Review of Halls Gap Flood Investigation – Final Report

May 2017

Wimmera CMA

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PROJECT DETAILS

Project Name	Review of Halls Gap Flood Investigation
Client	Wimmera CMA
Client Project Manager	Abdul Aziz
Water Technology Project Manager	Ben Hughes
Report Authors	Ben Hughes
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Cover Photo: Stoney Creek shopping complex (Wimmera Region Flood Report – January 2011)

15 Business Park Drive
Notting Hill VIC 3168

Telephone (03) 8526 0800
Fax (03) 9558 9365

ACN No. 093 377 283
ABN No. 60 093 377 283

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1. BACKGROUND

Halls Gap is situated within the Grampians National Park in the Fyans Valley. The surrounding catchment is very steep with inundation caused by Fyans Creek and the gullies flowing from Mount Difficult (including Stoney Creek). Fyans Creek rises south of Halls Gap around Cathedral Rock and flows north into Lake Bellfield. The Wannon River flows south along the same valley beginning its journey on the opposite side of Cathedral Rock. From Lake Bellfield, Fyans Creek flows through Halls Gap approximately 4.5 km downstream, and then on to Mount William Creek. Numerous gullies along the Mount Difficult Range flow from west to east through the township and into Fyans Creek. Stoney Creek is the largest of these gullies. Areas which are of known flood risk include:

- Fyans Creek;
- Mount Difficult gullies south of Glen Street;
- Valley floor south of Hemley Court;
- Mount Difficult Range gullies from Glen Street to Stoney Creek; and
- Eastern and Western side of the range downstream of the Lake Bellfield wall.

These locations are highlighted in Figure 2-1.

2. PROJECT PURPOSE

2.1 Overview

The Halls Gap Flood Investigation[1] provided information on flood levels and flood risk between the Lake Bellfield wall and the Ararat-Halls Gap Road, limited to east of Grampians Road. The study found that the township is subject to flash flooding with significant flood events occurring in 1946, 1992, 1996 and 2005. Since the project's completion the area has been subject to multiple significant storm and flood events, most notably the January 2011 event which inundated several homes and businesses. The steep terrain contributes to the rapid generation of significant runoff volumes from relatively minor rainfall events. This project was commissioned to review and update the existing Halls Gap flood model by verifying to recent flood events, consider the impact of climate change, and model several Lake Bellfield level scenarios.

This report documents the work undertaken during the Halls Gap Flood Study Review in its entirety.

2.2 Project Scope

The tender specification is very clear on the scope of the project, identifying six stages which describe the key tasks required to meet the overall project objective. These include:

1. Engage and consult with the technical review committee based on the requirement of the project;
2. Undertake data collation activities to ensure accurate flood mapping is developed based on recent flooding information;
3. Review and update hydrologic and hydraulic models;
4. Provide flood behaviour and flood intelligence products for a range of flood scenarios within the study area, from 50% AEP up to the Probable Maximum Flood (PMF);
5. Test model scenario for climate change and spillway overtopping scenario for Lake Bellfield; and,

[1] Water Technology (2008), Halls Gap Flood Investigation, report prepared for Wimmera CMA

6. Report on all elements of the project undertaken.

The previous hydraulic model extent is shown in Figure 2-1.

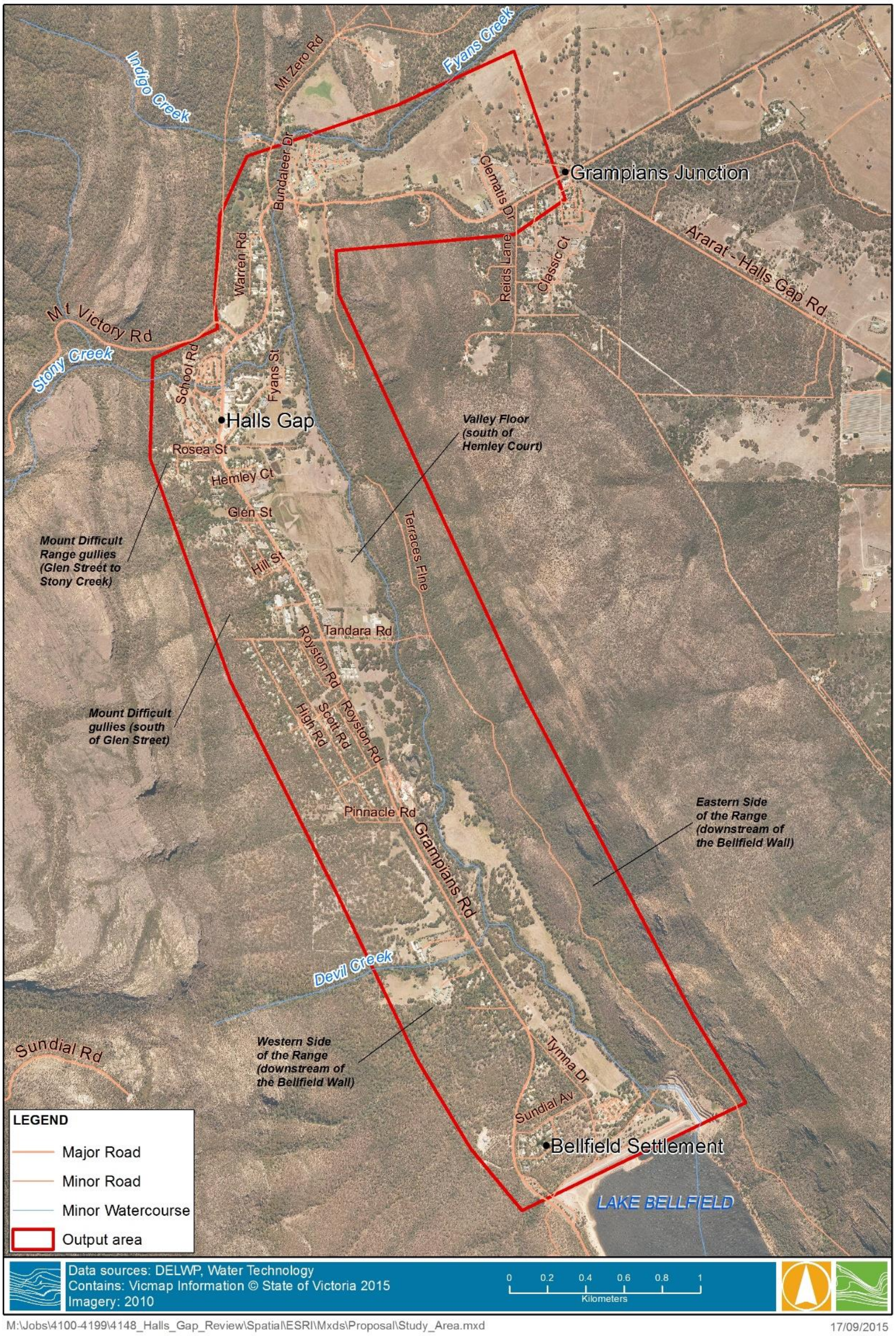

Figure 2-1 Study area

3. DATA COLLATION AND REVIEW

3.1 Overview

To update previous hydrologic and hydraulic modelling of Halls Gap and Fyans Creek, this project identified all available sources of information and potential data gaps. The available information was reviewed and utilised where appropriate.

3.2 Previous Studies

The waterways within the study area have been subject to numerous hydrologic and hydraulic investigations. These investigations were utilised in the development of this project. The most relevant investigations to this project are shown below:

- Water Technology – Halls Gap Flood Study (2008)
- BMT WBM – Mt. William Creek Flood Study (2014)
- Water Technology – Review of Storage Operation During Floods (2011)
- Water Technology – Stoney Creek Footbridge Hydraulic Assessment (2013)
- Water Technology – Royston Road Subdivision Design (2011)
- Northern Grampians Shire Council – Halls Gap Drainage Investigations (2006-7)
- URS – Lake Bellfield Flood Study (2001)

The Halls Gap Flood Study and the Review of Storage Operation During Floods, were most relevant for this project as they contained the most recent and relevant information. They are summarised in the following sections of this report.

3.2.1 Halls Gap Flood Study

Overview

The Halls Gap Flood Study[1] was funded by Wimmera CMA in conjunction with Northern Grampians Shire Council and completed by Water Technology. The study provided information on flood levels and flood risks within the township of Halls Gap. The study was funded under the Natural Disaster Risk Management Studies Programme by the Australian and Victorian Governments with a contribution from the Northern Grampians Shire Council.

The study area modelled the Lake Bellfield catchment area and the lake itself using a RORB rainfall-runoff routing model. A hydraulic model was developed from downstream of the Lake Bellfield wall to the Halls Gap-Ararat Road. The previous hydraulic model covered the same extent as the model which will be delivered through this project.

Hydrology

The hydrology for the Halls Gap Flood Study was structured around determining accurate design flows for Fyans Creek downstream of Lake Bellfield and numerous gullies either side of the Halls Gap Valley Floor. These inflows were determined using a RORB rainfall-runoff routing model. The RORB model applied was a modified version of that employed during the Lake Bellfield Flood Study[2] URS (2001).

Modifications included changes to model structure to reflect the focus on the flood estimation along the gullies. The RORB model was also extended to the streamflow gauge on Fyans Creek at the Grampians Road Bridge. In total 82 sub-catchments were delineated.

[2] URS (2001), Lake Bellfield Flood Study (Commissioned by GWMWater)

Attempts to calibrate the RORB model were made using the Fyans Creek at the Grampians Road Bridge streamflow gauge. The events chosen were August and December 1992. However, the ability to calibrate the model was limited by the following:

- Limited concurrent pluviograph and streamflow data from the Wartook and Grampians Road Bridge gauge
    - The two 1992 events were selected from a limited period of concurrent record, both events were fairly short duration high intensity events
- In both cases anecdotal descriptions of rainfall along Fyans and Stoney Creeks don't match that recorded at the Wartook gauge and the gauge record wasn't considered representative of what occurred in the area of interest.

Due to the limitations in using historic streamflow and rainfall gauge records the RORB model parameters were determined through the application of regional prediction equations with comparison to the modelling undertaken in the Lake Bellfield Flood Study[2].

Regional estimates of RORB kc were made using the prediction equations outlined in the RORB User Manual[3], as shown in Table 3-1. These values compared to an adopted value of 30 in the Lake Bellfield Flood Study[2].

Table 3-1 Fyans Creek RORB model – Regional kc estimates

Source	Regional Relationship	Kc
ARR99 Victoria (Mean Annual Rainfall < 800 mm)[4]	$Kc = 0.49\ A^{0.65}$	11.9
ARR99 Victoria (Mean Annual Rainfall > 800 mm)[4]	$Kc = 2.57\ A^{0.45}$	23.3
Pearse et al 2002[5]	Kc = 1.25 dav	21.7

The Halls Gap Flood Study adopted a kc value of 21.7 as calculated by Pearse et al[5] similar to the kc estimates from ARR87[6] (where MAR > 800 mm). It was highlighted there was considerable uncertainty in the adopted kc value. The dav for the RORB model was 17.38 km.

Design modelling utilised ARR87 Zone 2[6] temporal patterns in the study for all events, adopting a uniform spatial rainfall pattern. The design rainfall areal reduction factors, developed by Siriwardana and Weinmann (1999)[7] were employed.

The study report states that Lake Bellfield was assumed to be full at the commencement of the design flood events, however no reference to the actual level is made.

The design flows determined for Fyans Creek and Stoney Creek are shown in Table 3-2.

[3] Laurenson, Mein and Nathan (2010), RORB Version 6 Runoff Routing Program User Manual
[4] Engineers Australia (1999), Australian Rainfall and Runoff
[5] Pearse et al (2002), A Simple Method for Estimating RORB Model Parameters for Ungauged Rural Catchments
[6] Engineers Australia (1987), Australian Rainfall and Runoff
[7] Siriwardena and Weinmann (1996), Derivation of areal reduction factors for design rainfalls in Victoria, Report No. 96/4, CRC for Catchment Hydrology

Table 3-2 Fyans Creek Catchment – RORB model design peak flows

Location	Design Peak Flow (m^3/s)				
	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Fyans Creek upstream Stoney Creek confluence	10.4	16.1	24.2	31.6	39.7
Stoney Creek upstream Fyans Creek confluence	12.5	19.3	28.9	37.5	46.7
Fyans Creek at Grampians Road Bridge	20.1	32.2	48.9	64.1	81.8

Hydraulics

Hydraulic modelling was completed using DHI's two-dimensional hydraulic modelling software package, MIKE21. As discussed in Section 2 the hydraulic modelling covered the Halls Gap Valley floor from downstream of the Lake Bellfield Wall to the Halls Gap-Ararat Road. Additional to the valley floor the 2D hydraulic model covered areas west of Grampians Road, however this area was clipped out of the mapped model results due to the view the model results were not of sufficient accuracy along the steep narrow gullies of the Mt Difficult Range.

The hydraulic model topography was developed using the following data sources:

- A regular spot elevation grid and linear feature breaklines
- Field survey from Northern Grampians Shire Council drainage investigations[8].

As there was no real calibration data available and limited historic events, no hydraulic model calibration was attempted.

Hydraulic modelling was undertaken using a steady state approach with design peak flows entering the hydraulic model as source points. Given the uncertainty in both hydrologic and hydraulic analysis this degree of conservatism was deemed appropriate.

3.2.2 Review of Storage Operation during Floods[9]

Grampians Wimmera Mallee Water (GWMWater) commissioned Water Technology to carry out a review of the future operation of the key GWMWater reservoirs using experiences from the September 2010, December 2010 and January 2011 floods as a basis for proposing improvements to these operations. The operation of Lakes Bellfield, Lonsdale, Wartook, Rocklands Reservoir, Taylors Lake and the Wimmera Inlet Channel during the September 2010, December 2010 and January 2011 floods was reviewed and used as a basis for proposed operational improvements.

Lake Bellfield is the most recent storage constructed by GWMWater and was completed in 1966. It is located on Fyans Creek, with a catchment area of 9,600 hectares, mainly within National Park. The Lake is GWMWater's third largest, with a total storage capacity of 78,560 ML. It is a very deep online storage, with a small surface area and therefore has relatively small evaporation losses[10]. According

[8] BMT WBM – Mt. William Creek Flood Investigation (2013)
[9] Water Technology – Review of Storage Operation During Floods, Grampians Wimmera Mallee Water (2011)
[10] Barlow - Wimmera / Mallee Headworks System Reference Manual (1987)

to Barlow (1987), natural inflows from the catchment are quite low and given its shape and low natural inflow, water was retained in this dam in preference to other nearby storages. It harvests an average annual volume of 27,100 ML. Previously it was mainly used in conjunction with Lake Lonsdale to store its natural inflows and enable a much more efficient operation of the system.

In current operation, Lake Bellfield is filled partially by local catchment runoff, made up by winterfill diversions from the Wannon River between the months of June to October (inclusive) and is still kept as full as possible[11].

The GWMWater Operation Inspection and Maintenance Manual[12] contains useful information regarding Lake Bellfield. This document suggests that in 1992 design flows were estimated for Lake Bellfield, with a 1% AEP 18 hour storm producing an inflow of 11,920 ML/d and an outflow of 6,050 ML/d. The document also states that Bellfield has a target operating level of 275.97 m AHD, 53 cm below the Full Supply Level of 276.5 m AHD, allowing 2,500 ML of flood storage. It also says that if the reservoir is fully drawn down the reservoir would be expected to spill every 5 to 6 years, but if kept close to Full Supply Level it would spill every year. It is uncertain what these design flows and conclusions regarding spillway overflows are based on.

A single 1,200 mm manually operated cone valve outlet with a capacity of 856 ML/d can release flows into Fyans Creek downstream of the dam wall. The outlet is at an elevation of 244.49 m AHD, at the base of the dam wall, and is located around 32 metres below Full Supply Level so it can be operated at most storage volumes. When flowing at full capacity the velocity in the outlet pipe is close to 9 m/s.

The dam has a spillway on the right hand side, cut into natural rock. The spillway operates at the Full Supply Level of 276.5 m AHD and has a fixed, ogee shaped crest. It has been designed to pass all floods, up to the 1 in 11,000 year ARI flood without risking the dam embankment from overtopping.

A table of basic information about Lake Bellfield is shown in Table 3-3.

[11] GHD - Report for the Wimmera-Glenelg REALM Model Update, produced for the Department of Sustainability and Environment(2011)
[12] GWMWater (2010), Bellfield Reservoir Operation, Inspection and Maintenance Manual

Table 3-3 Basic Information for GWMWater's Lake Bellfield storage

Storage details	Lake Bellfield
Capacity (ML)	78,550
Surface area (Ha)	480
Maximum depth (m)	36.3
Year constructed	1966
Catchment name	Fyans Creek
Catchment area (Ha)	9,600
Average annual flows (ML/year)	31,000
Outlet	A single 1,200 mm cone valve outlet at an elevation of 244.49 m AHD with a capacity of 856 ML/d
Recreation	Yes
Manned?	Yes
Use	Primary source for WMPP Supply Systems 1, 2, 3 & 4. Supply to headworks towns

3.3 Streamflow, Water Level and Rainfall Gauges

3.3.1 Streamflow gauges

Several streamflow gauges provide information on the streamflow of Fyans Creek. The location of the gauges within the study area is shown below in Figure 3-1, with their gauge number and period of gauge record shown in Table 3-4 .

Table 3-4 Streamflow gauges on Fyans Creek

Gauge Name	Gauge Number	Gauge Record
Fyans Creek @ Grampians Road Bridge	415217	1960 - Current
Fyans Creek @ Lake Bellfield	415214	1960 - Current
Fyans Creek @ Fyans Creek	415250	1988 - Current

Along with flow and water level recordings quality code information is also supplied to provide guidance on the quality of flow estimations.

3.3.2 Rainfall Stations

The closest Bureau of Meteorology (BoM) sub daily rainfall gauge is located at Wartook Reservoir, there is also a sub daily gauge location at Mt William. There are also non BoM sub daily gauges located at the Lake Bellfield dam wall and the Halls Gap Police Station. Daily rainfall gauges in close proximity to Halls Gap are located at the following locations:

- Wartook Reservoir
- Halls Gap
- Lake Lonsdale
- Pomonal
- Grampians (Mount William)

The location of rainfall gauges within and surrounding the study area is shown in Figure 3-1, aside from the non BoM gauges for which the exact coordinates are unknown.

Figure 3-1 Streamflow and Rainfall Gauges around Halls Gap

3.4 Report for Landslide Susceptibility Zoning

Northern Grampians Shire Council commissioned GHD to complete Landslip Susceptibility Zoning for the Halls Gap township. The project was completed in September 2011 and outlined areas that are susceptible to landslips. Works in these areas should trigger a planning permit and potentially planning controls. These areas were included in Northern Grampians Shire Council Planning Scheme Amendment C42, as shown in Figure 3-2. The Landslide Susceptibility Zoning is relevant to this project because the LSIO and FO layers generated from this project will adjoin them covering the gullies in some form of planning control along their length.

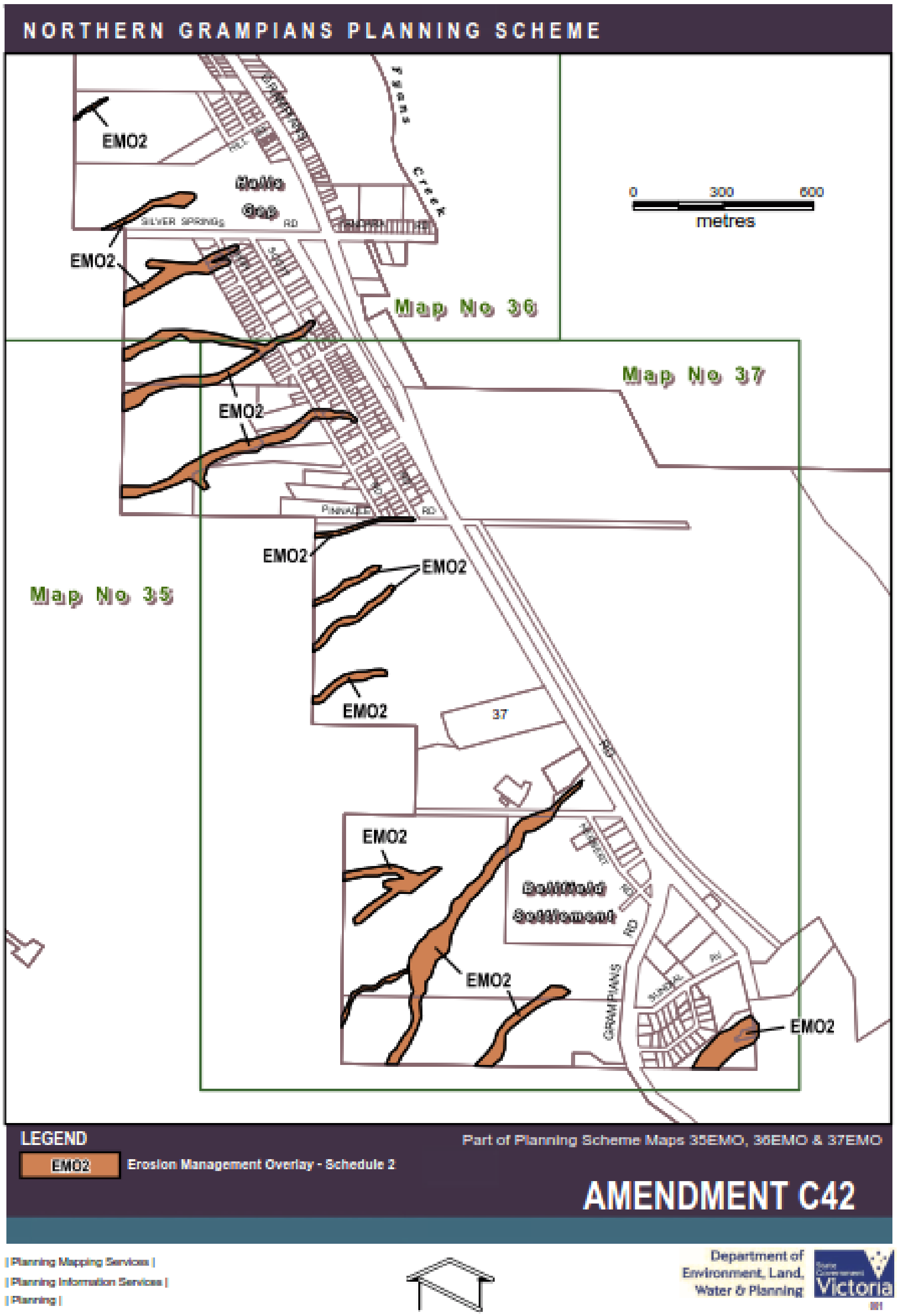

Figure 3-2 Planning Scheme Amendment C42 mapping

4. JANUARY 2011 HISTORIC EVENT

4.1 Rainfall

Rainfall in mid-January 2011 caused widespread flooding across Victoria, with the Wimmera Region particularly impacted. Rainfall began on the 9th January as significant rain fell across north-western Victoria. As the rainfall moved south east it intensified over the period Wednesday the 12th to Friday the 14th, breaking previous records at Rupanyup, Longerenong, Horsham and Halls Gap gauges. Halls Gap and Mount William in the Grampians recorded heavy rain, with cumulative totals of 146.6 mm and 132.8 mm for the gauges respectively. Halls Gap and the Grampians also recorded the highest monthly rainfall in the state with 297.0 mm and 289.6 mm respectively. On Thursday the 13th the system progressed eastward moving rainfall to the north, central and eastern areas of Victoria. On the evening of Friday the 14th the low pressure system cleared the state.

