Ararat
Flood Investigation
Summary Report

July 2017

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PROJECT DETAILS

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Cover Photo: Flooding on the Western Highway during January 2011 flood event (Ararat Advertiser)

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1. INTRODUCTION

1.1 Overview

Water Technology was commissioned by the Glenelg Hopkins CMA to undertake the Ararat Flood Investigation. The study included detailed hydrological and hydraulic modelling of the Hopkins River and a number of small tributaries in the vicinity of Ararat, flood mapping of the Ararat township and recommendations for flood mitigation works.

The following Summary Report (R05), provides a summary of four previous milestone reports produced earlier in the project. This report acts as an executive summary of the entire study. A description of each of the staged reports is included below.

R01 - Ararat Flood Investigation – Data Review (Water Technology 2014)

Review of flood related information for the study area, a review of available topographic and structure data (bridges and culvert information), and verification of topographic data. The report also provided a proposed outline of the hydrologic analysis and hydraulic modelling methodology.

R02 - Ararat Flood Investigation – Preliminary Hydrology Report (Water Technology 2015a)
Preliminary hydrology modelling and analysis report, summarising results of RORB modelling including calibration and design event modelling.

R03 - Ararat Flood Investigation – Hydrology and Hydraulics Report (Water Technology 2015b)
Hydrologic and hydraulic modelling and analysis report, summarising results of RORB modelling, of hydraulic model construction and calibration and results of design event simulations.

R04 - Ararat Flood Investigation – Study Report (Water Technology 2017)

Detailed study report which presented the findings of the previous milestone reports.

R05 - Ararat Flood Investigation – Summary Report (Water Technology 2016e) – this report

Summary of all four reports described above (this report).

These five reports detail the approaches adopted, the findings and recommendations, of the Ararat Flood Investigation. The reports are supported by a number of standalone PDF flood maps and digital deliverables.

1.2 Study Area

Ararat is located in western Victoria, approximately 190 km north-west of Melbourne, on the Western Highway. The study area includes Ararat township, Greenhill Lake, the rural locality of Dobie and agricultural land to the east of Ararat. Ararat is located within the municipality of Ararat Rural City Council (ARCC).

Several small tributaries to the Hopkins River flow through Ararat township; the most significant of these is Cemetery Creek. Cemetery Creek flows from west to east around the northern extent of Ararat then turns to the south flowing into the Hopkins River at the Ararat Racecourse. A smaller tributary known as the South Drainage Line is located in the south of the township and flows into the Hopkins River further downstream near the waste water treatment facility.

The study area and significant watercourses are shown in Figure 1-1.

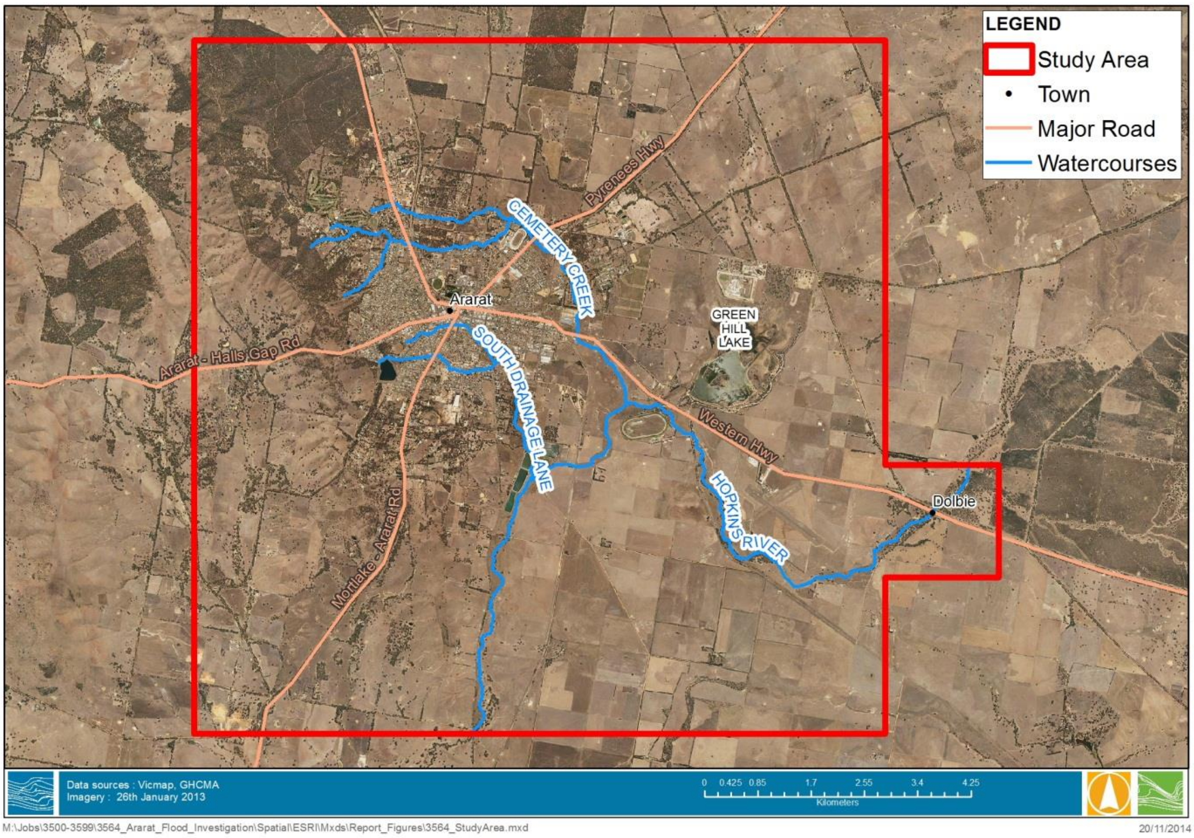

Figure 1-1 Ararat study area and major waterways

2. AVAILABLE INFORMATION

2.1 Flood Related Studies

There has been no detailed flood mapping previously undertaken in Ararat, however the Ararat Stormwater Study, undertaken in 1998 by Sinclair Knight Merz, assessed the existing stormwater system and made a number of recommendations. This included the development of an Integrated Catchment Management approach to addressing stormwater issues.

Currently no Land Subject to Inundation overlay (LSIO) or Floodway overlays (FO) exist in Ararat or along the Hopkins River in the vicinity of Ararat.

2.2 Available Hydrological Data

2.2.1 Streamflow Data

Streamflow data was required for the hydrological analysis. Only one streamflow gauge was available for use in this study, the Hopkins River at Ararat gauge (236219). The gauge is located south of Ararat approximately 3 km downstream of the confluence of the Hopkins River and Cemetery Creek as shown in Figure 2-1. The Hopkins River at Ararat gauge has a relatively short streamflow record of 25 years.

Streamflow records for the significant events of 2010 and 2011 were sourced from the Department of Environment, Land, Water and Planning (DELWP). Quality codes provided from the DELWP water monitoring database show the streamflow records for the Hopkins River at Ararat gauge were generally of good quality during those events, however there is some extrapolation of flows during the peaks of significant events.

No gauge records exist on Greenhill Lake, Cemetery Creek or any of the other smaller tributaries which flow through Ararat. Details of the Hopkins River at Ararat gauge are shown in Table 2-1.

Table 2-1 Streamflow gauge details

Station Name	Station No.	Status	Data Type	Period of record
Hopkins River @ Ararat	236219	Active	Instantaneous Flow	May 1989 – Current

Figure 2-1 Location of Streamflow Gauge

2.2.2 Rainfall Data

Overview

Both pluviograph and daily rainfall records were required for the hydrological analysis. Pluviographs record rainfall data at a sub daily scale, indicating the temporal rainfall pattern while the more common daily rainfall data provides the spatial rainfall variation over the catchment. Figure 2-2**Error! Reference source not found.** shows the location of the pluviograph and daily rainfall stations used in the analysis.

