Coleraine Flood Investigation
Final Summary Report

Reference: R.M000136.008.03
Date: January 2019

In association with

Michael Cawood & Associates Pty Ltd

MCA

and utilis

Document Control Sheet

Client	Southern Grampians Shire Council
Client Contact	Graeme Jeffery – Glenelg Hopkins CMA
Project Manager	Dexter Reynolds
Report Name	Coleraine Flood Investigation – Final Summary Report
Report Reference	R.M00136.008.03
Authors	Dexter Reynolds – Venant Solutions Andrew Northfield – HARC Brad Henderson - Utilis Michael Cawood – Michael Cawood & Associates

Issued to	Version Number				
	0	1	2	3	4
Glenelg Hopkins CMA	15/11/2018	Not issued	10/12/2018	15/01/2019	

	Name	Signature	Version Number	Date
Prepared by	Dexter Reynolds		3	15/01/2019
Reviewed by	Mark Jempson		3	15/01/2019

Venant Solutions Pty Ltd
Suite 101, 26-30 Rokeby St
Collingwood VIC 3066
T: 03 9089 6702
ABN: 15 166 193 219
www.venant solutions.com.au

Executive Summary

This report outlines the objectives, methodology and key findings of the Coleraine Flood Investigation undertaken by Venant Solutions on behalf of Southern Grampians Shire Council. The project was delivered by Venant Solutions in association with other leading floodplain management, risk and planning specialist including HARC, Utilis and Michael Cawood and Associates. This report summarises the various detailed technical reports produced during the course of the investigation.

Coleraine has a known history of flooding with records of at least 7 significant events occurring since settlement in 1870, 1893, 1946, 1975, 1983, 1991 and most recently in 2016 which inundated 24buildings (residential, commercial and industrial). Of these, the 1870 event was particularly significant with 11 recorded deaths. The only flood mapping for the town prior to this investigation was derived by the 2001 flood data transfer project (FDTP). This provided an inadequate "guestimate" of the potential 1% AEP flood extent and level of hazard in the centre of town.

The flood investigation has (for the first time) produced a range of reliable flood mapping information for Coleraine covering the full suite of design flood events (20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP & probable maximum flood (PMF)) commonly considered in contemporary floodplain management practice. The 1% AEP flood extent and depth map produced by this investigation is presented in Figure 1. This body of information is a prerequisite for the effective implementation of measures to reduce the impact of flooding on the Coleraine community into the future.

Industry best practice methodologies (e.g. latest Australian Rainfall & Runoff (AR&R 2016) catchment hydrology methodologies and high resolution (2m grid cell) mapping) have been applied to the development of the hydrologic and hydraulic models which underpin the flood investigation outputs.

Further to this, the application of the adopted modelling methodologies (including associated assumptions) and setup of the models themselves underwent a rigorous 3rd party peer review process managed by DELWP and the Glenelg Hopkins CMA. Investigation of the sensitivity of the modelling outputs to changes in key factors influencing flood behaviour including surface roughness (eg changes in vegetation cover), blockage of key flow conveyance structures (e.g. bridges) and climate change induced changes in flood flow (due to change in rainfall intensity) were also completed.

The rigour applied throughout the investigation has ensured high confidence outputs. The degree of confidence in the outputs has been further validated by the ability of the developed models to accurately replicate observed flood levels attained by historical events including 1946, 1983, 2010 and 2016 (note that the 2010 event was included in this analysis to check the accuracy of the flood model in replicating minor events).

It was important to place the magnitude of these events into context. The modelling exercises estimated the magnitude of these historical events as follows:

- 1946 – in the order of 0.5% AEP (200 yr ARI)
- 2016 – in the order of 2% AEP (50yr ARI)
- 1983 – in the order of 3.3% AEP (30yr ARI)
- 2010 – in the order of 20% AEP (5yr ARI)

It should be noted here that anecdotal evidence provides a strong indication that the 1870 flood was substantially larger than the flood in 1946. However, the 1870 event was not included in the historical flood analysis due to lack of reliable flood level and rainfall data.

An additional source of potential flooding in Coleraine is the Young-Robertson Street drain system comprising the Railway Reserve and East Park lakes and connecting drainage corridors which then flow into Bryan Creek. This system collects runoff from the steep slopes on the south side of the town and has been designed to provide a degree of flow retardation. However, this investigation has identified that the Young-Robertson Street drain system presents an additional flood risk to Coleraine, beyond flood events in Bryan Creek. It is important to note that whilst flooding in this part of Coleraine (McLeod St to Whyte St) is shown on the same maps as floods in Bryan Creek – flooding caused by flows breaking out of the Young-Robertson Street Drain system may not occur at the same time as floods in Bryan Creek.

Community knowledge of flood risk at Coleraine was sought throughout the investigation. This knowledge was a key input to the modelling exercise. The community was provided with opportunity to offer input into the investigation as well as the opportunity to review and provide support and criticism to the outputs at key stages. Four formal community engagement sessions were held in Coleraine during the course of the investigation. In addition to gathering vital local knowledge, these sessions also provided a transparent two-way knowledge transfer connection between the community and the project team. A high degree of rigour was also applied to this engagement process with various community members engaged on a one-on-one basis outside the formal engagement sessions.

Given the lack of stream gauges within the catchment, community knowledge was paramount to the investigation and the study team thank Coleraine community for their substantial contribution to its successful delivery. Community knowledge of the September 2016 flood was particularly significant in this regard.

A key element in the determination of the overall level of risk posed by flooding to Coleraine was to estimate the level of potential damage to the town in dollar terms. The project produced a ranged estimate of the average annual damages (AAD) using three industry standard methods (ANUFLOOD, O2 and WRM) as summarised in Table 1 below. The estimated long-term cost of flood related damage to Coleraine ranks highly when compared to other at-risk locations in the Glenelg Hopkins Region.

Table 1 Flood damages estimation summary

AEP (%)	Total No. of Properties Inundated	No. of Properties with above floor flooding	ANUFLOOD Method Total Damages ($)	O2 Method Total Damages ($)	WRM Method Total Damages ($)
20%	8	1	$28,000	$73,000	$74,000
10%	16	5	$89,000	$178,000	$171,000
5%	23	6	$117,000	$292,000	$254,000
2%	60	20	$641,000	$1,234,000	$1,022,000
1%	72	41	$1,506,000	$2,755,000	$2,196,000
0.5%	103	69	$3,254,000	$5,720,000	$4,448,000
0.2%	135	90	$5,220,000	$9,183,000	$6,984,000
PMF	336	320	$39,345,000	$92,008,000	$58,157,000
		AAD	**$105,000**	**$217,000**	**$162,000**

Following the damages assessment, structural and non-structural options were investigated to mitigate the impact of floods. Structural measures are physical works that alter the flood behaviour. Non-structural options include planning controls and emergency management measures.

Five potential physical works options were investigated using the hydraulic model and Benefit versus Cost analysis. The options assessed were those ranked highest by the community at the second community engagement session and through discussion with the Project Reference Group (PRG) comprised of representative from Southern Grampians Shire, Glenelg Hopkins CMA, DELWP, VICSES, CFA, Coleraine Development Association, Venant Solutions and Utilis. The options investigated were:

- Raising the Bryan Creek walking track to create a levee
- Raising Turnbull St to create a levee
- Lengthen the Glenelg Highway bridge to increase its flow capacity
- Removal of vegetation in the creek channels
- Modifications to the Young Street and Robertson Street drain

The assessment found that the Bryan Creek walking track option would have a Benefit to Cost Ratio (BCR) of around 1.0 and the Young Street and Robertson Street Drain option a BCR of around 2.7, and hence both options are recommended for a more detailed assessment.

The existing planning controls (Land Subject to Inundation Overlay (LSIO) and Floodway Overlay (FO) for Coleraine are based on the above mentioned rudimentary FDTP mapping from 2001. These have been deemed as insufficient and findings from the flood investigation have shown that the extent of these existing overlays is inadequate. It is recommended that the existing planning controls are amended based on the outputs of this investigation. The suggested amendments, including new LSIO and FO mapping have been documented and delivered to Council as a separate output.

In general terms, the level of hazard posed by floods in Coleraine is low until flood magnitude approaches the 2%AEP (50yr ARI) event – similar to the September 2016 flood. To facilitate effective use of the information derived from the flood investigation, the Coleraine section of the Southern Grampians Shire Municipal Emergency Management Plan (MEMP) has been replaced with a comprehensive set of property inundation tables and associated flood intelligence information. The property inundation tables show when, where and by how much (water depth), flood-prone buildings in the town are likely to experience over floor flooding. This information is critical to facilitating effective flood response in Coleraine by the community, SES (assisted by the CFA) and Council and has been delivered to VICSES and Council separately.

Apart from the ubiquitous “bush telegraph”, a flood warning or alerting system does not currently exist for Coleraine. Assessment and documentation of the feasibility of establishing an effective flood warning or alerting system was completed during the final phases of the project. Estimation of the effective flood warning time has been critical to this assessment. The effective flood warning time is the time between the detection of rainfall likely to cause a flood and the first significant impacts of flooding in the township – i.e. the time available for the community to take effective action to reduce flood impacts.

Under existing conditions (at the time of writing), the effective flood warning time for Coleraine is estimated to be no more than around 3 hours during a large flood and around 4 to 5 hours for a small flood. This places Coleraine within the flash flooding category.

Indicative flood/no-flood tools have been developed as an element of the flood warning feasibility assessment. If these tools are used (adopted by VICSES, council and community) in concert with the flood intelligence and mapping delivered by this investigation, the effective flood warning time could be extended to around 6 to 8 hours for a large flood and to around 7 to 10 hours for a small flood.

A further increase in effective flood warning time of at least 1 to 2 hours (or more depending on equipment configurations) could be expected with improved rainfall monitoring and installation of water level gauges. The effective flood warning time for Coleraine under existing conditions (assuming daylight hours) and the increases associated with upgrade of rain and water level monitoring capability (TFWS elements) are summarised in Table 2.

Table 2 Summary of Estimated Effective Flood Warning Time Under Existing Conditions and with TFWS Improvements

Relative size of flood	Catchment response time	Time to peak from start of rain	Estimated Effective Flood Warning Time		
			Existing conditions (daylight hours)	Minimum investment in TFWS elements (indicative tools, intelligence, mapping only)	Significant investment (attention to all TFWS elements)
Large	8 hours	15 to 17 hours	3 hours	6 to 8 hours	7 to 10 hours
Small	12 to 14 hours	More than 17 hours	4 to 5 hours	7 to 10 hours	8 to 12 hours

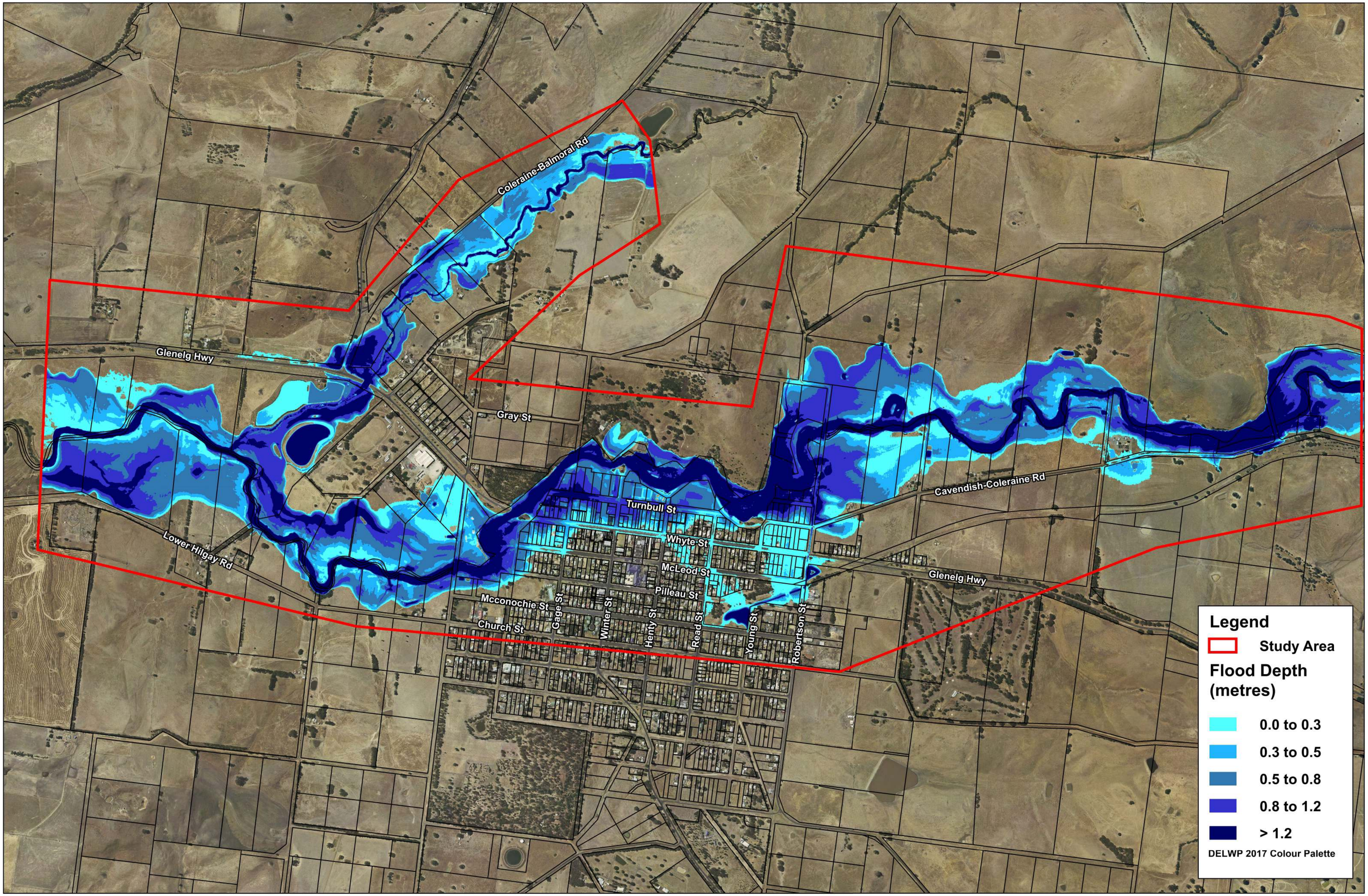
The achievable response action at Coleraine prior to the completion of this investigation (without regard for time of day or night) was likely to be limited to issue of a VicEmergency warning of likely flooding (with an Emergency Alert if it was assessed there was a risk to life) together (in small floods) with the possibility of some (limited) door knocking with advice to enact individual flood plans.