Table 4-1 January 2011 Daily Rainfall Totals around Halls Gap

Date	Pomonal	Grampians (Mount William)	Wartook Reservoir	Halls Gap	Lake Lonsdale
10th Jan	8.8	6.8	4	4.6	8.8
11th Jan	7.4	1.4	0.4	0.4	1.6
12th Jan	85.4	134.6	110.6	135	76
13th Jan	0	3.4	0.6	0.2	0
14th Jan	109	132.8	88	146.6	84
15th Jan	0	0	0.4	0	0
6 day Total	**210.6**	**279.0**	**204.0**	**286.8**	**170.4**

Note: Rainfall totals for the 24 hour period to 9am.

4.2 Lake Belfield Operation

Several high rainfall events occurred in the Lake Bellfield catchment prior to January 2011, including August, September and December 2010. Figure 4-1 below shows Lake Bellfield's storage level (Stage) against Full Supply Level (FSL) during the flooding events in late 2010 and early 2011. It also shows the calculated inflow to Lake Bellfield (from changing storage volume), any releases (Rout) or spillway discharges (Spill) and the flow in Fyans Creek downstream of Lake Bellfield. This data was provided by GWMWater.

There were no releases or spills from Lake Bellfield during any of the flood events in September 2010, December 2010 or January 2011.

The January 2011 event generated the highest inflows of all the 2010-2011 events, with the peak inflow measured as 8,571 ML/d on 13th January. This was almost six times larger than the September 2010 event and resulted in an increase in volume of 11% during a single day (13th to 14th January).

Anecdotal evidence suggests that GWMWater was monitoring outflows to the Wimmera Mallee Pipeline (WMP) during this period, following the large rainfall event and the rising reservoir level. Comments added by the Reservoir Keeper into GWMWater's MS Excel spreadsheet of data, reflect that on 12th January, the 8 am reading was followed by an additional check of storage level and volume at 3.30 pm (269.08 m AHD and 47,338 ML). This was also done on 13th January at 8 am and 3.30 pm

(269.43 m AHD and 48,618 ML, 62%) and again at 9 pm (270.14 m AHD and 51,262 ML). This indicated a rate of rise of 105 mm in 5.5 hours. The spreadsheet contains no further details of water level readings[9].

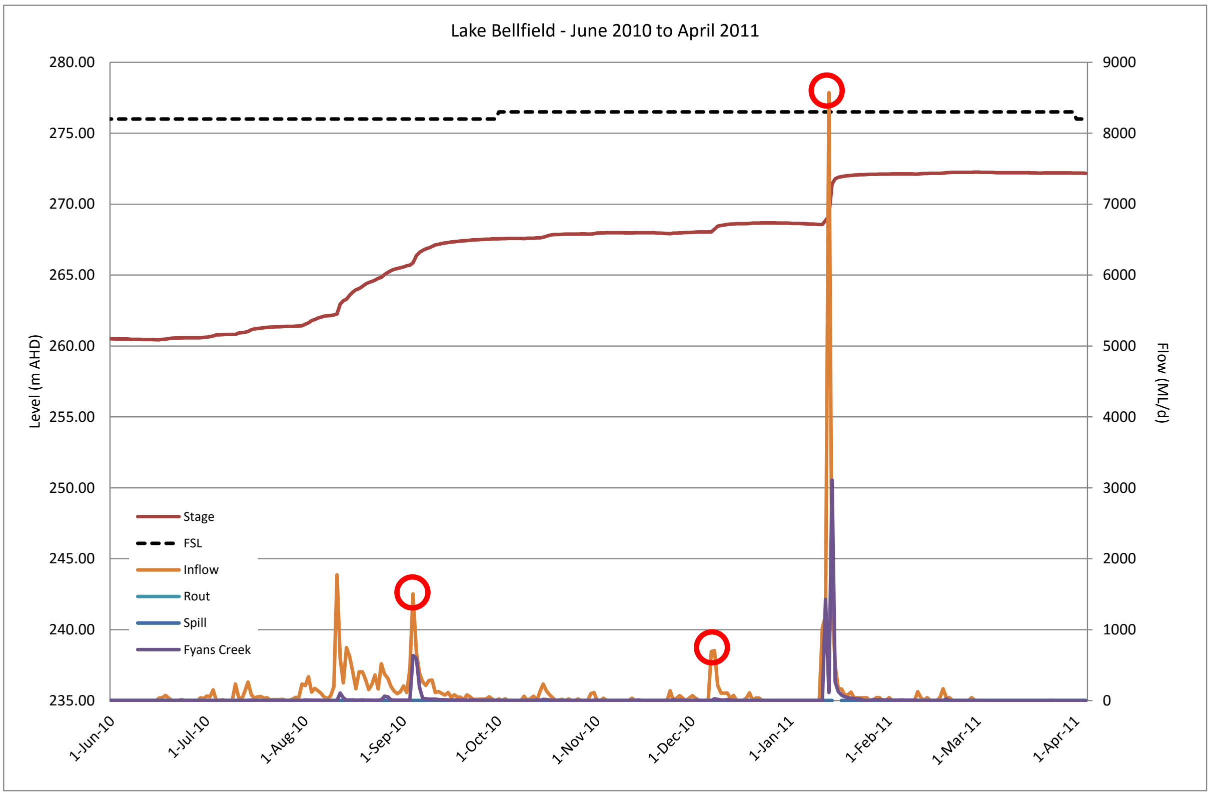

Figure 4-1 **Lake Bellfield storage trace and inflow and outflows for the September and December 2010 and January 2011 events, shown as red circles.**

4.3 Anecdotal Inundation

The January 2011 event was the largest flood on record in many townships throughout the Wimmera region, causing significant flood related damage. Halls Gap began to flood late on Wednesday the 12th January. Flood waters overtopped the main road through town, with water levels reaching the Stoney Creek shopping complex boardwalk on the Thursday afternoon. The majority of shops on the boardwalk were sandbagged, initially it was thought inundation had occurred from Stoney Creek however photos and modelling have indicated the potential for overland flow from behind the shopping complex as a potential factor. Water inundated eight shops in the Stoney Creek shopping complex, but no houses were affected above floor level. The event caused septic tank overflows and cut urban water sewer mains north of the township as well as the power supply.

No residential dwellings within Halls Gap were inundated. This compares to an estimated 6 inundated properties in the Halls Gap Flood Study for a 1% AEP event. By the Saturday evening, water levels had receded with access to the township limited to heavy vehicles. This long duration of inundation is due to two storm events, with heavy rainfall falling on Tuesday night and again on Thursday.

Landslides were observed throughout the Grampians National Park which severely restricted access to some areas. Inundation through the Stoney Creek shopping complex is shown in Figure 4-2.

Prior to this project there were no peak flood height survey marks available for Halls Gap, however, several community members with memory of peak heights and the areas inundated were able to provide the opportunity for survey to be captured. Several points were captured in the Stoney Creek complex.

Figure 4-2 Inundation through the Stoney Creek shopping complex

4.4 Surveyed Flood Marks

The Site Visit and Data Collation Report[13] produced as part of this project recommended observed flood heights be surveyed to better understand the level and extent of inundation observed during January 2011. Post this recommendation Wimmera CMA contacted a number of landholders, residents or witnesses who were known to be impacted or known to have a good understanding of the inundation that occurred. Six survey locations were identified through this process:

- Stoney Creek Shopping Complex
- Tandara Road
- 188 Grampians Road
- Aspect Villas
- Brambuk
- Bellfield Pump Station

These locations are shown in Figure 4-3. Half of the surveyed locations are in steep terrain, including Brambuk, 188 Grampians Road and Bellfield Pump Station. Levels in the Stoney Creek Shopping Complex, Tandara Road and Aspect Villas are more representative of floodplain levels along the valley floor. In areas of steep terrain flood heights are difficult to survey and did not match with modelling due to the steep water surface grade, impact of localised structures and debris. This is especially the case for Halls Gap where large debris flows occurred during January 2011. An example of the impact

[13] Water Technology (2016), Review of Halls Gap Flood Investigation – Site Visit and Data Collation Report (Commissioned by Wimmera CMA)

a building can have on flood levels which could not be represented by floodplain modelling is shown in Figure 4-3.

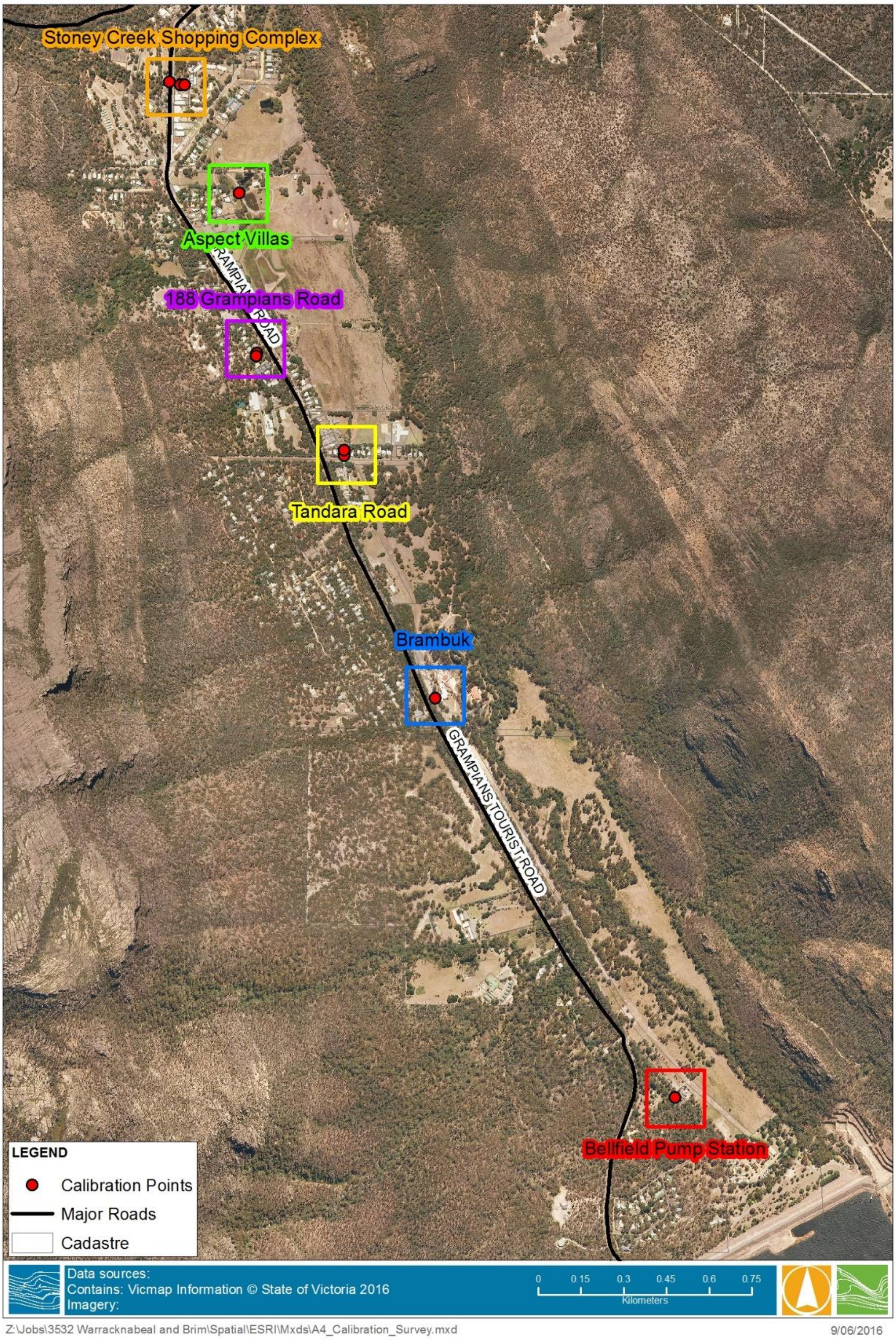

Figure 4-3 Survey flood height locations

Figure 4-4 Photo taken in Halls Gap during January 2011

5. PROJECT CONSULATION

5.1 Overview

A key element in the development of the Review of the Halls Gap Flood Investigation was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions, social media and meetings with a Project Steering Committee containing several members of the community. The community consultation sessions were largely managed by the Wimmera CMA and Northern Grampians Shire Council. The aims of the community consultation were as follows:

- To raise awareness of the study and to identify key community concerns; and
- To provide information to the community and seek their feedback/input regarding the study outcomes including the existing flood behaviour and proposed mitigation options for the township.

5.2 Steering Committee and Technical Working Group

The Flood Investigation Review was led by a Steering Committee consisting of representatives from Wimmera CMA, Northern Grampians Shire Council, State Emergency Service (SES), Parks Victoria, GWMWater and Water Technology.

The Steering Committee met on three occasions at key points throughout the study, to manage the development of the investigation.

5.3 Community Consultation

All community meetings were supported by media releases to local papers and meeting notices advertising meetings well in advance. The following community meetings were held as part of the consultation process:

- Initial community meeting held at the Halls Gap Recreation Reserve on 3rd December 2015. The first public meeting was held to outline the objectives of the study to the community, communicate what the community can expect from the study and gather input from the community on observed inundation and potential mitigation solutions;
- Second community meeting held at the Halls Gap Recreation Reserve on 3rd August 2016. The second community meeting presented calibration results for the January 2011 flood event. Community feedback was sought on the flood modelling results; and
- Third community meeting held at the Halls Gap Recreation Reserve on 17th November 2016. The final public meeting presented the planning scheme layers. Community feedback was sought on the study outcomes.

Additional to the formal community meetings, several site visits and meetings with Parks Victoria, Northern Grampians Shire Council and members of the public to confirm the hydraulic model results were also held.

6. MODELLING

6.1 Modelling Methodology

There was no streamflow gauge information available to use for the RORB model calibration, with no historic floods recorded on the gauges within the study area. However, during the January 2011 event a number of buildings were flooded above floor and some peak level survey information was collated during this project. The observations made and information captured during the January 2011 event enabled the hydrologic model calibration to be completed in combination with the hydraulic model. The RORB modelling produce flows to input into the hydraulic model which produced flood levels and extents, which were compared to observations. If the comparison of the flood levels and extents are reasonable to observations then it can be concluded that the assumptions made in both the hydrology and hydraulic modelling are likely to be reasonable. This approach was undertaken during the Natimuk Flood Investigation[14] with great success.

6.2 RORB

6.2.1 Model Structure

Overview

The RORB model developed by URS[2] and expanded during the Halls Gap Flood Study[1] was used as the basis for the rainfall-runoff routing modelling in this project. Some modifications were made to the model structure including the delineation of smaller sub catchment areas between the Lake Belfield Wall and the Fyans Creek and Stoney Creek confluence, the introduction of 19 interstation areas representing the various catchment areas, varying fraction impervious values and reach types.

Subareas and Interstation Areas

The introduction of multiple interstation areas allows for varying kc and loss vales. The interstation area breakup included:

- Upstream of Lake Bellfield (Interstation Area 1)
- Mt Difficult Range gullies (Interstation Areas 2-17)
- Stoney Creek (Interstation Area 18)
- Mt William Range gullies and catchment areas downstream of the Stoney Creek confluence (Interstation Area 19)

The RORB interstation areas between Lake Bellfield and Stoney Creek are shown in Figure 6-1. Unfortunately, no graphical files were available for the previously developed URS RORB model. By dividing the catchment area between Lake Bellfield and Stoney Creek into smaller subareas and setting multiple interstation areas it allows varying KC values to be determined based on the subarea sizes and reach lengths for each Mt Difficult Range Gully. The area of the refined subareas from the previous RORB modelling was also recomputed to allow better definition of the routing along the Mt Difficult gullies, before the hydraulic model inflow points. The redefined RORB sub catchment areas are shown in Figure 6-2.