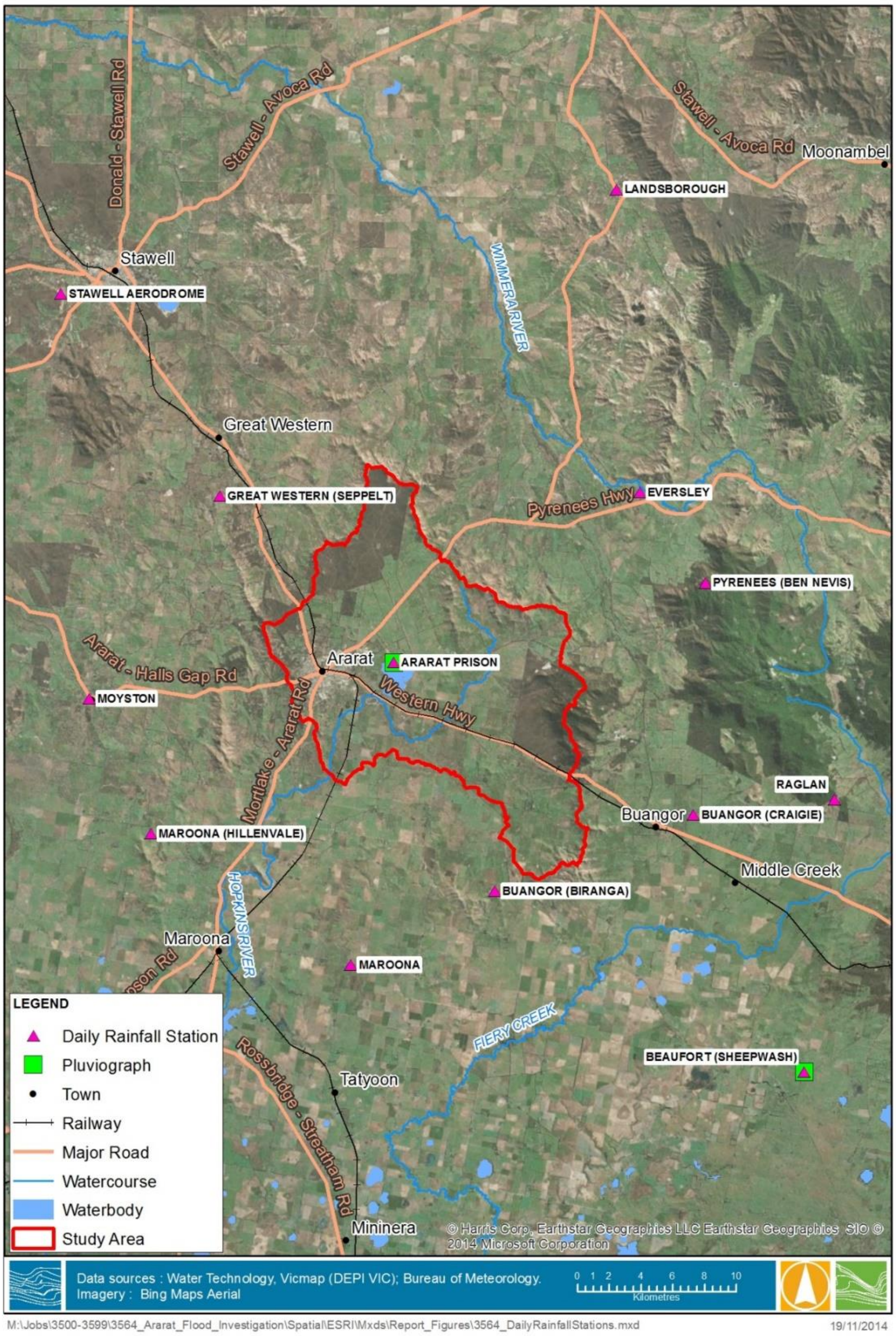

Figure 2-2 Rainfall Gauge Locations

Daily Rainfall Stations

Daily rainfall records were obtained from a number of stations spread out across the region. The daily rainfall stations used in the analysis are listed in Table 2-2. Data was extracted for three rainfall events which occurred during the 2010/2011 period when a number of significant flood events occurred around the state. Further information regarding the selection of these historic events for use in the hydrological and hydraulic analyses is provided in Section 3.

Table 2-2 Daily Rainfall Data Records

Station ID	Station Name	Start Date	End Date	Jan 2011 Rainfall (mm)	Sep 2010 Rainfall (mm)	Aug 2010 Rainfall (mm)
79014	EVERSLEY	1888	2014	144	69	67
79019	GREAT WESTERN (SEPPELT)	1891	2014	185	45	54
79027	LANDSBOROUGH	1901	2014	155	68	36
79034	MOYSTON	1886	2013	180	38	69
79101	PYRENEES (BEN NEVIS)	2007	2014	157	65	73
79105	STAWELL AERODROME	1996	2014	166	51	39
89045	BUANGOR (BIRANGA)	1949	2014	172	35	63
89053	MAROONA	2001	2014	N/A	34	63
89082	BEAUFORT (SHEEPWASH)	1968	2014	155	38	63
89085	ARARAT PRISON	1969	2014	169	42	57
89107	RAGLAN	1993	2014	248	100	84
89109	BUANGOR (CRAIGIE)	1996	2014	171	55	65

January 2011 event – 5 day rainfall from 9am 9th- 9am 14th (daily gauges)
September 2010 event – 3 day rainfall from 9am 3rd - 9am 6th (daily gauges)
August 2010 event – 4 day rainfall from 9am 9th - 9am 13th (daily gauges)

Pluviograph Stations

Pluviograph data recorded every six minutes was available at the Ararat Prison (89085) pluviograph station and was extracted for the January 2011, September 2010 and August 2010 historic events.

The nearest pluviograph station other than at Ararat is located at Beaufort, 42 km to the south-east of the study area. All areas within the catchment are located closer to the Ararat Prison, so the Ararat gauge was used to extract historic temporal patterns for all part of the catchment.

2.3 Flood Records

2.3.1 Historical Records

The city of Ararat has a long history of flooding with inundation occurring from both the Hopkins River and the smaller tributaries which run through the township. Notable flood events mentioned in documentation and within the media include 1933, 1982, 2010 and 2011. The January 2011 flood event is considered the largest event on record in the upper Hopkins River catchment.

2.3.2 Recent Flood Events

Three historic flood events were selected for inclusion to the hydrology model (RORB); August 2010, September 2010 and January 2011 events. The three events formed the basis for flows into the hydraulic model and were chosen due to the availability of gauge records and surveyed flood marks. It is good practice to vary event size when calibrating hydrological and hydraulic models to ensure the model is valid in both large and smaller events. The January 2011 event is the largest on record in the Hopkins River while the other two events are considerably smaller.

A number of surveyed flood marks were provided by Glenelg Hopkins CMA for the three historic events. The flood levels were vital to validate the modelling. Additional data such as anecdotal evidence, photos and videos were also sourced from local residents during community consultation sessions.

The calibration marks available for the 2010/2011 events are shown below in Figure 2-3. Additional discussion regarding the validity of the available flood marks is provided in Section 4.2.

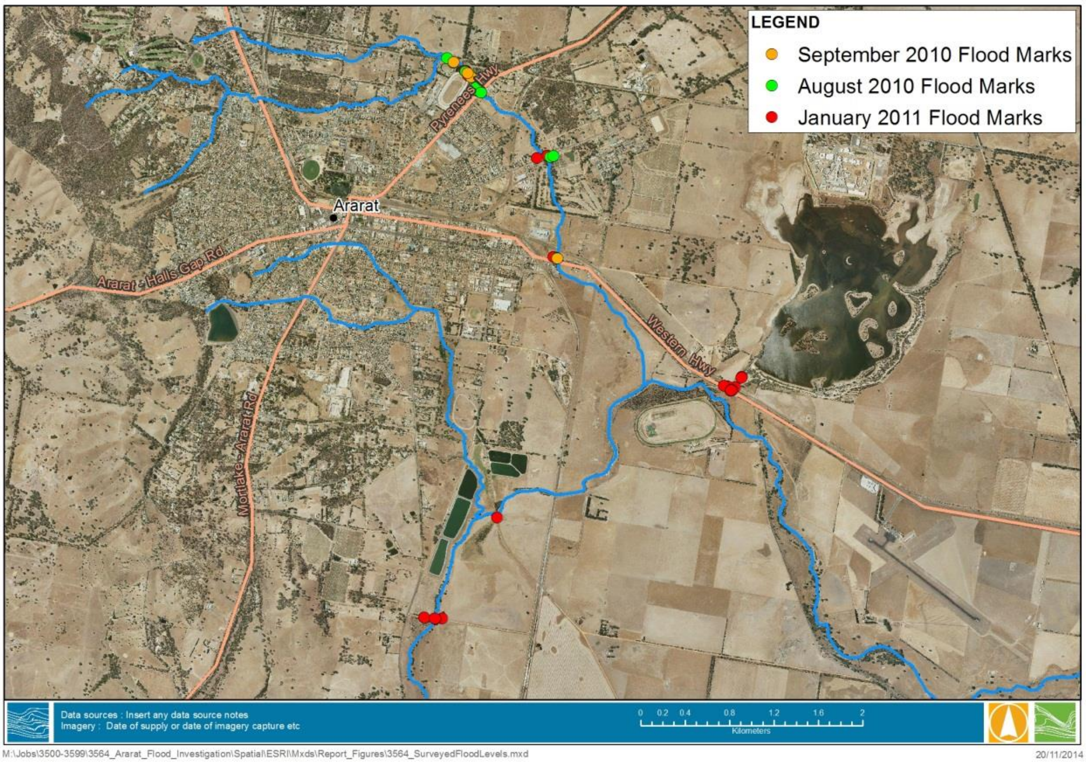

Figure 2-3 Surveyed flood marks around the study area for the flood events of 2010/2011

January 2011

The January 2011 event is the largest on record on the Hopkins River. The gauge in Ararat recorded a peak flow of 96 m^3/s. Elevated water levels in the Hopkins River lead to overtopping of the Western Highway and inundation of the Ararat Racecourse. Flooding was also observed in Cemetery Creek and some of the other tributaries which pass through the township.

There were 27 surveyed flood marks available on both the Hopkins River and Cemetery Creek. These marks were used for validation of the hydrological and hydraulic modelling in this study. Additional anecdotal evidence became available during the community consultation process.

September 2010

The September 2010 event was significantly smaller than January 2011 with a peak flow of 37 m^3/s recorded in the Hopkins River gauge at Ararat. Flooding was also reported in Cemetery Creek and 14 flood marks were surveyed following the event in Cemetery Creek only. While not a particularly large event, this event was chosen as a historical event for use in model calibration due to the availability of surveyed data and the potential for anecdotal evidence to become available during the community consultation process.

