]; Handmer (1997)[18], (2000)[19], (2001)[20], (2002)[21]; Comrie, (2011)[22] is that the status of all elements of the system must be given appropriate resourcing if the system is to be made capable of functioning effectively. A further lesson is that flood warning systems (and investments in their implementation) that over-emphasise the collection of input data and / or the production of flood forecasts relative to the attention given to other elements (such as message construction, the information provided in the messages and the education of flood prone communities about floods and flood warnings) will fail to fully meet the needs of the at-risk communities they have been set up to serve.

The Total Flood Warning System Concept

In 1995 the Australian Emergency Management Institute, following a national review of flood warning practices after disastrous flooding in the eastern states in 1990, published a best-practice manual entitled '*Flood Warning: an Australian Guide*'[23]. In describing practices for the design, implementation and operation of flood warning systems in Australia, the manual introduced the concept of the 'total flood warning system' (TFWS). It also re-focused attention on flood warning as an effective and credible flood mitigation measure but made it clear that successful system implementation required the development of some elements that hitherto had been given little attention as well as the striking of an appropriate balance between each of the elements. In particular, it was noted that more attention needed to be given to risk communication and the education of communities about the flood risk, the measures that people could take to alleviate the problems that flooding causes and the place of warnings in triggering appropriate actions and behaviours. It also clearly enunciated the need for several agencies to play a part, with clearly-defined roles and with the various elements carefully integrated, and for the members of flood liable

[16] Smith, D.I. and Handmer, J.W. (eds) (1986): *Flood Warning in Australia: Policies, Institutions and Technology*. Centre for Resources and Environmental Studies, Australian National University, Canberra.

[17] Phillips, T.P. (1998): *Review of Easter Floods 1998: Final Report of the Independent Review Team to the Board of the Environment Agency: Volume 1.*

[18] Handmer, J.W. (1997): *Flood Warnings: Issues and Practices in Total System Design.* Flood Hazard Research Centre, Middlesex University.

[19] Handmer, J.W. (2000): *Are Flood Warnings Futile? Risk Communication in Emergencies*. The Australasian Journal of Disaster and Trauma Studies. Volume: 2000-2.

[20] Handmer, J.W. (2001): *Improving Flood Warnings in Europe: A Research and Policy Agenda.* Environmental Hazards. Volume 3:2001

[21] Handmer, J.W. (2002): *Flood Warning Reviews in North America and Europe: Statements and Silence.* The Australian Journal of Emergency Management, Volume 17, No 3, November 2002.

[22] Comrie, N. (2011): *Review of the 2010-11 Flood Warnings and Response: Final Report.* 1 December 2011.

[23] Australian Emergency Management Institute (AEMI) (1995): *Flood Warning: An Australian Guide*.

communities to be involved. Put another way, "*effective warning systems rely on the close cooperation and coordination of a range of agencies, organisations and the community*"[24] .

While the original manual has been updated and republished as Manual 21 of the Australian Emergency Manuals Series[25], the concepts, practices and key messages from the original manual endure.

The philosophy that underlies the TFWS concept coupled with the need for a coherent set of linked operational responsibilities and overlapping functions is documented and discussed in the context of guiding principles for effective early warning in UN (1997)[26].

Total Flood Warning System Building Blocks

An effective flood warning system comprises much more than a data collection network, forecasting model and flood level (or flow) prediction.

An effective flood warning system is made up of several building blocks. Each building block represents an element of the Total Flood Warning System. The blocks (derived from EMA, 2009[27]) along with the basic tools to facilitate delivery against each of the TFWS elements are presented in Table E2.

Experience shows that flood warning systems that are not designed in an integrated manner and that over-emphasise flood detection (say) at the expense of attention to the dissemination of warnings, local interpretation and community response inevitably fail to elicit appropriate responses within the at-risk community. It is essential that the basic tools against each of the building blocks are appropriately developed and integrated. Such a system considers not only the production of a timely alert to a potential flood but also the efficient dissemination of that alert to those, particularly the threatened community, who need to respond in an appropriate manner. A community that is informed and flood aware is more likely to receive the full benefits of a warning system.

OVERVIEW OF FLOOD WARNING SYSTEM FOR ROCHESTER

Introduction

Rochester is located on the Campaspe River floodplain around 36km downstream (to the north) from Barnadown and approximately 7.5km downstream from Campaspe Weir. The area has little topographic relief and the river channel at Rochester has limited capacity leaving the town susceptible to flooding. When channel capacity is exceeded, widespread flooding results adjacent to the river and along a number of flood effluent paths. The Campaspe River and flooding at Rochester are described in more detail in earlier sections of this report. A brief history of past floods is also provided.

The analyses undertaken in support of the Rochester Flood Investigation suggest that typically, flood forecast and warning lead times to Rochester of around 24 hours could be expected to be consistently achievable. The use of a rainfall – runoff model could be expected to increase this lead

[24] Department of Transport and Regional Services (DoTARS) on behalf of the Council of Australian Governments (CoAG) (2002): *Natural Disasters in Australia. Reforming Mitigation, Relief and Recovery Arrangements: A report to the Council of Australian Governments by a high level officials' group.* August 2002 published 2004.

[25] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

[26] United Nations (UN) (1997): *Guiding Principles for Effective Early Warning*. Prepared by the Convenors of the International Expert Groups on Early Warning of the Secretariat of the International Decade for Natural Disaster Reduction, IDNDR Early Warning Programme, October 1997, Geneva, Switzerland.

[27] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

time to 30 hours or more. Forecast lead times are likely to be perhaps a little shorter for really big floods and longer for smaller floods.