[14] Water Technology (2011), Natimuk Flood Investigation, Wimmera CMA

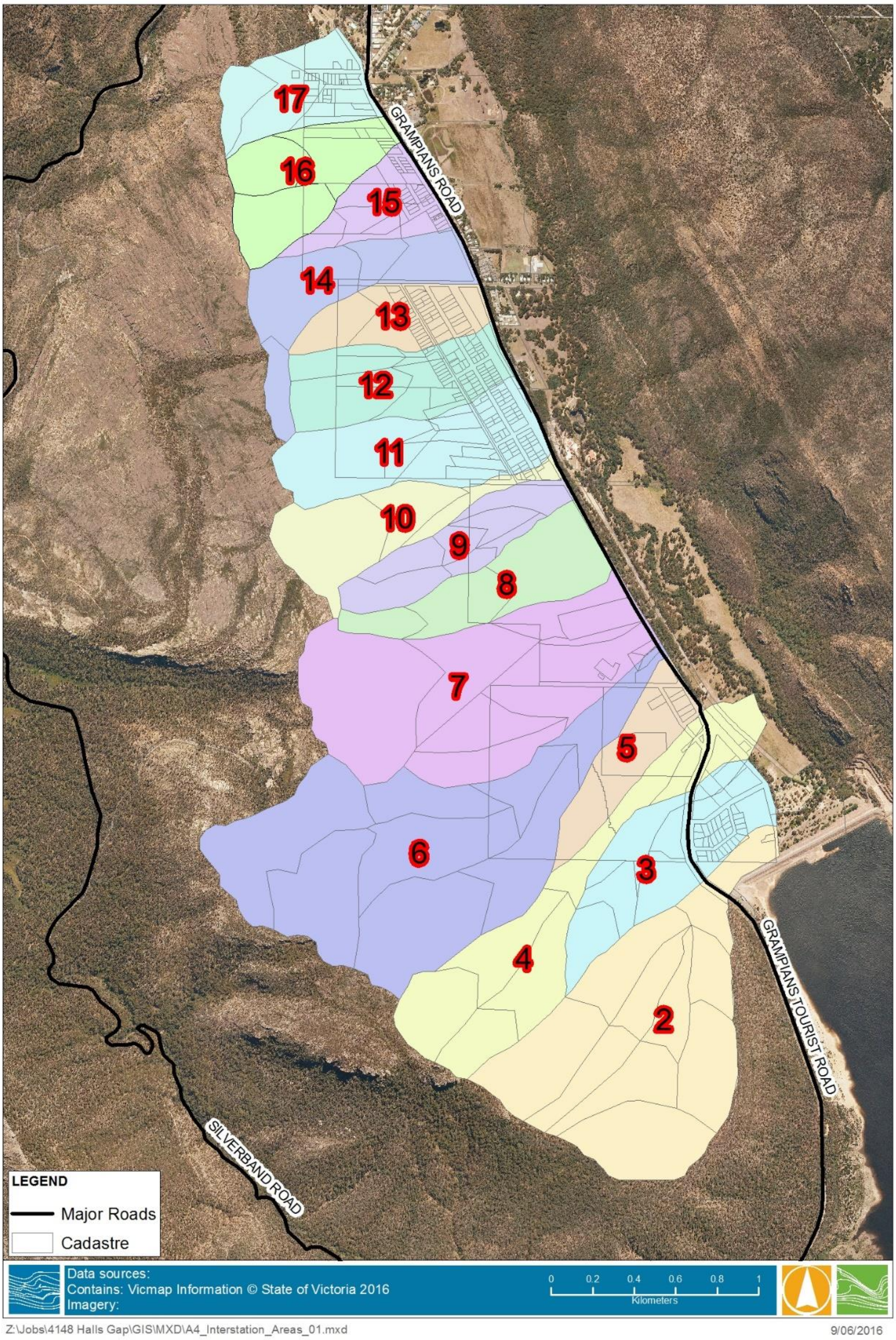

Figure 6-1 RORB interstation areas

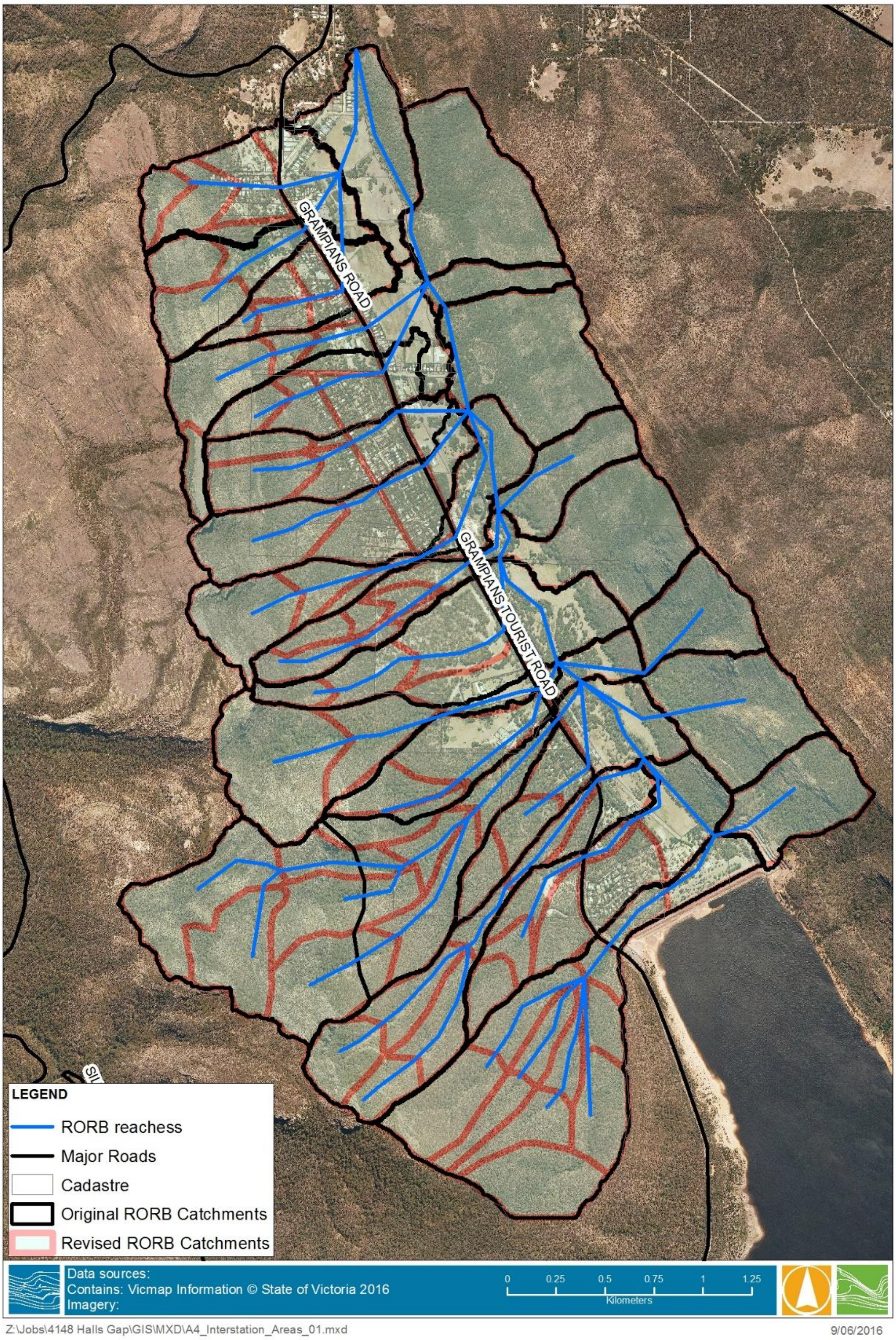

Figure 6-2 Previous and revised RORB sub catchments

Fraction Impervious

The RORB model requires Fraction Impervious (FI) values for each subarea. FI values are general calculated based on the Planning Scheme Zones and then reviewed and amended as necessary based on recent aerial photos. Typical FI values based on Planning Scheme Zones are shown in Table 6-1.

Table 6-1 RORB Model fraction impervious values and zones[15]

Zone	Description	Typical Fraction Impervious
FZ	Farming Zone	0.1
PCRZ	Protection of natural environment or resources.	0
PPRZ	Main zone for public open space, incl golf courses.	0.1
PUZ1	Power lines, Pipe tracks and retarding basins	0.05
PUZ2	Schools and Universities	0.7
PUZ3	Hospitals	0.7
PUZ7	Museums	0.6
RDZ1	Major roads and freeways.	0.7
RLZ	Predominantly residential use in rural environment.	0.2
TZ	Small township with little zoning structure	0.55

The previous modelling adopted by both URS and Water Technology used a FI value of 0 for all subareas given the majority of the subareas are within the Grampians National Park. This value was considered too low due to the proportion of rock in the Fyans Creek catchment and it was revised to 0.2. During the design modelling sensitivity testing will be completed assessing the impact of the fraction impervious on design flows. The study team could not readily find academic supporting evidence for changing the fraction impervious to a value higher than 0.

Reach types

In RORB there are for types of reach available; Natural, Excavated but Unlined, Lined or Piped, and Drowned. The previous Halls Gap RORB model adopted a Natural reach type for all of reaches except those through Lake Belfield which were specified as Drowned. This study updated the RORB reaches between Lake Bellfield and Stoney Creek to Excavated but Unlined. Natural reaches do not have a slope assigned to them and given the extremely steep nature of some of the RORB reaches it was determined this grade would be better included. Excavated but Unlined include grade and were determined as a better choice.

Lake Bellfield

Lake Bellfield was included in the RORB model using the stage storage information provided by GWMWater for the reservoir. Discharge over the spillway was also modelled using a height flowrate relationship provided by GWMWater. These relationships were already included in the RORB modelling completed during the Halls Gap Flood Study.

6.2.2 Model Parameters

m

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

The RORB *m* value is typically set at 0.80. There are alternate methods for determining *m*, such as Weeks (1980),[16] which uses multiple calibration events to select *kc* and *m*. However, given the absence of streamflow data and uncertainty surrounding the temporal and spatial distribution of rainfall across the study catchment during the calibration event, a change to the *m* value from 0.8 would be difficult to justify. The previous modelling used a *m* of 0.8.

kc

The RORB model *kc* value can be estimated using a range of prediction equations, as shown below in Table 6-2. These equations generally use catchment area or D_{av}, (the average flow distance in the channel network of sub area inflows) to describe the model, and were developed using different data sets (or subsets of the same data set). The kc value used during the previous RORB modelling was calculated using the Victoria Data Pearse equation. This calculated a whole catchment kc of 21.7.

Table 6-2 Method of kc value calculation

Method	Equation
Default RORB	$kc = 2.2*A^{0.5}$
Vic MAR<800 mm - Eq 3.21 ARR (BkV) [6]	$kc=0.49*A^{0.65}$
Victoria data (Pearse et al, 2002)[5]	$kc=1.25*D_{av}$
Aust wide Dyer (1994) (Pearse et al 2002)[5]	$kc=1.14*D_{av}$
Aust wide Yu (1989) (Pearse et al 2002) [5]	$kc=0.96*D_{av}$

This study used the same method of kc calculation for each interstation area individually. The kc prediction equation used was that developed by Pearse using Victorian data. This was chosen because the study area is within Victoria and it is consistent with the previous modelling completed during the Halls Gap Flood Study.

[16] Weeks, W. D. (1980). Using the Laurenson model: traps for young players. Hydrology and Water Resources Symposium, Adelaide, Institution of Engineers Australia

Table 6-3 Calculated interstation area Kc values

Interstation Area	Area (km^2)	Kc
1 – US Lake Belfield	10.03	12.5
2	1.51	1.9
3	0.69	0.9
4	1.67	2.1
5	0.42	0.5
6	1.74	2.2
7	1.1	1.4
8	0.59	0.7
9	0.77	1.0
10	0.85	1.1
11	0.71	0.9
12	0.7	0.9
13	0.68	0.9
14	0.45	0.6
15	0.55	0.7
16	0.47	0.6
17	0.35	0.4
18 - Stoney Creek	2.96	3.7
19 – Mt William Gullies and DS Stoney Creek	5.95	7.4

Losses

An initial and continuing loss model was chosen for the Halls Gap RORB model. The initial and continuing loss model has traditionally been used for rural flood investigations in Victoria and was again adopted for this study. After a sustained dry period the Fyans Creek catchment may be dry, and with the onset of rain, a large portion of the initial rainfall may infiltrate into the soil, be lost to storage in the catchment or be intercepted by vegetation etc. Alternatively, with significant rainfall in the lead up to an event the catchment may be wet, with the initial infiltration loss much lower. This process is modelled using an initial loss parameter. After the initial loss, the infiltration rate will slow to a relatively constant continuing loss closer to the saturated hydraulic conductivity of the soil, this is represented by the continuing loss in RORB.

For the January 2011 verification event the RORB losses were chosen and the resulting hydrographs extracted and modelled in the hydraulic model. The hydraulic model results were then compared to observations. The losses were then adjusted and the process repeated until the modelled flooding replicated the observed flooding in Halls Gap.

Australian Rainfall and Runoff[17] recommends derived loss rates for numerous catchments separated into States, with loss rates for areas of Victoria north and west of the Great Dividing Range given as similar to areas of New South Wales. These values for New South Wales are separated into east of the western slopes and arid zone with mean annual rainfall less than 300 mm. The values for east of the western slopes were adopted as an indicative guide to the loss values which may be expected for the Halls Gap catchment, as the annual rainfall is greater than 300 mm (976.6 mm at the Halls Gap daily rainfall gauge - 079074).

6.3 Hydraulic Model Structure

6.3.1 Overview

The hydraulic model structure used during the Halls Gap Flood Study was adopted for this project with several changes. The original hydraulic model was a Mike21 model with 2D components only. The model was modified to a MikeFlood model with Mike21 (2D) and Mike11 (1D) components. The 1D model components added for calibration and design modelling were different due to the addition of extensive pipe infrastructure between the January 2011 event and this study. The 1D components for calibration and design are discussed separately in their individual sections. The complete hydraulic model structure and extent with the full included pipe network is shown in Figure 6-3.

[17] AR&R (1987), Australian Rainfall and Runoff - Volume 1, Book II, Chapter 6

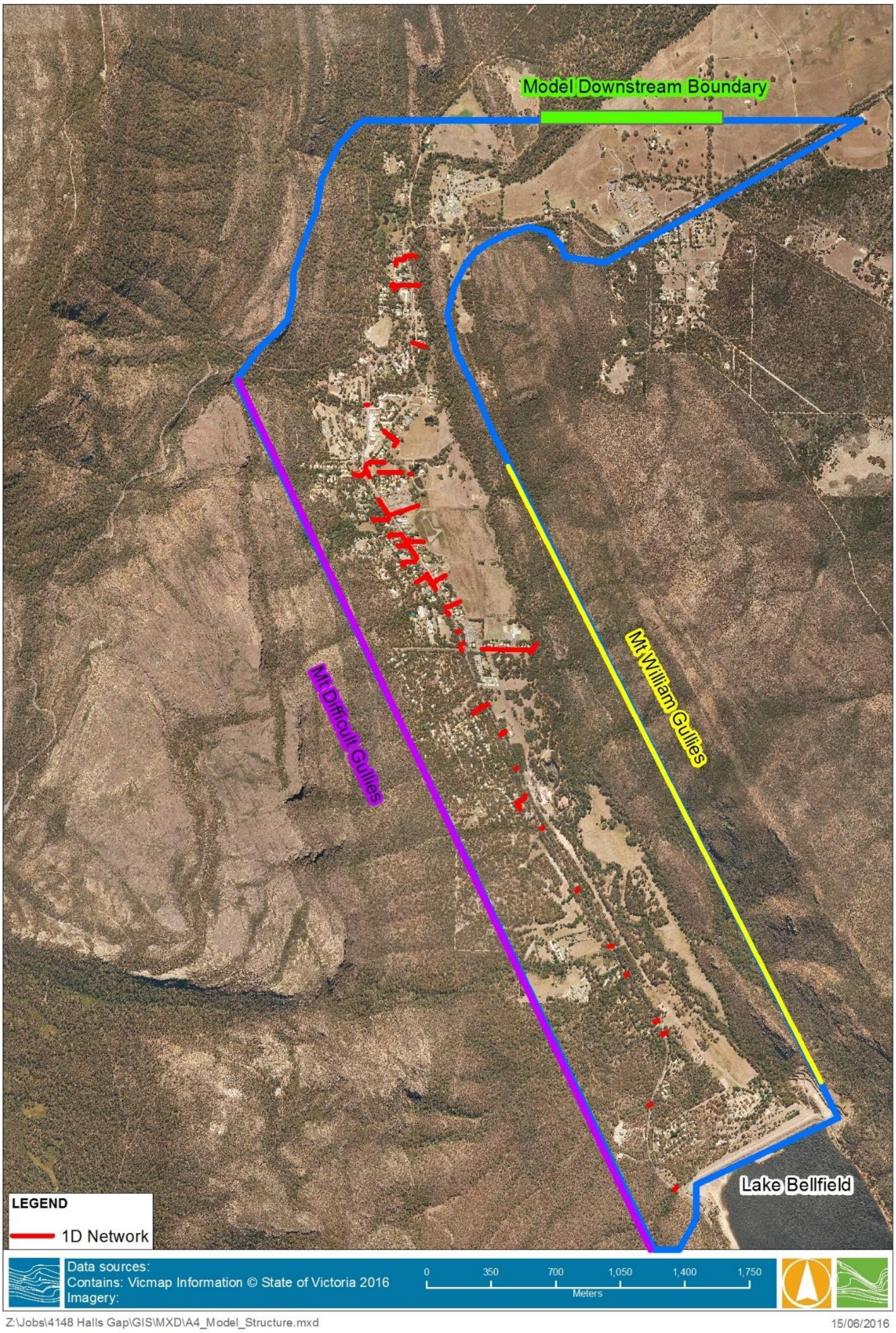

Figure 6-3 MikeFlood hydraulic model extent and structure

6.3.2 Waterway and floodplain roughness

The same waterway and floodplain roughness values adopted during the Halls Gap Flood Study were adopted during this project. This included the floodplain roughness values shown in Table 6-4. These values are based on the classifications made in Open Channel Hydraulics[18].

Table 6-4 Waterway and floodplain roughness values

Description	Manning's "n"
Grassed floodplain	0.03
Roads	0.02
Treed areas	0.07
Buildings	0.125

During the calibration phase a very high stream roughness of 0.2 was required in the Stoney Creek channel in the Stoney Creek shopping complex. This is discussed further in Section 6.4.4.

6.4 Calibration

6.4.1 Overview

As discussed in Section 6.1 the RORB and hydraulic model calibration was undertaken concurrently. The RORB model adopted loss and kc values, which were then modelled to produce hydrographs for input to the hydraulic model. The hydraulic model was run and compared to the available observed flood heights and anecdotal observations.

6.4.2 January 2011

Observed Rainfall

The January 2011 rainfall event was modelled in RORB using the model structure discussed in Section 6.2.1. The observed data input to the model included a rainfall temporal pattern measured at the Lake Mt William sub daily rainfall gauge and a rainfall spatial pattern calculated by creating a TIN of the observed daily rainfall totals. Unfortunately, an issue with the Lake Wartook sub daily gauge resulted in no data being recorded. As a result of the missing data the Mt William gauge was used, RORB modelling included rainfall occurring between 9am 11/01/2011 and 9am 14/01/2011. The rainfall temporal pattern is shown in Figure 6-4 with the rainfall spatial pattern shown in Figure 6-5. The gauges used in calculation of the spatial pattern are shown in Table 6-5 including their daily rainfall totals.

[18] Chow (1959), Open Channel Hydraulics.

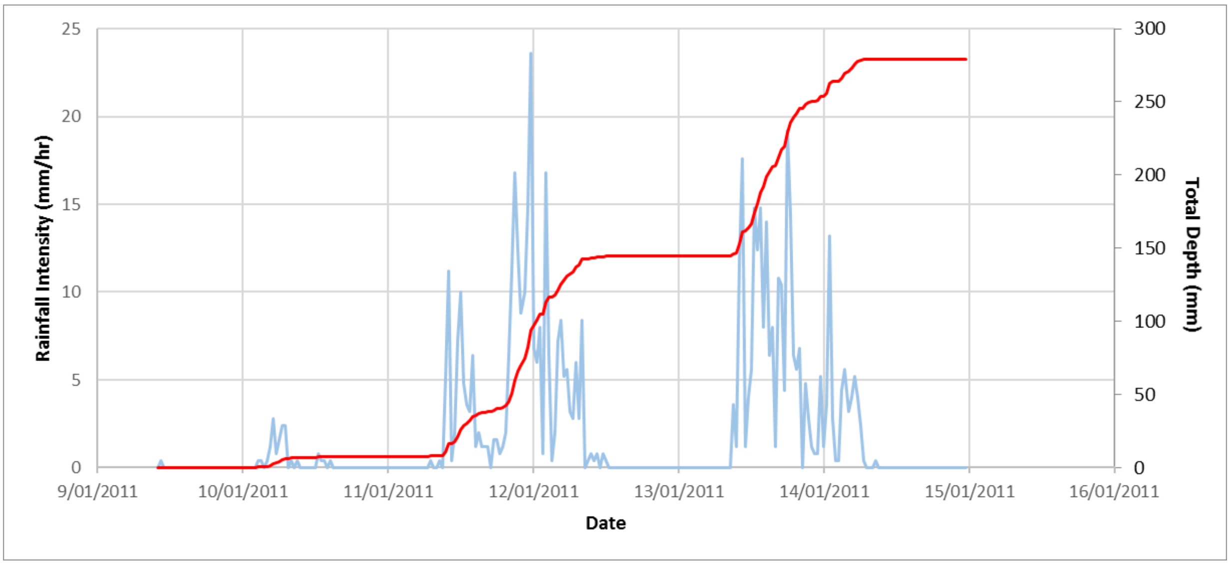

Figure 6-4 January 2011 temporal pattern – Mt William sub-daily gauge

Table 6-5 January 2011 spatial pattern rainfall totals for the 72 hours prior to 9am on the 14th January

Station No.	Name	Total Rainfall (mm)
79008	CLEAR LAKE (MARLBRO)	150.4
79010	DRUNG DRUNG	115.4
79015	GLENORCHY	142.6
79019	GREAT WESTERN (SEPPELT)	185.4
79026	LAKE LONSDALE	170.4
79032	MORRL MORRL (VALLEY VIEW)	147
79036	NATIMUK	144.4
79046	WARTOOK RESERVOIR	203.6
79050	MOYSTON (BARTON ESTATE)	172
79073	POMONAL	210.6
79074	HALLS GAP (POST OFFICE)	286.8
79077	DADSWELLS BRIDGE	156
79078	TELANGATUK EAST (MILINGIMBI)	135.4
79080	STAWELL	166.2
89003	BALMORAL (POST OFFICE)	120.8
89019	MIRRANATWA (BOWACKA)	158
89043	GATUM (ORANA)	127.2
89085	ARARAT PRISON	169.2
89034	WILLAURA (MAIN ST)	118.2
89053	MAROONA	170
79103	Mt WILLIAM	279

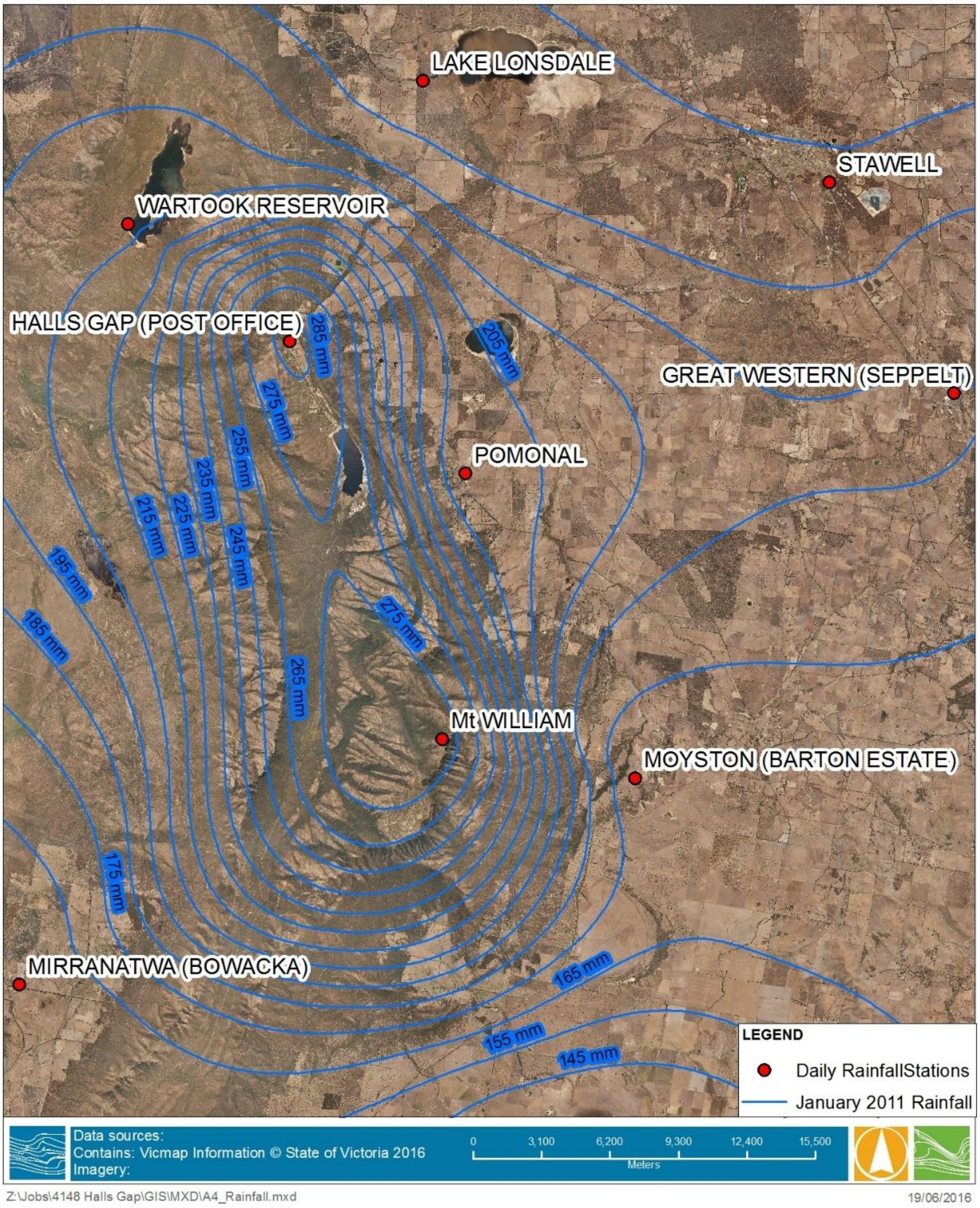

Figure 6-5 January 2011 spatial pattern

6.4.3 Losses

The RORB model was run using several loss values uniformly applied across the Fyans Creek catchment. An initial loss of 10 mm and a continuing loss of 2 mm/hr was shown to produce inflows which best matched anecdotal and surveyed flood levels. Further discussion of the impact of losses on peak flows is discussed during sensitivity testing in Section 6.4.5.