The Flood Warning Assessment element of the project has determined that adopting and making best use of the immediate deliverables from this investigation (i.e. the indicative flood / no flood tools, flood intelligence and flood mapping) and using rainfall data available from BoM, will extend the effective flood warning time, as per Table 2 above. In turn this will increase the opportunity for the community and CFA in association with VICSES to implement effective flood response actions. This has been assessed as being achievable in the near term with minimum investment. The assessment has also identified a range of other more sophisticated opportunities that further extend the effective flood warning time. These require a more significant commitment to and investment in rainfall and water level monitoring instrumentation, together with associated systems to alert emergency services and individuals to the exceedance of trigger values (i.e. improved monitoring and messaging system with automated elements). Consistent with the Victorian Floodplain Management Strategy, while capital costs may be shared between the Victorian and Australian Governments, all on-going operation and maintenance costs would become a Council responsibility. The assessment report also noted work by the Bureau of Meteorology, VICSES and Emergency Management Victoria on the Automated Alerting Project and the potential this has for alerting to (for example) flash flooding at Coleraine.

In light of the outcomes of the investigation, it is recommended that:

- GHCMA, DELWP and Council adopt the supplied VFD GIS outputs of the investigation as well as formally declaring the flood levels as per the Water Act 1989.
- Council review and adopt the draft planning controls developed as part of this investigation to appropriately manage future development within the town.
- Council undertake a detailed study investigating the mitigation option to construct a levee along the Bryan Creek walking track to reduce the flood risk to the community.
- Council undertake a detailed study investigating the mitigation option for modifications to the Young Street and Robertson Street drain.
- With regards to flood risk and emergency management:

- In the near-term, VICSES in association with Council to engage with the community to improve flood awareness and response during a flood event. This includes sharing flood intelligence captured to the MFEP with the community along with the mapping products and the flood/no flood tools developed as part of this investigation. It is suggested that as a minimum, this will increase effective flood warning time and the opportunity for initiation of appropriate flood response actions by the community as well as additional door knocking and the start of strategic sandbagging by emergency services.
- In the medium term, Council to permanently instrument the Douglas Road site and install staff gauges at the Glenelg Highway Bridge in town to increase flood awareness and community engagement. Together, and particularly if the instrumentation allows automated alerting of emergency services and the community to likely flooding, these measures are estimated to give additional confidence in expected flood severity along with an increase in the time available to implement appropriate flood response actions.
- In the longer-term, Council investment in additional and more sophisticated instrumentation to monitor rainfall and water levels coupled with measures or systems to automatically alert emergency services and individuals to the exceedance of trigger values. It is estimated that together these measures would achieve a further increase in effective flood warning time. However, implementation would require significant investment and long-term commitment from Council.



Title: Coleraine Flood Investigation
1% AEP Peak Flood Depth

Figure: 1

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR

Date: Oct 2018

Filepath:S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.00_DraftFinalReport\Fig1_E01_100y_025_dmax.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au

Contents

List of Figures

List of Tables

Glossary

AEMI	Australian Emergency Management Institute.
Annual Exceedance Probability (AEP)	The probability or likelihood of an event occurring or being exceeded within any given year, usually expressed as a percentage. Is the inverse of ARI.
Average Annual Damages (AAD)	The average damages cost in dollars per year. Due to the infrequent nature of flooding this value does not represent the damages from a particular flood event but represents the average dollar value of damages over a long period of time.
ARI	Average Recurrence Interval.
Australian Height Datum (AHD)	The national height datum that approximately corresponds to the mean sea level around Australia. The level is represented by metres above or below this level.
AWS	Automatic Weather Station.
BoM	Bureau of Meteorology.
Catchment	The area of land that contributes to flooding at a particular location. Includes upstream creeks / tributaries and may cover an area of several hundred or thousand square kilometres.
CMA	Catchment Management Authority.
DEM	Digital Elevation Model.
DELWP	Department of Environment, Land, Water and Planning.
EA	Emergency Alert.
Effective Flood Warning Time	The time available after receiving advice of an impending flood before flood water prevents appropriate flood response action.
EMA	Emergency Management Australia.
EMMV	Emergency Management Manual Victoria.
EMV	Emergency Management Victoria.
ERTS	Event Reporting Radio Telemetry System.
FFWS	Flash Flood Warning System.
Flood Model	A flood model combines both the hydrologic and hydraulic models to represent flooding behaviour at a particular location.
FO	Flood Overlay.
Floodplain	Low lying that is usually dry but may be covered by flood water from time to time. Causes of flooding include when a river or creek overflows its banks, when ocean storm tide inundates low land, or when stormwater ponds in low areas.
GIS	Geographic Information System.
GHCMA	Glenelg Hopkins Catchment Management Authority.
Hydraulic Model	A hydraulic model simulates hydrodynamic flow behaviour of floods. Used to determine extent, level, depth, velocity, hazard of a flood based on flows from the hydrologic model.
Hydrologic Model	A hydrologic model simulates catchment response to rainfall. The model simulates the rate of response and timing of the runoff (rainfall excess) and delay or lag to generate flows at particular locations within the catchment.

ICSM	The Australian and New Zealand Spatial Information Council's Intergovernmental Committee for Surveying and Mapping.
LFG	Local Flood Guide (also referred to as a Flood Action Guide).
LGA	Local Government Authority.
LiDAR	Light Detection and Ranging – ground survey captured by an aerial flyover using a laser. The time delay in laser pulse returns provides the distance, the refraction index of the return laser pulse provides information on the properties of the surface struck. For example, water, soil, tree/vegetation, metal roofing, road, etc. LiDAR is typically post-processed to remove spurious information and forms the basis of the DEM.
LoRaWAN	SGSC's Long Range Wide Area Network.
LSIO	Land Subject to Inundation Overlay
Manning's n	A roughness coefficient that is used to represent the hydraulic roughness of a land use or material.
MFEP	Municipal Flood Emergency Plan.
NDRGS	The Natural Disaster Resilience Grants Scheme
Non-structural flood mitigation measures	Measures aimed at reducing flood risk and flood damages by moving people away from flood waters. Typical measures include land-use planning, flood warning, public awareness and education programs, etc.
PALS	Portable Automated Logger System. Used for the collection of water level and related data and, subject to mobile phone network coverage, remote provision of that data in real time.
Pluviograph	Rainfall vs. time data series, typically reported at either steady time intervals (for example every 30 minutes) or a time is reported each time 0.2 mm (for example) of rainfall is recorded.
PMF	Probable Maximum Flood – the flood resulting from the PMP, very rare event, typically has a 1 in 1,000,000 chance of occurring in any given year.
PMP	Probable Maximum Precipitation – The greatest probable depth of rainfall over a given catchment area. Typically, rarer than a 1:1,000,000 chance of occurring in any given year.
PRG	Project Reference Group.
PSM	Permanent Survey Mark – Marks are managed by DELWP and are distributed throughout Victoria.
QA	Quality Assurance.
Response time (in the context of this investigation)	Time between start of heavy rain and Bryan Creek beginning to rise at Coleraine.
RFMS	Regional Floodplain Management Strategy.
RORB	A node-link conceptual hydrologic modelling package that simulates catchment response and converts rainfall into runoff.
Runoff	The proportion of rainfall that is converted to flow after depression storage, groundwater infiltration, evaporation and evapotranspiration, has been removed.
SGSC	Southern Grampians Shire Council.
SLS	Service Level Specification (a BoM publication).
SMS	Short Message Service (a text).

Stage	The water level above a point. E.g. above the zero mark on a gauge.
Stage – Damage relationship	The relationship between river (flood) height and the amount of damage sustained by the built environment.
TFWS	Total Flood Warning System.
TUFLOW GPU	A 1D-2D implicit (TUFLOW Classic) or explicit (TUFLOW GPU) solver hydraulic modelling package.
UN	United Nations.
VFD	Victorian Flood Database – a database of flood information managed by DELWP.
VFMS	Victorian Floodplain Management Strategy.
VFWCC	Victorian Flood Warning Consultative Committee.
VICSES	Victoria State Emergency Services.

1 Introduction

This document provides a summary of the various hydrologic and hydraulic modelling reports along with the damages, mitigation, planning and flood warning and intelligence assessments undertaken for the Coleraine Flood Investigation commissioned by the Southern Grampians Shire Council in July 2017. The project was delivered by Venant Solutions in association with other leading floodplain management, risk and planning specialist including HARC, Utilis and Michael Cawood and Associates. Whilst this document contains a comprehensive overview of the works undertaken as part of the investigation it is recommended to refer to the individual reports delivered during the course of the study for greater discussion and analysis as many sections have been significantly edited for brevity.

The township of Coleraine is situated on the floodplain near the confluence of Bryan Creek and Konong Wootong Creek. Downstream of Coleraine, Bryan Creek flows into the Wannon River which ultimately feeds into the Glenelg River. Flooding in Coleraine is primarily riverine flooding from Bryan Creek, with flows from the downstream Konong Wootong Creek contributing to backwater effects on water levels in the town.

An additional source of inundation for the town is local runoff which is designed to flow into the Young-Robertson Street drain system comprising of the Railway Reserve and East Park lakes, and connecting drainage corridors, which then flow into Bryan Creek. It must be recognised that flooding in this area is caused by runoff from the south side of town (not Bryan Creek) and may not occur at the same time as a Bryan Creek Flood. Flooding caused by this mechanism is yet to be observed in Coleraine at the time of writing.

The town has a history of flooding with records of at least 7 significant events occurring since settlement in the year of 1870, 1893, 1946, 1975, 1983, 1991, and most recently, in 2016 which inundated several residential, commercial and industrial buildings. Existing flood mapping of the town was produced as part of the 2001 flood data transfer project which provided limited information and is considered quite dated, being based on old analytical techniques.

1.1 Catchment Description

The catchment area for the Coleraine Flood Investigation is located in the western district of Victoria in the foothills of the Grampian ranges as shown in Figure 1-1. Bryan Creek is the primary watercourse that flows through Coleraine and is a tributary of the greater Wannon River system. The catchment originates in the Dundas Ranges which form the northern extent of the catchment near Vasey. The catchment flows in a generally south to south-westerly direction towards the Wannon River. In addition to Bryan Creek there are many smaller contributing waterways within the catchment; including Young, Chin Chap, Hawkins, Log Hut, Robson, Hassall and Konong Wootong Creeks. Of these, only Konong Wootong Creek is included within the detailed Study Area. In total, the contributing catchment covers an area of approximately 403 km^2.

In general, the catchment consists of rolling hills with pasture rising from a level of approximately 76 m AHD at the confluence of the Bryan Creek and Konong Wootong to approximately 400 m AHD over a distance of approximately 30 kilometres. The catchment is therefore quite steep: one of the steepest in the region. As a result, the effective flood warning time is short. Floods rise quickly, and velocities can be high as described by residents who experienced flooding in 2016 The average annual rainfall is approximately 630 mm/year. Land use in the catchment is predominantly primary industries such as agriculture, particularly sheep and cattle grazing.

Within town there are two manmade small lakes located on Young Street and Robertson Street. The Young Street lake is located upstream of the Robertson Street lake. The lakes are connected by an open drain system. The purpose of the Young Street and Robertson Street drain is to capture and redirect flows from the south around the town and towards Bryan Creek. Figure 1-2 shows the Young Street Lake and Figure 1-3 the Robertson Street Lake.