August 2010

The August 2010 event was smaller than both of the other calibration events with a recorded peak flow of 27 m^3/s at the Hopkins River gauge at Ararat. Flooding was observed in Cemetery Creek and 10 flood marks were surveyed following the event along Cemetery Creek which is why this was selected as the third historical event to be used for model calibration.

Other events

Other significant flood events occurred in 1909, 1933, 1982 and 1989 and December 2010. These events were not modelled due to the limited availability of data describing the events.

2.4 Physical Features

2.4.1 Topographic and Physical Survey

LiDAR

Three LiDAR datasets were provided as described below:

- GHCMA Floodplains LiDAR - 1m resolution LiDAR dataset with a stated vertical accuracy of +/- 0.1m. On review the dataset was observed to have some erroneous areas and gaps within the study area.
- GHCMA ISC Rivers LiDAR - 2m resolution LiDAR dataset with a stated vertical accuracy of +/- 0.2m. On review no significant offset was observed between this dataset and the Floodplains LiDAR dataset.
- A VicRoads LiDAR dataset was provided in 1m interval contours, with an unknown reported accuracy. A 2m DEM was created from the contours dataset. On review the VicRoads dataset was observed to be generally 0.3 m lower than the Floodplains dataset, the dataset was reviewed and compared as part of the data verification process.

The Glenelg Hopkins CMA Floodplains LiDAR dataset, with its greater reported level of accuracy, formed the basis for the hydraulic modelling with the other two datasets used to fill the gaps within the study area.

Field Survey

Information (dimensions, inverts) regarding the key hydraulic structures along the main tributaries and drainage lines in the study area was required for input into the hydraulic model.

A significant amount of relevant data was made available by Ararat Rural City Council including dimensions of key culverts and pipes and a list of critical pits. A number of structures were also measured by hand during the site visit.

There are a large number of hydraulic structures present in the catchment that were included in the hydraulic model (approximately 156).

Additional survey was not required other than measurements taken during a number of site visits.

Drainage Network

Details of the underground drainage network are important for the establishment of the hydraulic model and identification of flood related drainage issues.

Ararat Rural City Council provided Water Technology with GIS data of the drainage network for the study area which included pits, pipes and culverts. The drainage data was supplied in MapInfo tab file format, which were checked and modified to fit the modelling inputs. Engineering adjustments were also made to eliminate or refine abnormal drainage data where required.

All bridges, culverts and pipes along the mapped watercourses and drainage lines were included in the hydraulic model. Pipe specifications were obtained from drainage data provided by Ararat Rural City Council or measured during site visits.

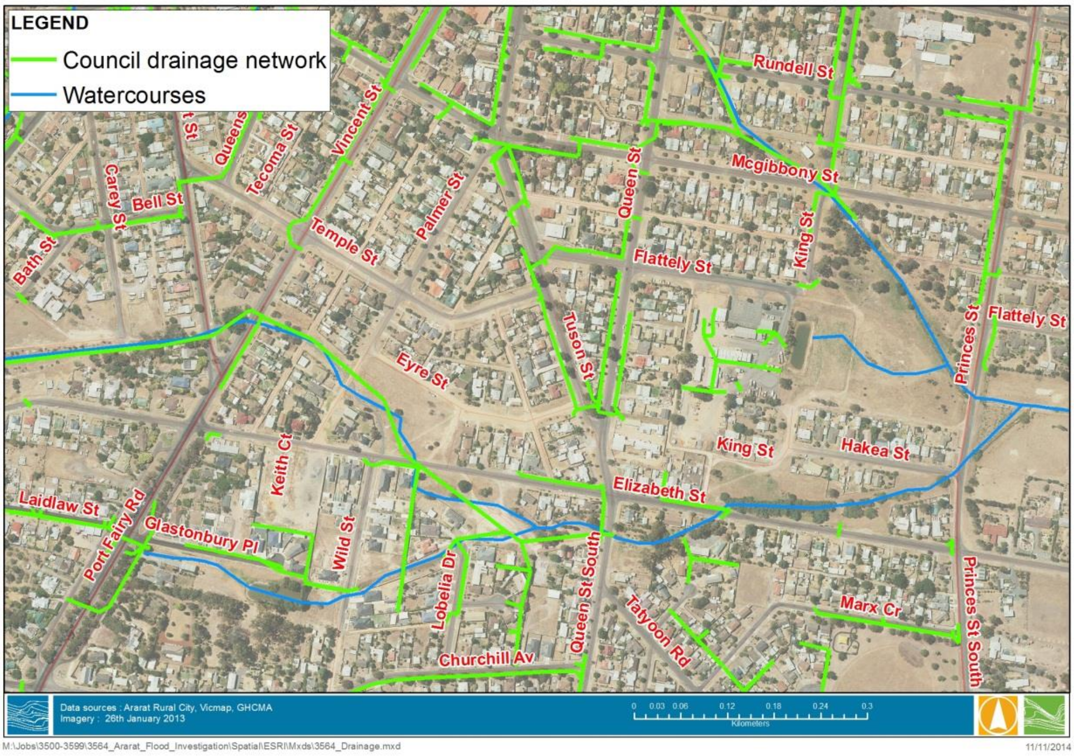

Figure 2-4 Example of GIS drainage data provided by Ararat Rural City

3. HYDROLOGICAL MODELLING

3.1 Overview

A hydrological model of the catchment was developed for the purpose of extracting design flows to be used as boundary conditions in the hydraulic model. The rainfall-runoff program RORB (Version 6.15) was utilised for this study, developed using MiRORB (MapInfo RORB tools).

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. Rainfall is input to the centroid of each subarea, losses are then deducted, and the excess routed through the reach network.

The following methodology was applied to develop the RORB model and complete the hydrological analysis:

- The Hopkins River catchment within the study area was delineated using ArcHydro GIS software and the available topographical data;
- The catchments were divided into subareas based on topography and required hydrograph print (result) locations;
- The local catchments near the city of Ararat were delineated to a much finer scale as a number of small tributaries are to be mapped and require a minimum of five subareas above the

upstream end of each tributary. Interstation areas were used at the outlets of the local tributaries due to the finer catchment delineation.

- A RORB model was constructed using appropriately selected model parameters, reach types, fraction impervious values and rainfall files;
- The model was run for three historic events (August 2010, September 2010, January 2011) and the model calibrated using the streamflow record at the Hopkins River at Ararat streamflow gauge. Parameters for the local tributaries near Ararat were determined based on a ratio of the RORB routing parameter Kc to D_{av} (the average flow distance in the channel network of sub area inflows) for the broader catchment. Hydrographs were then extracted at appropriate locations for use as inflow boundaries for the hydraulic model;
- As the local catchments are effectively ungauged the historic event flows were tested in the hydraulic model and the results compared against available flood data from those historic events. Available data included flood survey, photos and anecdotal reports.
  Once the historic events were verified and design parameters adopted, the RORB model was run for a range of design flood events – 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP. Design hydrographs were then extracted for input into the hydraulic model.

3.2 Summary of RORB Design Flows

Table 3-1 below displays the peak flows at key locations for the range of design events.

Based on comparisons with the design peak flows the January 2011 is estimated to be approximately a 1% AEP flood event in the Hopkins River and a 2% AEP event on the local tributaries. The September 2010 is estimated to be approximately a 5 % AEP flood event in the Hopkins River and smaller than a 20% AEP event in the local tributaries. The August 2010 is estimated to be approximately a 10 % AEP flood event in the Hopkins River and smaller than a 20% AEP flood event in the local tributaries.

Table 3-1 RORB Design Flows at Key Locations

Locations	AEP Peak Flow (m^3/s)						
	0.2%	0.5%	1%	2%	5%	10%	20%
Cemetery Creek Outlet	92.5	68.9	55.6	36.7	28.4	17.9	11.5
South Drain Outlet	55.6	43.8	35.8	28.3	19.0	13.5	9.40
Greenhill Lake outflow	83.9	58.9	45.8	31.7	14.6	7.57	2.96
Hopkins River at Dobie	158	114	84.5	62.1	32.4	16.7	6.14
Hopkins River at Ararat Gauge	336	241	180	129	66.3	31.9	17.3

4. HYDRAULIC MODELLING – DETAILED 1D/2D MODEL

4.1.1 Overview

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

- One dimensional (1D) hydraulic model of key waterways, drainage lines and hydraulic structures;
- Two dimensional (2D) hydraulic model of the broader floodplain; and
- Linked one and two dimensional hydraulic model to accurately model the interaction between in bank flows (1D) and overland floodplain flows (2D).

The hydraulic modelling suite, TUFLOW, was used in this study. TUFLOW is a widely used hydraulic model that is suitable for the analysis of overland flows in urban areas. TUFLOW has five main inputs:

- Topography and drainage infrastructure data;
- Rainfall data (used when a rainfall-on-grid methodology is adopted);
- Catchment losses (used when a rainfall-on-grid methodology is adopted);
- Roughness; and,
- Boundary conditions.

There are no known existing detailed flood models within the study area other than small scale models developed for individual flood prone developments. A TUFLOW model was constructed that included the local catchments around Ararat as well as Greenhill Lake and a section of the Hopkins River and floodplain. Flows were introduced into the model using a series of inflow boundaries. TUFLOW then routed flows through the catchment both overland across the 2D domain and underground through the 1d pipe network in some locations. Where the capacity of the underground drainage network is exceeded, flows surcharge back to the surface via the pit connections and are routed overland in the 2D domain producing overland flood extents, depths and velocities.