6.4.4 Observed data comparison

As discussed in Section 4.4, surveyed flood heights were captured at six locations along the study area. A comparison between surveyed and modelled data is included for each of these locations in the following sections.

Stoney Creek Shopping Complex

There were seven surveyed levels in the Stoney Creek Shopping Complex, including:

- Top of Stoney Creek Bridge (upstream)
- Soffit of Stoney Creek Bridge (upstream)
- Halls Gap Bakery Floor Level
- Natural Surface near Halls Gap Bakery (approx.)
- Flood level in Livefast Café
- Floor level in Livefast Café
- Natural surface near Livefast Café (approx.)

Of these levels approximate January 2011 flood levels can be ascertained from the soffit and pavement height of the Stoney Creek Bridge, the Halls Gap Bakery floor level and the Flood Level in Livefast Café. There are also several photos of the Stoney Creek Shopping Complex available.

Anecdotal observations and photography at the Stoney Creek Bridge indicate the bridge wasn't overtopped but the flood level exceeded bridge soffit and there as a large backwater generated by the bridge[19]. The bridge soffit was surveyed at 228.51 m AHD, with the road pavement at 229.35 m AHD. The hydraulic model results show a level of 229.30 m AHD immediately upstream of the bridge. This is very close to the pavement height without overtopping of the bridge, replicating the anecdotal observations.

The Stoney Creek Bakery has a floor level of 227.83 m AHD; this level was exceeded during January 2011[20]. Livefast Café has a floor level 227.82 m AHD, with an observed flood height of 227.90 m AHD. Modelling of the January 2011 event shows a flood level of 227.82 m AHD at the front of the Halls Gap Bakery and 227.80 m AHD at the front of the Livefast Café. These levels correspond with the observed levels relatively closely, within 0.1 m of the observed level in Livefast Café. The modelled flood levels, survey point locations and hydraulic model results are shown in Figure 6-6.

In order to achieve the water levels within the Stoney Creek shopping complex that were observed during January 2011 a high roughness value of 0.2 was adopted downstream of the Grampians Road bridge. This value was high in order to represent the highly turbulent water in this location which is demonstrated in the photos or Stoney Creek and the level of erosion that occurred to Stoney Creek during the event.

[19] Pers. Comm. Engineer, Northern Grampians Shire Council
[20] Pers. Comm. Stoney Creek Bakery Employees during 01/02/2016 site visit

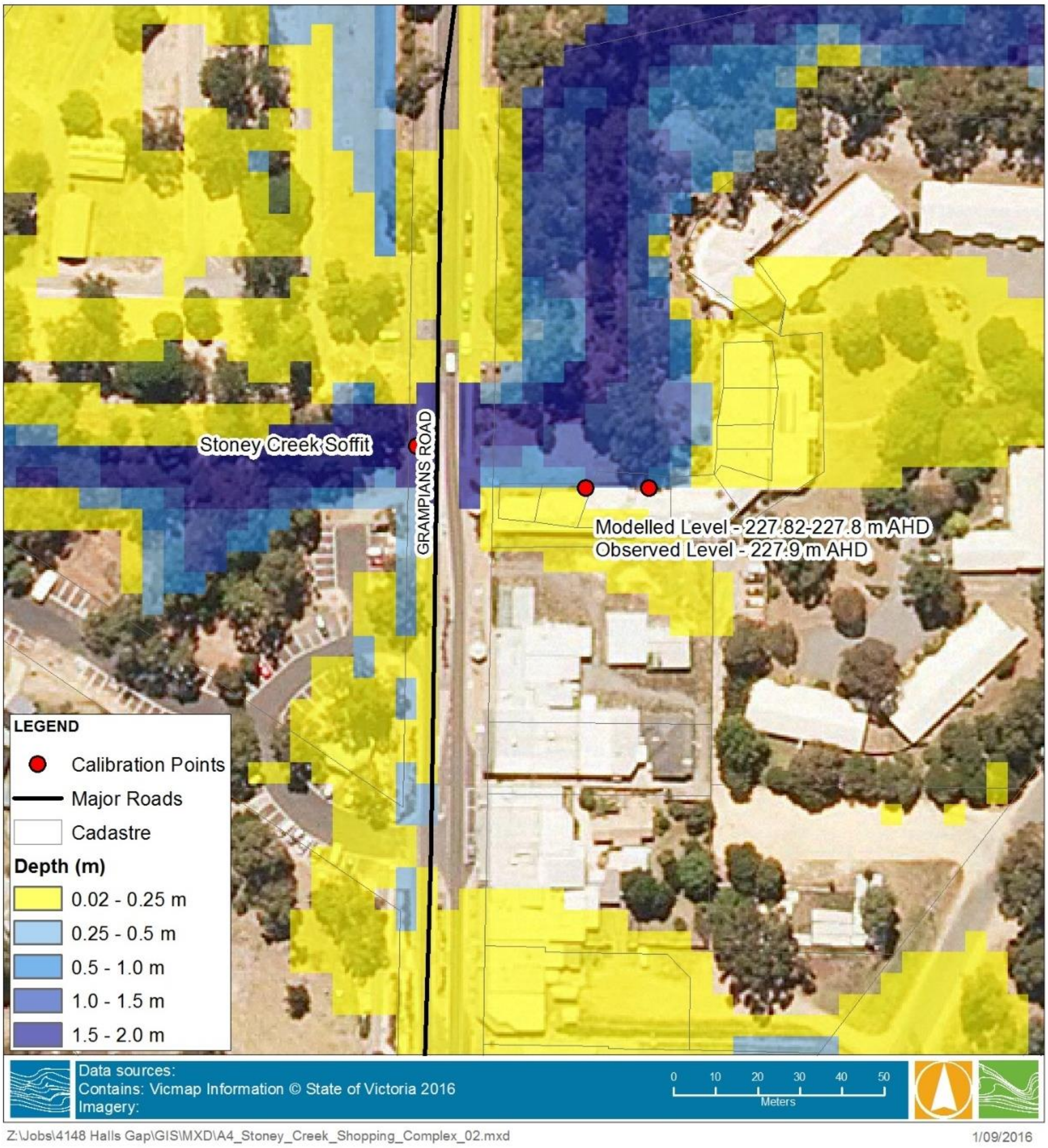

Figure 6-6 January 2011 - Stoney Creek Shopping Complex modelled observed flood levels and observed survey locations

Several ground based photos were also available to verify the hydraulic model results, Figure 6-7 shows a photo taken in the Stoney Creek Shopping Complex looking along Stoney Creek. The photo was taken after the peak of the event on Stoney Creek with a debris line above the captured water level. This extent is matched closely with the model results. The photo also appears to show water pushing up against the shopping complex walkway. This can also be seen in Figure 6-8.

Figure 6-7 January 2011 – Flooding in the Stoney Creek shopping complex looking west from the Stoney Creek Bridge[21]

Figure 6-8 January 2011 - Stoney Creek Shopping Complex looking west from the front of Lifefast Cafe[22]

[21] Stawell Times News - http://www.stawelltimes.com.au/story/3666043/mega-gallery-2011-wimmera-floods-throwback-thursday/#slide=93

[22] Stawell Times News - http://www.stawelltimes.com.au/story/3666043/mega-gallery-2011-wimmera-floods-throwback-thursday/#slide=94

Tandara Road

There were four surveyed levels completed at 3 Tandara Road, consisting of the ground and flood levels at a gas tank, when compared to the aerial photography these points seem too far apart. Comparison between the modelled and observed flood levels is shown in Figure 6-9. The difference between modelled and observed levels was 0.07 m and 0.15 m for the northern (house) and southern (gas tank) points respectively.

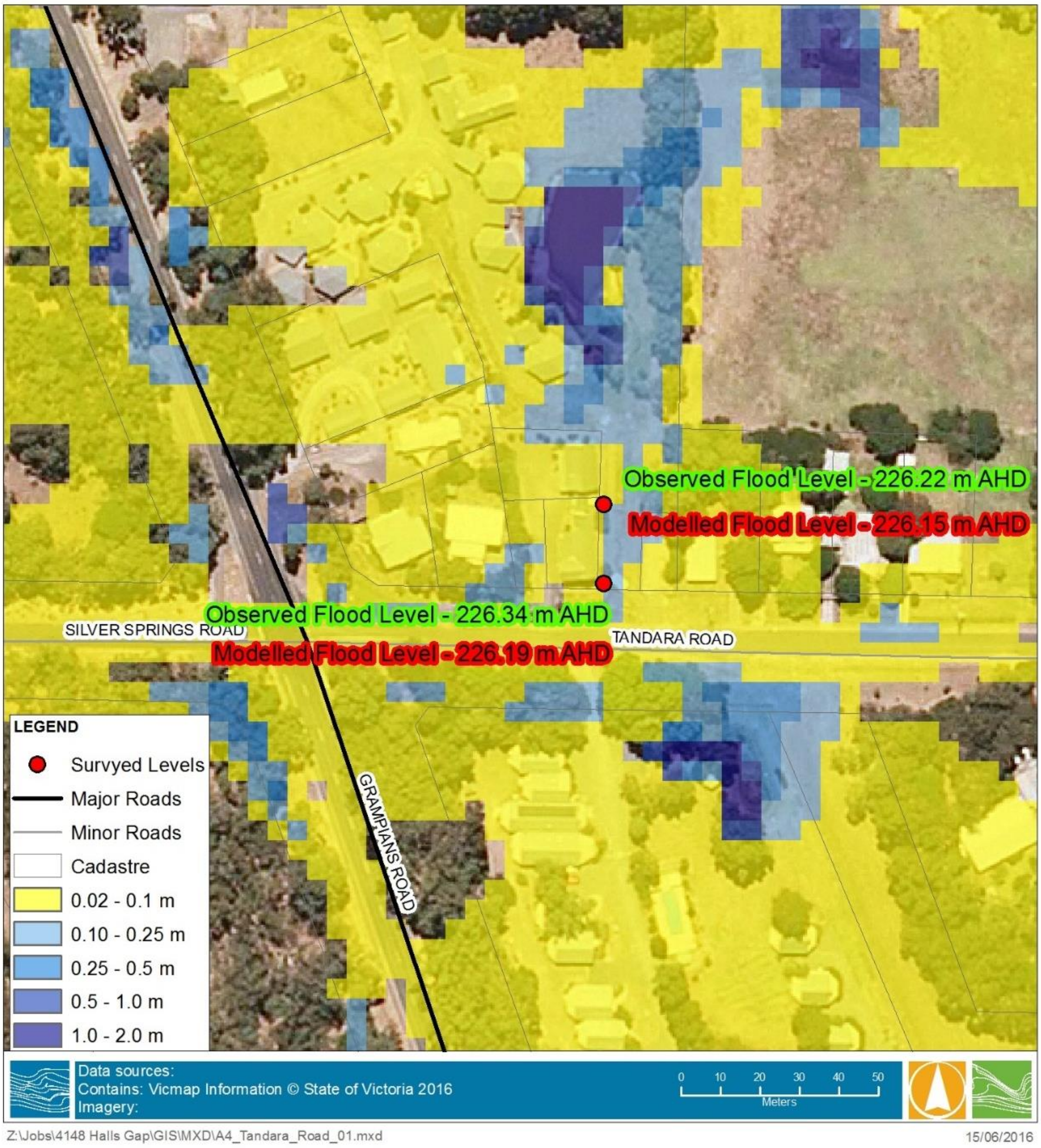

Figure 6-9 January 2011 – Observed and modelled flood levels at 3 Tandara Road, Halls Gap

188 Grampians Road

There were five levels surveyed at 188 Grampians Road, these included:

- Flood level on house
- Ground level at house
- Flood level on shed
- Ground level at shed
- Centre of drain near shed

These surveyed levels were provided at two coordinate locations, as shown in Figure 6-10. The figure shows neither surveyed points close to a shed to the level determined for the house at no near the building on the property where the points are located. Review of the addresses available on Google Maps reveals that the address where points are located is 1 Hill Street, with 188 Grampians Road is on the other side of Hill Street to the north. The surveyed levels between the two locations are also quite different with a 1.2 m difference in flood level between the two locations.

Comparisons at this location were not able to be made due to inaccuracies in the survey.

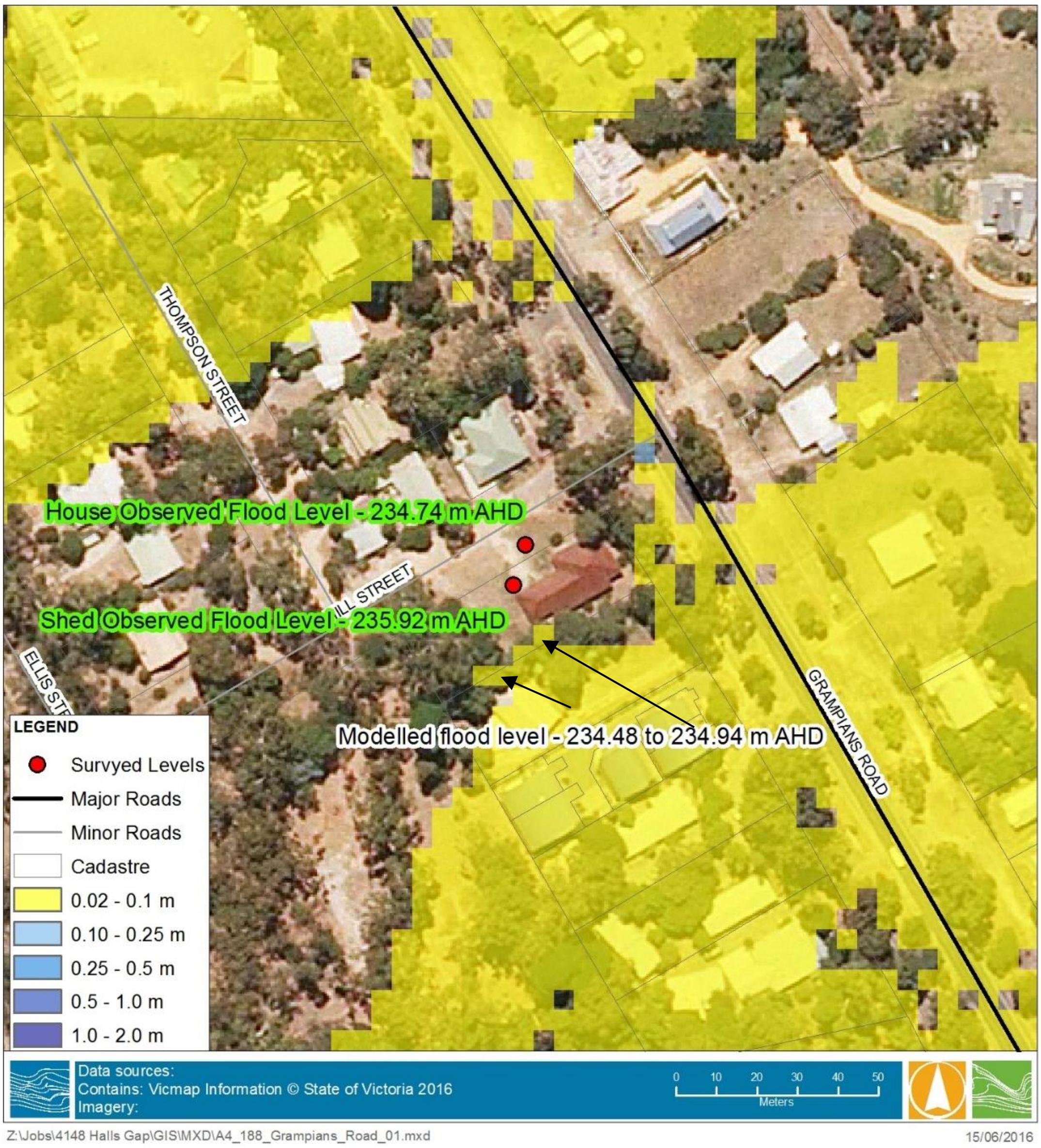

Figure 6-10 January 2011 – Observed flood levels and modelled extent at 188 Tandara Road, Halls Gap

Aspect Villas

There were two levels surveyed at Aspect Villas, one ground level and one flood level mark on a board walk. The observed flood height was 223.74 m AHD, this compared to a modelled level of 223.56 m AHD. The difference in modelled and observed flood levels was 0.18 m. The survey location, modelled extent and observed and modelled flood levels are shown in Figure 6-11.

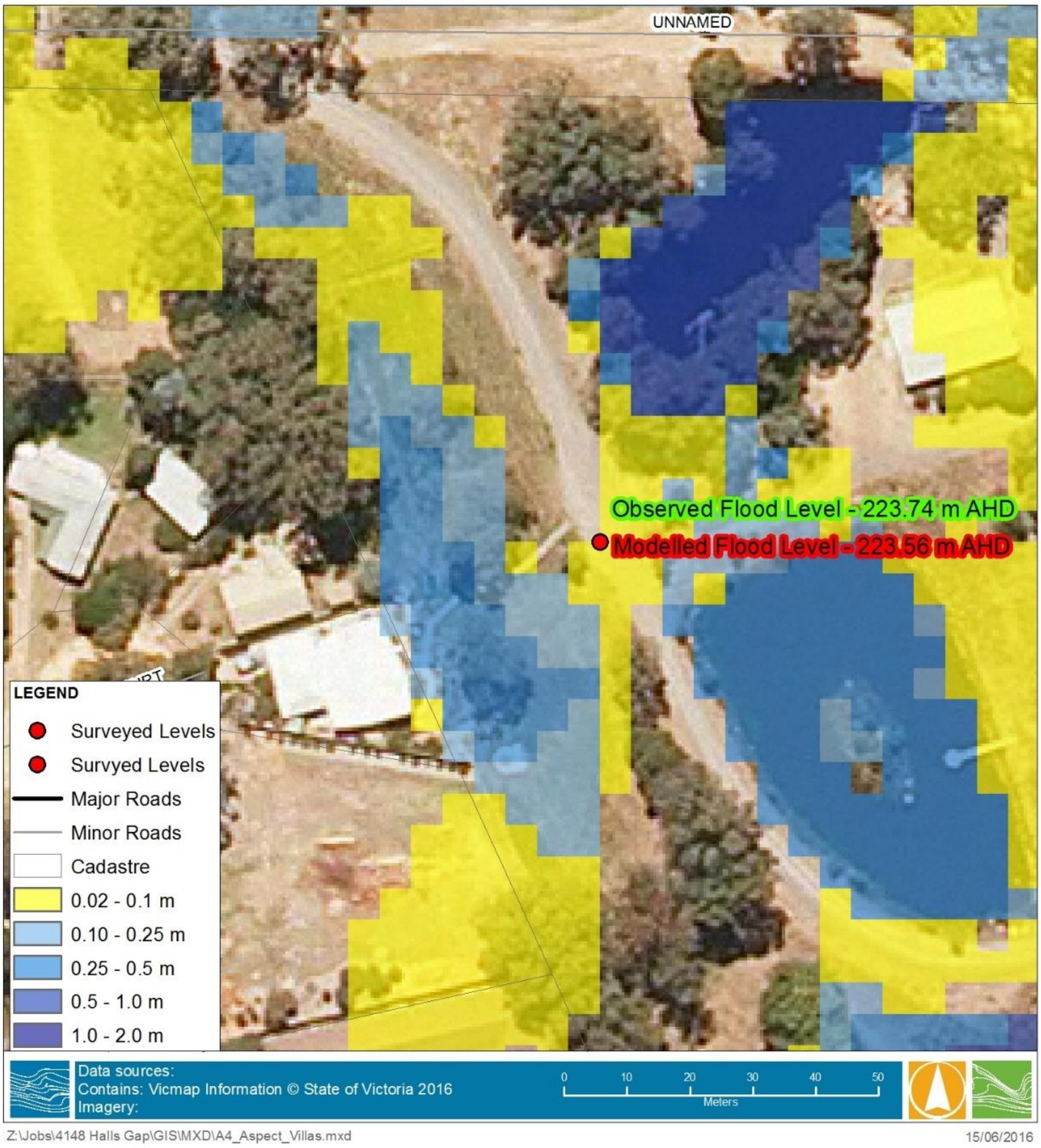

Figure 6-11 January 2011 – Observed and modelled flood levels at Aspect Villas, Halls Gap

Brambuk Cultural Centre

There were three levels surveyed at the Brambuk Cultural Centre, a building silt level, a flood level on the window and a road level. All levels were provided for the one location, as shown in Figure 6-12. The survey point location is at the front of the Parks Victoria Office. The surveyed flood levels were 233.14 m AHD for silt on the building and 233.77 m AHD for the building window level which was thought to be an indication of the flood height during January 2011[23]. The modelled flood levels at the Parks Victoria building vary from 232.93 to 232.48 m AHD from the front to the back of the building.