A flood warning system already exists for Rochester. In summary this comprises:

- A data collection network to support flood forecasting activities. The network comprises a number of rainfall and river level monitoring sites within and adjacent to the catchment (see Table E1 and Figure E1 below). As most sites are multi-purpose (i.e. not installed purely for flood warning purposes), the network is funded by a mix of stakeholder agencies.
- Access to data from the data collection network via the BoM's website. Data is available at intervals ranging from around 30 minutes to daily (around 9am) with most data updated every 3 hours or so during a flood event.
- A rainfall – runoff model developed and maintained by the Bureau of Meteorology (BoM) for the whole catchment. The model provides forecast river flows and levels for key locations. One of these locations is the Rochester Syphon gauge (406202) which is located around 3km north (downstream) from Rochester where the Waranga Western Irrigation Channel passes under the Campaspe River.
- Established flood class levels for Rochester and Campaspe Weir.
- A Municipal Flood Emergency Plan that includes intelligence on flood impacts within Rochester. The Plan is being updated as part of this study.
- Local arrangements for disseminating flood related information within Rochester and surrounds.
- Established procedures for initiating and continuing a coordinated operational response in times of flood.
- A Local Flood Guide for Rochester that outlines flood consequences and reflects learnings from the September 2010 and January 2011 floods.

Table E1 The existing data collection network for the Campaspe catchment

Rainfall stations	River level / flow stations
Blue Mountain	Campaspe River at Redesdale
Mt Macedon	Lake Eppalock head gauge and downstream
Pyalong	Axe Creek at Strathfieldsaye
Vaughan	Campaspe River at Barnadown
Redesdale	Mt Pleasant Creek at Runnymede
Lake Eppalock	Campaspe River at Campaspe Weir
Runnymede	Campaspe River at Rochester town gauge[1]
Campaspe Weir	Campaspe River at the Rochester Syphon
Rochester Syphon	Campaspe River at Echuca[2]
Kyabram	
Other rain gauges further outside the catchment	

1 The town gauge is not telemetered and has to be read manually. This becomes difficult as flood waters rise. There are no formal arrangements for reading the gauge and providing the data to the BoM.

2 The Campaspe River gauge at Echuca is not telemetered and has to be read manually. There are no formal arrangements for reading the gauge and providing the data to the BoM.

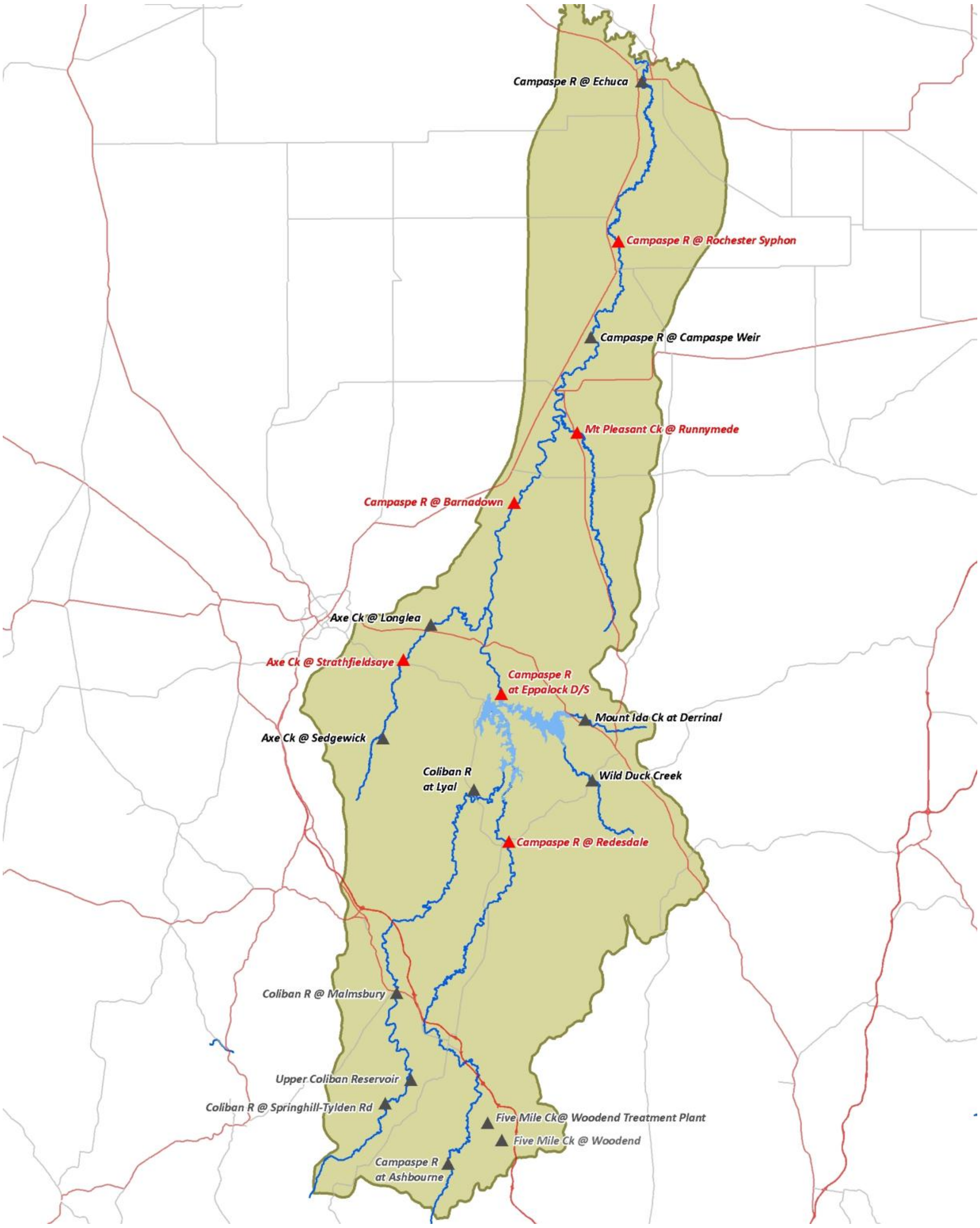


Figure E1 Campaspe catchment map showing river level / flow stations available for flood warning

Key: ▲ BoM flood warning sites

▲ Other river level / flow gauging stations

Review of the existing flood warning system

Table E2 provides a brief description of the basic tools needed to deliver against each TFWS building block. It also provides an outline review of the response to each element within the existing flood warning system for Rochester together with suggested and possible improvements.