The 2D model extents are shown below in Figure 4-1. Full detail regarding the hydraulic model development can be found in the main study report.

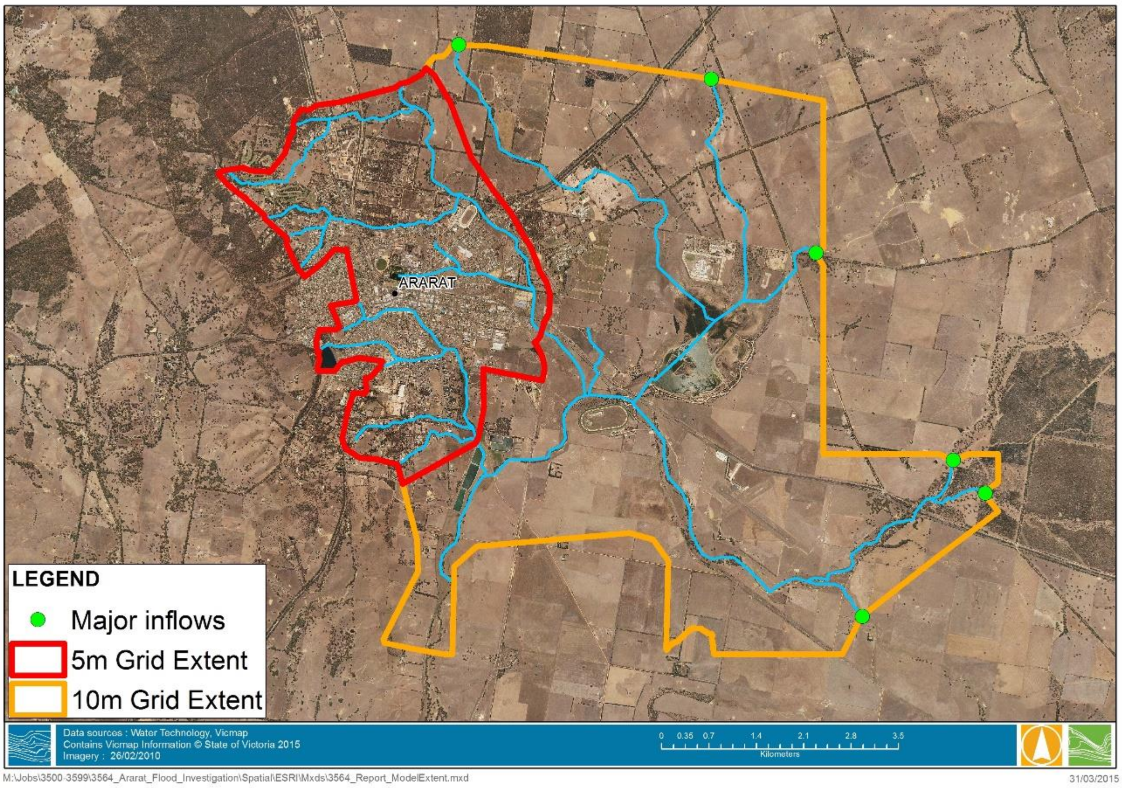

Figure 4-1 Extent of TUFLOW model with 5 m and 10 m grid domains shown

4.2 Hydraulic model calibration

4.2.1 Overview

The hydraulic model was calibrated against observed flood data by fine-tuning the hydraulic model parameters. This process was completed jointly with the hydrological calibration due to the limited and poor quality gauge data as previously discussed. Surveyed flood marks (provided by Glenelg Hopkins CMA), flood imagery and anecdotal reports were used in the calibration. The historic events used in the model calibration were the August 2010, September 2010 and January 2011. Overall a good calibration was achieved across the three events although the calibration was challenging due to the limited number and quality of surveyed flood points. Full detail regarding the hydraulic model calibration can be found in the study report.

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 often 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 being deposited during the recession of a flood. Survey is often collected well after the event.

4.3 Design Flood Modelling

The TUFLOW model was run with flows extracted from the RORB model for the 1, 1.5, 6 and 9 hour rainfall event durations for each of the required design events under existing conditions. Preliminary results had indicated that those duration events were the critical events across much of the catchment including all areas of interest. The 1 and 1.5 hour events tended to be the critical duration events on the tributaries in Ararat while the longer durations were critical along the larger watercourses including the Hopkins River.

4.4 Discussion

The flood mapping provides significantly more detail than any previous mapping of the study area. Upon completion of the study the outputs can be used to better manage development within the study area, and also predict and manage flood conditions during times of emergency.

The following comments describe the key flood characteristics across the study area for each design event.

20% AEP Flood Event

- Two house flooded over-floor in Queen St (South Drain) and Packard drive.
- Warrak Road begins overtopping near the eastern boundary of the Hopkins Correctional Centre.
- Shallow flooding across Pyrenees Highway (near corner of Noahs Ark Rd) (less than 150mm).
- Flooding across Down Road at Three Mile Creek (Over 300 mm).
- Water accumulating along the sides of roads, and on the upstream side of larger roads.
- Significant overbank flooding along the Hopkins River.

10% AEP Flood Event

- One additional house flooded over-floor compared to the 20% AEP event – located in King St (North Drain)
- Roads which cross South Drain begin overtopping (Queen, King, Princes and Albert Streets).
- Roads which cross North Drain begin overtopping (King and Baird Streets)
- Warrak Road overtopping both to the east and west of the Hopkins Correctional Centre (depths less than 200mm).
- Water becoming deeper along the sides of roads, and on the upstream side of larger roads.
- Flooding on the smaller local roads getting more extensive and a little deeper. Some roads will need to be closed due to depth considerations.

5% AEP Flood Event

- One commercial property (Tobin Street) and nine houses flooded over-floor all located along local tributaries in Ararat.
- Deeper flooding (more than 300mm) across Pyrenees Highway (near corner of Noahs Ark Rd)
- Shallow flooding (less than 200mm) across Mortlake-Ararat Road and Viewpoint Street from Oliver's Gully.
- Flooding across Grano Street from Cemetery Creek.
- Breakouts from the Hopkins River, across the race track.
- Water becoming deeper along the sides of roads, and on the upstream side of larger roads.
- Flooding on the local roads getting more extensive and deeper. Some roads will need to be closed due to depth and velocity considerations.
- Larger roads likely to be now wet.

2% AEP Flood Event

- Twenty five (25) buildings flooded over-floor in Ararat (includes 1 commercial buildings) predominately along the local tributaries.
- Campbell Street overtopping at North Drain and Tobin Street and King Street overtopping at South Drain.

- Water deeper along the sides of roads.
- Flooding on the local roads getting more extensive and deeper.

1% AEP Flood Event

- Significant breakouts from the Hopkins River leading to overtopping of the Western Highway and Geelong Road to the south of Greenhill Lake, and inundation of the Ararat racecourse. Widespread inundation of agricultural areas on the floodplain.
- The local Ararat tributaries, which include Cemetery Creek and South Drain, break out and overtop roads in a number of locations. Breakouts and inundation of properties are generally shallow however there are several location where deeper inundation was identified.
- Thirty eight (38) buildings flooded over-floor in Ararat (includes 3 commercial buildings) predominately along the local tributaries.
- Shallow flooding across Western Highway from small tributary 280m to the north of Wilmot St (less than 150mm in depth).
- Flooding on the local roads getting more extensive and deeper.
- See additional problem areas detailed below in Section 4.4.1

4.4.1 Problem Areas in the 1% AEP Flood Event

In reviewing the results of the 1% AEP event a number of specific problem areas within the study area were observed where roads are overtopped or inundation is impacting a number of properties. A list of problem areas in events equal to or larger than a 1% AEP flood event is provided below with the locations marked in the flood maps provided in Figure 4-2 and Figure 4-3. It should be noted that this is not a complete list of all properties impacted by flooding.

Cemetery Creek and minor tributaries

1. Overtopping of Saw Pit Flat Road (depths of 0.3 m), Banfield St (depths of 0.2 m), Beveridge St (depths of 0.3 m).
2. Inundation around the velodrome including roads and agricultural land around the velodrome such as Nott Road.
3. Significant banking up of water behind the Maryborough railway line leading to inundation of agricultural land on either side of the creek.
4. Overtopping of Grano Street to depths of 0.35 m from Cemetery Creek with inundation to 4-5 properties on the upstream side of Grano Street.
5. Insufficient capacity through culverts under Melbourne railway line resulting in water banking and then flowing east into the low lying areas on the north side of the railway line around Green Hill Drive and Nott Street. Water banks up behind the railway line to depths of 2.9 m in those areas and discharges through a small arched culvert under the railway line.
6. Inundation of 7-8 properties on Best and Blake Streets due to insufficient capacity in the lined drain at the rear of the properties
7. Inundation to several properties on Grano Street near the corner of Blake Street due to insufficient capacity in the culverts under Grano Street and the lined channel upstream of Grano Street.

South Drain and minor tributaries

8. Shallow inundation of several residential and commercial properties near the corner of Tobin and Viewpoint Streets due to insufficient capacity in the lined channel in that area.
9. Inundation of approximately 15 residential properties near the corner of Queen and Rundell Streets due to insufficient capacity in the lined channel in that area. Associated overtopping

of Moore Street (depths of 0.3 m), Queen Street (depths of 0.5 m), Rundell Street (depths of 0.4 m) and King Street (depths of 0.4 m).