Figure 6-12 also highlights the Brambuk Cultural Centre entry and Parks Victoria Office building. Photos of these locations were captured by Parks Victoria staff during January 2011 and are shown in Figure 6-13 and Figure 6-14 respectively.

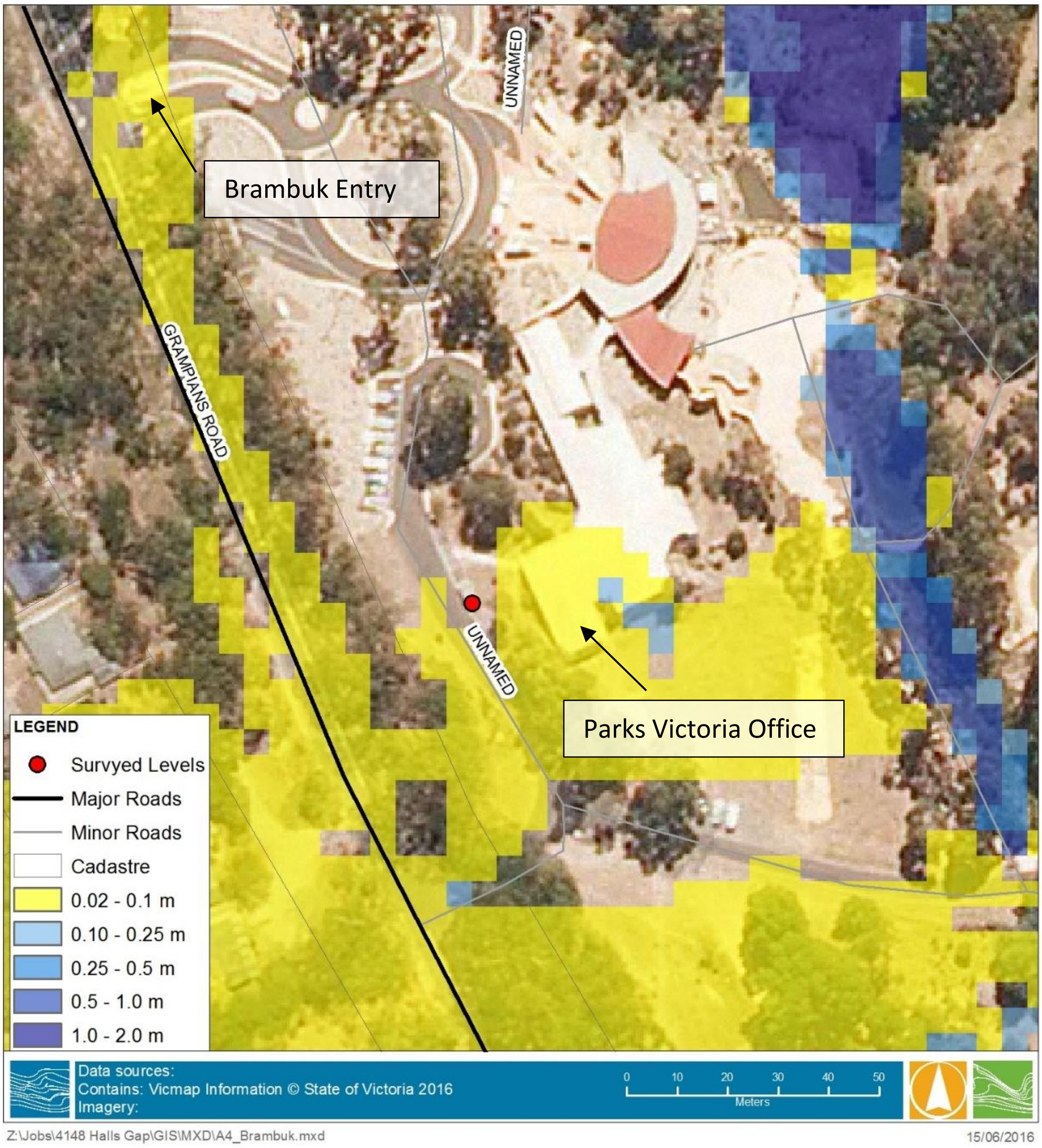

Figure 6-12 January 2011 – Survey data location and modelled flood extent at Brambuk, Halls Gap

Hydraulic modelling of the January 2011 event replicates observations in the photos with water flowing along Grampians Road and at the Brambuk entry, as well as from the south west toward and through the Parks Victoria Office. Unfortunately, the survey is unclear and confusing and makes it difficult to draw any further comparison.

[23] Pers. Comm. With Parks Victoria staff.

Figure 6-13 January 2011 – Brambuk Cultural Centre entry, Halls Gap

Figure 6-14 January 2011 – Parks Victoria Building, Halls Gap

Bellfield Pump Station

There were five levels surveyed at the Bellfield Pump Station, these were as follows:

- 414 Grampians Road, road level
- 414 Grampians Road, flood level
- Top of levee bank
- Road level at levee bank
- Pump station ground level

Similar to the Brambuk Cultural Centre these levels were provided for the one location, as shown in Figure 6-15. The surveyed flood level was 240.06 m AHD, while the modelled flood level was 242.67 m AHD. This indicates a difference in water level of around 2.6 m. Given the large difference in modelled and surveyed levels it is likely either the location of the point is incorrect or the surveyed level is incorrect. The observed flood level would be below the ground surface at its current height.

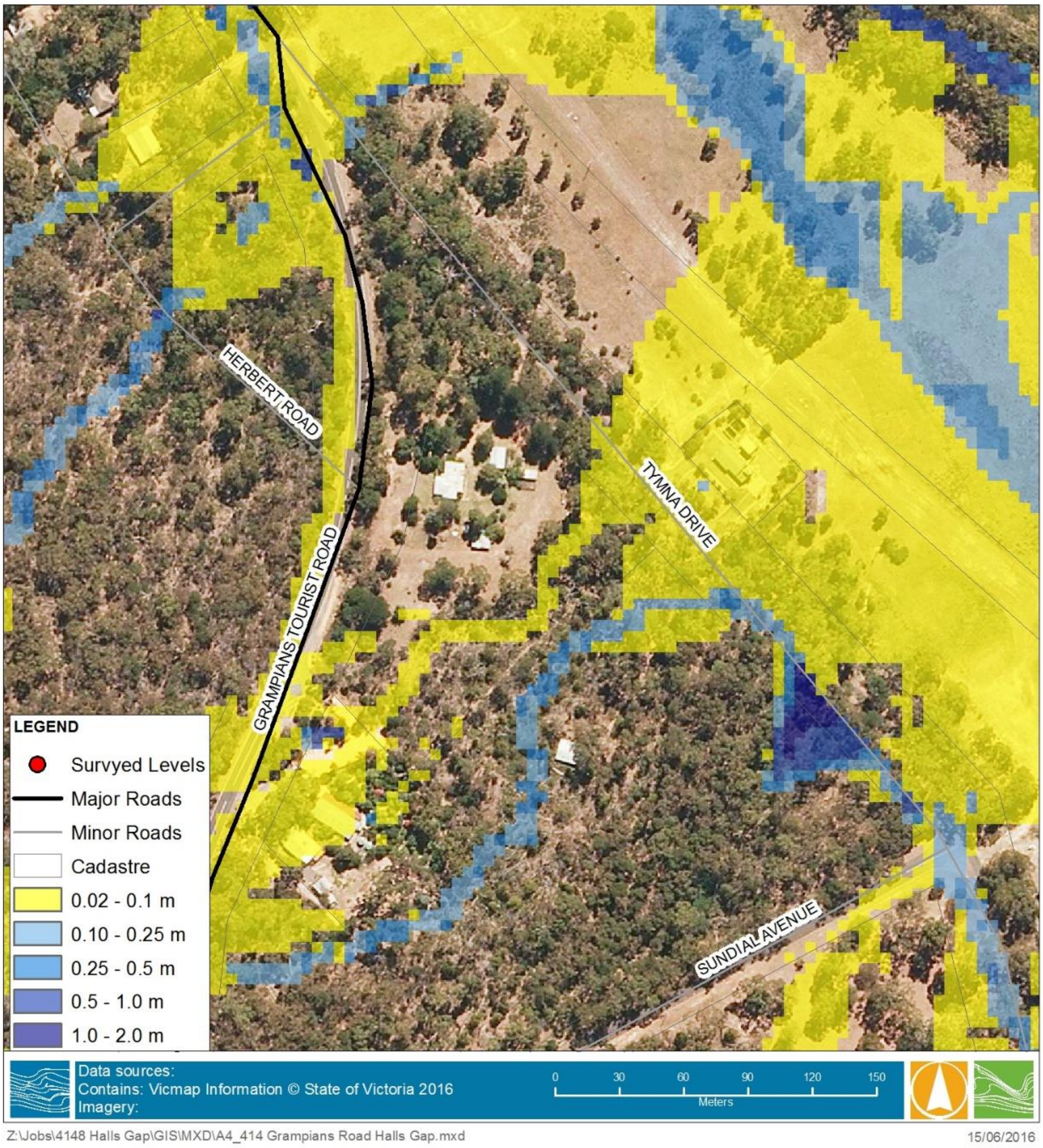

Figure 6-15 January 2011 – Bellfield Pump Station Survey

Discussion

The model results show a general match to the observed flood levels and extents based on the available anecdotal information. During the initial stages of the model calibration there were a number of areas which warranted further checking and discussion with members of the community, Northern Grampians Shire Council and Parks Victoria employees who were present at the time of the January 2011 inundation. The information from the community fed into and provided more surety in the model verification process.

Given the very high velocities and grade of the floodwater along the Mt Difficult Gullies and Stoney Creek, matching peak water levels is highly dependent on localised influences. The input of the community was extremely important for this project due to the number of inflow locations and without much detailed formal observations.

6.4.5 Flows Sensitivity Testing

The sensitivity of initial and continuing losses on Fyans Creek flood behaviour were tested using the January 2011 event. Initial loss values of 10 mm, 20 mm and 30 mm were trialled with a continuing loss of 2 mm/hr, the generated hydrographs downstream of Stoney Creek are shown in Figure 6-16. Continuing loss values were trialled using values of 1 mm/hr, 2 mm/hr and 3 mm/hr with an initial loss of 10 mm. The generated hydrographs downstream of Stoney Creek are shown in Figure 6-17.

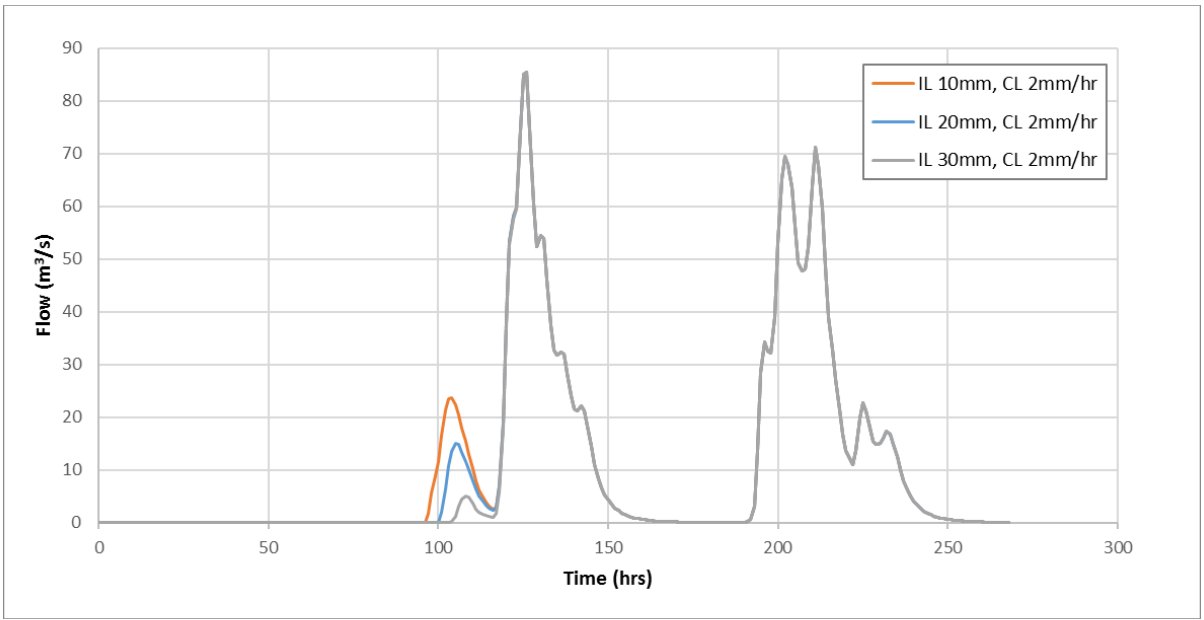

Figure 6-16 January 2011 – Fyans Creek Initial Loss Sensitivity Testing

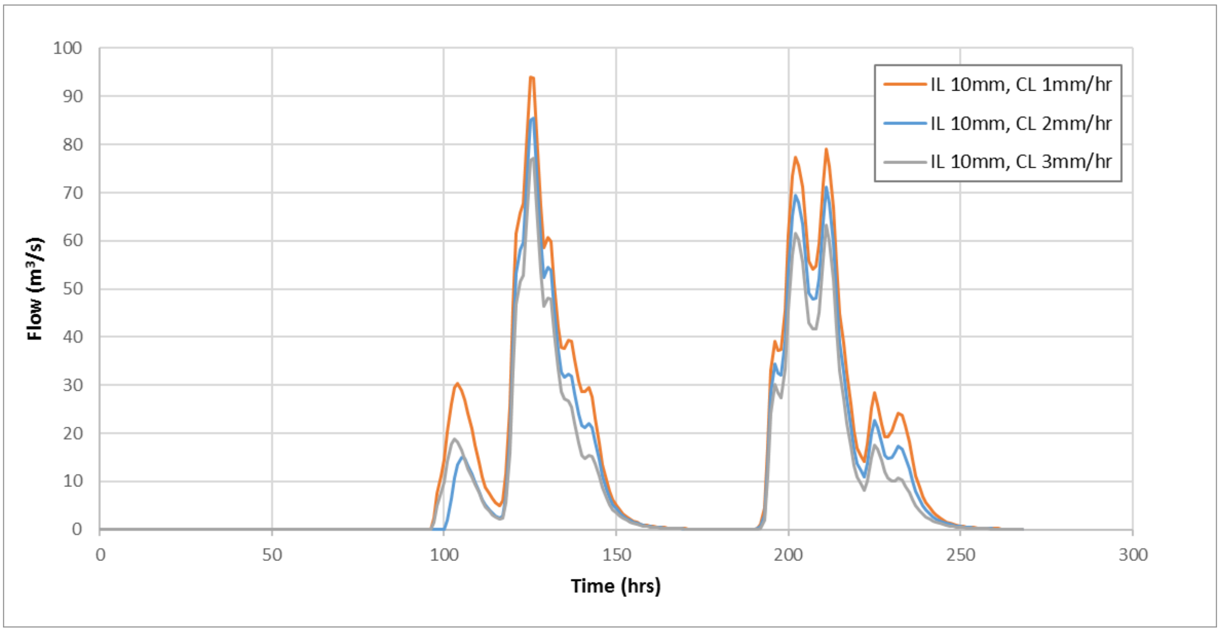

Figure 6-17 January 2011 – Fyans Creek Continuing Loss Sensitivity Testing

The impact of the initial loss on the January 2011 event was shown to be minimal with a change in a small initial peak, but no change in the main high flow peak. Varying the continuing loss changed the peak flows slightly with an increase in continuing loss of 1 mm/hr equating to a reduction in peak flow of between 8.1 and 8.5 m^3/s, or approximately 10%.

7. DESIGN MODELLING

7.1 Hydrology

7.1.1 Overview

RORB modelling used for the basis of design flow estimates used a combination of the original Halls Gap Flood Study parameters and revised parameters adopted during the calibration modelling.

Design flows were determined using the RORB model for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events. As specified in the project brief Lake Bellfield was modelled at its Full Supply Level of 276.5 m AHD.

7.1.2 Design Rainfall

Design rainfall depths were determined using the BoM Online Intensity Frequency Duration (IFD) Data System[24] (prior to ARR revision) using the coordinates of the Lake Bellfield wall, approximately the centre of the Fyans Creek catchment upstream of Halls Gap. This generated the IFD parameters shown in Table 7-1. These values vary slightly from those adopted during the original Halls Gap Flood Study, most likely because the online tool was not available at the time the study was completed.

Design temporal patterns for Zone 2[25] were used for events up to and including the 0.5% AEP event. A uniform spatial pattern was adopted for all design events. The temporal and spatial patterns adopted are the same as those used during the Halls Gap Flood Study and are considered appropriate.

Table 7-1 IFD parameters

IFD Parameter	Value
1 hour duration 2 year ARI	19.13
12 hour duration 2 year ARI	4.14
72 hour duration 2 year ARI	1.21
1 hour duration 50 year ARI	40.58
12 hour duration 50 year ARI	7.84
72 hour duration 50 year ARI	2.34
Regional skew G	0.37
Geographic factor F2	4.36
Geographic factor F50	14.8

Probable Maximum Precipitation (PMP) depths were determined using the Generalised Southeast Australia Method (GSAM) and Generalised Short Duration Method (GSDM)[26]. The determined depths for each event duration are shown in Table 7-2. Temporal patterns were extracted from the Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method[26].

[24] http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml
[25] Engineers Australia (1987), Australian Rainfall and Runoff
[26] BoM (2006), Guidebook to the Estimation of Probable Maximum Precipitation: GENERALISED SOUTHEAST AUSTRALIA METHOD

Table 7-2 PMP depths

Method	Event Duration (hrs)	Depth (mm)
GSDM	0.5	200
	0.75	250
	1	290
	2	430
	3	530
	5	660
	6	700
GSAM	24	730
	36	830
	48	890
	72	940
	96	960

7.1.3 Kc

As discussed in Section 6.2.2, the kc value for each interstation area was calculated based on the Pearce Equation[5], this equation was developed using streamflow data specific to Victoria.

The kc values used for each interstation area are shown in Table 6-3.

7.1.4 Losses

Previous design modelling of Fyans Creek completed in the Halls Gap Flood Study and Lake Bellfield Flood Study adopted initial and continuing loss values of 20 mm and 2 mm/hr. Given the hydraulic modelling completed in this project indicated that a continuing loss of 2 mm/hr showed a relatively good match to the observed data during the January 2011 verification this loss value was adopted for design purposes. However, the modelling completed did not provide much of an indication on the suitability of an initial loss value due to the lack of influence on peak flows. To test the sensitivity of the initial loss on the design flows in Fyans Creek and Stoney Creek, losses of 10 mm, 20 mm and 30 mm were modelled with a continuing loss of 2 mm/hr. The 18 hr and 6 hr events were shown as the critical durations for Fyans Creek and Stoney Creek respectively. A comparison of the modelled hydrographs for Fyans Creek downstream of Halls Gap is shown in Figure 7-1 with a comparison of the hydrographs compared at Stoney Creek shown in Figure 7-2.