Table E2 Flood Warning System Building Blocks and Review Comments for the existing flood warning system for Rochester with due regard for the EMMV, Commonwealth-State arrangements for flood warning service provision (BoM[28], VFWCC[29] and EMA[30])

Flood Warning System Building Blocks	Basic Tools	Review Comments: Current Flood Warning System for Rochester
DATA COLLECTION & COLLATION	Data collection network (e.g. rain and stream gauges)	The existing data collection network is considered sufficient to support a rainfall – runoff flood forecasting model to Rochester and provide an adequate indication of rainfall rates and depths across the catchment together with response from the main streams, with two exceptions. Only one of those exceptions is relevant to Rochester. The Rochester town gauge needs to be telemetered so that current levels are available from the BoM's website and BoM can forecast to the town gauge rather than to the Syphon (see discussion below). Automated river level monitoring equipment along with a logger and modem needs to be installed at the town gauge site (just upstream of the Kyabram - Rochester Road Bridge) to address this deficiency. If responsibilities for funding and operation of this gauge cannot be resolved quickly (i.e. before end June 2013), an interim arrangement should be initiated whereby the BoM establishes a formal agreement with either a local resident, the Shire or another entity to obtain gauge readings routinely but particularly in the lead up to and during flood events. It is noted that data from Campaspe Weir is not currently available from the BoM's website. It is understood that this is temporary and is a consequence of the gauge now being set to AHD while the flood class levels remain at local datum. Ground survey will resolve the issue. Could consider relocating the rain gauge at the Syphon to the town gauge site.
	System to convey data from field to central location and / or forecast centre (e.g. radio or phone telemetry).	Data transmission / collection arrangements are considered to be adequate other than for the Rochester (and Echuca) town gauges. The installation of telemetry at the Rochester town gauge site, similar to what is being used at other sites within the catchment and compatible with existing systems, will resolve this issue. BoM to establish interim data transfer arrangements if manual readings are required prior to installation of new equipment.
	Data management system to check, store, display data.	Data is accessible from the BoM's website. A change at Rochester will require BoM to add this site to website data tables.
	Arrangements and facilities for system / equipment	Robust commercial arrangements exist between data collection network stakeholders

[28] Bureau of Meteorology (1987): *Flood Warning Arrangements - Papers prepared for discussions with Victorian Agencies,* December 1987

[29] Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria.* February 2001.

[30] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

Flood Warning System Building Blocks	Basic Tools	Review Comments: Current Flood Warning System for Rochester
	maintenance and calibration. For example, the Regional Surface Water Monitoring Partnership, data QA'ing and warehousing, etc.	and a service provider for site and equipment maintenance and for data QA'ing and archival. Similarly robust procedures exist to assist the installation of new equipment and inclusion of the site in the Surface Water Monitoring Partnership.
DETECTION & PREDICTION (i.e. Forecasting)	Rainfall rates and depths likely to cause flooding together with information on critical levels / effects at key and other locations.	The BoM rainfall – runoff model outputs a forecast hydrograph for key locations within the catchment including for Rochester Syphon. This informs the BoM public-issue warnings on the likelihood and scale of flooding. Flood intelligence extracted from the Rochester Flood Investigation deliverables will provide information on critical levels and impacts. BoM need to be advised of these critical levels and impacts so that forecasts can include information on when critical levels will be exceeded (on both the rise and the fall) rather than concentrating on the peak level and time.
	Appropriately representative flood class levels at key locations plus information on critical levels / effects.	It is necessary to know the levels at which floods begin to impact on the community in order to establish an effective flood warning system. In effect, to ensure that flood warnings are only provided when the consequences of flooding within an at-risk community are sufficient to warrant a warning and the coordinated mobilisation of resources to affect an appropriate response. Flood class levels, determined against standard definitions[31] are used to establish a degree of consistency in the categorisation of floods. Flood class levels exist for the Rochester town gauge. A review of these levels in the context of BoM definitions and against the intelligence and inundation maps generated by the Rochester Flood Investigation suggests that they are about right. The flood class levels for Campaspe Weir have not been reviewed as the correction to AHD is not known. As the river is well confined at the Weir even under very high flow conditions, flows / levels / trends at the site provide a good indication of likely impacts at Rochester. Thus deliverables from the Rochester Flood Investigation will facilitate such a review, once corrected levels have been determined.
	Flood forecast techniques (e.g. hydrologic rainfall - runoff model, stream flow and / or height correlations, simple nomograms based on rainfall).	An overview of flood warning services provided within Victoria by the BoM is available in Appendix F. BoM currently forecast to the Rochester Syphon, because it is rated and data is readily available during flood events. This gauge is approximately 3km downstream from town, is set to local datum and because of site characteristics and flood behaviour driven by breakouts, does not capture all flow and is not representative of what is happening in

[31] Standard definitions for minor, moderate and major flood class level are available from the Bureau's website.