1.2 Objectives of the Flood Investigation

The key objectives of the study were as follows:

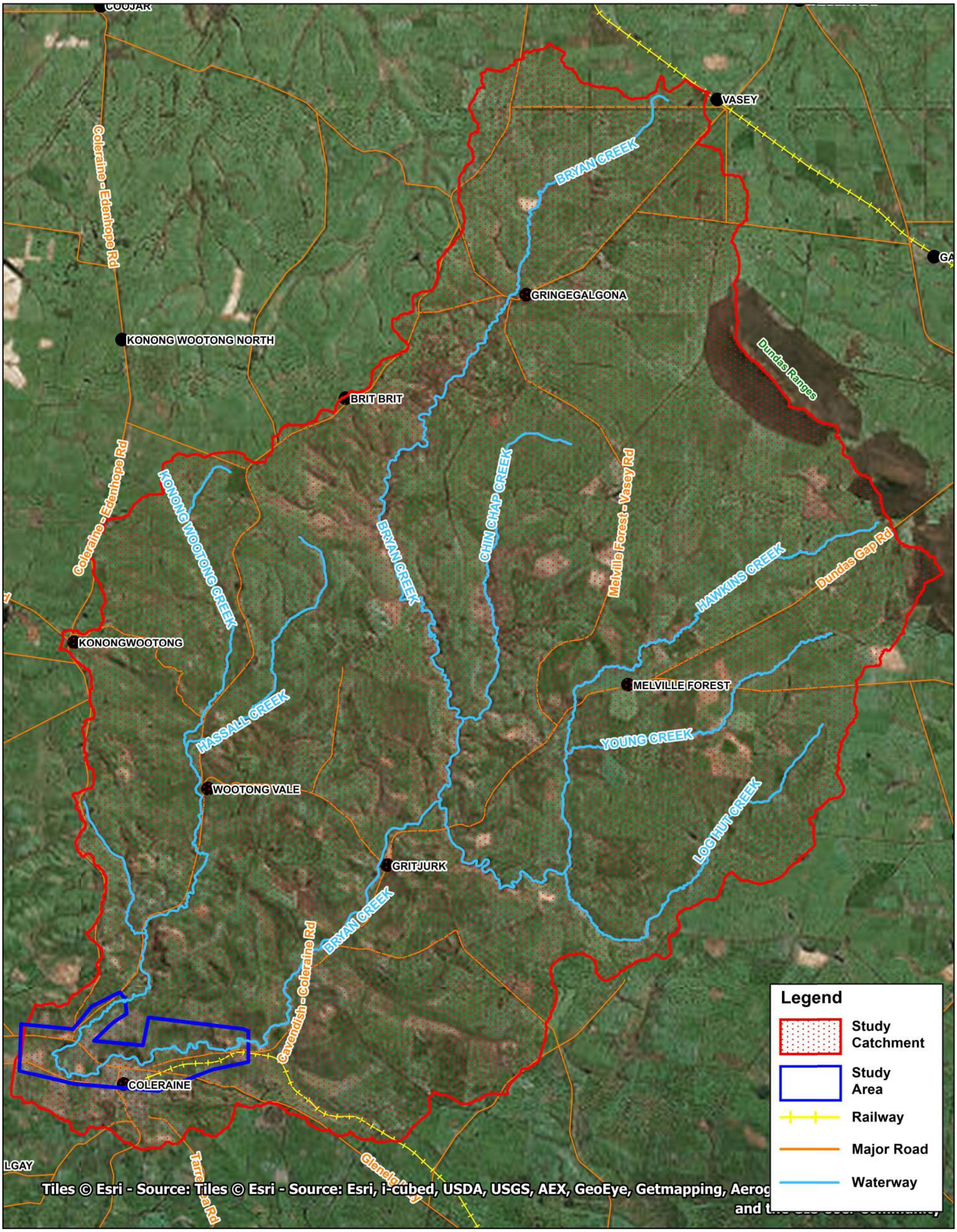
1. To consult and engage key stakeholders throughout the project including the Coleraine community and the Project Reference Group through community consultation. Through this process local knowledge and information is captured and utilised to ensure a robust outcome to the study.
2. To develop new Hydrologic and Hydraulic models that accurately represent the characteristics of the catchment including calibration to historic events and sensitivity analysis.
3. To provide updated flood risk mapping products suitable for inclusion in the Victorian Flood Database and prepare documentation with respect to a potential Amendment of the existing Planning Scheme.
4. To document and prepare emergency management tools such as updates to the Municipal Flood Emergency Plan and to provide an assessment on the feasibility of a Flood Warning System for the Coleraine community.
5. Undertake a flood damages assessment and investigate potential mitigation options to relieve or reduce flooding to the community.
6. Report and create media (including visual media) that documents the process and findings of this study.

1.3 Purpose of this report

This report addresses Objective 6 and provides a summary of the works undertaken to address Objectives 1, 2, 3, 4, 5 and 6. Where necessary this report draws on the reporting from earlier stages of the study which should be read in conjunction with this report when additional information is required. These reports document in detail the methodology and findings of the various stages undertaken as part of the Coleraine Flood Investigation. These detailed technical reports include:

- Coleraine Flood Investigation - Data Report (Venant Solution, 2017);
- Coleraine Flood Investigation - Hydrology Report (Venant Solution, 2018a);
- Coleraine Flood Investigation - Hydraulic Model Report (Venant Solution, 2018b);
- Coleraine Flood Investigation - Flood Damages and Mitigation Report (Venant Solution, 2018c);
- Coleraine Flood Investigation - Douglas Road PALS Assessment (Venant Solution, 2018d); and
- Coleraine Flood Investigation - Flood Warning Assessment (Venant Solution, 2018e).

Readers are encouraged to read the original reports should they require additional information on the methodology undertaken or wish for expanded commentary that has been removed from this summary report.



Title: Coleraine Flood Investigation
Study Catchment

Figure:	Rev:	Scale		By: DR
1-1	A	N 0 2.5 5km Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.00_DraftFinalReport\Fig1-1_Catchment.WOR

Figure 1-2 Young Street Lake and Spillway

Figure 1-3 Robertson Street Lake and Outlet Control (concrete box in front of green fence)

2 Community Engagement

Engaging with the Coleraine community during the course of the study was undertaken to significantly improve the outcomes of the study through both the input of local residents and the opportunity it provides to raise the community's flood awareness. Whilst the community has varying degrees of understanding of the flood risk through historic events and cultural local knowledge, a key delivery of the success of the study was documenting and formalising this knowledge to enable more formal institution knowledge. Institution knowledge is extremely important for organisations such as Council, the CMA and VicSES who may need to plan for as well as respond and act during a flood event. Without formalised knowledge these organisations may not otherwise be aware of historic flooding experienced by the community. Community engagement was undertaken in a variety of formats including:

- Directly through the project team;
- The Project Reference Group;
- Formal community consultation sessions; and
- Informal and ad-hoc one on one meetings with community members.

2.1 Project Reference Group

To ensure a robust outcome for the study a Project Reference Group (PRG) was established to oversee the project and facilitate the communication between the project team and the various stakeholder agencies and the local community. To achieve the aims of the PRG, members represent the various government agencies as well as members of the local community. These individuals and agencies are listed below in Table 2-1.

In addition to facilitating communication between the individual agencies, representatives of the PRG were responsible for feeding back information to their respective agency when required. Where appropriate PRG members were encouraged to contribute by providing input and direction to the study with the aim of improving the project delivery or outcome.

Table 2-1 Project Reference Group

Agency	Representative
Project Team	Dexter Reynolds (Venant Solutions) Brad Henderson (Utilis)
Coleraine Development Association	Howard Templeton (local community member)
Coleraine CFA	Dick McIntosh (local community member)
Department of Environment, Land, Planning & Water	Simone Wilkinson
Glenelg Hopkins Catchment Management Authority	Graeme Jeffery
Southern Grampians Shire Council	Michael McCarthy Rhassel Mhasho
VicSES	Ken Smith

2.2 Community Engagement Meetings

During the study four townhall style community engagement sessions were run by Council at the Coleraine Senior Citizens Hall. These sessions generally took the form of a formal presentation followed by a QA session then discussions with individual members of the community. In attendance at the meetings were representatives from the study team, Council, the GHCMA, VICSES and other members of the PRG.

2.2.1 Session 1: Project Inspection and Data Acquisition

The primary purpose of this sessions was to raise awareness of the flood study and to obtain the following information from residents:

1. Locations of historical flood levels and extents, photos and unofficial rainfall records;
2. Anecdotal information on flooding, e.g. velocity, time to peak;
3. Community's understanding of flood information and flood warnings and their effectiveness.

During the session preliminary mapping was presented to facilitate the community recollections. The community was encouraged to mark the drawings showing their recollection of flood extents. This information was fed back to the model calibration process. Following on from this meeting several members of the community were met 1 on 1 to further discuss their experiences; refer to Section 2.3 below.

2.2.2 Session 2: Model Calibration & Mitigation "Optioneering"

The primary purposes of this session was to seek feedback from the community on the model calibration and to obtain input on potential mitigation measures. Attendees were shown large plans of the flood extents and animations for each calibration event as well as the draft 1% AEP flood extent. The attendees were asked to comment on how the model results match their recollections of the flooding. Generally, the community were supportive of the modelling presented with a few minor suggestions for improvement where the modelling was slightly divergent locally from the observed. This information was then fed back into the modelling process for final calibration runs.

The community was also asked for their thoughts on any mitigation options that they would like to see investigated further. A list of options was then compiled and voted upon by the community, an example voting sheet is shown in Figure 2-2. These were collated and discussed with the PRG at the conclusion of the meeting and led to the adoption of five options for further investigation.

2.2.3 Session 3: Mapping, Damages, Mitigation & Planning

This session provided the community with updated calibration mapping as well as final mapping showing the full suite of design flood events. The outcomes from the flood damages and mitigation assessments were also presented.

During the session the draft planning maps were presented and discussed with the community.

2.2.4 Session 4: Flooding Warning, Intelligence, Visual Media & Conclusion

The primary purpose of this session was to provide the community with a summary of the findings of the flood warning feasibility assessment as well as present the visual media documentary. The visual media documentary provides an overview of many of the findings and key information in an easy to digest format and provides a record of the works undertaken as part of the study.

2.3 Direct Community Engagement

In addition to the town hall style more formal community meetings several 1 on 1 meetings were held with various members of the community. These are detailed in Section 3.3.

Figure 2-1 Community Members Viewing Mapping during the 1st Community Engagement Meeting

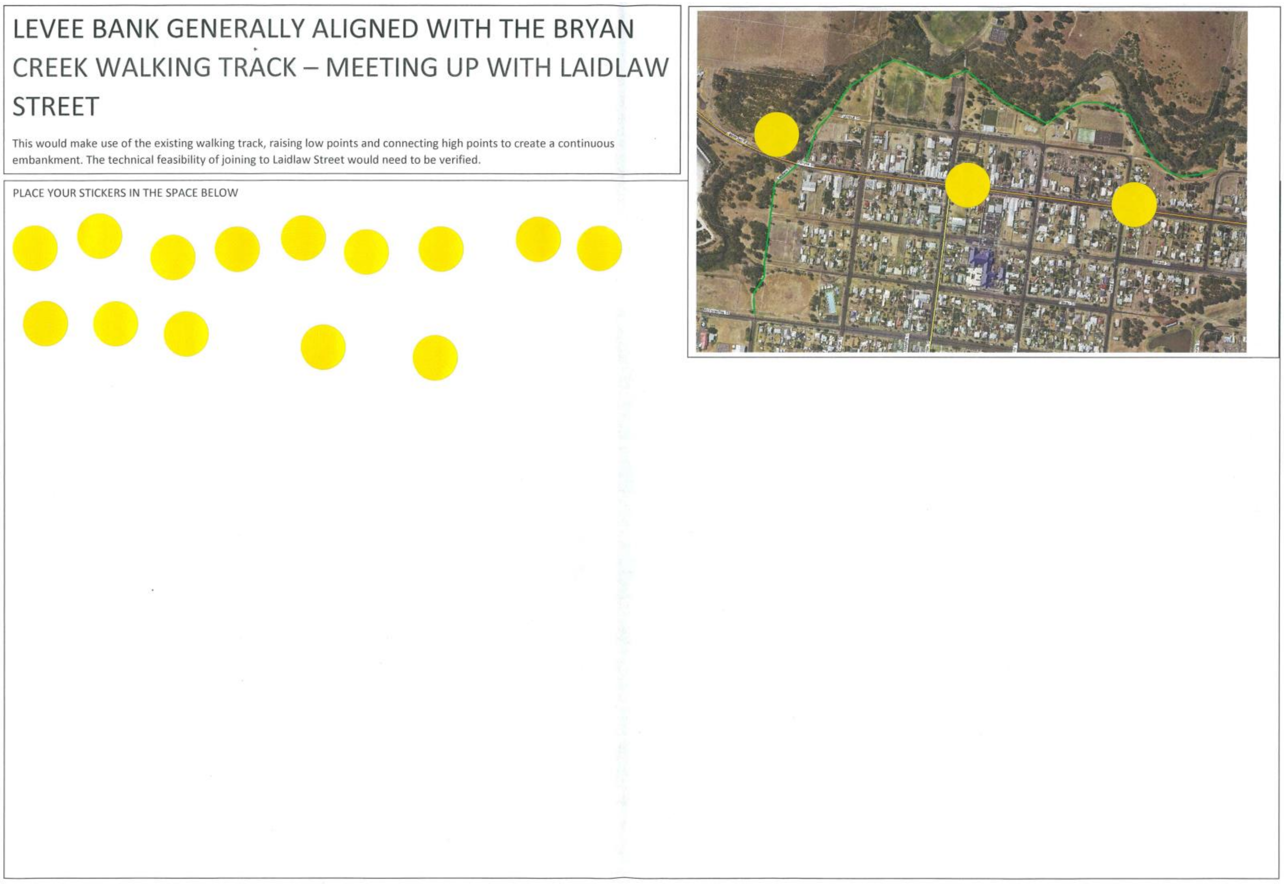


Figure 2-2 Example Mitigation Voting Sheet from the 2nd Community Engagement Meeting

3 Data

This section provides a summary of the data collection undertaken as part of the Coleraine Flood Investigation, additional information can be found in the individual technical reports listed in Section 1.3. A comprehensive data collection and collation process was undertaken to ensure that the best possible data was used to guide and inform the Coleraine flood investigation.