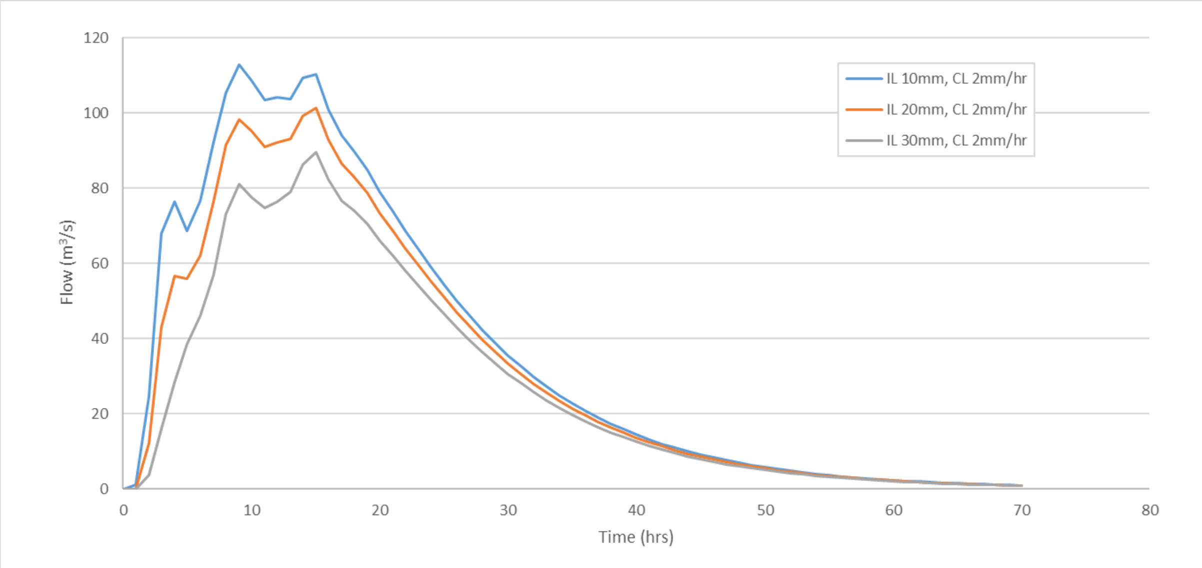

Figure 7-1 1% AEP – 18 hr, Fyans Creek Continuing Loss Sensitivity Testing

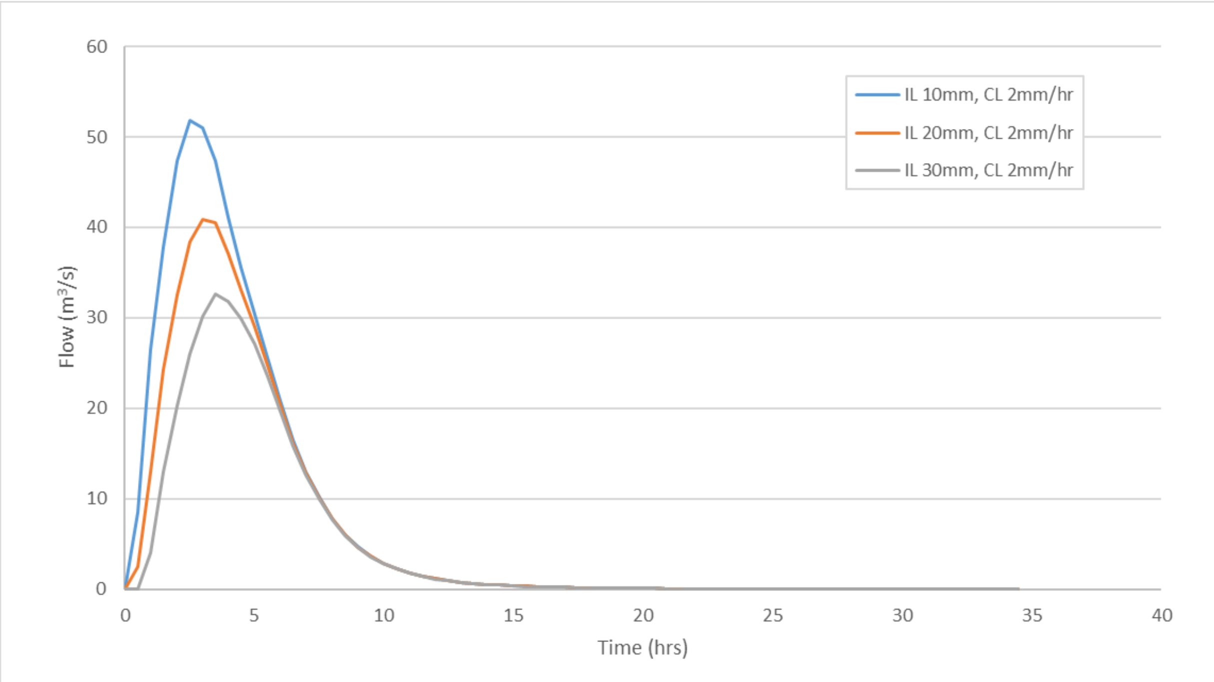

Figure 7-2 1% AEP – Stoney Creek Continuing Loss Sensitivity Testing

The impact of increasing the initial loss on the 1% AEP event by 10 mm shows a general decrease in peak for both Fyans Creek and Stoney Creek by around 11-12 m^3/s. This is around a 10% reduction in peak flow for Fyans Creek and 20-25% for Stoney Creek.

The January 2011 verification modelling of Stoney Creek produced a peak flow of 41.0 m^3/s. This is around a 1% AEP flow when comparing to design modelling with an initial loss of 20 mm and continuing loss of 2 mm/hr. Using a continuing loss of 10 mm and continuing loss of 2 mm/hr the 2% AEP flow is around 41.5 m^3/s, which would make January 2011 a 2% AEP event.

To assist in determining an approximate AEP of the January 2011 event the 24 hr rainfall totals for the Halls Gap rainfall gauge and Mt William sub daily rainfall gauge were compared to the design depths determined by the BoM IFD parameters. On the 12th and 14th of January the Halls Gap daily gauge recorded 135 mm and 146.6 mm respectively. This compares to the 24hr IFD 1% AEP rainfall total of

147.6 mm and a 2% rainfall total of 129.6 mm. This places the 24hr total recorded on the 12^{th} between a 1 and 2% AEP event, while the 24hr total occurring on the 14^{th} is greater than a 1% AEP event.

IFD analysis of the Mt William sub daily rainfall data indicated that the three-hour rainfall total on the evening of January 12^{th} was a 1.25% AEP rainfall event.

Modelling completed during recent studies in the Wimmera region have indicated the upper catchment areas produced flows approximately equal to a 1% AEP event[27,28].

It was determined an initial loss of 20 mm and continuing loss of 2 mm/hr would be adopted for design modelling during the Halls Gap Flood Investigation Review. This is in line with previous modelling completed during the Halls Gap Flood Study and Bellfield Flood Study. It also results in the January 2011 event corresponding with a 1% AEP event which it was shown to be in other parts of the upper Wimmera catchment.

7.1.5 Results

The RORB model was run for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events, for durations ranging from 1 to 72 hours. The Probable Maximum Flood (PMF), was also run for events ranging from 72hrs to 0.5hrs. Fyans Creek (downstream of Lake Bellfield) was shown to have a critical duration of 72 hours for all modelled AEPs, while Stoney Creek (at Grampians Road) has a critical duration of 48 hours for all modelled AEPs. The Mt Difficult and Mt William gullies had critical durations varying with AEP. The PMF had a critical duration of 6hrs for Fyans Creek, 2hrs for Stoney Creek and 1hr for the Mt William and Mt Difficult gullies. The critical durations for the gullies, Fyans Creek and Stoney Creek are shown in Table 7-3.

Table 7-3 AEP critical durations

<table>
<tr><th rowspan="2">AEP (%)</th><th colspan="3">Critical Duration (hours)</th></tr>
<tr><th>Fyans Creek</th><th>Stoney Creek</th><th>Gullies</th></tr>
<tr><td>50</td><td rowspan="7">48</td><td rowspan="7">72</td><td>24</td></tr>
<tr><td>20</td><td>24</td></tr>
<tr><td>10</td><td>12</td></tr>
<tr><td>5</td><td>12</td></tr>
<tr><td>2</td><td>3</td></tr>
<tr><td>1</td><td>3</td></tr>
<tr><td>0.5</td><td>3</td></tr>
<tr><td>PMF</td><td>6</td><td>2</td><td>1</td></tr>
</table>

As the frequency of the design events increased, the critical duration of the gullies decreased.

Hydrographs at the two major inflow points, Stoney Creek and Fyans Creek downstream of Lake Bellfield are shown in Figure 7-3 and Figure 7-4 respectively for their critical durations.

[27] Water Technology (2012), Natimuk Flood Investigation
[28] Water Technology (2016), Warracknabeal and Brim Flood Investigation

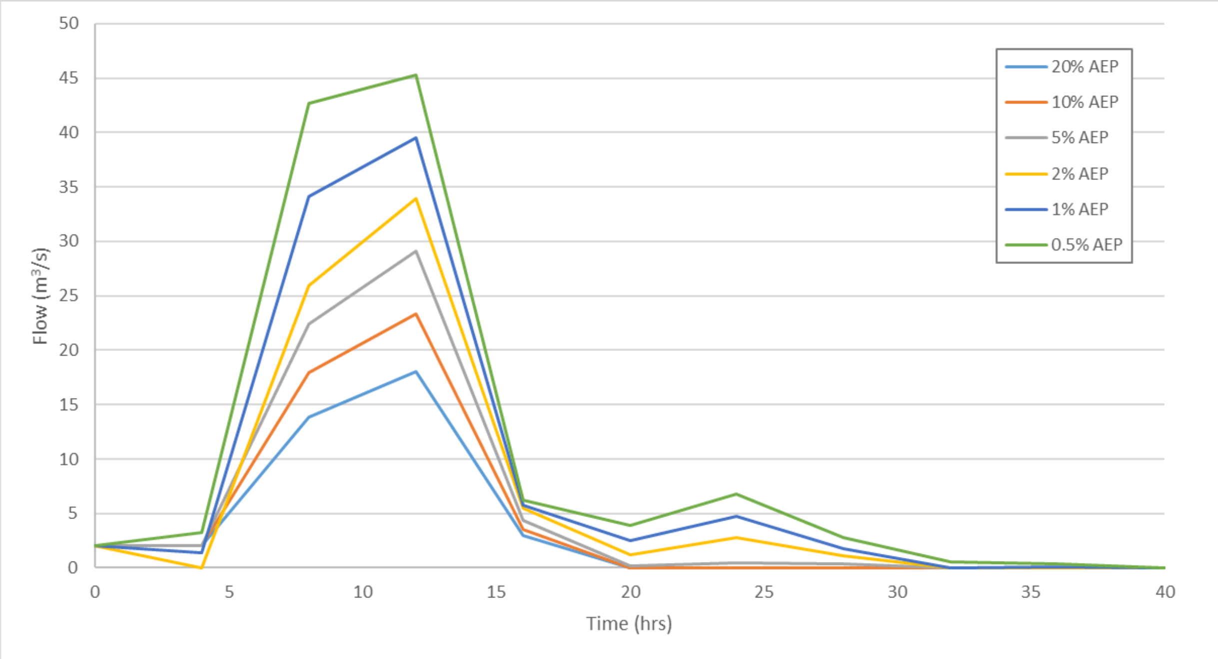

Figure 7-3 Stoney Creek inflows – All AEPs 72hr duration

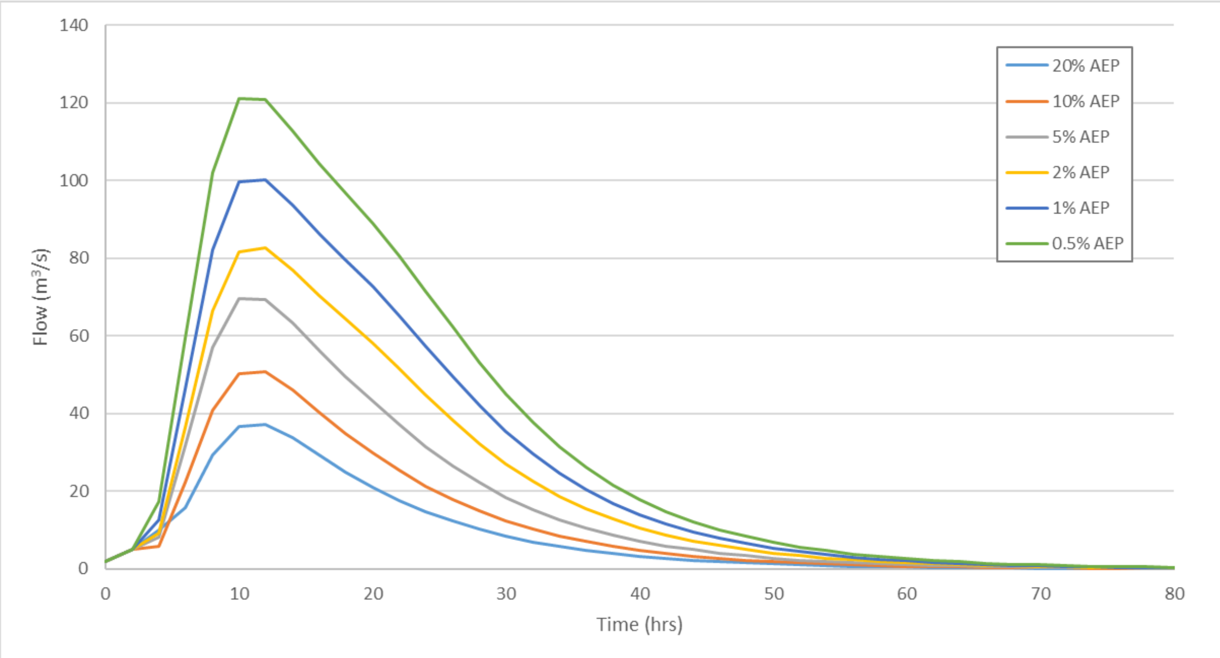

Figure 7-4 Fyans Creek inflows – All AEPs 48hr duration

7.1.6 Climate change modelling

The impacts of climate change were tested by increasing the rainfall intensity by 5% per degree of warming, in line with latest guidance from Australian Rainfall and Runoff[29]. A scenario of 2°C of warming (i.e. 10% increase in rainfall intensity) was adopted for this sensitivity test. This is consistent

[29] Engineers Australia (2014), Australian Rainfall and Runoff Discussion Paper: An Interim Guideline for Considering Climate Change in Rainfall and Runoff (Draft). Report No. ARR D3

with 'Climate Change in Australia Projections'[30] report which suggests for an intermediate climate scenario, a temperature increase of between 1.1°C to 2.0°C is likely for the Southern Slopes of Australia. Climate change modelling was undertaken for the 1% AEP event for the 48 hour, 72 hour and 3 hour duration events representing the critical durations of Fyans Creek, Stoney Creek and the gullies respectively. The increase in flow due to the increase in rainfall intensity for each Fyans Creek, Stoney Creek and Interstation Area 2 (Mt Difficult gully immediately downstream of Lake Bellfield) is shown in Figure 7-5, Figure 7-6 and Figure 7-7 respectively.

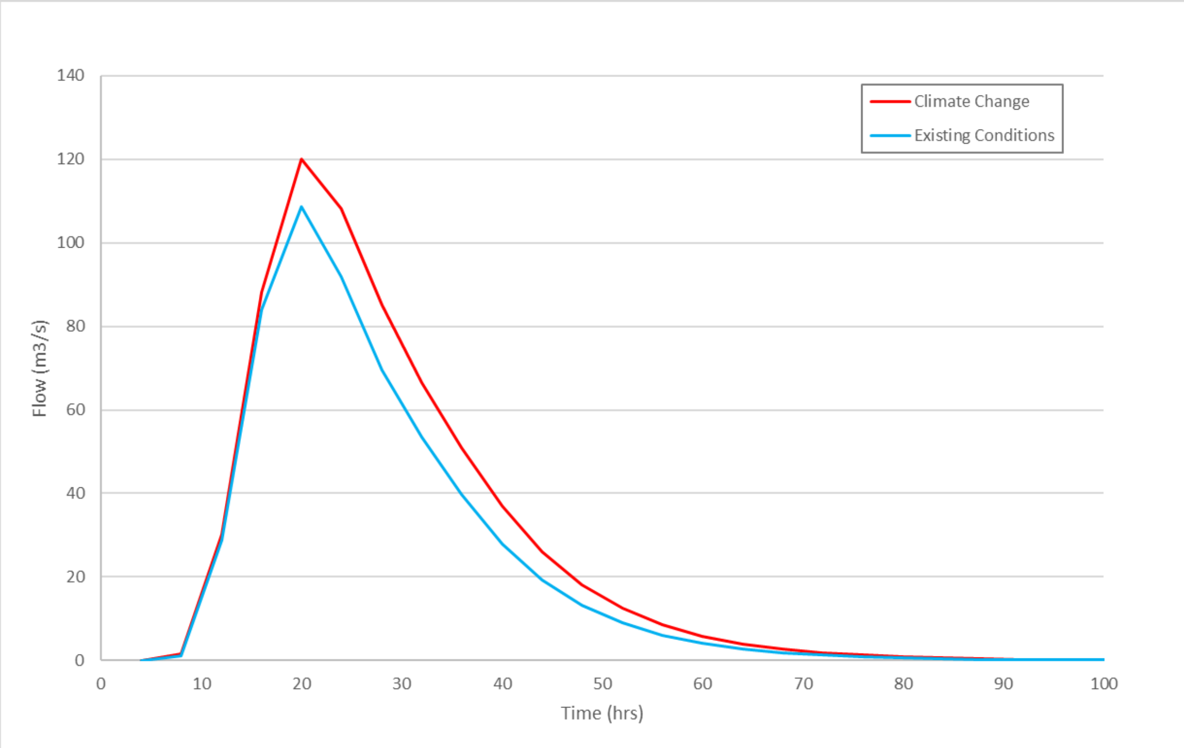

Figure 7-5 Climate Change Sensitivity Test for 1% AEP, 72hrs – Fyans Creek

[30] CSIRO (2005), Climate Change in Eastern Victoria - Stage 1 Report: The effect of climate change on coastal wind and weather patterns. CSIRO.

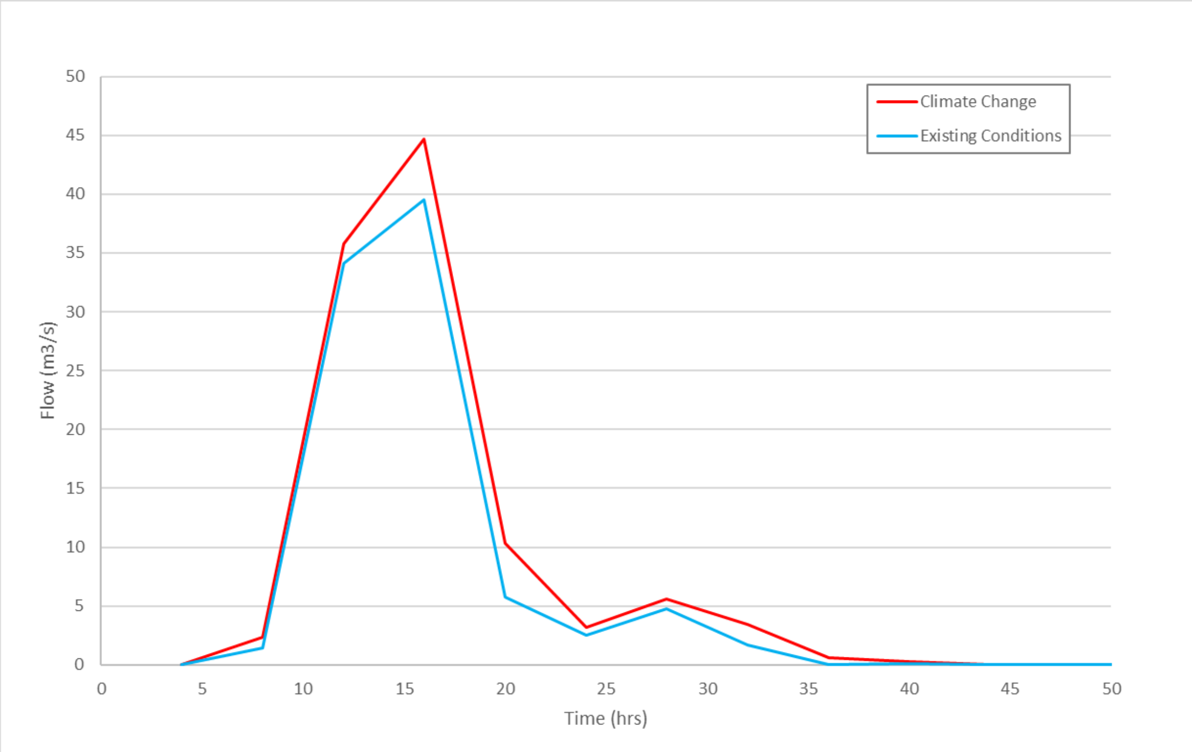

Figure 7-6 Climate Change Sensitivity Test for 1% AEP, 72hrs – Stoney Creek

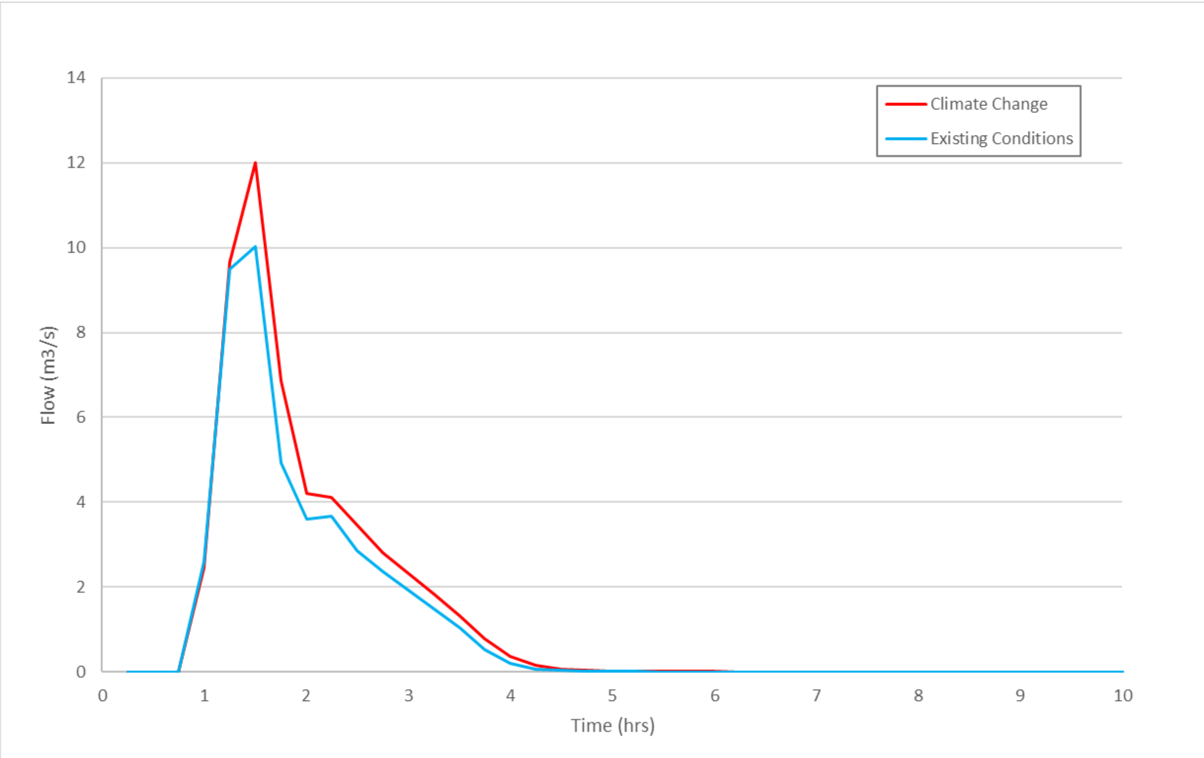

Figure 7-7 Climate Change Sensitivity Test for 1% AEP, 3hrs – Interstation Area 2

An increase in rainfall intensity by 10% caused a range of flow increases across the three durations, the peak flow increases are shown in Table 7-4.