Flood Warning System Building Blocks	Basic Tools	Review Comments: Current Flood Warning System for Rochester
		the town. As the Rochester town gauge site is not rated, the BoM rainfall – runoff model is currently unable to output a hydrograph (forecast) for that site. The Rochester Flood Investigation has demonstrated that at high flows, significant breakouts occur upstream from the Syphon with the result that flows bypass the gauge. As flows through Rochester increase, water levels at the Syphon experience only very small increases. This explains why the relationship developed by BoM between water levels at the Syphon gauge and the town gauge does not work well / is not robust: at high flows town gauge forecasts developed from this relationship are not reliable. The Rochester Flood Investigation has developed a rating for the town gauge. If this was loaded to the rainfall- runoff model, BoM would be able to forecast to the town gauge. The model could also output the predicted hydrograph for Campaspe Weir which would assist in quality controlling the forecast for Rochester. Alternatively or as a further check, the model could output the predicted hydrograph for Barnadown and the relationship between water level at Barnadown and the town gauge developed by NCCMA and included in the Campaspe MFEP could be used to verify the Rochester prediction. It is understood, however, that BoM would be reluctant to do this (forecast to the town gauge) without assured access to river level data from the town gauge during a flood event.
INTERPRETATION (i.e. an ability to answer the question *"what does this mean for me - will I be flooded and to what depth"*.	Interpretative tools (i.e. flood inundation maps, flood information cards, flood histories, local knowledge, flood response plans that have tapped community knowledge and experience, flood related studies and other sources, etc.).	The Campaspe Shire MFEP contains intelligence about flood risk and consequences at Rochester. The Rochester Flood Investigation has added to the store of flood intelligence in relation to the consequences associated with a range of design flood events as well as the record flooding experienced in January 2011. Flood extent, depth and hazard mapping has been incorporated into the MFEP together with information about which properties are likely to experience over-ground and over-floor flooding along with the expected depth of that flooding. Information on flood behaviours has also been added. While all required actions at various flooding depths remain to be completed on the Rochester Flood Intelligence Card, the MFEP provides a strong base to initiate a timely and considered response to (forecast) flooding at Rochester. In order to assist community members and stakeholder agencies to determine the likely effects of a potential flood, Council should make the flood inundation and depth maps and relevant Appendices of the MFEP readily available to the Rochester community. This will also inform their development of individual flood response plans (see below).

MESSAGE CONSTRUCTION	Warning messages / products and message dissemination system.	During times of flood, the Control Agency (VICSES) appoints an IC and establishes an ICC. Flood warning messages are constructed within the ICC as and when required using VICSES templates. Such messages draw on BoM flood forecasts and on intelligence contained in the MFEP. In severe flood situations, the Emergency Alert would be used to disseminate critical information and key messages.
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	Formal media channels[32] – TV, radio and print.	BoM issues flood forecasts to the media and agencies including VICSES. VICSES as the Control Agency for flood also issue flood warning messages that include more detailed information including flood consequences to the media and to a wider audience via the electronic media, websites and social media. Local arrangements would be initiated if and as required if door knocking or other information dissemination arrangements were required. These arrangements should be documented in the MFEP.
	Fax / faxstream, phone / pager (e.g. SMS, voice), voice messaging systems (e.g. Xpedite), tape message services, community radio, internet (e.g. BoM & VICSES websites, email, social media), national Emergency Alert system.	
	Flood wardens	
	Door knocking	
	Informal local message / information dissemination systems or 'trees'.	
	Opportunity for at-risk communities to confirm warning details.	

[32] ABC Radio has entered into a formal agreement with the Victorian Government and the Bureau of Meteorology to broadcast, in full, weather related warnings including those for flood. The agreement provides for the interruption of normal programming at any time to allow the broadcast of warning messages. This agreement will ensure that flood (and other) warnings issued by the Bureau are broadcast in their entirety and as soon as possible after they are received in the ABC's studio.

RESPONSE	Flood management tools (e.g. MFEP complete with inundation maps and 'intelligence', effective public dissemination of flood information, local flood awareness, individual and business flood action plans, etc.). Flood response guidelines and related information (e.g. Standing Operating Procedures). Comprehensive use of available experience, knowledge and information.	A critical issue for flood response at Rochester is the determination of whether weatherboard buildings should be sandbagged / protected or emptied of items susceptible to damage from floodwater and evacuated. Arrangements established in conjunction with Council and VICSES for making this determination and for initiating the relocation of goods and occupants should be detailed in the MFEP. Arrangements established by Council / VICSES for the supply of sandbags and sand within Rochester with sufficient lead time to enable non-weatherboard buildings and / or buildings at risk of minimal over-floor flooding (see list in MFEP) to be sandbagged / protected should be detailed in the MFEP. Local experience gained during the September 2010 and January 2011 floods has been captured to the MFEP and the Local Flood Guide. Evacuation arrangements / planning for Rochester (Appendix E of the MFEP) remain to be completed. The MFEP remains to be reviewed and signed-off by the Campaspe MEMPC. A Local Flood Guide that outlines local flood consequences and includes other useful and relevant information has been prepared by VICSES and disseminated. It is also available from the VICSES website. Following (or perhaps in concert with) formal adoption of the updated MFEP by Council, Council should encourage and assist residents and businesses to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.
REVIEW	Post-event debriefs (agency, community), etc. Data from Rapid Impact Assessments. Flood 'intelligence' and flood damage data from the event collected by residents, Council, NCCMA, etc. Review and update of personal, business and other flood action plans.	Local flood intelligence (i.e. flood characteristics, impacts, etc.), response plans, local flood awareness material including the Local Flood Guide, etc. have been updated following the January 2011 flood. Council to develop, review and update protocols in conjunction with VICSES and with input from NCCMA and other stakeholders as required => who does what when and process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP and personal / business flood action plans. This will maintain the currency and relevance of flood related material and assist informed and timely response. Ensure that as part of the above, information contained in Rapid Impact Assessment is captured to the MFEP.

<table>
<tr><td rowspan="5">AWARENESS</td><td>Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, etc.).</td><td rowspan="5">Studies repeatedly show that communities that are not aware of flood hazard are less capable of responding appropriately to flood warnings or alerts and experience a more difficult recovery than a flood-aware community. Thus, the emphasis of activities that aim to maintain and renew flood awareness at Rochester should be on an awareness of public safety issues and on demonstrating what people can do to stay safe and protect their property from flooding.

Flood intelligence delivered by the Rochester Flood Investigation has been captured to the MFEP.

Council to consider installing flood markers indicating the heights of previous floods (e.g. on power poles, street signs, public buildings, sides of bridges, etc.).

Council to consider the preparation and distribution of property specific flood depth charts and / or meter box flood level stickers for each property within Rochester subject to over-ground flooding up to and including the 200-year ARI event. The data to inform the charts can be extracted from the hydraulic model developed for the Rochester Flood Investigation.