3.1 Data Sources

Data was sourced from various agencies and individuals. We thank these agencies and individuals for their contribution to the success of this study:

- Glenelg Hopkins CMA (GHCMA);
- Southern Grampians Shire Council (SGSC);
- Department of Environment, Land, Water and Planning (DELWP);
- VicRoads;
- Bureau of Meteorology (BoM);
- Coleraine Historical Society; and
- Members of the local Coleraine Community.

3.2 Historic Information

As part of the investigation, Utilis undertook research into historic flood events for Coleraine and spent Tuesday 1 August with volunteers of the Historic Centre and members of community. There are varying amounts of flood information for the known flood events. In each case, there has been stories of tragic loss, damage, heroism and community spirit. In its handbook – "Managing the floodplain: a guide to best practice in flood risk management in Australia" – the Australian Emergency Management Institute defines minor, moderate and major flooding as:

Minor flooding causes inconvenience such as minor roads closures and the submergence of low-level bridges. The lower limit of this class of flooding on the reference gauge may be the initial flood level at which landholders and townspeople begin to be flooded.

Moderate flooding refers to the inundation of low-lying areas, which requires stock to be removed and/or some houses to be evacuated. Main traffic routes may be covered.

Major flooding refers to when appreciable urban areas and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

Based on the testimony of residents and that from the research of historic news articles, each of the known floods and storms were classified as minor, moderate or major. These are summarised in Table 3-1.

3.2.1 Summary of Coleraine's Flood History

Table 3-1 Summary of Coleraine's flood history

Flood Event	Severity Estimate	Comment
1852	Unknown	The obituary of Dawson McKerbey who died in 1916 references a big flood in 1852 that he experienced.
October 1870	Major	The Albion newspaper reported 11 lives lost during event. The Albion also reported on the speed and severity of the event. 'The flood came with such awful suddenness and disappeared so rapidly, that the shock to the system of many made way for incredulity'.
September and October 1893	Minor to Major	From 1 September to 20 October there were at least three flood events through Coleraine. The largest flood through this time occurred on Sunday 24 and Monday 25 September. It was reported in the Hamilton Spectator on 26 September that the flood may have been the equal or larger than 'the great flood' of 1870. No lives were lost, but 1,970 sheep were said to have been destroyed. Further, the rainfall total in the area over the two days was said to be 2 inches 41 points (~65 mm).
March 1946	Major	Over the three days of 15-18 March 1946, the most widespread flooding ever recorded occurred across the western district. Coleraine's rainfall to Saturday 16 March at 6:00 pm has been reported to be 122 mm. Extensive damage – no lives at Coleraine lost.
September 1975	Minor	The Spectator reported on 27 September 1975 that flooding reached back streets with sandbagging undertaken as a precautionary measure.
September 1983	Moderate	The Melville Forest BoM gauge received 29.6 mm on 8 September and a further 20.6 mm the following day. This resulted in a flood event that covered much of Turnbull Street and the Western end of Whyte Street. The Tippett Butcher shop at number 108 Whyte Street was flooded above floor.
August 1991	Minor	Little is known about the flood event that occurred in August 1991. Photos received from Kathy Hutchins show flooding at the corner of Gage and Turnbull Street along with flooding of the Tippett butcher shop (108 Whyte Street).
December 2010	Minor	Despite heavy rain, this flood was significantly smaller than the September 1983 event.
September 2016	Major	There is a significant record of photos and testimony from residents in the wake of the flood. For residents with or without flood experience in Coleraine – a common refrain is that this flood came quickly. It is noted that similar behaviour was recorded as having occurred during the 1870 flood event. Within about an hour, the flood had presented to the town and peaked between 8-10am in the morning. The flood caused extensive damage and several residents were evacuated. This flood event has caused emotional injury among many residents.

3.3 Community Flood Intelligence

Direct engagement with the community provided valuable information that enabled the modelling to be verified with a higher level of confidence than would otherwise have been possible. The direction, level and velocity of the historical floods can be verified by photos, video and testimony of residents. This section documents the testimonials collected from the community.

3.3.1 Flood Intelligence - 65 Turnbull Street

The late Di McDonald - 65 Turnbull Street - experienced flooding at her property on several occasions.

Figure 3-1 Di McDonald (dec.) out front of her house 65 Turnbull St

Di had a wealth of knowledge of the creek and has experienced both the 1983 and 2016 floods first hand. While her house was not flooded above floor, her property was extensively damaged. Her home was built in 1947, a year after the devastating 1946 flood. She attributes the floor level being built above the 1946 flood level as the reason the 2016 flood did not enter the house. Di commented on the unusual swiftness of the flood waters rising. As a resident that knows the creek well, she has experienced floods that were slower to rise, but far louder. The 2016 flood was unusual to Di as she could not hear it coming unlike previous floods. Di was evacuated through the back fence of her property and acknowledges the work of Vickery Bros. staff in getting her out and sandbagging her home.

VENANT SOLUTIONS

3.3.2 Flood Intelligence - 75 Turnbull Street

Del Coward- 75 Turnbull Street Coleraine was evacuated during the 2016 flood.

Figure 3-2 Del Coward out front of 75 Turnbull St

Although the house was not flooded above floor, her property was extensively damaged and her car was damaged beyond repair. Her testimony supports that of all other residents – that the most significant feature of the 2016 flood was its rapid rise to peak. The flood waters pooling under her house after the flood caused extensive nuisance as well.

3.3.3 Flood Intelligence - 108 Whyte Street

Teagan and James Beaton were living at 108 Whyte Street when the flood hit. At 7.15 am when Teagan looked out the backyard to see only puddles. By 8.15am they were evacuating.

Figure 3-3 Teagan Beaton showing flood level at 108 Whyte St

In the image above – Teagan is pointing out the peak level of the floodwater on the fence in the backyard. Bryan Creek is about 500 m behind this fence and the curvature on the iron was caused by the force of floodwater against it. Teagan and James have provided numerous photos from the flood. The damage is still evident today as is the height of the floodwater in the house.

Figure 3-4 Flood Mark Visible at 108 Whyte St

3.3.4 Surveyable Flood levels

From the consultation and independent research undertaken, 8 additional flood levels, beyond those already collected by the GHCMA, were identified and surveyed for the September 2016 flood event. The location and details of the flood levels surveyed are documented below in Table 3-2. These survey marks were collected and included in the joint calibration of the hydrologic and hydraulic models, refer to Section 4.3.

Table 3-2 Surveyed Flood levels

Address	Location Description	Evidence	Flood Date	AHD	Peak	Mark reliability
110 Whyte St	Top of the window sill, east side of house	As per Coleraine Albion report, 11 April 1946	16/03/1946	85.63	Y	medium
110 Whyte St	Front veranda deck level	Peak was "just below the top of the veranda" according to newspaper report.	10/09/1983	84.62	Y	high
108 Whyte St	Taken from 20mm below the bottom of 2nd weatherboard above veranda deck level, east side of house	Tippets Butchers as per silt line visible in 1983 photo from Hamilton Spectator	10/09/1983	84.64	Y	high
105 Whyte St	At the base of Vickery Bros. workshop roller door.	As per testimony from Geoff Vickery	27/08/1991	84.48	Y	high
Power Pole – Gage St	At the base of power pole in front of dividing fence between 1 & 5 Gage St.	This is an "at least level" for the 1991 flood based on photography.	27/08/1991	84.38	N	high
Nature Strip – Gage St	On the nature strip in front of 5 Gage St. Position marked by orange peg.	Estimated from 1991 historical flood photo	27/08/1991	84.54	Y	high

Address	Location Description	Evidence	Flood Date	AHD	Peak	Mark reliability
Post Office	On top of the Post Office front step - east (Hamilton) end	As per Coleraine Albion report, 11 April 1946	16/03/1946	86.21	Y	medium
82 Whyte St	At the base of the vertical board on the double doors, Winter St side of building	As per historical photo and testimony - L.McDonald	16/03/1946	86.39	Y	medium

3.4 Gauge Data

3.4.1 Streamflow Gauges

There are numerous streamflow gauges located around the Bryan Creek catchment but none within it. The streamflow gauge stations used in the hydrological investigation are shown in Table 3-3. Streamflow data was downloaded from the Department of Environment, Land, Water and Planning (DELWP) water monitoring site (http://data.water.vic.gov.au/monitoring.htm).

Table 3-3 Streamflow Gauge Data used for Calibration and Verification

Station No.	Name	Date of Available Data	Maximum Gauged Level (m)	Maximum Recorded Level (m)	Date Maximum Recorded Level	Catchment Area (km^2)
238223	Wando River @ Wando Vale	15/04/1964 – current	2.93	3.10	18/09/1978	174
238228	Wannon River @ Henty	27/02/1967 – current	5.20	5.83	08/09/1983	269
238219	Grange Burn @ Morgiana	08/07/1963 - current	4.96	5.37	31/08/2004	997
238220	Dundas River @ Cavendish	11/07/1963 - current	4.57	4.63	14/09/2016	211

3.4.2 Rainfall Data

Three data sources were available to determine the amount of rainfall that fell over different parts of the catchment (spatial pattern) for each of the historical events, namely:

- Australian Water Availability Project (AWAP) (Raupach et al., 2009);
- Pluviographs; and
- Daily Rainfall Gauges.

3.4.3 Previous Investigations

In June 2010 Cardno calibrated four RORB models on the surrounding catchments, Grange Burn, Henty Creek, Dundas River and Wando River. The RORB models and associated storm files were supplied by the Glenelg Hopkins Catchment Management Authority. These calibrated catchments were used to inform the decision on the appropriate RORB model parameters for the Coleraine area.

3.5 Topography

Topographic data based on aerial captured ground survey, otherwise known as LiDAR, was used to generate a Digital Elevation Model (DEM) of the study area. The DEMs form the basis of the hydraulic modelling. The topographic data sourced for this assessment are summarised in Table 3-4 below. The coverage of the two high resolutions LiDAR datasets are shown in Figure 3-5.

Table 3-4 Summary of Topographic Data

Dataset	Resolution	Quoted Accuracy	Supplier	Comment
ISC Rivers (2010)	1m	Horizontal – 0.3m Vertical – 0.2m	GHCMA	
South Western Towns Project (2015)	1m	Horizontal – 0.3m Vertical – 0.1m	DELWP	Flown March 2016. Does not cover the full hydraulic study area
VicMap 2008 DTM 20m	20m	Horizontal – 12.5m Vertical – 5.0m	DELWP (formally DEPI/DSE)	The catchment topography was assessed using this data set. Not used for hydraulic modelling
Bryan Creek Ground Survey	N/A	N/A	GHCMA	Survey believed to be undertaken in late 2007. Survey extracted from supplied HEC-RAS Model. Additional cross-section survey was undertaken in 2017 at a number of these to compare waterway bed changes. See below for additional details.
Permanent Survey Marks	N/A	Horizontal – scaled off 1:100,000 maps Vertical – 1mm	DELWP	
Spot Survey	N/A	Horizontal < 40mm Vertical < 20mm	GHCMA	Ground survey & flood mark survey

3.5.1 Bryan Creek Cross-Section Changes

Based on GHCMA experience the channel morphology of Bryan Creek has been historically affected by large volumes of in-stream sand. An additional check was undertaken to validate the channel morphology information applied in the hydraulic model. This involved re-survey (undertaken in late 2017) of five of the river cross sections surveyed in 2007. The results of this check revealed that the Bryan Creek bed morphology has changed little since 2007. The minimal changes that are evident could easily be attributed to slight horizontal changes in the survey peg locations. Only one pool showed significant aggradation, approximately 1.0 metre higher in the 2017 survey.