10. Inundation of Department of Housing (DOH) units on Tobin Street, depths of up to 0.35 m. Associated overtopping of Tobin Street (depths of 0.4 m). 11 properties flooded above floor in the 1% AEP event within the DOH units.
11. Overtopping of Vincent and Palmer Streets with inundation to several properties in that area.
12. Overtopping of Queen Street South and Elizabeth Street with shallow inundation of several properties in that area.

Hopkins River and major tributaries

13. Insufficient capacity under the Maryborough Railway Line leading to water backing up behind the railway line and a 700 m long overtopping of the Pyrenees Highway (depths up to 0.4 m).
14. Warrack Road being overtopped at several locations in the vicinity of the prison (depths up to 0.35 m)
15. Significant breakouts from the Hopkins River leading to overtopping of Geelong Road and the Western Highway near the corner of Geelong Road. Depths of up to 0.4 m across the Western Highway near the Green Hill Lake outlet.
16. Widespread inundation of the Ararat Racecourse, to depths of 0.8 m in some low-lying areas, however the racecourse buildings largely remain flood-free.

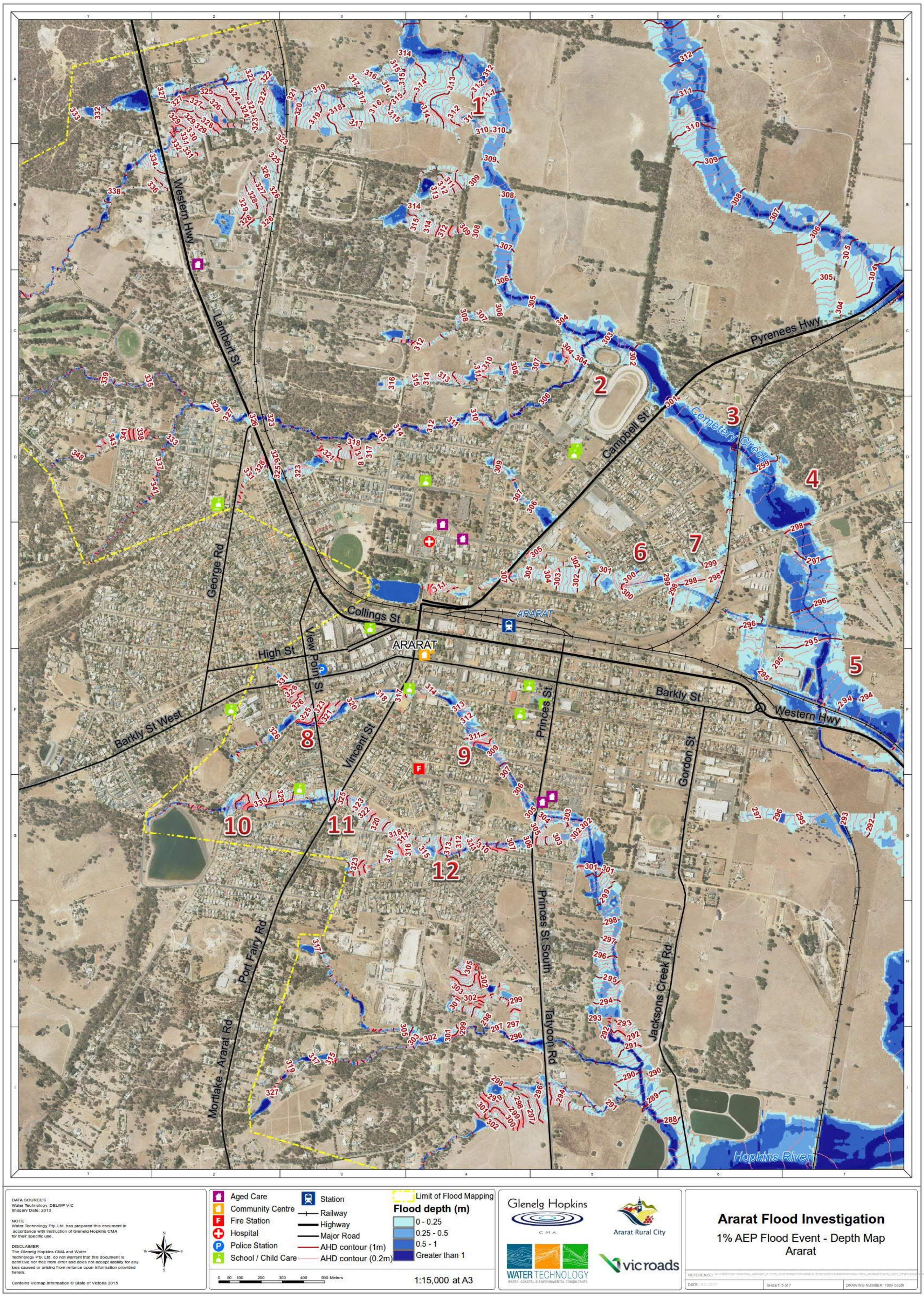

Figure 4-2 **Draft 1% AEP Flood map of Ararat township with problem areas marked (refer section 4.4)**

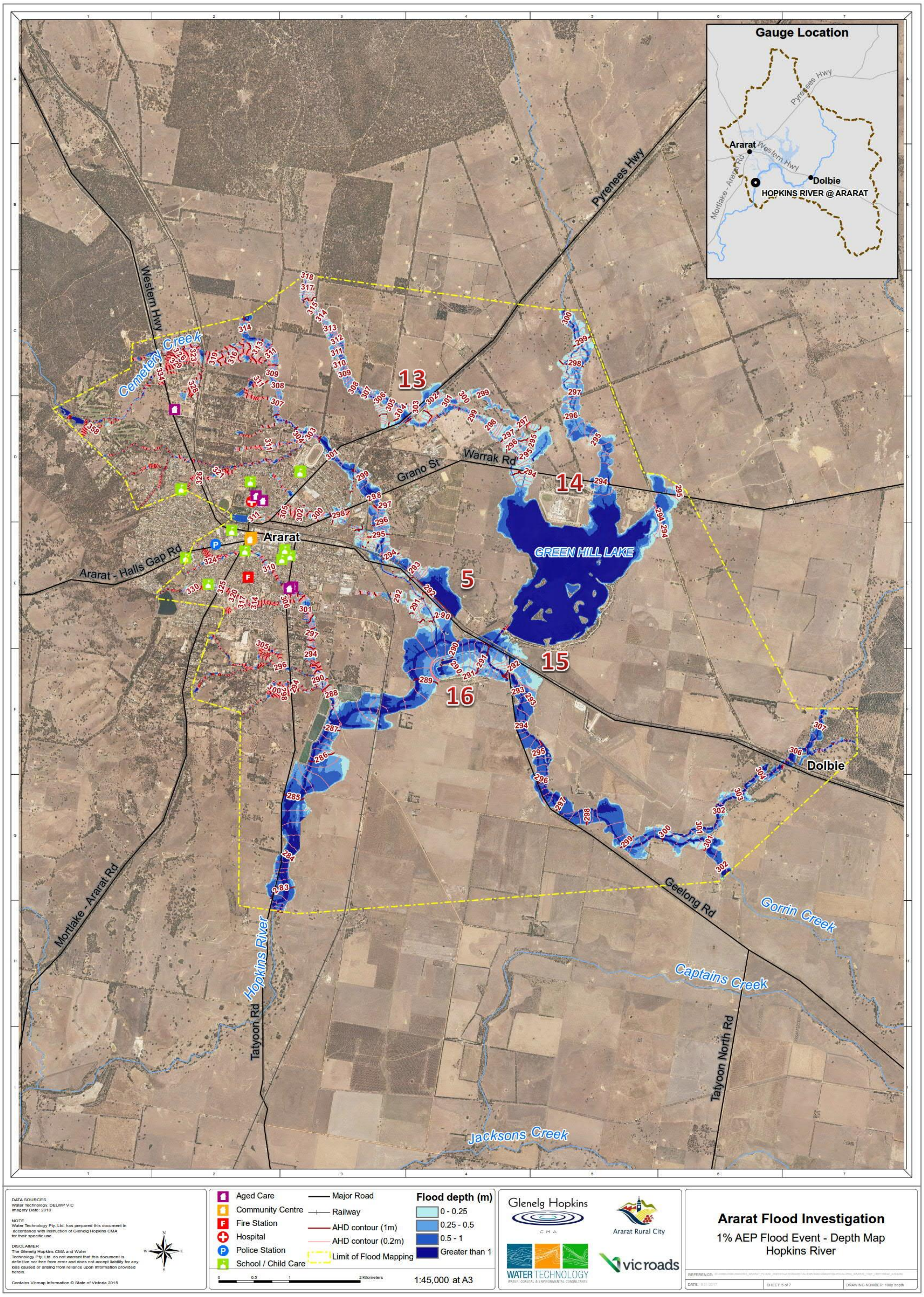

Figure 4-3 Draft 1% AEP Flood map of study area with problem areas marked (refer Section 4.5)

5. STORMWATER DIRECT RAINFALL MODELLING

5.1.1 Overview

A second hydraulic model was constructed in this project for the purpose of rainfall on grid (ROG) modelling to identify overland flow paths and stormwater problem areas within the catchment. The model consisted of a 5 metre 2D model domain with rainfall applied directly onto the model space across the entire city of Ararat. The outlying areas including the Hopkins River floodplain were excluded from the stormwater model to ensure model run times were feasible. The ROG modelling has resulted in a useful dataset that identifies overland flow paths and drainage hotspots across the entire city area of Ararat.