Council to consider making the MFEP publicly available (Council offices, library, website) with a summary provided in Council welcome packages for new residents and business owners and with annual rate notices.

Council to consider loading and maintaining other flood related material on its website with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp).

Council in conjunction with VICSES, to periodically providing feature articles to local media on previous flood events and their effects on the community. This could extend to establishing photo displays of past flood events in local venues (these could be permanent).

Flood awareness material needs to be revisited and updated routinely in order to accommodate lessons learnt, additional or improved material and to reflect advances in good practice in a timely manner.

Establish protocols for routinely repeating distribution of flood awareness material.

Decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at key locations within Rochester and where there is appreciable danger to human life due to flood depth and / or velocity (e.g. as indicated by the flood hazard maps delivered by the Rochester Flood Investigation).</td></tr>
<tr><td>Activities and tools (e.g. participative community flood education, flood awareness raising, flood risk communication) that aim to build flood resilient communities (i.e. communities that can anticipate, prepare for, respond to and recover quickly from floods while also learning from and improving after flood events).</td></tr>
<tr><td>Community education and flood awareness raising including VICSES FloodSafe and StormSafe programs.</td></tr>
<tr><td>Local flood education plans – developed, implemented and evaluated locally (e.g. Cities of Maroondah, Whitehorse, Wodonga, Benalla and Greater Geelong).</td></tr>
<tr><td>Flood response guidelines, residents’ kits, flood markers, flood depth indicators, flood inundation maps and property listings, property specific flood depth charts, flood levels in meter boxes and on rate notices, etc. for properties identified as being subject to flooding through the Rochester Flood Investigation.</td></tr>
</table>

SUGGESTED ACTIONS AIMED AT IMPROVING THE TFWS

A staged approach to the refinement of the flood warning system for Rochester is proposed. The stages have been ordered and the tasks within each stage grouped to facilitate incremental growth of the TFWS elements in a balanced manner and with full regard for community feedback received as part of this study. Early work is directed at addressing deficiencies in the existing data collection network and forecasting capability. The availability of a flood forecast centred on Rochester is fundamental to the use of deliverables from this study to inform future flood response and awareness activities. Following resolution of the forecasting issue, other activities can occur in the knowledge that required data is / will be available and that arrangements are in place that will enable maximum benefit to be derived from any information or programs delivered to the community. A timetable and priorities have not been attached to the suggested actions other than for establishing BoM access to Rochester town gauge data and the development of a capability to deliver flood forecasts for the town gauge rather than the Syphon.

Stage 1A

1. Acknowledging that there is a high need to change the flood forecast location from the Rochester Syphon to the town gauge, Council, DSE and BoM to determine the responsible entity/ies in relation to "ownership" of an upgraded and telemetered river monitoring station at Rochester where ownership is considered to denote responsibility for funding and site functionality and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with associated payments. VFWCC[33] provides guidance on this matter although recommendation 1 from the Comrie Review Report[34] suggests that some clarifications may be required.

   The estimated capital cost of this installation, comprising concrete instrument housing on concrete pad, HS dry bubbler and pressure transducer, Campbell logger, modem, solar panel, antenna and cabling, is likely to be of order $25,000 + GST. This cost could be reduced by ~$2,000 if a less robust instrument housing was used. Cost includes estimated allowances for cultural heritage assessment and service checks and marking at site. Based on current rates, on-going costs are likely to be order $3,000 + GST per year without gaugings

2. As part of the above, consider relocating the rain gauge at the Syphon to the town gauge site. This would increase the estimated capital cost by around $2,500 + GST and on-going costs by around $1,000 + GST per year using current rates.

3. Council with the support of VICSES, NCCMA, DSE and the Rochester community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for activities listed below and aimed at upgrading the TFWS for Rochester.

Stage 1B

1. If responsibilities for funding and operation of the upgraded gauge at Rochester cannot be resolved quickly (i.e. unlikely to be resolved before the end of June 2013), it is suggested that interim arrangements are initiated whereby the BoM establishes a formal agreement with either a local resident, the Shire or another entity to obtain manual gauge readings routinely but particularly in the lead up to and during flood events.

[33] Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria.* February 2001.

[34] Comrie, N. (2011): *Review of the 2010-11 Flood Warnings and Response: Final Report.* 1 December 2011.

2. Following establishment of gauge reading arrangements, BoM to add the site to river level bulletins, data tables and other related products accessible via the BoM website as appropriate.

Stage 2

1. BoM to rework the Campaspe River flood forecast model so that predictions can be provided for Rochester town rather than for the Syphon. Without this change, the TFWS for Rochester is compromised and the benefits expected from this study will not be realised. The rating developed for the town gauge as part of this study may be of interest to the BoM and assist the change. In view of the critical nature of this activity in relation to flood preparedness and response at Rochester, it is suggested that a very high priority is allocated to this work with a planned completion date of end July 2013 (i.e. before possible spring flooding).
2. VICSES in conjunction with Council to advise BoM of critical levels and impacts at Rochester. This is aimed at BoM delivery of flood forecasts that include information on when these critical levels will be exceeded (on both the rise and the fall) along with the peak level and time.
3. Following BoM resolution of the AHD gauge zero conversion issue at Campaspe Weir and availability of data once again via the BoM website, VICSES in conjunction with Council to review these flood class levels. As the river is well confined at the Weir even under very high flow conditions, flows / levels / trends at the site provide a good indication of likely impacts at Rochester. Thus deliverables from the Rochester Flood Investigation will facilitate and inform the review. It is suggested that this review should be completed by the end of July 2013 (i.e. before possible spring flooding).

Stage 3

1. Following resolution of gauge “ownership” responsibilities and Surface Water Monitoring Partnership arrangements, the responsible entity (or as agreed between involved parties), to initiate actions to purchase, install and commission the required equipment at Rochester.
2. Following achievement of full operational status at the upgraded Rochester river monitoring site and if not already done, BoM to add the site to river level bulletins, data tables and other related products accessible via the BoM website as appropriate.