3.5.2 Summary of LiDAR Verification

The LiDAR datasets form the basis of the hydraulic modelling and were reviewed and validated against other known levels in the study area. A review of the two high resolutions LiDAR datasets provided for this flood investigation was undertaken by comparing the LiDAR DEMs with other known survey information. From this assessment it was determined that the South Western Towns LiDAR data, whilst having a slight positive bias (typically within ± 100 mm), was overall suitable for the purposes of this assessment.

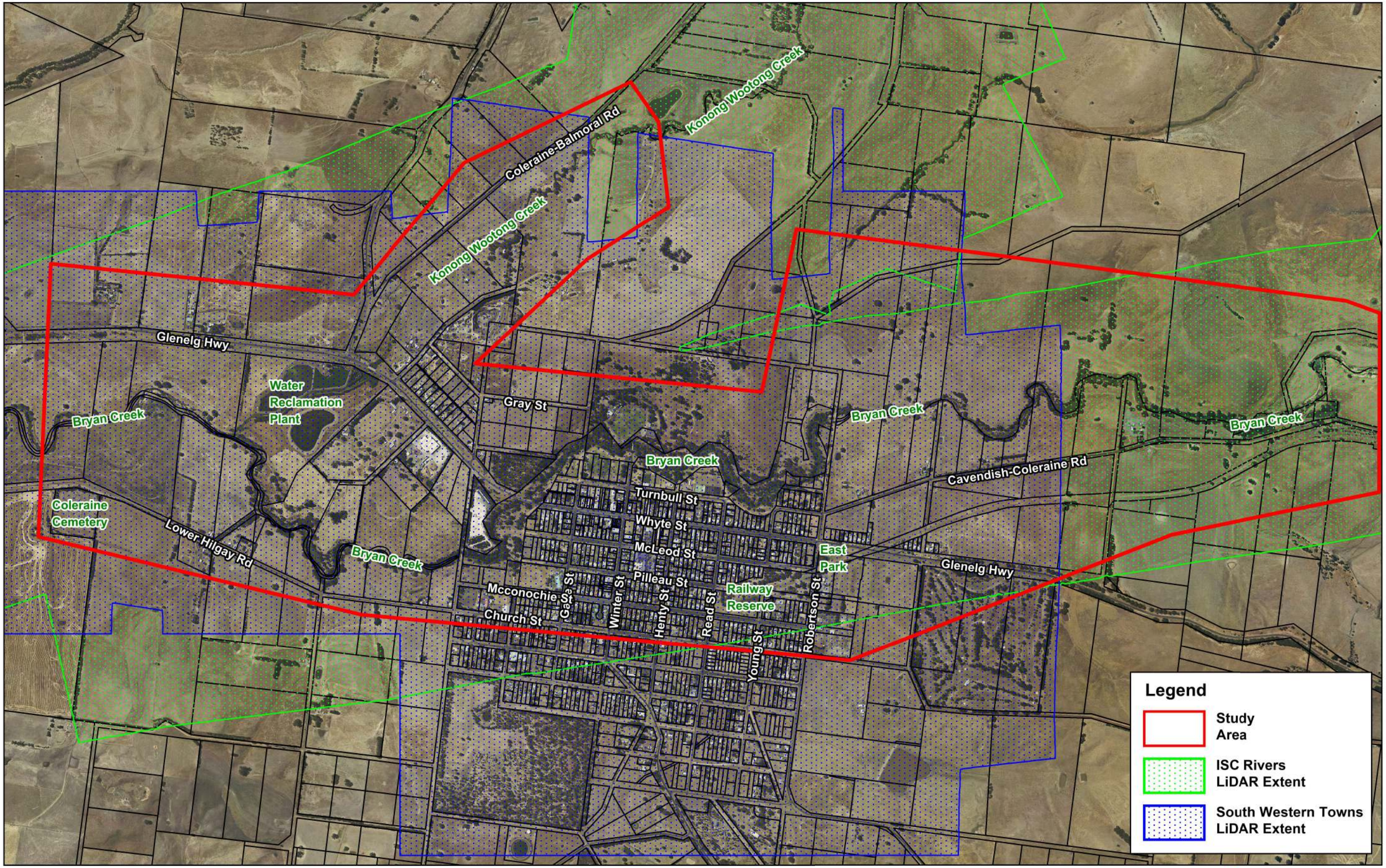
The ISC Rivers LiDAR meanwhile was found to have a significant high bias suggesting a systematic error in the data capture by the supplying organisation. A review of the data suggests a systematic error in the LiDAR of roughly 300 mm. This was discussed with GHCMA who agreed that for the purposes of the study this LiDAR dataset would be universally lowered by 300 mm. Once adjusted the ISC Rivers LiDAR showed a significant improvement to the overall fit to the comparison survey data, though the fit was not as good as the South Western Towns LiDAR and was therefore only used in areas not covered by the South Western Towns LiDAR.

3.6 Hydraulic Structures

Hydraulic structures consist of culverts and bridges that convey storm or flood waters through embankments. Riverine flooding from Bryan and Konong Wootong Creeks was the focus of this study and not a detailed local stormwater flood assessment. Therefore, the three main hydraulic structures within the study area are the two bridges on the Glenelg Highway and the bridge on Winter St over Bryan Creek that connects the Queens Park oval with the town. Details for these bridges were provided by SGSC and VicRoads with the dimensions sanity checked in the field by Venant Solutions staff using a laser measure.

Whilst the focus of the study is on riverine flooding, an assessment of local catchment runoff along the Young-Robertson Street drain which consists of the Coleraine Railway Reserve and East Park was a requirement of the study. Within the reserves are the two manmade lakes and several culverts along the drain. A review of the two lakes showed that, as configured, there is minimal flood storage capacity because the permanent water level, controlled by an overflow spillway in the case of the Young St lake and a gloryhole outlet structure for the Robertson Street lake, keep the lakes close to full capacity. The Young Street lake spillway and lake level are shown in Figure 1-2, whilst Figure 1-3 shows the Robertson Street lake permanent pool outlet control structure. Both photos were taken standing on the spillways. Based on the 1% AEP flood results, both lakes reach approximately 2 metres above the permanent water level under flood conditions.

The culverts along the drain were field surveyed by Venant Solutions staff using a laser measure. The culvert inverts were matched to the LiDAR ground level data adjacent to the pipe inlets and outlets.



Title: Coleraine Flood Investigation
Study Area and LiDAR Coverage

Figure: 3-5

Rev: A

N

0 250 500m
Approx. Scale

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.00_DraftFinalReport\Fig3-5_LiDARCoverage.WOR

By: DR

Date: Oct 2018

4 Flood Model Development

This section summarises the hydrologic and hydraulic model development element of the investigation.

4.1 Hydrologic Model

A rainfall runoff model, RORB, was established for the catchment. RORB (Laurenson and Mein, 1995; Laurenson et al., 2010) is a general runoff and streamflow routing program that is used to calculate flood hydrographs from rainfall and other channel inputs. It subtracts losses from rainfall to determine rainfall excess and routes this through catchment storages to produce streamflow hydrographs at points of interest.

4.1.1 Model Layout

The rainfall runoff model RORB was used to model the rainfall-runoff relationship of the catchment. In general terms, development of a RORB model entails sub-dividing the catchment into a series of subareas to suit the catchment topography and other features such as the location of gauging stations and storage locations. The key RORB model schematisation is presented in Figure 4-1.

4.1.1.1 Adopted routing parameters

Following a comprehensive calibration and parameter translation from neighbouring gauged catchments appropriate routing parameters for the Coleraine catchment were determined.

4.1.2 Design Flood Hydrology

The 20%, 10%, 5%, 2%, 1% and 0.5% AEP and PMF hydrographs were required for input into the hydraulic model. In order to generate hydrographs the RORB model was run in the joint probability framework described in Section 4.

For the hydraulic model, hydrographs were extracted for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and PMF flood events the peaks of which are presented in Table 4-1.

Table 4-1 Peak Flows (m^3/s) from RORB model for Design Hydrographs

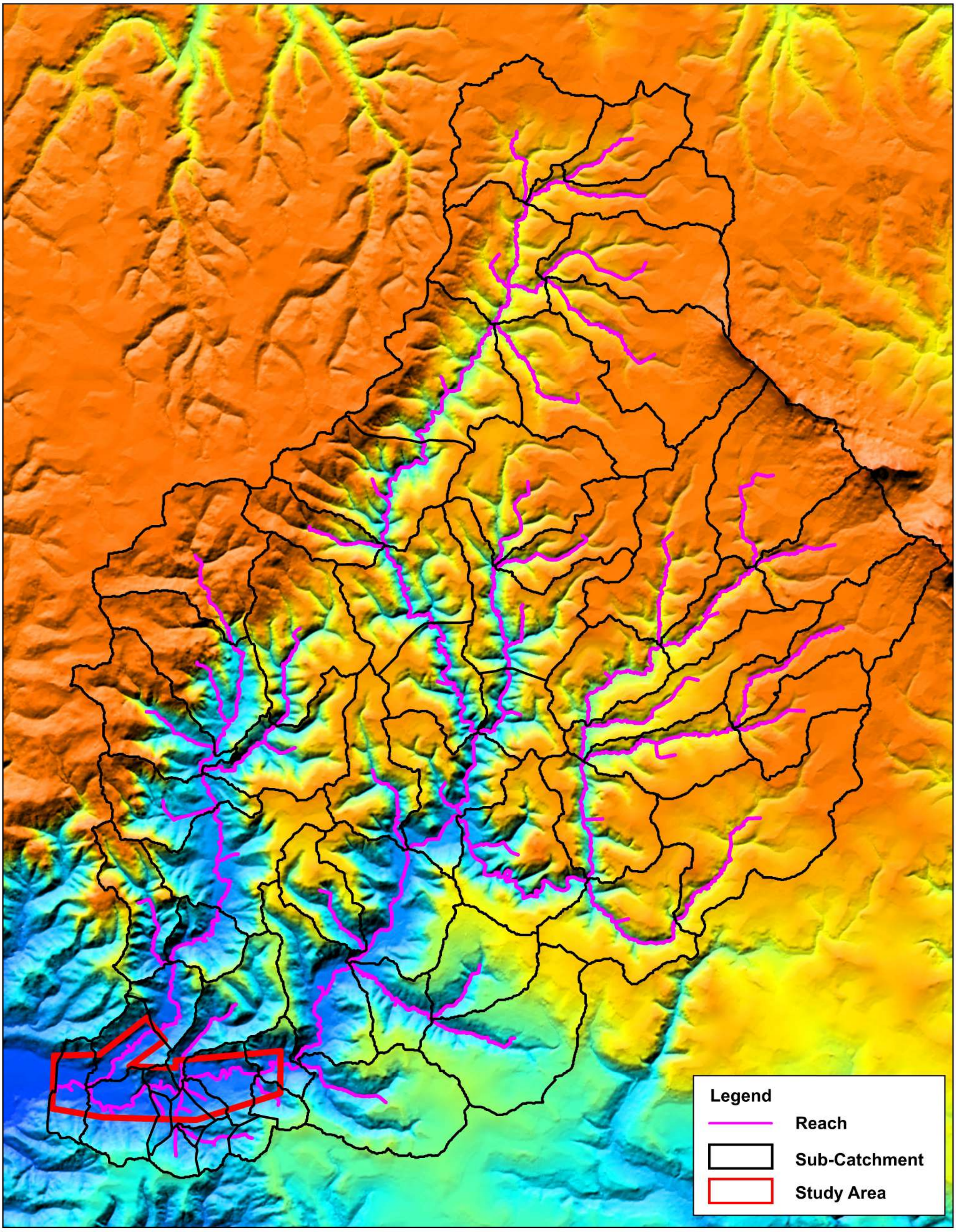
Location	AEP (%)						
	20%	10%	5%	2%	1%	0.5%	PMF
Upstream of Young Street Lake	3.6	5.5	7	9	12	14	91
Upstream of Town	41	71	110	183	247	321	4810
Konong Wootong Creek (upstream of Bryan Creek confluence)	20	33	49	74	96	121	1304
Downstream of Town	50	87	134	222	302	395	5851

4.1.3 Hydrologic Model Quality Assurance & Independent Review

To ensure that the hydrologic modelling undertaken are fit for purposes an extensive internal Quality Assurance (QA) review was undertaken. This review was undertaken by the Peter Hill who has extensive experience in the development of hydrologic models and in undertaking peer reviews. The QA review considered all modelling inputs and model outputs. Whilst not intended as an exhaustive list, the review considered the following aspects:

- Modelling methodology and fundamental model schematisation; and
- Model parameters were within typical ranges expected and unrealistic parameters were not being applied.

As per the DELWP peer review process mentioned above, the hydrologic modelling methodology and assumptions underwent blind review by 2 expert reviewers. A traffic light style report is generated by this review whereby any issues identified as “Red Light” (significant issues) trigger essential re-work before the hydraulics element of the project is accepted as final. No Red Light issues were identified by the DELWP peer reviewers who assessed the methodology and assumptions for the hydrologic element of the project.