The results of the ROG modelling can be used for planning purposes and to make a preliminary assessment of any future developments in areas away from the mapped tributaries. The results can be used as a trigger to undertake more detailed flood assessment by developers as required. It should be noted that only the 1% AEP flood event was run in the ROG model.

The results of the stormwater direct rainfall modelling can be found in the main study report.

6. FLOOD RISK MITIGATION

6.1 Overview

Mitigation measures provide a means to reduce existing flood risk. Mitigation measures can reduce existing flood risk by lowering the likelihood of flooding and/or lowering the flood damages (consequences) for a given flood depth. Mitigation measures can be broken into:

- Structural: Physical barriers or works designed to prevent flooding up to a specific design flood standard. Structural measures aim to reduce existing flood risk by reducing the likelihood of flooding at given locations. Structural works include levees, floodways, retarding basins, waterway works or improvements to hydraulic structures.
- Non-structural: Management and planning arrangements between relevant authorities designed to reduce flood related damages. Non-structural measures aim to reduce existing flood risk by lowering the consequences of flooding. Non-structural measures include land use planning, flood warning, flood response and flood awareness.

The following discussion outlines the preliminary assessment of structural mitigation measures for the study area. Non-structural mitigation measures are discussed further in Section 6.4.

6.2 Structural Mitigation Options

6.2.1 Overview

Structural mitigation measures are physical works to reduce the likelihood of flooding in a given location. The full list of potential structural mitigation measures for the Ararat Flood Investigation study area and the source of the suggestion are shown in Table 6-1.

Table 6-1 Suggested mitigation options

Option No.	Detail	Source
1	Kokoda Park Retention/Detention	Council

Option No.	Detail	Source
2	South Storm water Channel - Enlarge the culverts at Queen Street and review options for channel upgrade	Council
3	Enlarge culverts at the Pyrenees Highway on Cemetery Creek	Council
4	Detention/Retention on Olivers Gully	Council
5	Enlarge culverts at Grano St, Cemetery Creek	Council/Community
6	Enlarge culverts on Western Hwy and Railway near Green Hill Lake outlet	Council/Community
7	Improved drainage along Packard Drive	Water Technology
8	Enlarge channel and culverts around Grano St, North Drainage line	Water Technology
9	Small local bunds or levees protecting at risk properties	Water Technology
10	Culvert upgrade on Queen St South	GHCMA/Community
11	Deepening Alexandra Gardens Park Lake	Community
12	Cleaning/deepening Cemetery Creek between the Western Highway and the railway line	Community
13	Put a retention basin/wetland on Cemetery Creek downstream of the Western Highway/railway line	Community
14	Deepen Green Hill Lake to create more storage	Community
15	Removal willows and gorse around Elizabeth Street and Princes Streets	Community

Based on the above list and the results of design modelling two preliminary packages of mitigation options were recommended for initial detailed modelling. Both packages involved testing a number of mitigation measures aimed at reducing local flood risk. Based on the results of the preliminary modelling a final package of measures was then developed and modelled for the full range of design events. The results of the preliminary mitigation modelling can be found in the main study report.

6.3 Final Mitigation Package

The final mitigation package consisted of a range of protection measures and drainage upgrades including:

- A 230 m long levee/bund in the vicinity of Packard Drive to protect a number of properties from above and below flood flooding
- Culvert upgrades and a retarding basin along Oliver's Gully
- Numerous drain and culvert upgrades along South Drain to improve flood risk to a number of properties in close proximity to the drain.
- Drain and culvert upgrades along North Drain and a retarding basin at Kokoda Park to improve flood risk to a number of properties in close proximity to the drain, primarily downstream of Kokoda Park.

Modelling of the final mitigation package demonstrated that the combination of options is effective at reducing flood risk in Ararat across a range of design events. Based on the results it was deemed appropriate that the package undergo a full damages assessment and benefit-cost analysis.

The results of the final mitigation package modelling can be found in the main study report.

6.4 Non-Structural Mitigation Measures

6.4.1 Overview

Non-structural measures are floodplain management activities aimed at reducing future flood damages. Non-structural measures aim to reduce existing flood risk by lowering flood damages (consequences) at a given location (as opposed to structural measures which tend to reduce frequency or likelihood of flooding). Non-structural measures include:

- Catchment management
- Flood awareness, preparedness, warning and response
- Land use planning

Catchment management activities in the upstream catchment can influence the existing catchment runoff characteristics (flood peaks and volumes). Flood volumes and peaks are a function of the vegetation cover and land use within a catchment (in addition to topography). Much of the upper catchments of the study area are cleared for agricultural purposes however the lower catchments are developed with significant pressure for further development. As a result future catchment management opportunities to reduce flood risk through changes to land use are somewhat limited.

Flood awareness, preparedness, warning and response aims to reduce the growth in future flood damages by improving community awareness of flooding and emergency services response. Flood awareness within a community reflects the frequency of significant flooding i.e. infrequent insignificant flooding lead to lower community flood awareness. Given there has been only relatively minor flood events within the study area in recent years the community awareness of flooding around the study area is expected to be low. Added to that, there has been no detailed flood mapping available for this area prior to this study. The level of community awareness has been demonstrated to diminish over time if community flood awareness programs are not ongoing.

This study has also included an update of the Rural City of Ararat Municipal Flood Emergency Plan. This ensures flood intelligence gathered in the study was documented and likely flood impacts will be understood by emergency personnel. This will ensure informed, effective and timely action in future flood emergency situations.

Flood warning is discussed in Section 6.5 below.

Land use planning aims to reduce flood damages by providing appropriate guidelines/controls for land use and development. The Victorian Planning Provisions (VPPs) allow for zoning of land and the application of controls on the type of land use and permitted activities in areas prone to flooding. The VPPs provide for the following flood related zone and overlays:

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

The VPPs provide guidelines for the appropriate uses and/or development of land in LSIO, UFZ and FO areas. Further discussion of proposed land use planning mapping developed by this study for the study area is provided in Section 7.

6.5 Flood Warning Recommendations

Molino Stewart Pty Ltd undertook a thorough review of the existing flood warning arrangements and identified options for improvement. A separate flood warning report is available however the key components and recommendations have been provided below.
The following recommendations are made to provide an improved TFWS configuration.

1. Flood risk should be clearly communicated to property purchasers by Ararat Rural City Council (section 32 certificate) and made available to any person via the Ararat Flood Investigation Report on the Glenelg Hopkins CMA website.

2. The Ararat LGA page on the VICSES website should be updated to include a non-technical summary of the findings of the Ararat Flood Investigation including flood risk maps of affected areas.

3. The draft Ararat Rural City Flood Emergency Plan should be further updated to include the findings and TFWS recommendations from this report. It should be included on the Ararat LGA page on the VICSES website.

4. An Ararat Local Flood Guide be produced including details about alerting those residents particularly in the Ararat town tributaries.*

5. Emergency management plans including warning triggers should be prepared by owners of the Ararat Racecourse and the four at-risk businesses in the Ararat small tributary catchments.

6. Specific engagement activities should be used to educate the at-risk properties about their flood risks, alerting mechanisms and appropriate response.*

7. VICSES should interpret the flash flood data from the BoM and provide alerts to the highest flood risk properties.

8. VICSES should use social media to alert at-risk communities including reference to Severe Weather Warnings issued by the BoM.*

9. Ararat Rural City should update and maintain the Vulnerable Persons Register for those at-risk properties.

10. Further examination should be made of the social vulnerabilities in the floodplains and specific assistance measures included in the Ararat Rural City Flood Emergency Plan.

11. The general populace should be further educated in the risks of moving through floodwaters e.g. inundated roads.

12. A committee should be formed or an existing committee used to review the Ararat TFWS and ensure the effective integration of its components.

* Requires additional funding

7. DATASETS AND MAPPING

7.1 Overview

The flood mapping and datasets developed as part of the Ararat Flood Investigation are described in this section. Details are provided regarding the input data, methodology and outputs for the emergency response inundation and land use planning mapping.

7.2 Flood Inundation Mapping

7.2.1 Overview

Flood inundation maps were provided in pdf format for each flood event at a broad study area scale as well as three local extents focusing on the north, central and southern areas of the study area.

The following map components were generated:

- Flood extent with water level contours for all design events
- Depth shaded for all design events
- Velocity shaded for the 1% AEP design flood event
- Hazard polygons for the 1% AEP design flood event (see Section 7.2.5)

7.2.2 Flood Extent and Flood Depth Zones

The hydraulic analysis provides a regular grid of flood elevations across the hydraulic model study area. The flood extent was developed by converting the 5 m gridded model results into polygons. Shallow depths have not been removed from the results. The extent was smoothed to remove the sharp edges of the grid cells for visual mapping purposes.

Flood depths were classified for mapping using the following classifications:

- 0 m to 0.3 m
- 0.3 m to 0.5 m
- 0.5 m to 1.0 m
- 1.0 m to 2.0 m
- Greater than 2.0 m

7.2.3 Flood Elevation Contours

The flood elevations were contoured at 0.2 m intervals. The automatic contouring procedures can create erroneous flood elevation contours, therefore manual refinement of the flood contours was undertaken to improve their interpretability.