Stage 4

1. VICSES in conjunction with Council to establish and document in the MFEP arrangements for:
   - Determining whether weatherboard buildings should be sandbagged / protected or emptied of items susceptible to damage from floodwater and evacuated prior to flooding;
   - Initiating the pick-up and relocation of items susceptible to damage from floodwater from buildings likely to be flooded but not amenable to sandbagging;
   - Supply of sandbags and sand within Rochester with sufficient lead time to enable non-weatherboard buildings and / or buildings at risk of minimal over-floor flooding (see list in MFEP) to be sandbagged / protected.

Stage 5

1. Council and VICSES with input from others as required, to populate the “required actions” column of the Rochester Flood Intelligence Card for the various flooding depths listed.
2. Council, VICSES and VICPOL to complete the documentation / planning of evacuation arrangements for Rochester (Appendix E of the MFEP).
3. VICSES to initiate a community engagement program at Rochester aimed at communicating changes to the flood warning system along with evacuation arrangements. This may need to be repeated as the TFWS continues to mature.

Stage 6

1. Following formal adoption of the MFEP, VICSES to make the flood inundation and depth maps and relevant Appendices of the MFEP available on their website in order to assist community members and stakeholder agencies determine the likely effects of a potential flood and inform their development of individual flood response plans. Where possible, Council should also have these documents publicly available (Council offices, library, website)
2. Council to consider including flood related information in (say) Council welcome packages for new residents and business owners and with annual rate notices.
3. Council to consider loading and maintaining other flood related material on its website with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp).

Stage 7

1. VICSES in conjunction with Council to develop, review and update with input from NCCMA and other stakeholders as required. This should include who does what when and the process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP and personal / business flood action plans. This should include the capture of information contained in Rapid Impact Assessment reports.

Stage 8

1. Council to consider installing flood markers indicating the heights of previous floods (e.g. on power poles, street signs, public buildings, sides of bridges, etc.).
2. Council to consider the preparation and distribution of property specific flood depth charts and / or meter box flood level stickers for each property within Rochester subject to over-ground flooding up to and including the 200-year ARI event. The data to inform the charts can be extracted from the hydraulic model developed for the Rochester Flood Investigation.
3. Council in conjunction with VICSES, to periodically providing feature articles to local media on previous flood events and their effects on the community. This could extend to establishing photo displays of past flood events in local venues (these could be permanent).

Stage 9

1. VICSES in conjunction with Council to encourage and assist residents and businesses to develop individual flood response plans following (or perhaps in concert with) formal adoption of the updated MFEP.

Stage 10

1. VICSES in consultation with Council to establish protocols for routinely reviewing, updating and repeating distribution of flood awareness material.
2. Council to decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at key locations within Rochester and where there is appreciable danger to human life due to flood depth and / or velocity (e.g. as indicated by the flood hazard maps delivered by the Rochester Flood Investigation).

ACRONYMS

AEMI	Australian Emergency Management Institute
BoM	Bureau of Meteorology
DoTARS	Department of Transport and Regional Services
EMA	Emergency Management Australia
EMMV	Emergency Management Manual Victoria
EA	Emergency Alert
IC	Incident Controller
ICC	Incident Control Centre
MEMPC	Municipal Emergency Management Planning Committee
MFEP	Municipal Flood Emergency Plan
NCCMA	North Central Catchment Management Authority
TFWS	Total Flood Warning System
VICPOL	Victoria Police
VICSES	Victoria State Emergency Service

FLOOD WARNING REFERENCES

Australian Emergency Management Institute (AEMI) (1995): *Flood Warning: An Australian Guide*.

Bureau of Meteorology (1987): *Flood Warning Arrangements - Papers prepared for discussions with Victorian Agencies, December 1987.*

Comrie, N. (2011): *Review of the 2010-11 Flood Warnings and Response: Final Report.* 1 December 2011.

Department of Transport and Regional Services (DoTARS) on behalf of the Council of Australian Governments (CoAG) (2002): *Natural Disasters in Australia. Reforming Mitigation, Relief and Recovery Arrangements: A report to the Council of Australian Governments by a high level officials' group.* August 2002 published 2004.

Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

Handmer, J.W. (1997): *Flood Warnings: Issues and Practices in Total System Design.* Flood Hazard Research Centre, Middlesex University.

Handmer, J.W. (2000): *Are Flood Warnings Futile? Risk Communication in Emergencies*. The Australasian Journal of Disaster and Trauma Studies. Volume: 2000-2.

Handmer, J.W. (2001): *Improving Flood Warnings in Europe: A Research and Policy Agenda.* Environmental Hazards. Volume 3:2001.

Handmer, J.W. (2002): *Flood Warning Reviews in North America and Europe: Statements and Silence.* The Australian Journal of Emergency Management, Volume 17, No 3, November 2002.

Phillips, T.P. (1998): *Review of Easter Floods 1998: Final Report of the Independent Review Team to the Board of the Environment Agency: Volume 1.*

Smith, D.I. and Handmer, J.W. (eds) (1986): *Flood Warning in Australia: Policies, Institutions and Technology*. Centre for Resources and Environmental Studies, Australian National University, Canberra.

United Nations (UN) (1997): *Guiding Principles for Effective Early Warning*. Prepared by the Convenors of the International Expert Groups on Early Warning of the Secretariat of the International Decade for Natural Disaster Reduction, IDNDR Early Warning Programme, October 1997, Geneva, Switzerland.

Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria.* February 2001.

APPENDIX F FLOOD WARNING PROVIDED BY BOM

OVERVIEW OF FLOOD WARNING SERVICES PROVIDED BY BoM

Flood Warning Products

Flood Warning products and Flood Class Levels can be found on the BoM website. Flood Warning products include Severe Thunderstorm Warnings, Severe Weather Warnings, Flood Watches and Flood Warnings.