Title: Coleraine Flood Investigation
RORB Model Schematisation

Figure:	Rev:	Scale	Disclaimer	By: / Date:
4-1	A	0 2.5 5km Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: DR Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.00_DraftFinalReport\Fig4-1_RORB_Setup.WOR

4.2 Hydraulic Model

4.2.1 Hydraulic Model Development

To determine the various mapping outputs required for the study, specifically flood extent, flood depth, velocity, hazard and other hydraulic properties, a two-dimensional (2D) hydraulic model was developed. For the Coleraine Flood Investigation study, a linked 1D/2D hydraulic model was developed using TUFLOW Heavily Parallelised Compute (HPC).

Within the TUFLOW HPC model the waterway and floodplain were represented in the 2D domain, with culverts represented as embedded 1D elements. The model was developed primarily to assess flood risk to Coleraine from riverine flooding from Bryan Creek and the Konong Wootong Creek. Model runs were performed with the latest version (at time of model construction) build of TUFLOW HPC.

4.2.2 Modelling Events

The hydraulic model was run for the following events and scenarios:

- 1946, 2010, 1983 and 2016 historic flood event;
- Design Events – 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP flood events and the PMF; and
- Sensitivity testing including:
  - Changes in Manning's 'n' under the 1% AEP flood conditions;
  - Increase in rainfall intensity due to Climate Change; and
  - Effects of inlet blockage of structures during a 1% AEP flood event.

4.2.3 Topography and Grid Resolution

The geometry of the 2D floodplain and watercourses were established by reading in a uniform grid of square elements from the LiDAR DEMs. Bathymetry along Bryan Creek was included in the model based on the 2007 and 2017 survey cross-section data. Ground based survey was also captured along the walking track beside Bryan Creek. This data was used to reinforce the topography of the walking track within the hydraulic model.

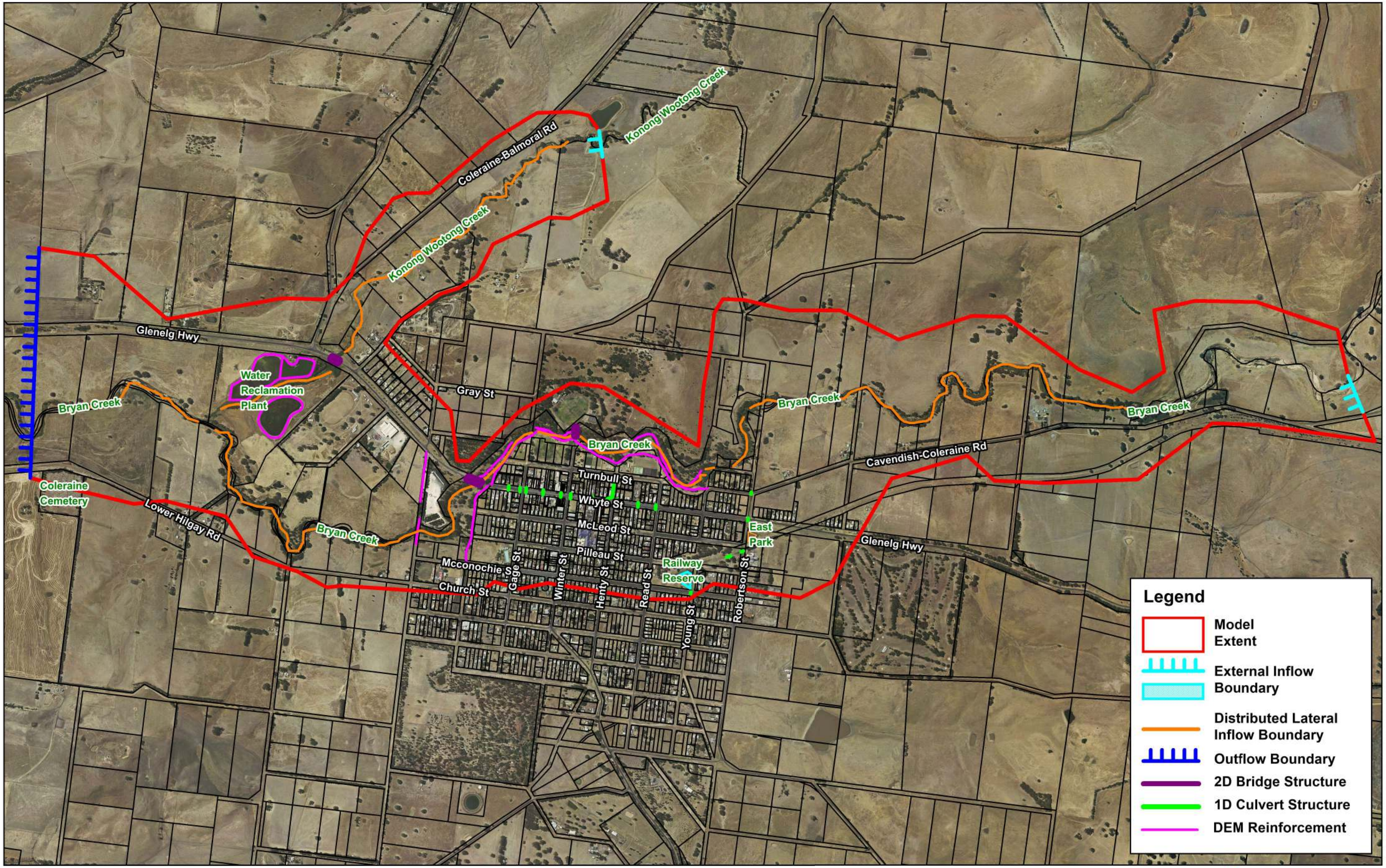
To ensure accurate representation of flooding within the catchment a grid size of 2 metres was adopted for model. In adopting this grid size, the above issues were considered in conjunction with the final objectives of the study.

4.2.4 Surface Roughness

The surface roughness layer, or Manning's 'n' layer, for the floodplain was based on:

- Areas of different land-use (as indicated by the planning scheme);
- Orthographic aerial photography; and
- Drone captured aerial video of Bryan Creek in June 2016 (pre flood) and during the September 2016 flood event.

The roughness schematisation was further confirmed during the site inspections. Initially these values were based on standard texts such as Open Channel Hydraulics (Chow 1959), but they were refined during the calibration and validation process.



Title: Coleraine Flood Investigation TUFLOW Schematisation	Figure: 4-2	Rev: A	N 0 375 750m Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.
Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-2_TUFLOW_Schematisation.WOR				By: DR Date: Oct 2018

4.3 Joint Model Calibration & Validation

Calibration of models to real world data is critical to ensure their outputs can be relied upon. Best practice in model calibration considers all available historic information, which typically would include stream gauge, historic flood extents and levels. The Coleraine catchment is ungauged. Therefore no stream gauge (flow) information exists to assist model calibration. Successful calibration to historic flood levels was therefore critical for Coleraine to demonstrate the model's ability to replicate the natural flood processes and provide confidence in the modelling outputs.

Due to the lack of stream gauge information a joint calibration (to historic flood levels) process was undertaken with the hydrologic and hydraulic models. For this study a multi-step model calibration and validation process was undertaken. The specific steps in the calibration and validation process undertaken for this study are outlined below:

(1) Collect and verify if possible relevant historic data including flood levels and historic photography and existing reports. This includes getting survey based on the historic data;

(2) Event selection;

(3) Hydrologic modelling using neighbouring catchment models and gauge information to inform hydrologic parameters;

(4) Optimise the TUFLOW model parameters for the calibration event within typical bounds;

(5) Jointly iterate the hydrologic and hydraulic modelling through a feedback process; and

(6) Validate the TUFLOW model against three independent flood events.

The following section documents the results of the calibration and validation process whilst the adopted parameters are documented above in Section 4.2.1.

4.3.1 Historic Calibration and Validation Event Selection

For this study the hydraulic model was calibrated to the event with the greatest amount of available data (September 2016). Through the calibration process parameters were adjusted within typical bounds until an acceptable fit to the historic flood levels was achieved.

The model was then validated by running three different flood events (December 2010, September 1983 and March 1946) in the hydraulic model and comparing the model outputs to the historic flood levels for those events. Only the hydrologic inputs were altered through the validation process with no changes made to the hydraulic model. The approximate AEP of each event is provided below in Table 4-2.

Table 4-2 Historical AEP of Rainfall Compared to AEP from RFFE and RORB

Event	AEP of Rainfall*	AEP from RFFE	AEP from RORB Verification
2016	1 in 10 – 1 in 20	1 in 400^	1 in 50
1983	1 in 5 – 1 in 10	1 in 50	1 in 30
1946	1 in 200 – 1 in 500	1 in 20,000^	1 in 200
2010	1 in 5	1 in 3	1 in 5
1870	Details unknown, larger than 1946 according to anecdotal information		

* Approximate AEP only as this varies depending on the length of time assumed for the event

^ The RFFE method (regional flood frequency estimation) only gives estimates up to and including the 1 in 100 AEP event, to produce the reported rarer AEP events the slope of the RFFE has been extended

4.3.2 Hydraulic Model Calibration Event – September 2016

The September 2016 event is not the largest event in living memory; that honour belonging to the March 1946 flood event. However, it is the largest event in recent history and has the most data to aid the calibration process of the model. Twenty one September 2016 flood levels were recorded by GHCMA throughout the study area.

Figure 4-4 presents the modelled flood extent along with a comparison to the flood levels. Overall a very good calibration was achieved with 17 of the 21 flood levels within ±100 mm. This is particularly pleasing given the lack of river gauge data in the catchment to provide some certainty in the flow rates. The remaining flood levels were also reasonably good with all but one flood mark within ±200 mm. A statistical assessment comparing the modelled and observed flood levels is presented in tabular format in Table 4-3 and graphically in Figure 4-3. These reinforce confidence in the level of calibration of the model to historical floods with the differences tightly bunched around the mean.

A comparison of a select few of the photographs and drone footage of the flood provided by the community is provided below in Table 4-4. In these comparisons the pink dot shows the approximate location of the photographer/drone with the arrow signifying the view direction. The solid blue line and shaded areas shows the modelled flood extent for the event.

Table 4-3 Statistical Comparison of Observed and Modelled Flood Levels - 2016 Flood Event

Data Source	Modelled - Observed
No. of PSM points	21
Mean (m)	0.00
Median (m)	0.02
Standard Deviation (m)	0.09
Lower Quartile (m)	-0.07
Upper Quartile (m)	0.06