Table 7-4 Climate change – peak flow increases

Event/Location	Existing Peak Flow (m^3/s)	Climate Change Peak Flow (m^3/s)	Increase in peak flow (m^3/s) (%)
48 hours/Fyans Creek DS Lake Bellfield	108.8	120	11.2 (10%)
72 hours/Stoney Creek at Grampians Road	39.5	44.7	5.2 (13%)
3 hours/Interstation area 2 at Grampians Road	10.0	12.0	2.0 (20%)

7.1.7 Lake Bellfield starting level sensitivity testing

Sensitivity testing of the Lake Bellfield level was completed for the 1% AEP event at a 72 hour duration (critical duration). Lake Bellfield levels of 80% and 90% were modelled and using the adopted design losses neither event caused a spill of Lake Bellfield. A reduction in the losses was required for the lake to spill. With an initial loss of 10mm and continuing loss of 2mm/hr and Lake Bellfield at 90%, the Lake Bellfield outflow reached a maximum of 10.7 m^3/s, opposed to 108.8 m^3/s adopted in the design modelling. The initial starting level of Lake Bellfield has a major influence on the downstream flows in Fyans Creek.

7.2 Hydraulics

7.2.1 Design Hydraulics

Design hydraulic modelling was completed adopting the same roughness values and topography determined in the hydraulic model calibration. Modelling was completed for the full suite of design events including the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events, and the PMF.

The hydraulic model was run for 72 hour and 48 hour event durations for the Fyans Creek and Stoney Creek inflows. In each case this was combined with the critical duration for the Mt William and Mt Difficult gullies, which varied with AEP. The critical duration for each AEP is discussed in Section 7.1.5 and shown in Table 7-3.

These events are overlayed in Figure 7-8 for the 48 hour event, with a closer perspective of the Halls Gap township shown in Figure 7-9. The 72 hour, 1% AEP flood depths are shown in Figure 7-10, with the 72 hour, 1% AEP flood velocities shown in Figure 7-11. In both of these scenarios the gullies were modelled with a 3hr duration.

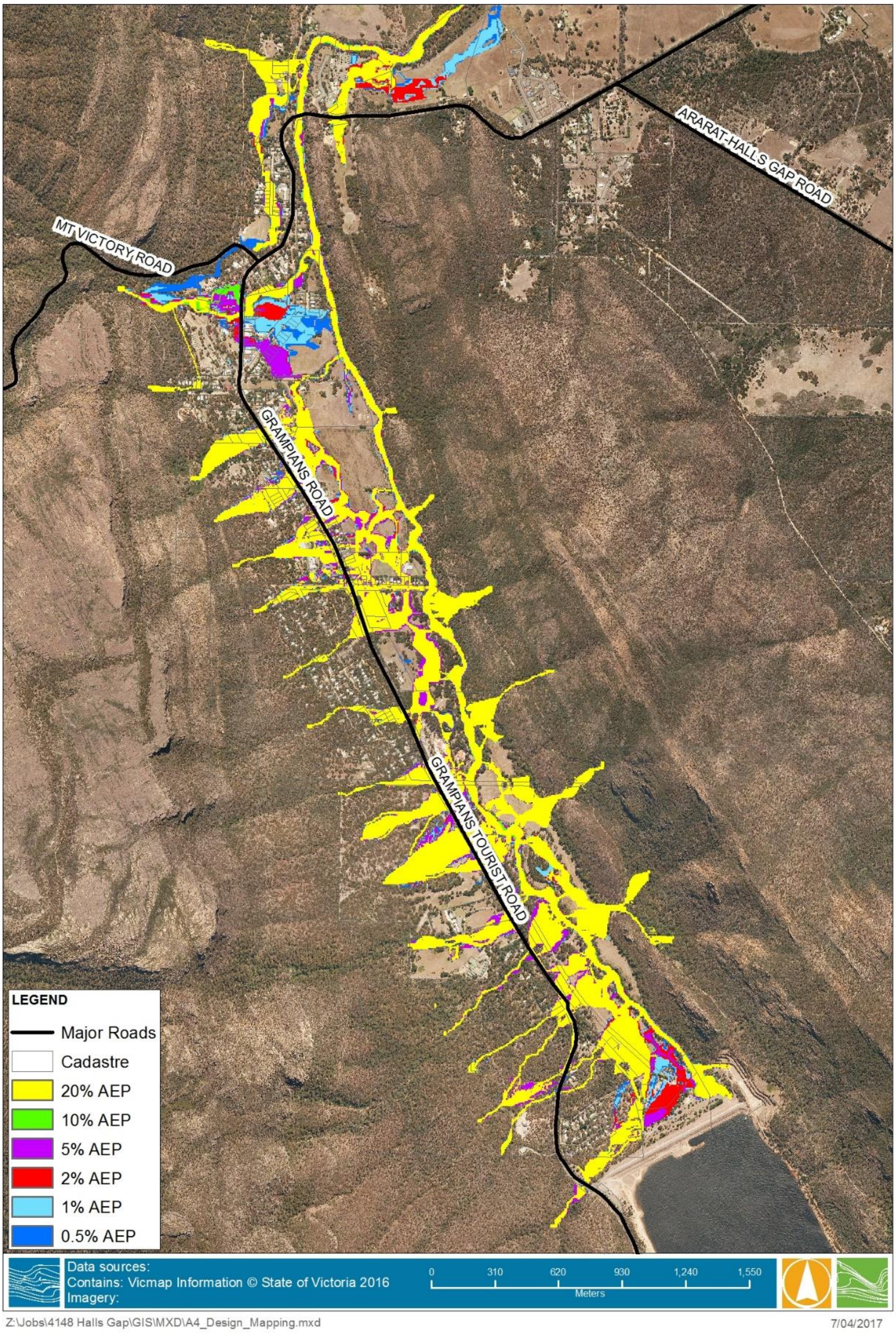

Figure 7-8 Design hydraulic model extents –hydraulic model area

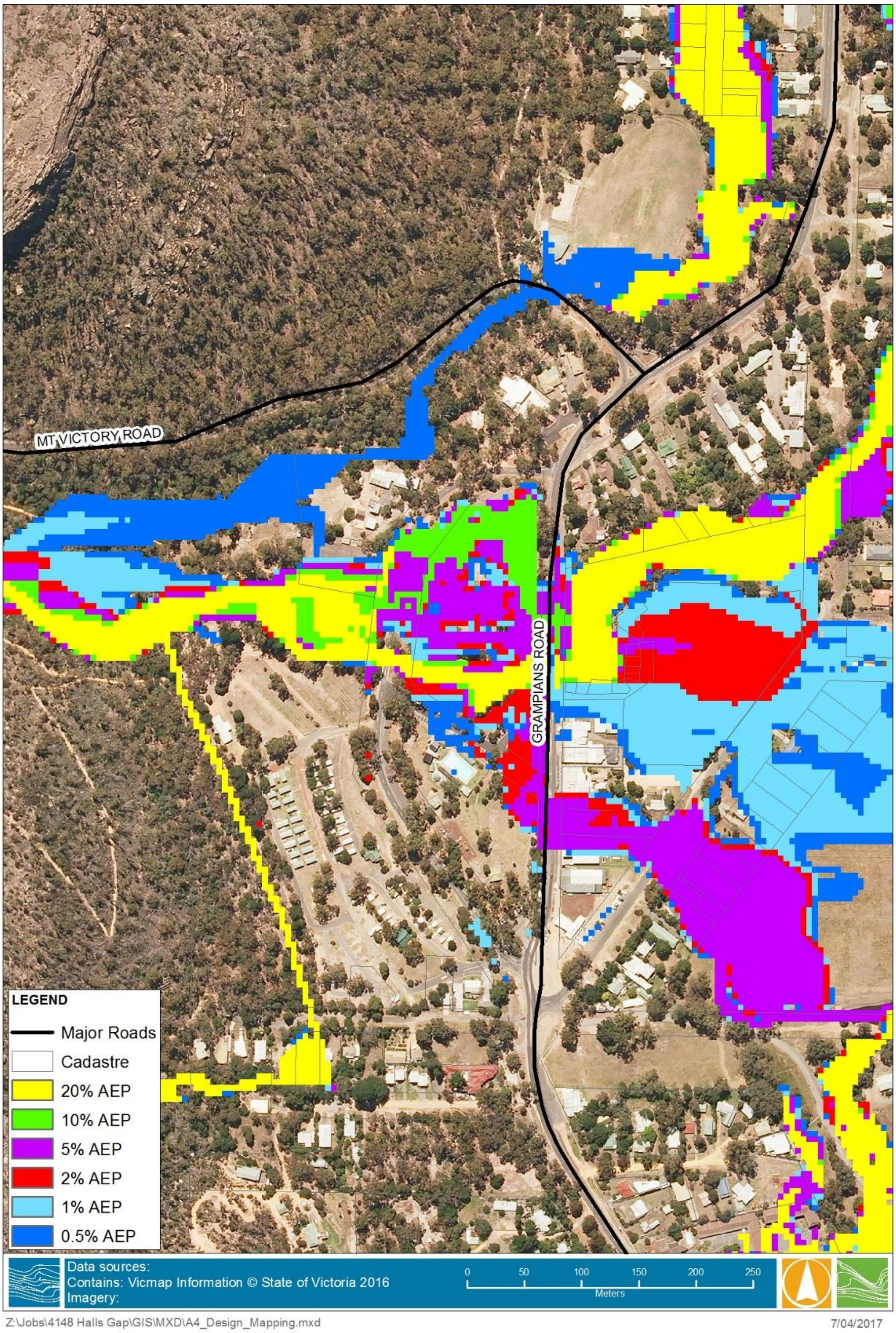

Figure 7-9 Design hydraulic model extents – central Halls Gap

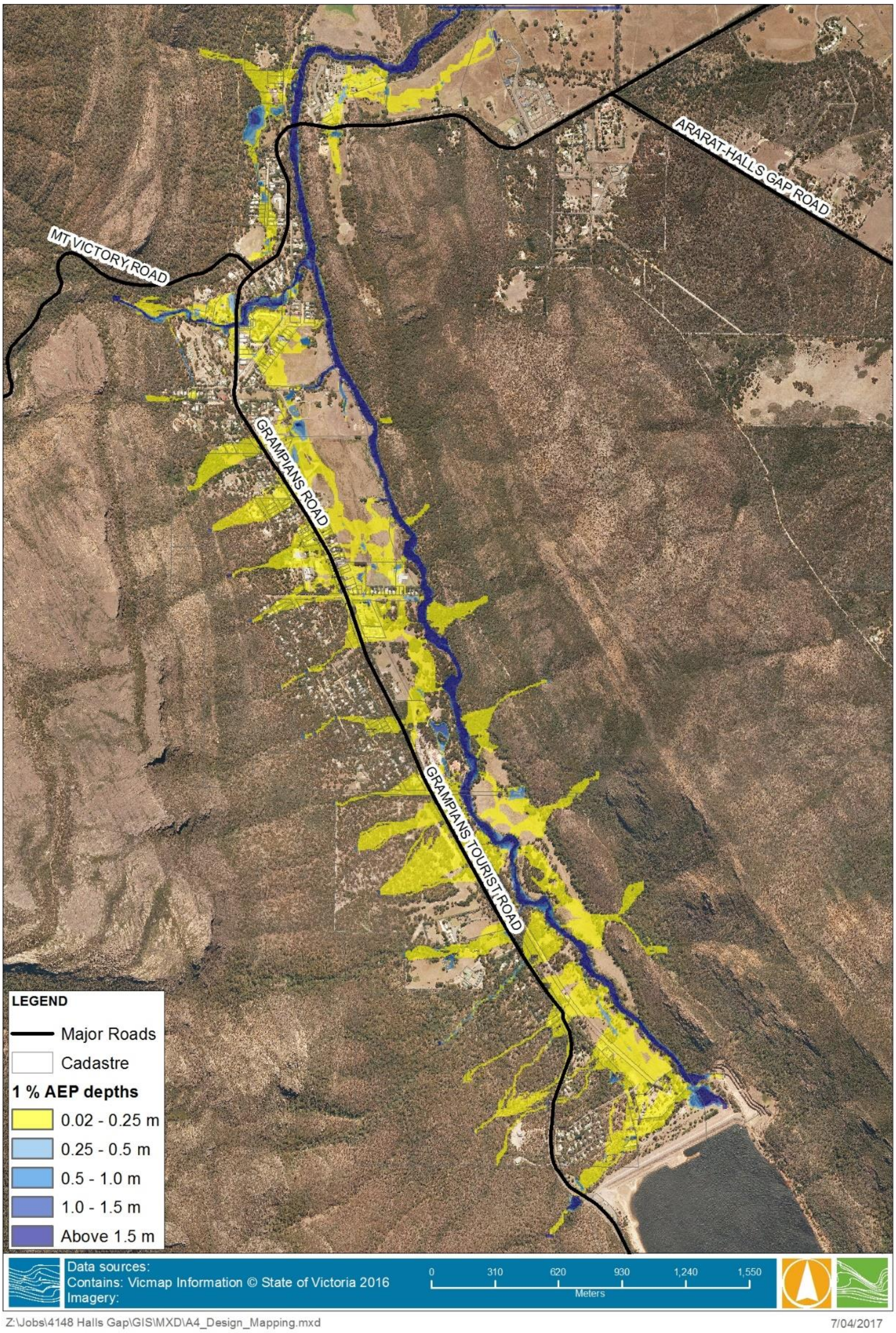

Figure 7-10 1% AEP, 48 hour duration depths (3hr duration for gully tributaries)

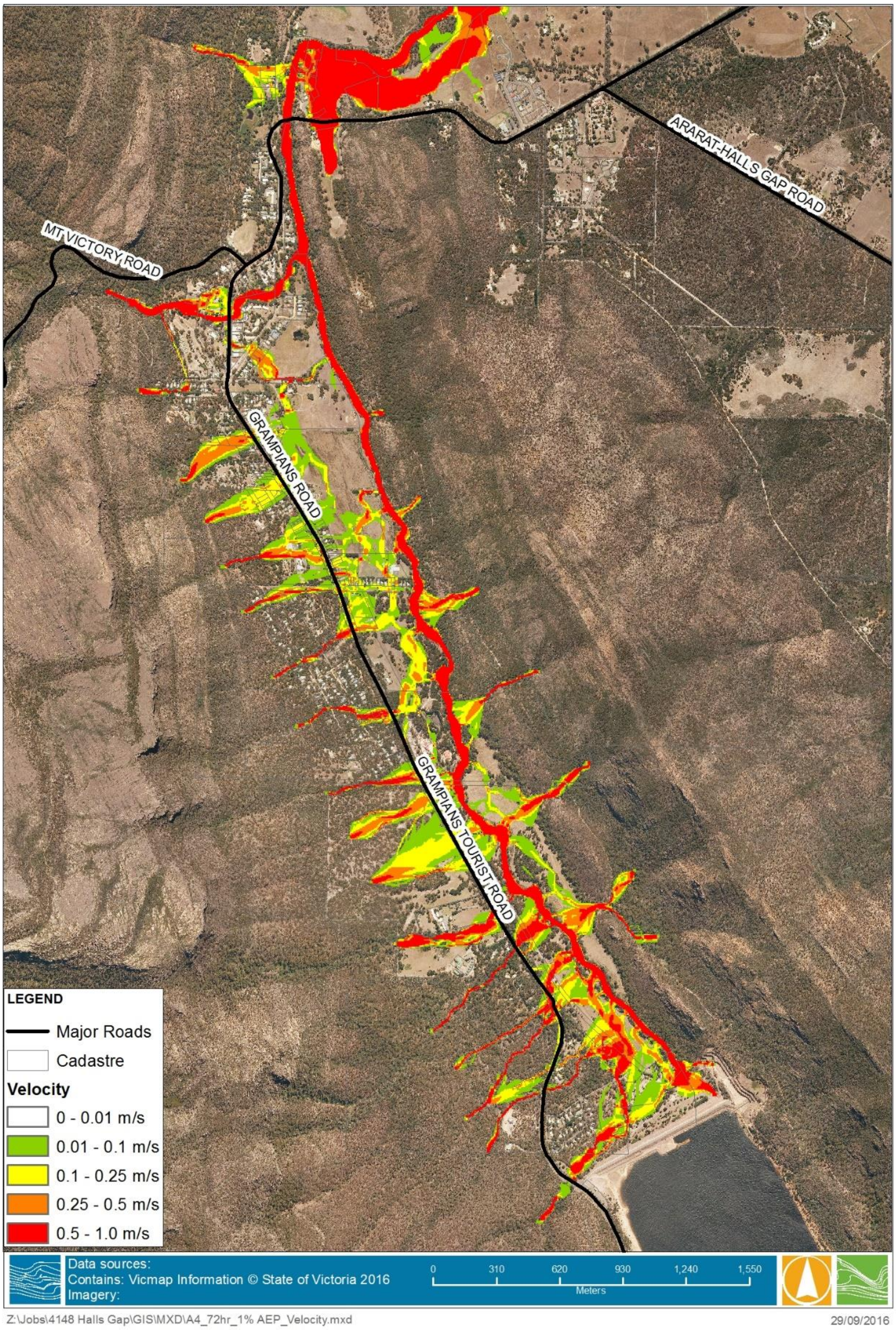

Figure 7-11 1% AEP, 48 hour duration velocities (3hr duration for gully tributaries)

The PMF event was modelled using combining the 6 hour Fyans Creek, 2 hour Stoney Creek and 1 hour gully inflows into one model run. The resulting depths over the study area are shown in Figure 7-12, with the central Halls Gap area shown in Figure 7-13.