Severe Thunderstorm and Severe Weather Warnings

The BoM can forecast the environment in which severe thunderstorms or small scale weather systems that are locally intense and slow moving may occur and provides a generalised service to that effect. However, it is not yet scientifically possible to predict individual flash flooding events except on time scales of tens of minutes at the very best.

The BoM issues warnings of flash flooding when it becomes apparent that an event has commenced which may lead to flash flooding or when flash flooding has commenced.

Flood Watches

Flood watches are issued by the BoM to notify communities and other stakeholders within broad areas (rather than specific catchments) of the potential flood threat from a developing weather situation. They provide a 'heads up' of likely flooding.

Flood watches are based on an assessment of the developing weather situation and indicators of current catchment wetness. They provide generalised statements about expected forecast rainfall totals, the current state of the catchments within the target area and the streams at risk from flooding. Instructions for obtaining rain and stream level observations and access to updated Watches and Warnings are also included.

Normally, the BoM would issue a Flood Watch 24 to 36 hours in advance of any likely flooding and issue updates as required. If at any time during that period there was an imminent threat of floods occurring within an area covered by the formal flood forecast and warning service, the Flood Watch would be upgraded to a Flood Warning.

Flood Warnings

Flood Warnings are firm predictions of flooding based on actual rainfall and river height information as well as the results of stream flow based models of catchment behaviour that take account of antecedent conditions (i.e. the 'wetness' of the catchment, storage levels within dams, etc.) and likely future rainfall. Releases from dams are an essential input to such models.

Flood warnings are categorised as 'minor', 'moderate' or 'major' (see BoM website for an explanation of these terms and current flood class levels) and indicate the expected severity of the flood for agreed key locations along the river.

Generally flood warnings are issued by the BoM to the media, VICSES, Council and other stakeholder agencies and organisations. VICSES promptly alerts and disseminates such warnings to other agencies and organisations. Stakeholder agencies and organisations, including Council, are responsible for onward dissemination of the warning details.

Flood warnings usually include:

- Rainfall amounts for selected locations within and adjacent to the subject catchment;
- River heights and trends (rising, steady, falling) at key locations within the subject catchment;
- Outflows (in ML/d) from any major storages within the catchment;
- Forecasts of the height and time of flood peaks at key locations;
- A weather outlook and the likely impact of expected rainfall on flooding; and
- A warning re-issue date and time.

Note 1: The term "local flooding" and "flash flooding" may be used for localised flooding resulting from intense rainfall over a small area.

Note 2: The term "significant rises" may be used in the early stages of an event when it is clear that river levels will rise but it is too early to say whether they will reach flood level.

Additional information (e.g. weather radar and satellite images as well as updated rain and river level information) can also be obtained from the Bureau's website (www.bom.gov.au/hydro/flood/vic) or for the cost of a local call on ☎ 1300 659 217.

Flood Class Levels

The occurrence of a certain class of flooding at one point in a catchment will not necessarily lead to the same class of flooding at other points – for example along the main river and its tributary creeks or along a drainage network's overland flow paths. This is because the floodplain physiography and use (and thus flood impact) varies along the river or flow path and also because antecedent conditions combined with where and how rainfall occurs (both in time and space) will drive how a flood develops and progresses.

It is emphasised that the flood class levels refer to that part of the watercourse where the flood effects can be related to the gauge reading.

It is important to remember that flood impact is dependent on more than the peak height or flow. The rate of rise, duration, extent and season of flooding are also important. For this reason, flood class levels can only be considered as a guide to flood severity.

APPENDIX G FLOOD WARNING SYSTEM PACKAGES

Recommendations	Estimated Cost		Essential System		Standard System		Complete System		Comments
STAGE 1A	Initial Cost	Ongoing Cost (p.a.)	Initial Cost	Ongoing Cost (p.a.)	Initial Cost	Ongoing Cost (p.a.)	Initial Cost	Ongoing Cost (p.a.)	
1) Acknowledging that there is a high need to change the flood forecast location from the Rochester Syphon to the town gauge, Council, DSE and BoM to determine the responsible entity/ies in relation to "ownership" of an upgraded and telemetered river monitoring station at Rochester where ownership is considered to denote responsibility for funding and site functionality and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with associated payments. VFWCC provides guidance on this matter although recommendation 1 from the Comrie Review Report suggests that some clarifications may be required. The estimated capital cost of this installation, comprising concrete instrument housing on concrete pad, HS dry bubbler and pressure transducer, Campbell logger, modem, solar panel, antenna and cabling, is likely to be of order $25,000 + GST. This cost could be reduced by ~$2,000 if a less robust instrument housing was used. Cost includes estimated allowances for cultural heritage assessment and service checks and marking at site. Based on current rates, on-going costs are likely to be order $3,000 + GST per year.	$25,000.00	$4,000.00	$25,000.00	$4,000.00	$25,000.00	$4,000.00	$25,000.00	$4,000.00	Included in all
2) As part of the above, consider relocating the rain gauge at the Syphon to the town gauge site. This would increase the estimated capital cost by around $2,500 + GST and on-going costs by around $1,000 + GST per year using current rates.	$2,500.00	$1,000.00			$2,500.00	$1,000.00	$2,500.00	$1,000.00	Included in Standard and Complete systems only
3) Council with the support of VICSES, NCCMA, DSE and the Rochester community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for activities listed below and aimed at upgrading the TFWS for Rochester.	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	Included in all - inkind cost
STAGE 1B									
1. If responsibilities for funding and operation of the upgraded gauge at Rochester cannot be resolved quickly (i.e. unlikely to be resolved before the end of June 2013), it is suggested that interim arrangements are initiated whereby the BoM establishes a formal agreement with either a local resident, the Shire or another entity to obtain manual gauge readings routinely but particularly in the lead up to and during flood events.	$1,000.00	$500.00	$1,000.00	$500.00	$1,000.00	$500.00	$1,000.00	$500.00	Included in all