7.2.4 Emergency Service Locations

The location of the following emergency services was included on the flood response maps:

- Hospital
- Fire Station
- Police Station
- SES Unit
- Aged Care Facilities

- Schools and Child Care Facilities
- Community Centre

7.2.5 Hazard Mapping

Hazard maps were developed as a significant output of the study. Analysis of flood hazard is used to determine if it is safe for people and vehicles leaving a property during a flood event. Flood hazard was derived for the study area based on Glenelg Hopkins CMA hazard guidelines. The flood hazard extents are based on the following criteria:

High Hazard

- depths greater than or equal to 0.5 metres; *or*
- velocity greater than or equal to 1.5 m/s; *or*
- the product of depth multiplied by velocity greater than or equal to 0.4 m^2/s.

Low Hazard

- depths less than 0.5 metres; *and*
- velocity less than 1.5 m/s; *and*
- the product of depth multiplied by velocity less than 0.4 m^2/s.

Two hazard extents were produced based on the above criteria. The extents can be utilised for both planning and emergency management purposes. The extents were provided as an output of the study in both PDF and digital format.

7.3 Flood Mapping for Land Use Planning

7.3.1 Overview

Land use planning controls and building regulations provide mechanisms for ensuring appropriate use of land and building construction, given the flooding risks to a particular area. Land use planning controls are aimed at reducing the growth in flood damages over time. The controls balance the likelihood of flooding with the consequences (flood risk).

7.3.2 Flood Related Planning Zone and Overlay Delineation

The FO and LSIO extents proposed for the Ararat Flood Investigation study area were based on consideration of the floodway and flood fringe definitions developed by Glenelg Hopkins CMA.

The following specific delineation criteria were applied:

Floodway (FO)

As a minimum, any land where best practice floodplain modelling indicates:

- The 1 % AEP flood depth is likely to reach or exceed 0.5 m; or
- The estimated 1 % AEP flood hazard factor (velocity x depth) can be expected to reach or exceed 0.4 m^2/s.

The land is delineated as floodway for the purpose of land use and development planning. It should be noted that the above criteria are subject to change pending advancements in flood hazard research.

Flood Fringe (LSIO)

Any land that is outside the floodway, but inside the 1 % AEP flood extent is delineated as within the flood fringe by default.

Planning Map Development Principals

The following principals were used to create the draft flood related planning maps:

- The floodway and flood fringe boundaries were defined using the criteria discussed previously.
- The raw flood boundaries were smoothed to create a visually enhanced representation of the floodway and flood fringe boundaries (smoothing from a grid outline to a more continuous boundary).
- Small "holes" less than 100 m^2 were filled in both the land subject to inundation and floodway overlays.

The flood related planning maps were developed in consultation with the Rural City of Ararat and Glenelg Hopkins CMA. Through this consultation, due consideration was given to local social, economic and environmental issues.

Planning Scheme Controls

Draft planning scheme controls were developed for the LSIO and FO for the study area, which seek to:

1. Minimise risks to life, health and wellbeing associated with flooding of the township;
2. Maintain to the maximum possible extent, the free passage and temporary storage of floodwaters;
3. Require new development to use materials, design and construction techniques to minimise likely damage by floodwater;
4. Ensure new development will not cause any significant rise in flood level or flow velocity to the detriment of other land holders or property;
5. Ensure flood damage costs are not compounded unduly;
6. Ensure existing development that is affected by flooding is maintained in a manner commensurate with the likely impacts from future flood events.

Figure 7-1 shows the draft Floodway Overlay and Land Subject to Inundation Overlay planning layers developed as an output of this study. It should be noted that the overlays were produced by combining the traditional 1D/2D and ROG modelling results. Where the traditional 1D/2D and ROG results intersect the traditional 1D/2D results were used in preference given the traditional modelling has been validated to a greater level than the ROG model. Both sets of a modelling were completed to a level of detail, utilising appropriate validation to ensure they were appropriate to be used for planning purposes.

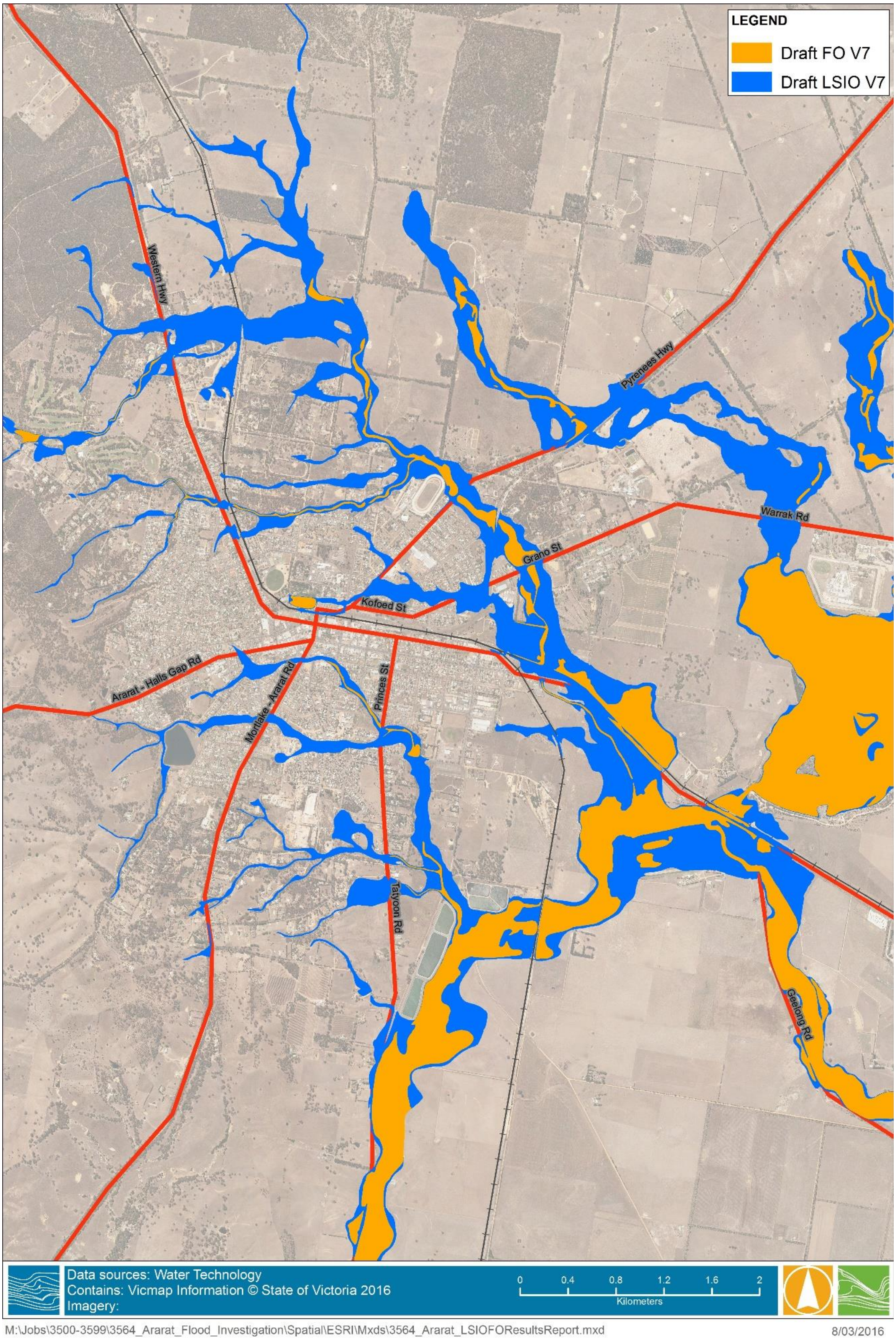

Figure 7-1 Draft FO and LSIO planning layers for Ararat

8. FLOOD DAMAGES ASSESSMENT

8.1 Overview

A flood damages assessment was undertaken for the study area under existing conditions. The flood damage assessment determined the monetary flood damages for both design floods (20%, 10%, 5%, 2%, 1% and 0.5% AEP flood events) and the final mitigation package. Floor level survey was obtained for more than 500 properties in the study area and this was used as one of the principal inputs for the damages assessment.

8.2 Existing conditions

The 1% AEP flood damage estimate for existing conditions was calculated to be more than $2.5 million. A total of 294 properties are flooded in a 1% AEP flood event, with 35 of those properties flooded above floor level. It is only in the 2% AEP flood event and greater that significant numbers of properties are flooded above floor. 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 to be **$147,134**. It is only in the 2% AEP flood event and greater that significant numbers of properties are flooded above floor.

Table 8-1 Flood damage assessment for existing conditions

Parameter	Annual Exceedence Probability					
	0.5%%	1%	2%	5%	10%	20%
Residential Buildings Flooded Above Floor	39	35	24	9	3	2
Commercial Buildings Flooded Above Floor	5	3	1	1	0	0
Properties Flooded Below Floor	274	256	231	191	130	105
Total Properties Flooded	**318**	**294**	**256**	**201**	**133**	**107**
Direct Potential External Damage Cost	$666,339	$565,082	$492,357	$348,900	$213,018	$159,286
Direct Potential Residential Damage Cost	$2,266,805	$1,871,060	$1,326,650	$437,236	$144,716	$110,830
Direct Potential Commercial Damage Cost	$326,207	$231,245	$37,479	$23,967	$0	$0
Total Direct Potential Damage Cost	**$3,259,351**	**$2,667,387**	**$1,856,486**	**$810,103**	**$357,734**	**$270,116**
Total Actual Damage Cost (0.8*Potential)	**$2,607,481**	**$2,133,910**	**$1,485,189**	**$648,082**	**$286,187**	**$216,093**
Infrastructure Damage Cost	**$562,738**	**$405,946**	**$301,277**	**$170,507**	**$88,934**	**$43,314**
Total Indirect Cost	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Cost	**$3,170,219**	**$2,539,855**	**$1,786,466**	**$818,589**	**$375,122**	**$259,407**
Average Annual Damage (AAD)	**$147,134**					

Note: the NSW Office of Water stage damage curves incorporate indirect costs into direct potential costs so they are not listed separately.