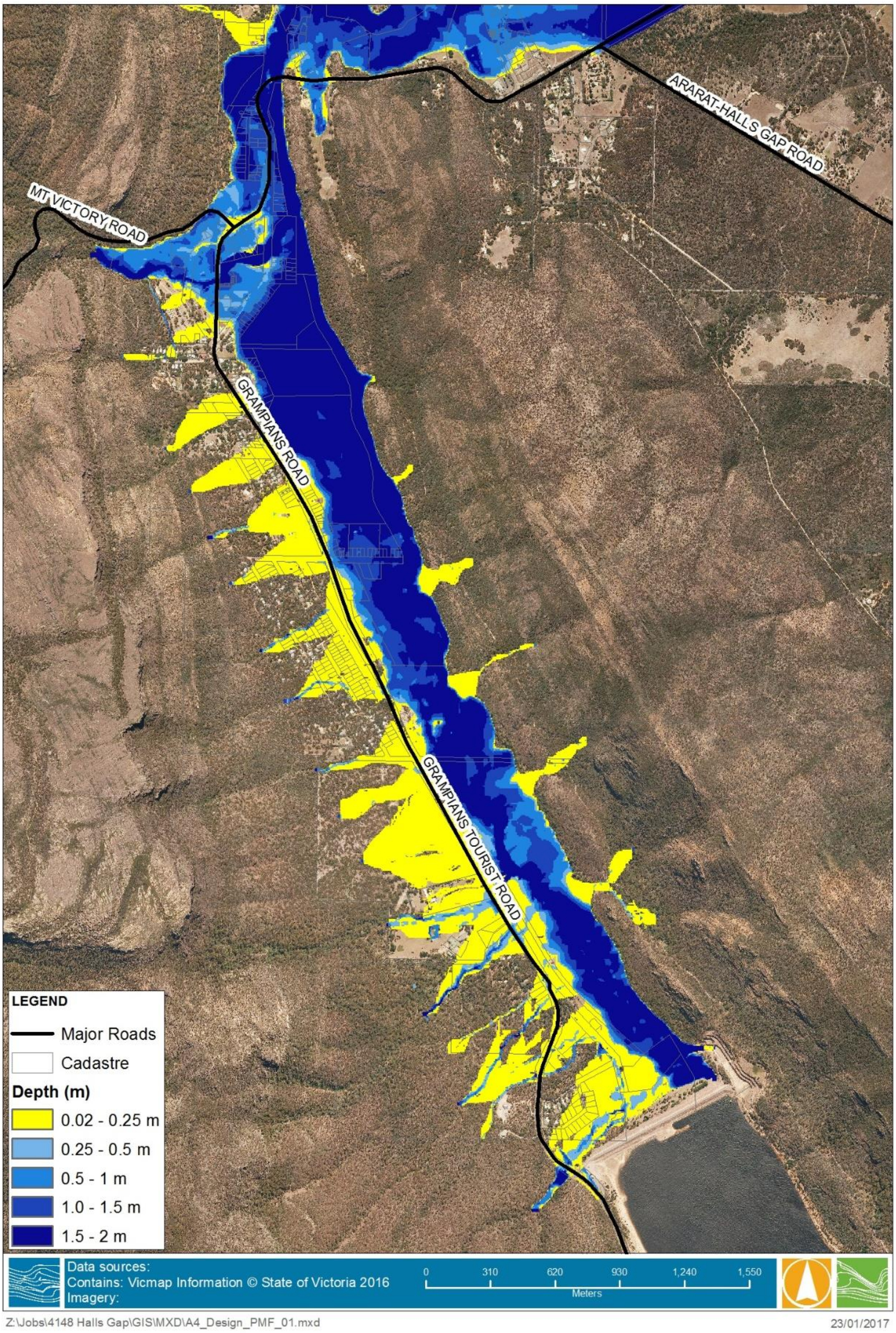

Figure 7-12 PMF depths – all study area

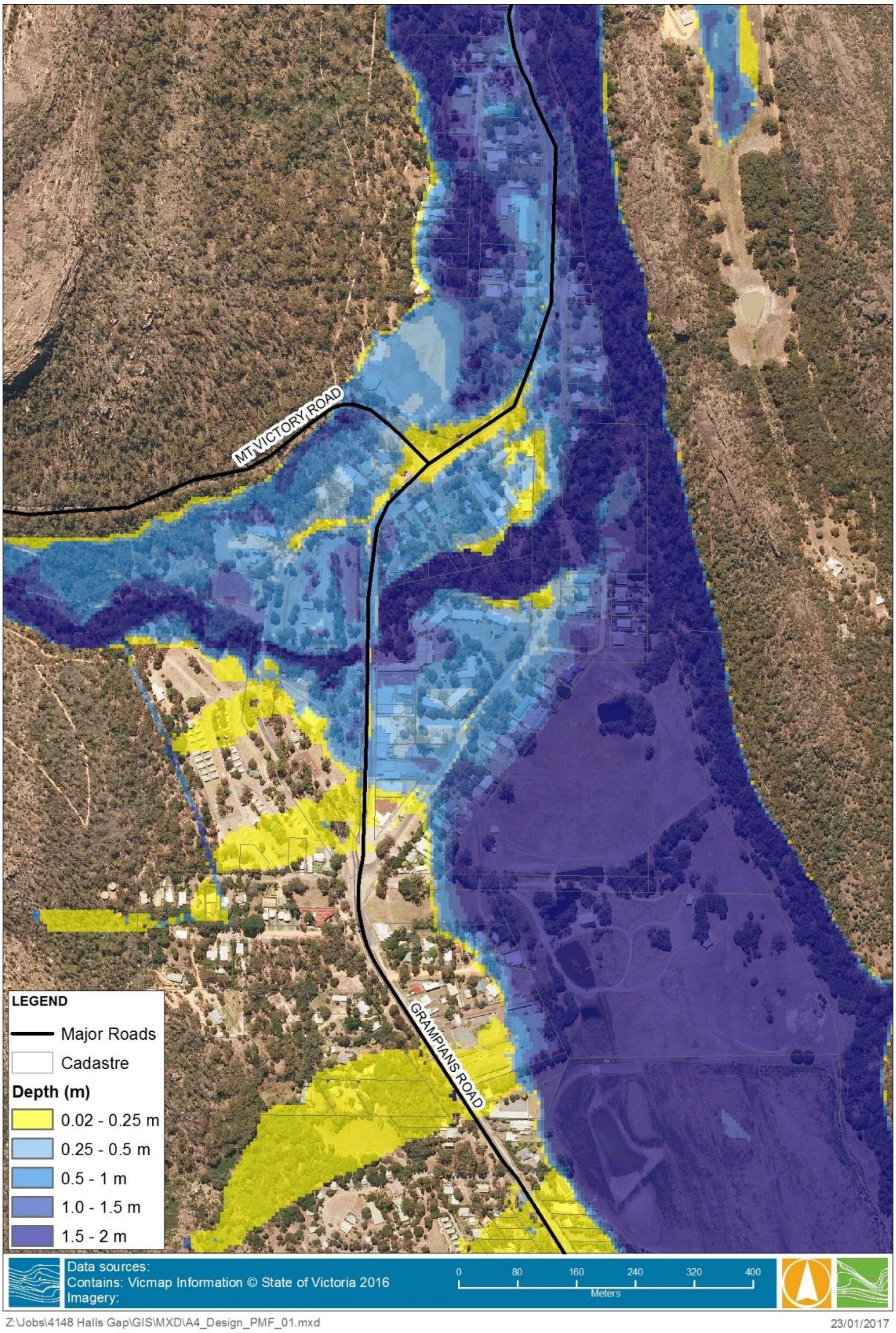

Figure 7-13 PMF depths – central Halls Gap area

7.2.2 Blockage of hydraulic structures

Blockage factors

The impact of structure blockage was assessed as a sensitivity test using the Australian Rainfall and Runoff Assessment Criteria[31]. The assessment criteria for the Stoney Creek bridge at Grampians Road and the remaining Grampians Road structures is shown in Table 7-5 and Table 7-6 respectively.

Table 7-5 Blockage assessment – Stoney Creek

Assessment	Description	Outcome
Debris Type and Dimensions	Logs, sticks, branches	
L_{10}	Average length of the longest 10% of the debris that could arrive at the site	3m
Debris Availability	Relatively clear stream and catchment, lots of rocks	Medium
Debris Mobility	Fast response times, main debris source close to stream, steep debris source.	High
Debris Transportability	Lots of meanders, rocky benches etc.	Medium
Site based Debris Potential (High/medium/low)	Based on Availability, Mobility and Transportability	Medium, High, Medium = DP Medium
AEP Adjusted Debris Potential	Observation of debris conveyed in streams strongly suggests a correlation between an event's magnitude and debris potential at a site	DP Medium, debris moving between 5% and 0.5% AEP event = Medium
Debris Blockage	Most likely inlet blockage	Medium AEP Adjusted Debris Potential and $L_{10} \leq W \leq L_{10}$= 10%

Table 7-6 Blockage assessment – Grampians Road Structures

Assessment	Description	Outcome
Debris Type and Dimensions	Logs, sticks, branches	-
L_{10}	Average length of the longest 10% of the debris that could arrive at the site	0.5m
Debris Availability	Thick vegetation, difficult to walk though, considerable fallen limbs	High
Debris Mobility	Fast response times, main debris source close to stream, steep debris source, streams frequently overtop their banks.	High
Debris Transportability	Low cross section grade, high velocity, steep, relatively shallow	High
Site based Debris Potential (High/medium/low)	Based on Availability, Mobility and Transportability	High, High, High = DP High
AEP Adjusted Debris Potential	Observation of debris conveyed in streams strongly suggests a correlation between an event's magnitude and debris potential at a site	DP High, debris moving between 5% and 0.5% AEP event = Medium
Debris Blockage	Most likely inlet blockage	High AEP Adjusted Debris Potential and $L_{10} \leq W \leq L_{10}$= 20%

[31] Engineers Australia (2013), Australian Rainfall and Runoff, Project 11 – Blockage of Hydraulic Structures

Blockage Modelling

The impact of culvert blockage was modelled for the 48 hour duration modelling on Stoney Creek and Fyans Creek, with 3 hour duration inflows for the Mt Difficult and Mt William gullies as modelled in the base design modelling. The Stoney Creek Bridge was blocked by 10%, and the Grampians Road structures were blocked by 20% as outlined above. The change in water levels and extent due to the blockage is shown in Figure 7-14.

The changes in water level along the Grampians Road structures was limited to less than 0.01 m with the majority of floodwater overtopping Grampians Road and the culverts carrying a relatively small proportion.

In the case of Stoney Creek, the relatively small degree of blockage has resulted in almost no change in water level.

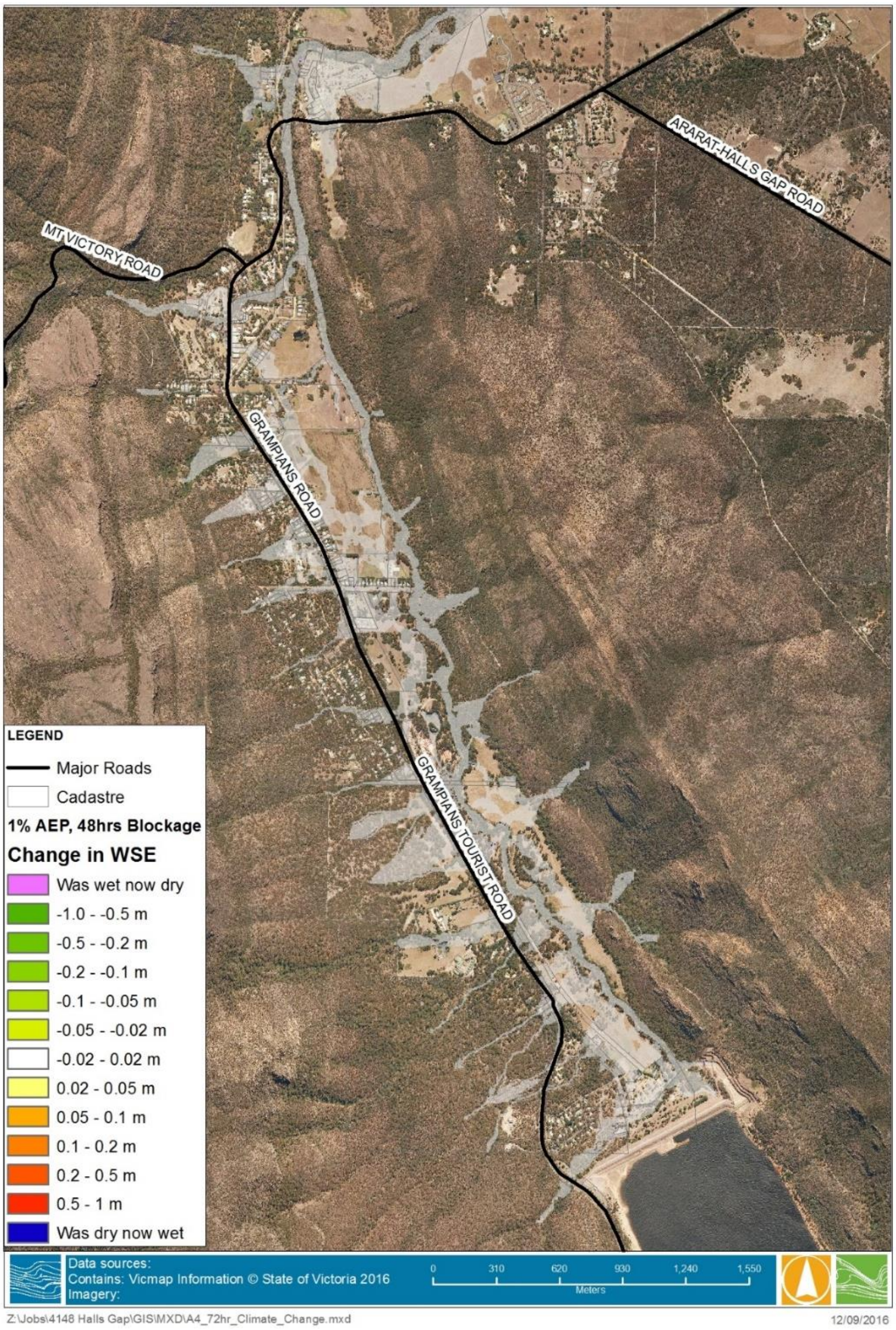

Figure 7-14 Change in water levels and extent due to blockage of hydraulic structures

7.2.3 Climate Change

A discussed in Section 7.1.6, the impact of climate change was modelled using a 10% increase in rainfall intensity. The intensity increase was modelled for the 1% AEP event, using the 72 hour and 48 hour durations for Stoney Creek and Fyans Creek, while the Mt Difficult gullies were modelled at a 3 hour duration in the same way as the base design modelling.

As expected the increase in rainfall intensity caused increases in water level and extent, however the increases were relatively limited. The increases in water level and extent due to the inclusion of climate change for the 72 hour event are shown in Figure 7-15.

Increases along the Mt Difficult and Mt William gullies were very minor at less than 0.01 m. There were some isolated increases in inundation extent. The increases in flow in these areas were reasonable, varying from 4% to 18%.

The increases in water level were greatest along Fyans Creek and Stoney Creek, reaching a maximum increase of around 0.25 m in Fyans Creek.

Increases in the Stoney Creek shopping complex were greatest for the 72 hour event, at 0.08 m. increases for the 48 hour event (critical duration) were around 0.04 m.

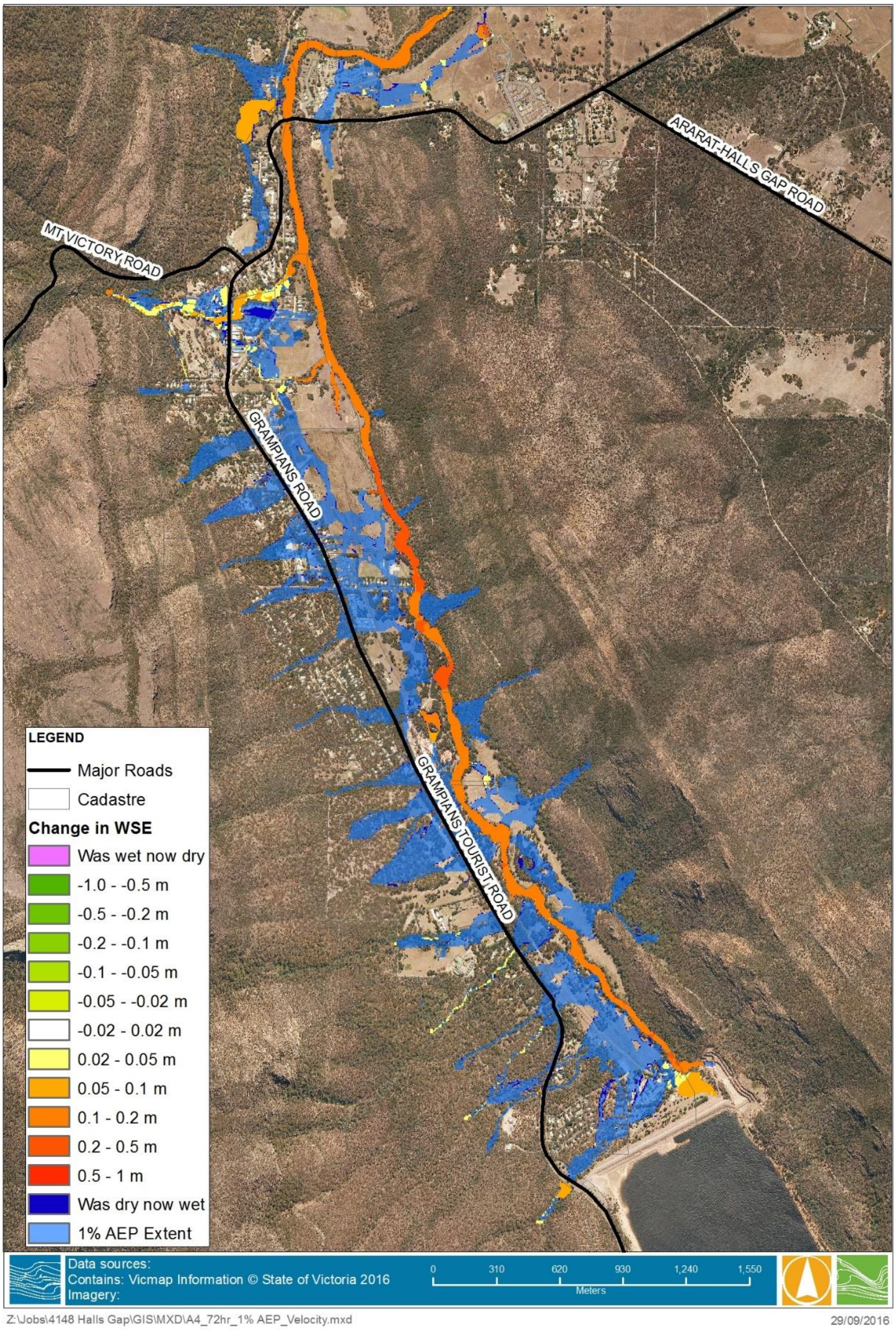

Figure 7-15 Change in WSE and inundation extent due to climate change, 72 hour event

8. MAPPING

On completion of the design modelling, mapping outputs were produced for the January 2011 calibration event and all design scenarios. This included flood intelligence outputs, including GIS grids of depth, velocity and flood hazard. Land Subject to Inundation (LSIO) and Flood Overlay (FO) planning scheme layers were also produced.

All mapping outputs were provided to Wimmera CMA. Draft LSIO and FO layers were produced as shown in Figure 8-1.

The LSIO was created using the 1% AEP extent as the basis, whereas the FO was created

No flood intelligence reporting was produced during this project.

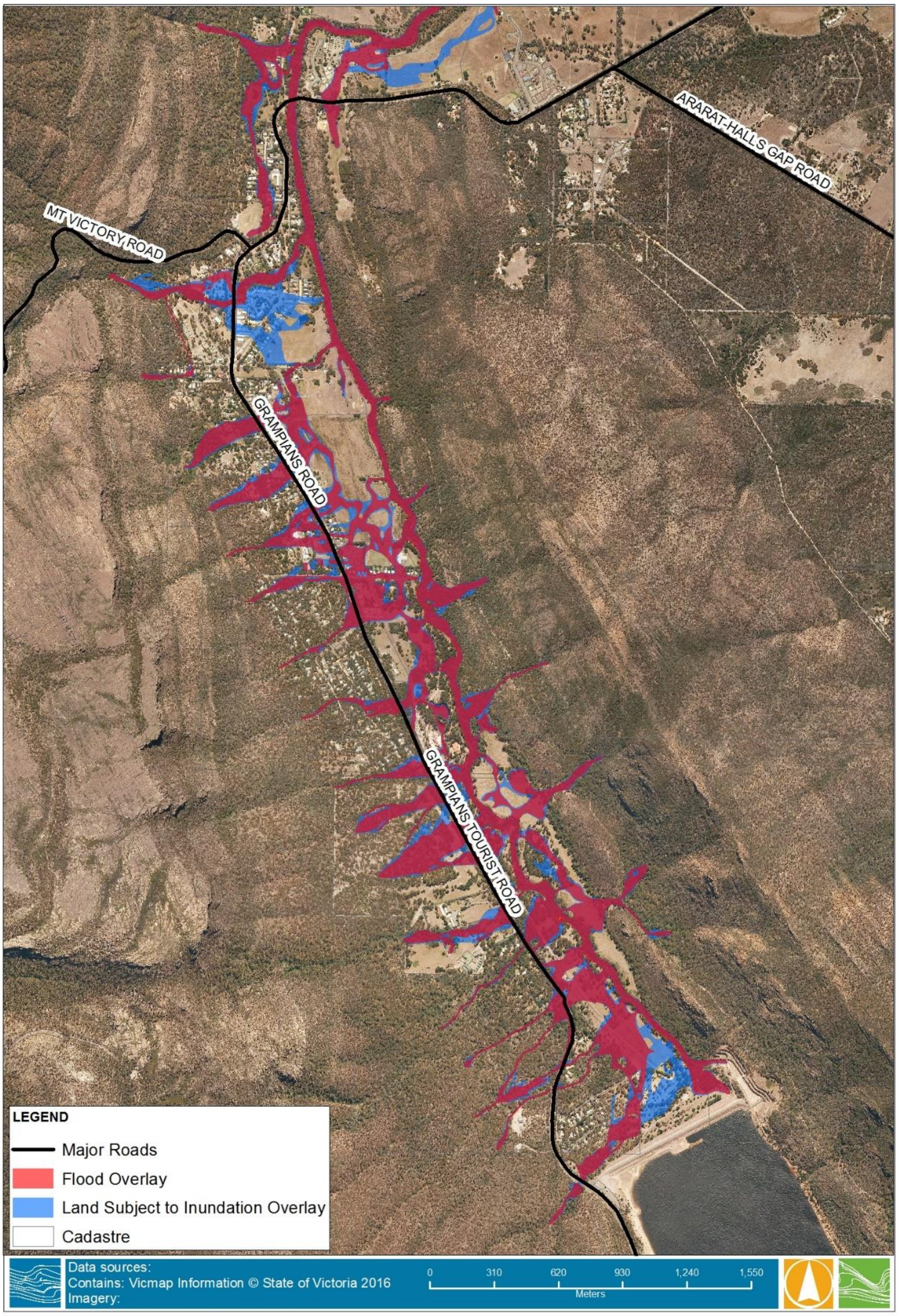

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Figure 8-1 Halls Gap LSIO and FO

9. DISCUSSION AND RECOMMENDATIONS

Modelling and mapping of Halls Gap has shown inundation along the Mt William and Mt Difficult Gullies to be relatively similar across the design events considered, this is due to their steep nature. During high frequency events flow remains in channel, but when the channel capacity is exceeded water flows overland rapidly at shallow depth. The area of the greatest floodplain risk and potential for flood damage (excluding damage due to landslips and erosion), is the Stoney Creek Shopping Complex. At around a 2% AEP flood event there is potential for buildings in the main shopping complex area including the Halls Gap Caravan Park.

Several recommendations are made, which have potential to reduce the flood risk for the Halls Gap township, these include:

- The LSIO and FO mapping outputs produced as part of this study be adopted in the Northern Grampians Shire Council Planning Scheme
- Mapping produced as part of this study be made available to the public to ensure properties along the Mt Difficult gullies area are aware of their flood risk
- A flood intelligence report be produced with the revised mapping outputs, this would be used for inclusion into the NGSC MFEP
- VICSES use the information created as part of this study for their Local Flood Guide
- VFD data is provided to DELWP to upload to FloodZoom for use in emergency flood events
- Further investigation be completed into a flood warning system, this could be combined with a land slide warning system given the similar driving factors.