2. Following establishment of gauge reading arrangements, BoM to add the site to river level bulletins, data tables and other related products accessible via the BoM website as appropriate.	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	Included in all - inkind cost
STAGE 2									
1. BoM to rework the Campaspe River flood forecast model so that predictions can be provided for Rochester town rather than for the Syphon. Without this change, the TFWS for Rochester is compromised and the benefits expected from this study will not be realised. The rating developed for the town gauge as part of this study may be of interest to the BoM and assist the change. In view of the critical nature of this activity in relation to flood preparedness and response at Rochester, it is suggested that a very high priority is allocated to this work with a planned completion date of end July 2013 (i.e. before possible spring flooding).	$5,000.00		$5,000.00		$5,000.00		$5,000.00		Included in all
2. VICSES in conjunction with Council to advise BoM of critical levels and impacts at Rochester. This is aimed at BoM delivery of flood forecasts that include information on when these critical levels will be exceeded (on both the rise and the fall) along with the peak level and time.									Produced as output of this study?
3. Following BoM resolution of the AHD gauge zero conversion issue at Campaspe Weir and availability of data once again via the BoM website, VICSES in conjunction with Council to review these flood class levels. As the river is well confined at the Weir even under very high flow conditions, flows / levels / trends at the site provide a good indication of likely impacts at Rochester. Thus deliverables from the Rochester Flood Investigation will facilitate and inform the review. It is suggested that this review should be completed by the end of July 2013 (i.e. before possible spring flooding).	$3,000.00		$3,000.00		$3,000.00		$3,000.00		Included in all
STAGE 4									
1. VICSES in conjunction with Council to establish and document in the MFEP arrangements for:									
➢ Determining whether weatherboard buildings should be sandbagged / protected or emptied of items susceptible to damage from floodwater and evacuated prior to flooding;	$1,000.00		$1,000.00		$1,000.00		$1,000.00		Included in all
➢ Initiating the pick-up and relocation of items susceptible to damage from floodwater from buildings likely to be flooded but not amenable to sandbagging;	$1,000.00						$1,000.00		Flood response cost, inc in Complete System only

➢ Supply of sandbags and sand within Rochester with sufficient lead time to enable non-weatherboard buildings and / or buildings at risk of minimal over-floor flooding (see list in MFEP) to be sandbagged / protected.	$1,000.00		$1,000.00		$1,000.00		$1,000.00		Included in all
STAGE 5									
1. Council and VICSES with input from others as required, to populate the “required actions” column of the Rochester Flood Intelligence Card for the various flooding depths listed.	$1,000.00		$1,000.00		$1,000.00		$1,000.00		Included in all
2. Council, VICSES and VICPOL to complete the documentation / planning of evacuation arrangements for Rochester (Appendix E of the MFEP).	$1,000.00		$1,000.00		$1,000.00		$1,000.00		Included in all
3. VICSES to initiate a community engagement program at Rochester aimed at communicating changes to the flood warning system along with evacuation arrangements. This may need to be repeated as the TFWS continues to mature.	$3,000.00	$1,000.00			$3,000.00	$1,000.00	$3,000.00	$1,000.00	Included in complete and standard systems only
STAGE 6									
1. Following formal adoption of the MFEP, VICSES to make the flood inundation and depth maps and relevant Appendices of the MFEP available on their website in order to assist community members and stakeholder agencies determine the likely effects of a potential flood and inform their development of individual flood response plans. Where possible, Council should also have these documents publicly available (Council offices, library, website).	$1,000.00	$500.00			$1,000.00	$500.00	$1,000.00	$500.00	Included in standard and complete systems only
2. Council to consider including flood related information in (say) Council welcome packages for new residents and business owners and with annual rate notices.	$5,000.00	$3,000.00					$5,000.00	$3,000.00	Included in complete system only
3. Council to consider loading and maintaining other flood related material on its website with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp).	$1,000.00	$500.00					$1,000.00	$500.00	Included in complete system only
STAGE 7									
1. VICSES in conjunction with Council to develop, review and update protocols with input from NCCMA and other stakeholders as required. This should include who does what when and the process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP and personal / business flood action plans. This should include the capture of information contained in Rapid Impact	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	Included in all - inkind cost

Assessment reports.									
STAGE 8									
2. Council to consider installing flood markers indicating the heights of previous floods (e.g. on power poles, street signs, public buildings, sides of bridges, etc.).	$10,000.00	$2,000.00					$10,000.00	$2,000.00	Included in complete system only
3. Council to consider the preparation and distribution of property specific flood depth charts and / or meter box flood level stickers for each property within Rochester subject to over-ground flooding up to and including the 200-year ARI event. The data to inform the charts can be extracted from the hydraulic model developed for the Rochester Flood Investigation.	$5,000.00	$1,000.00					$5,000.00	$1,000.00	Included in complete system only
4. Council in conjunction with VICSES, to periodically providing feature articles to local media on previous flood events and their effects on the community. This could extend to establishing photo displays of past flood events in local venues (these could be permanent).	$1,000.00	$1,000.00					$1,000.00	$1,000.00	Included in standard and complete systems only
STAGE 9									
1. VICSES in conjunction with Council to encourage and assist residents and businesses to develop individual flood response plans following (or perhaps in concert with) formal adoption of the updated MFEP.	$5,000.00	$3,000.00					$5,000.00	$3,000.00	Included in complete system only
STAGE 10									
1. VICSES in consultation with Council to establish protocols for routinely reviewing, updating and repeating distribution of flood awareness material.	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	Included in all, in-kind cost
2. Council to decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at key locations within Rochester and where there is appreciable danger to human life due to flood depth and / or velocity (e.g. as indicated by the flood hazard maps delivered by the Rochester Flood Investigation).	$3,000.00	$1,000.00					$3,000.00	$1,000.00	Included in complete system only
Total	**$75,500.00**	**$18,500.00**	**$38,000.00**	**$4,500.00**	**$44,500.00**	**$7,000.00**	**$75,500.00**	**$18,500.00**	