8.3 Final Mitigation Package

The AAD for the final mitigation option was estimated to be **$112,499**. During a 1% AEP flood event, the final mitigation option would reduce the total number of properties inundated above floor level from 38 properties to approximately 11. This reduces the AAD by more than $35,000 per year by implementing the final mitigation package.

8.4 Average Annual Damage Summary

The damage assessment demonstrates that the final mitigation package has a moderate impact on reducing the AAD in the study area as shown in the summary table in Table 8-2.

Table 8-2 Average Annual Damage Summary for Study Area

Options	Average Annual Damage
Existing Conditions	$147,134
Final Mitigation Package	$112,499*

* Indicative estimate

9. BENEFIT COST ANALYSIS

9.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the preferred mitigation package. 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.

9.2 Mitigation Option Costs

A summary of the cost estimates for the preferred mitigation package are shown in Table 9-1 below. The principal cost elements for the mitigation package include the construction of levee banks, channel works and culvert upgrades. The cost for the proposed levees, bunds and embankment walls were calculated based on the estimated volume of earth material required to construct the structures. Similarly the cost for the channel works were determined using a standard excavation rate based on the earthwork removed.

A 30% contingency cost was added along with engineering and administration costs. An annual maintenance cost of 3% of the construction cost was also factored in for all works.

Table 9-1 Preferred Mitigation Package Cost Breakdown

Option	Total Construction Cost	Annual Maintenance
Final Mitigation Package	$6,458,000	$3,000

9.3 Benefit Cost Analysis

The results of the benefit cost analysis are shown below in Table 9-2. The preferred mitigation package achieves a relatively low benefit-cost ratio of 0.07, this is unsurprising given the low number of properties inundated above floor in Ararat particularly in the more frequent events. Nonetheless the mitigation package offers significant benefit to the community and improves a number of long-standing drainage issues around Ararat.

Table 9-2 Benefit Cost Analysis

	Existing Conditions	Final Mitigation Package
Average Annual Damage (AAD)	$147,134	$112,499*
Annual Maintenance Cost		$3,076
Annual Cost Saving		$49,527
Net Present Value		$905,338
Capital Cost of Mitigation		$6,457,698
Benefit – Cost Ratio		**0.07***

* Indicative value

10. STUDY DELIVERABLES

10.1 Overview

The study deliverables provide a comprehensive set of data that support the study outcomes. The deliverables were supplied on a study USB and consist of background data and outputs as listed below:

- Animations of the 5% AEP flood, 1% AEP flood and PMP events at points of interest
- Digital copies of study reports in PDF format.
- Study survey data (LIDAR, structures, cross-sections and floor levels)
- Other input data including rainfall and flow data
- A property database including flood information
- Digital copies of maps (PDF format)
- GIS datasets for the model results (MapInfo and ArcGIS format)
- The hydrologic and hydraulic model input and result files
- Standalone Flood Visualisation Tool for Ararat

A readme.txt file was included on the disk that describes the directory structure of the data contained on the disk.

10.2 Mapping Outputs

Details are provided of the study outputs for emergency response, and land use planning mapping including:

- Data sets: grids and shapefiles/tab files
- Planning layers
- Flood response inundation maps
- VFD layer updates

10.2.1 Datasets

The following datasets were provided. All GIS files were provided in ESRI and MapInfo format.

Grids

Gridded datasets of model results were provided for the following:

- PMF – maximum depth, hazard and water surface elevation,
- Climate change sensitivity (10%, 1% and 0.5% AEP flood events) – maximum depth, hazard and water surface elevation,

- Design events (10%, 20%, 5%, 2% 1% & 0.5% AEP flood events) – maximum depth, hazard, velocity and water surface elevation.

Shapefiles/Tab files

ERSI shapefiles and MapInfo Tab files were provided for the following:

- Flood extents
- Floor levels
- Mapping limits
- Water surface elevation (flood level) contours

10.2.2 Maps

Flood inundation maps were provided in pdf format for each flood event at a broad study area scale as well as three local extents focusing on the north, central and southern areas of the study area. The map base is cadastre as supplied in 2013 and is subject to change.

The following map components were generated:

- Flood extent with water level contours for all design events
- Depth shaded for all design events
- Velocity shaded for the 1% AEP design flood event
- Hazard polygons for the 1% AEP design flood event (see Section 7.2.5)

Each map includes:

- Flood extent,
- Flood level contour at 0.2 m and 1m intervals,
- Depth of inundation,
- Identification of essential services,
- Road/street names,
- Cadastral base,
- Land marks, including all physical man-made features particularly those affecting flood flows and distribution.

Soft copies were provided as PDFs. Related GIS files were provided in ESRI and MapInfo format.

10.2.3 Flood Extent Mapping (VFD Compliant)

All flood mapping data was prepared to the VFD metadata specifications.

10.2.4 Land Use Planning Maps

A draft LSIO/FO map was produced as part of the Planning Scheme Amendment documentation and were provided on the study USB.

11. CONCLUSIONS

11.1 Overview

The Ararat Flood Investigation was successful in providing a much improved understanding of flood behaviour through the study area so that future planning decisions may be soundly based and measures may be put in place to minimise risk to the community. The investigation provides a comprehensive analysis and review of existing and future potential flood risk in the township and surrounding area. The study involved:

- Collection and review of a range of data relevant to the definition of flooding within the study area.
- A survey analysis to develop a detailed description of the study area topography as a basis for analysis and mapping.
- A rigorous hydrologic analysis to develop robust design flood estimates for the study.
- Development of a detailed hydraulic model that is capable of predicting flood impacts in both the Hopkins River Catchment and local Ararat tributaries including Cemetery Creek under a range of conditions.
- Quantification of flood risk in terms of flood damages.
- Thorough sensitivity testing of the hydraulic results under both existing conditions and for climate change scenarios (10%, 20% and 30% increase in rainfall intensity).
- Examination of a range of potential flood mitigation options for different areas within the catchment.
- Review of flood warning and emergency management for the catchment including recommendations for development of a total flood warning system,
- Planning Scheme Amendment documentation for the study area.

11.2 Key Outcomes

The key findings and outcomes of the Ararat Flood Investigation are:

Study Area Hydrology & Hydraulic Characteristics - The study area covers the whole of the Ararat township and outlying area, and includes a number of small tributaries which traverse the township as well as the Hopkins River and floodplain located immediately to the east of the township. Flooding within the study area generally occurs through two mechanisms:

1. Flooding in Hopkins floodplain due to widespread and prolonged rainfall;
2. Flash flooding in the Ararat local tributaries due to intense local rainfall; and

The tributary catchments have shorter critical storm durations than the main Hopkins River floodplain, meaning that they are responsive to short, high intensity storms, whereas the Burrumbeet Creek flows are more responsive to sustained long duration rainfall. The critical duration rainfall events were found to be 1 to 1.5 hours for the local tributaries and 6 to 9 hours for the Hopkins River floodplain.

Stormwater Analysis - In additional to the analysis of riverine inundation described an analysis of stormwater inundation was also undertaken. The stormwater analysis was based on Council's GIS drainage dataset and included all pipes down to 450 mm diameter. The analysis identified a number of stormwater problem areas within the catchment which are described in Section 5.

Flood Mitigation – Mitigation of flood risk in the study area was examined with a number of different measures assessed. A package of mitigation works was recommended which provides significant benefit to the community and consists of drainage upgrades, levees and retarding basins. The recommended package provides the most benefit in terms of reduction in flood impacts and damages to the community relative to the cost of implementation. Due to the limited warning time for much of the study area flood warning, emergency management and planning controls for reducing flood risk are also key mitigation measures for reducing flood risk in the study area.

Planning Controls –The most appropriate flood-related planning controls for study are Land Subject to Inundation (LSIO) and Flood Overlay (FO). Draft overlays were produced along with draft planning documentation to accompany a Planning Scheme Amendment.

11.3 Recommendations

Following the investigations undertaken for the study it is recommended that:

- The GHCMA and Rural City of Ararat adopt the determined design flood levels and proceed with the planning scheme amendment process.
- In conjunction with VICSES, the Rural City of Ararat and GHCMA continue to engage the community in the treatment of flood risks through regular flood awareness programs such as the VICSES FloodSafe program, starting with the development of a local flood guide.
- In consultation with VICSES, the Rural City of Ararat and GHCMA explore further the recommendations for enhanced flood response through co-operation with SES and Police, utilising the flood inundation maps and flood intelligence tools included in the Municipal Flood Emergency Plan (MFEP). Consideration should be given to the use of the MFEP during an emergency.
- The Rural City of Ararat and GHCMA explore further the recommendations for the development of the proposed Total Flood Warning System around Ararat in conjunction with the BoM and SES.