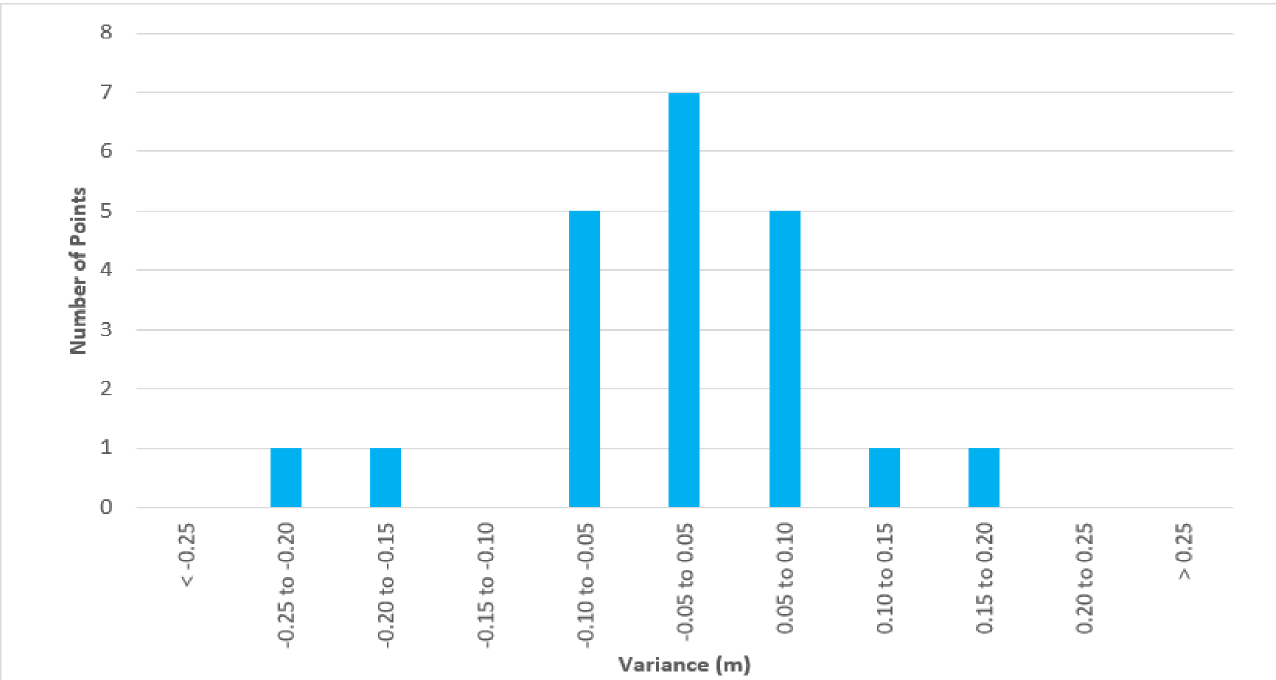


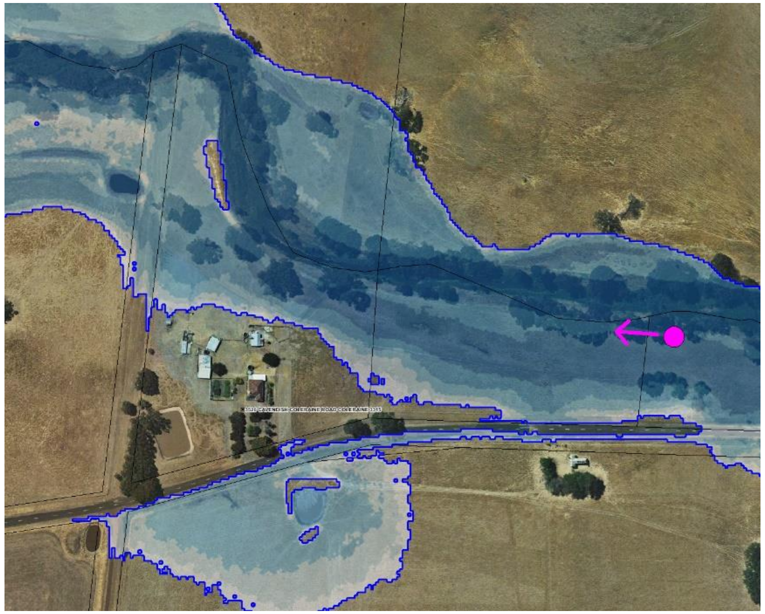
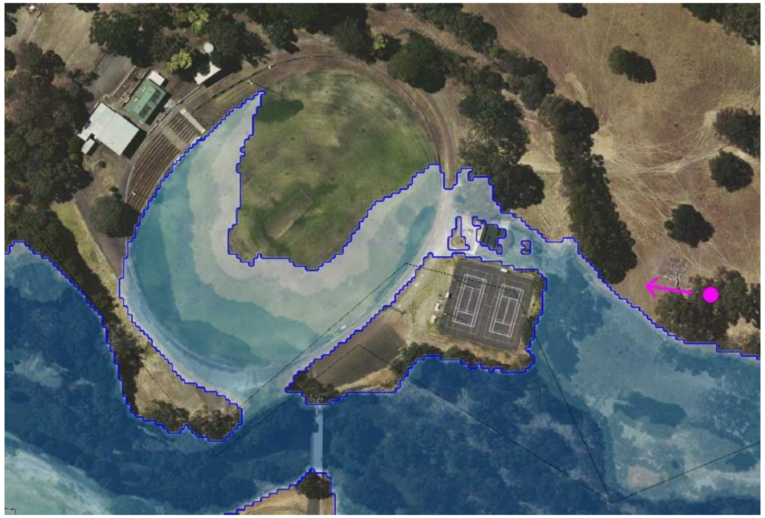
Figure 4-3 Histogram of Observed and Modelled Flood Levels - 2016 Flood Event

Table 4-4 Comparison of Photography and Modelled Flood Extent - 2016 Flood Event

Description	Photography	Flood Model Extent
Flooding along Whyte St. Photo taken between 88 and 90 Whyte St looking eastwards. Both model and photo show flooding up to the end of the car parking bays. Photo provided by Jac Bailey.		
Flooding along Whyte St. Photo taken in front of 99 Whyte St looking westward. Both model and photo show flooding over the road beginning near the intersection of Whyte St and Gage St. See drone footage below for a difference perspective. Photo provided by Jac Bailey.		

VENANT SOLUTIONS

Description	Photography	Flood Model Extent
Flooding at the intersection of Read and Turnbull St. Photo taken in front of 5 Read St looking towards Bryan Creek. Both model and photo show flooding over the crown of the road approximately in line with the driveway of 2 Read St. Photo provided by Jac Bailey.		
Flooding along Gage St, taken above Whyte St. Model matching drone footage. Flood waters extend up to McLeod St with the crown being crossed in front of 15 Gage St. Flooding also matching at the carpark between 103 and 105 Whyte St. Drone footage provided by David Vickery		

Description	Photography	Flood Model Extent
Flooding near 3526 Cavendish-Coleraine Road. Note: drone footage taken after peak. Model matching drone footage well. On the northern (right) side of the images the flood waters extend to the two trees clearly visible in the aerial photography in the flood model results. Evidence of flooding to the south of Cavendish-Coleraine Road. Drone footage provided by David Vickery		
Flooding of Queens Park Oval. Note: drone footage taken after peak. Model matching drone footage well. Floodwaters flowing around tennis courts. Flood waters within the oval extend on the pitch in a crescent up to the northern most building. Flood waters re-join Bryan Creek in the area immediately after Winter St bridge. Drone footage provided by David Vickery		

4.3.3 Hydraulic Model Validation Event – September 1983

The September 1983 flood event was significantly smaller than the event in September 2016. No flood level data existed for the 1983 flood prior to this study. Historical photographs discovered by Utilis enabled survey of two flood levels to AHD with reasonable confidence.

Figure 4-5 shows the results of the hydraulic model validation. As can be seen in Figure 4-5 one of the flood levels is within ±100 mm whilst the other flood level was just outside of this range.

4.3.4 Hydraulic Model Validation Event – March 1946

The March 1946 flood event is the largest flood event to occur in living memory. A larger event is known to have occurred in the catchment in 1870, however the only available information is of low reliability unsuitable for model validation, so this event was not included in the validation runs. Therefore, for the purposes of this study the March 1946 flood event is the largest flood event that was investigated in detail.

For the March 1946 flood event five flood levels were available. It is noted that there is considerable uncertainty in the reliability of these flood levels due to the age and sources of these marks. The results of the validation of the March 1946 flood event are presented in Figure 4-6. The results of the model validation are very good given the limited information available and uncertainty in these flood levels and potential changes to the catchment since 1946.

4.3.5 Hydraulic Model Validation Event – December 2010

Despite heavy rainfall, the December 2010 flood event was significantly smaller than even the September 1983 flood.

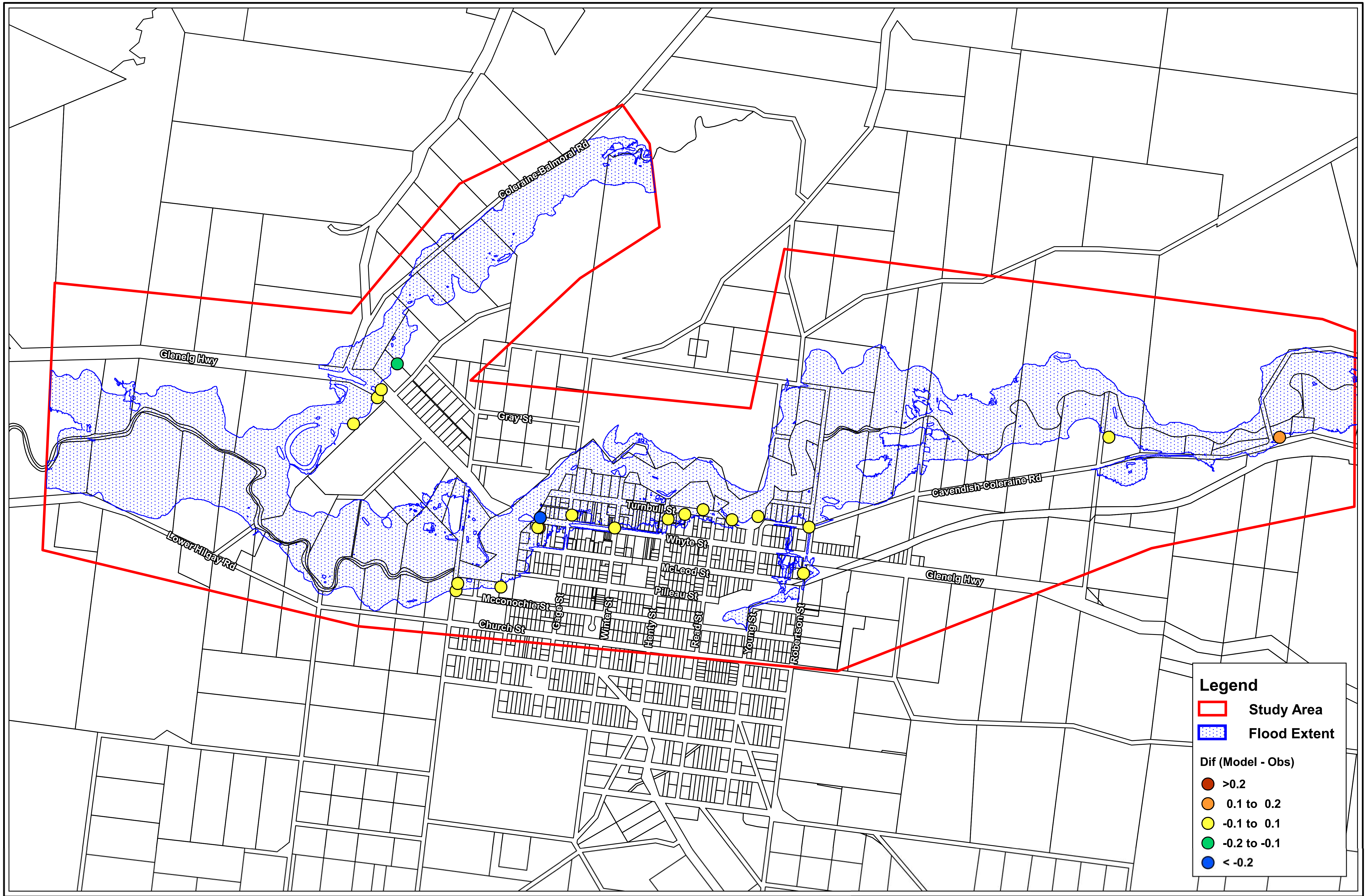
Figure 4-7 shows the results of the hydraulic model validation. As can be seen in Figure 4-7 two of the flood levels are within ±100 mm with one mark slightly high at 120mm. Given the comparatively small flow this is believed to be a very good result. Due to the number of marks a statistical analysis was not undertaken.

4.3.6 Calibration and Validation Summary

Overall a very good calibration has been achieved for the calibration event and the three validation flood events. This is based on the available flood levels, photography and community feedback. Table 4-5 below summarises the difference in modelled and observed flood levels for each of the historic events investigated as part of the study.

Table 4-5 Summary of Modelled and Observed Level Differences

Event	No. Marks	0 to ±50mm	±50 to ±100mm	±100 to ±150mm	±150 to ±200mm	>±200mm
2016 calibration	21	7 (33%)	10 (47%)	1 (5%)	2 (10%)	1 (5%)
1983 validation	2	1 (50%)		1 (50%)		
1946 validation	5	2 (50%)	1 (20%)	1 (20%)	1 (20%)	
2010 validation	3	2 (67%)		1 (33%)		
Totals	**31**	**12 (39%)**	**11 (35%)**	**4 (13%)**	**3 (10%)**	**1 (3%)**



Title: Coleraine Flood Investigation September 2016
Comparison of Observed and Modelled Flood Levels

Figure: 4-4

Rev: A

N

0 250 500m
Approx. Scale

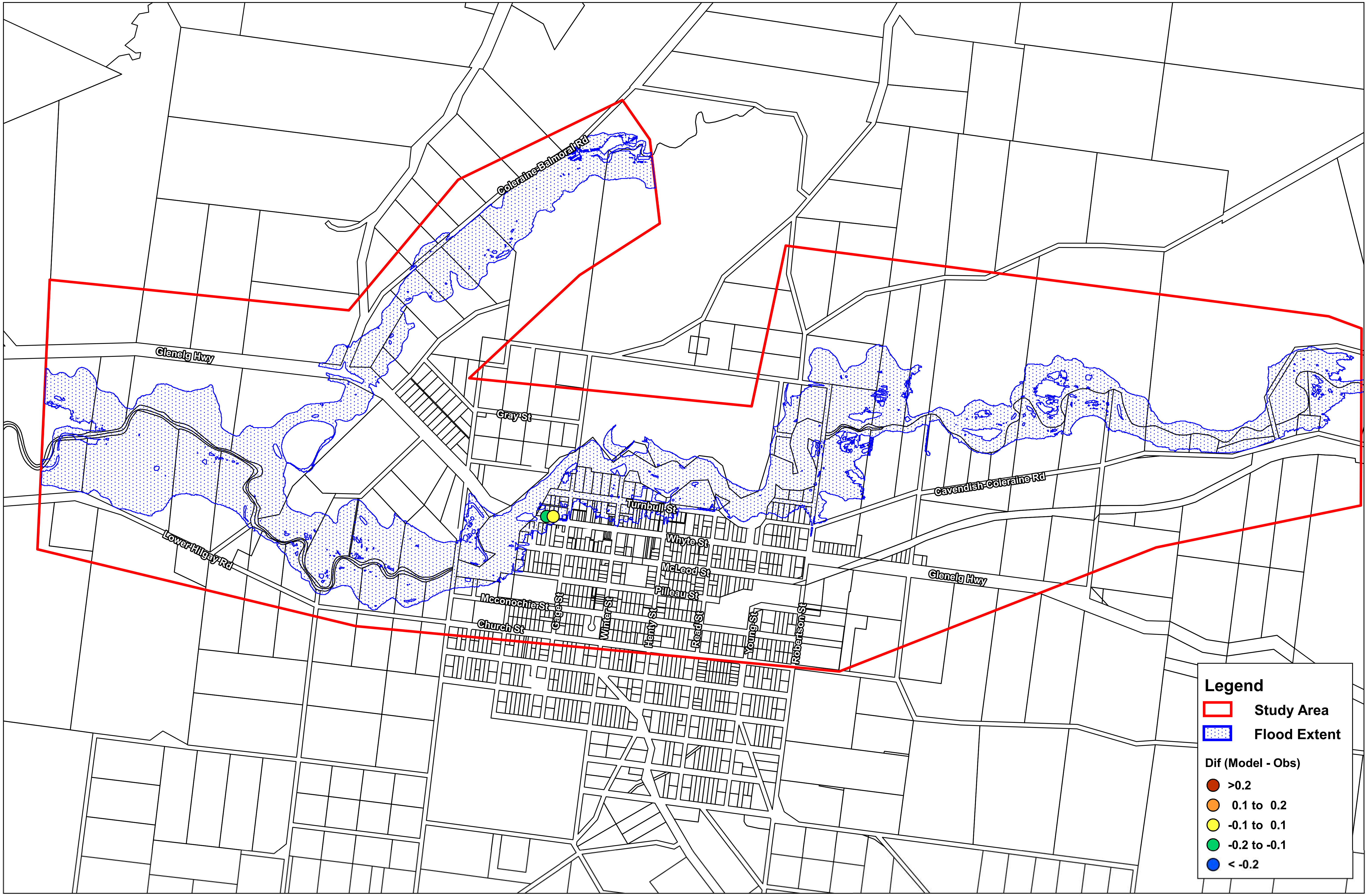
This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR

Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-4_Cal_Sept2016_025.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title: Coleraine Flood Investigation September 1983
Comparison of Observed and Modelled Flood Levels

Figure: 4-5 | Rev: A

N

0 250 500m
Approx. Scale

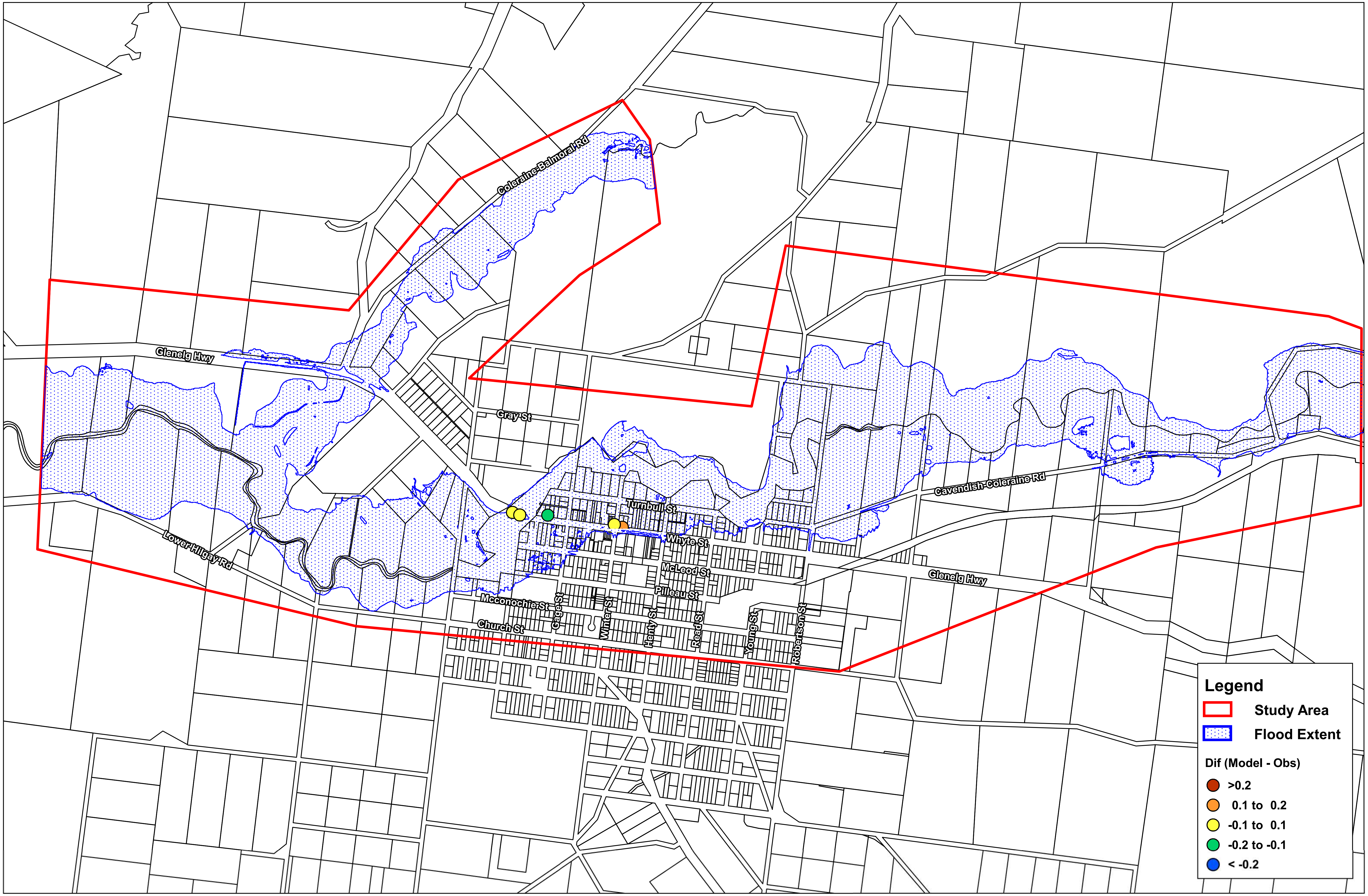
This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR
Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-5_Cal_Sept1983_025.WOR

VENANT SOLUTIONS

PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au

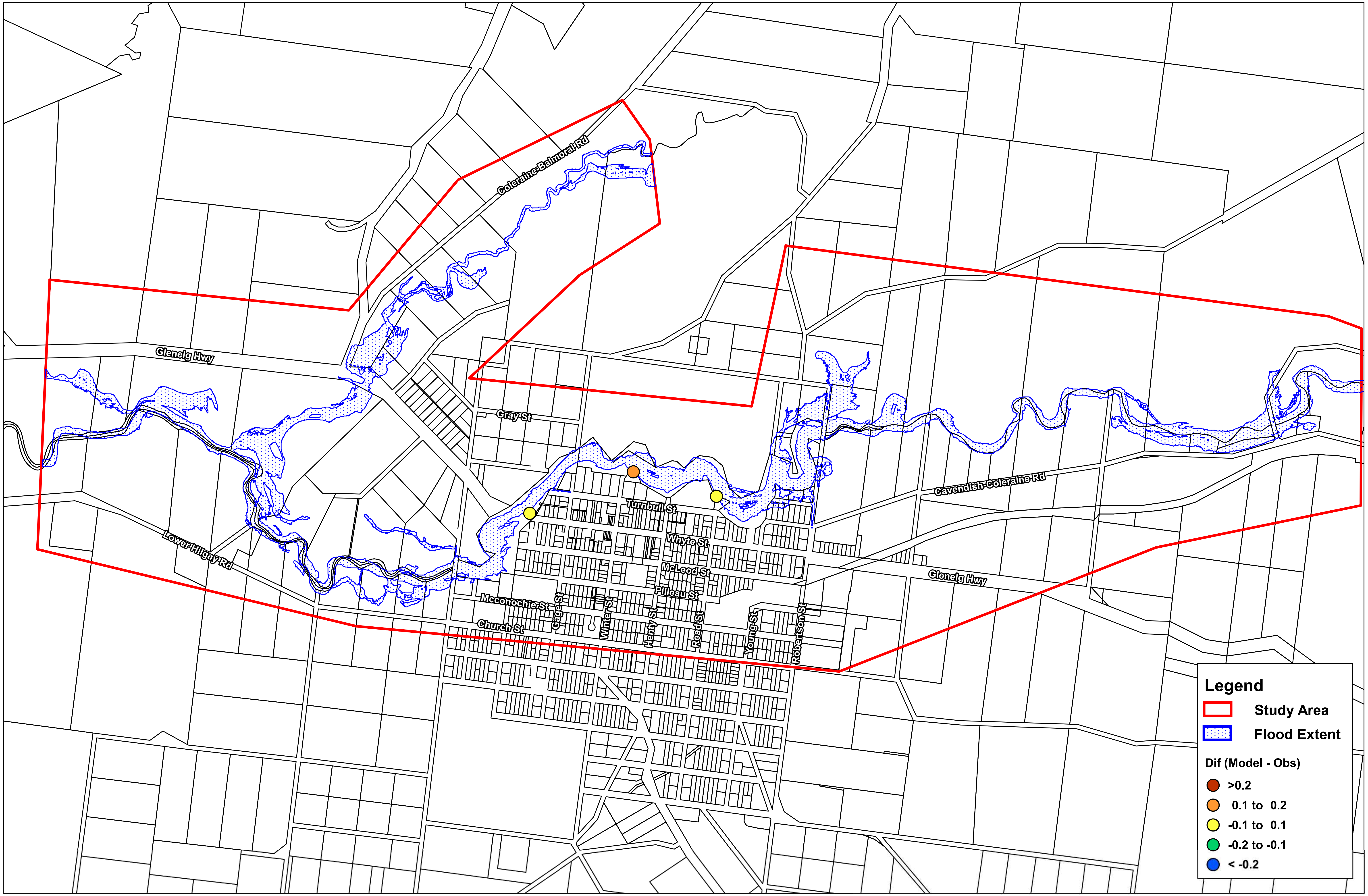


Title:
Coleraine Flood Investigation March 1946
Comparison of Observed and Modelled Flood Levels

Figure:	Rev:		Scale		By:	Date:
4-6	A	N	0 250 500m Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	DR	Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-6_Cal_Mar1946_025.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title: Coleraine Flood Investigation December 2010
Comparison of Observed and Modelled Flood Levels

Figure: 4-7 | Rev: A

N

0 250 500m
Approx. Scale

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR
Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-7_Cal_Dec2010_025.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au

4.4 Design Event Flood Mapping

This section presents an overview of the mapping process and describes the existing conditions flood mapping outputs.

4.4.1 Mapping Process

TUFLOW tracks the maximum of each map output during the simulation period on a geo-referenced grid cell by grid cell basis for each computation cell within the hydraulic model. As discussed above, for each AEP two durations were run representing the different shorter time of concentration for the Young Street and Robertson Street drain and the longer time of concentration for the larger Bryan Creek and Konong-Wootong Creek catchment. For each AEP investigated a peak flood envelope was created from the individual durations for each map type (depth, velocity, hazard), effectively creating a maximum of the maximums.

The colour palette and ranges have been adopted from the DELWP 2017 standard flood mapping guide. It is recognised that these may not be the best way of illustrating the mapping for all catchments but have been adopted to maintain consistency with other Victorian flood studies.

4.4.2 Description of Flood Behaviour

Figure 4-8 presents the peak flood depths for the 1% AEP design flood event. The remainder of the depth maps for the design floods are provided in the detailed hydraulic model report (Venant Solutions 2018b). Note that all mapping outputs (flood level, extent, depth velocity, hazard) have been delivered to Southern Grampians Shire Council and Glenelg Hopkins CMA as GIS layers in MapInfo, ArcGIS and Geodatabase formats.

In broad terms, the mapping results show that flooding (out of bank flows) in Coleraine commences during quite frequent flow events (i.e. less than the 20% AEP). These small events are generally of minor consequence in terms of impact on the township, the main impact being flooding of Turnbull Street when flow in Bryan Creek reaches the 20%AEP level. However it should be noted that the modelling indicates that 20%AEP flows in the Young-Robertson drain are likely to break out and potentially cause overfloor flooding at 14 McLeod Street. As previously mentioned, a flood caused by the Young-Robertson Street Drain may not occur in concert with a flood in Bryan Creek.

In terms of hazard, the mapping outputs show that significantly hazardous flooding in Coleraine only occurs when flood magnitude approaches or exceed the 2% AEP event. Flood hazard becomes extreme in some area during these larger events.

Further detail on flood behaviour is provided under Section 9.1.

4.4.3 Flood Velocity Mapping

Flood mapping of the velocity at peak flood levels for the 1% AEP flood event under existing conditions is presented in Figure 4-9, the remainder of the flood velocity maps are provided in the hydraulic model report (Venant Solutions 2018b) and as GIS layers.

In general, flood velocities within the study area were found to be relatively low. Where the floodplain contracted, velocities tended to increase as would be expected. Higher than average velocities were noted along the main flow paths including Turnbull St and within the waterways, particularly around the permanent pools due to their lack of vegetation inhibiting flow.

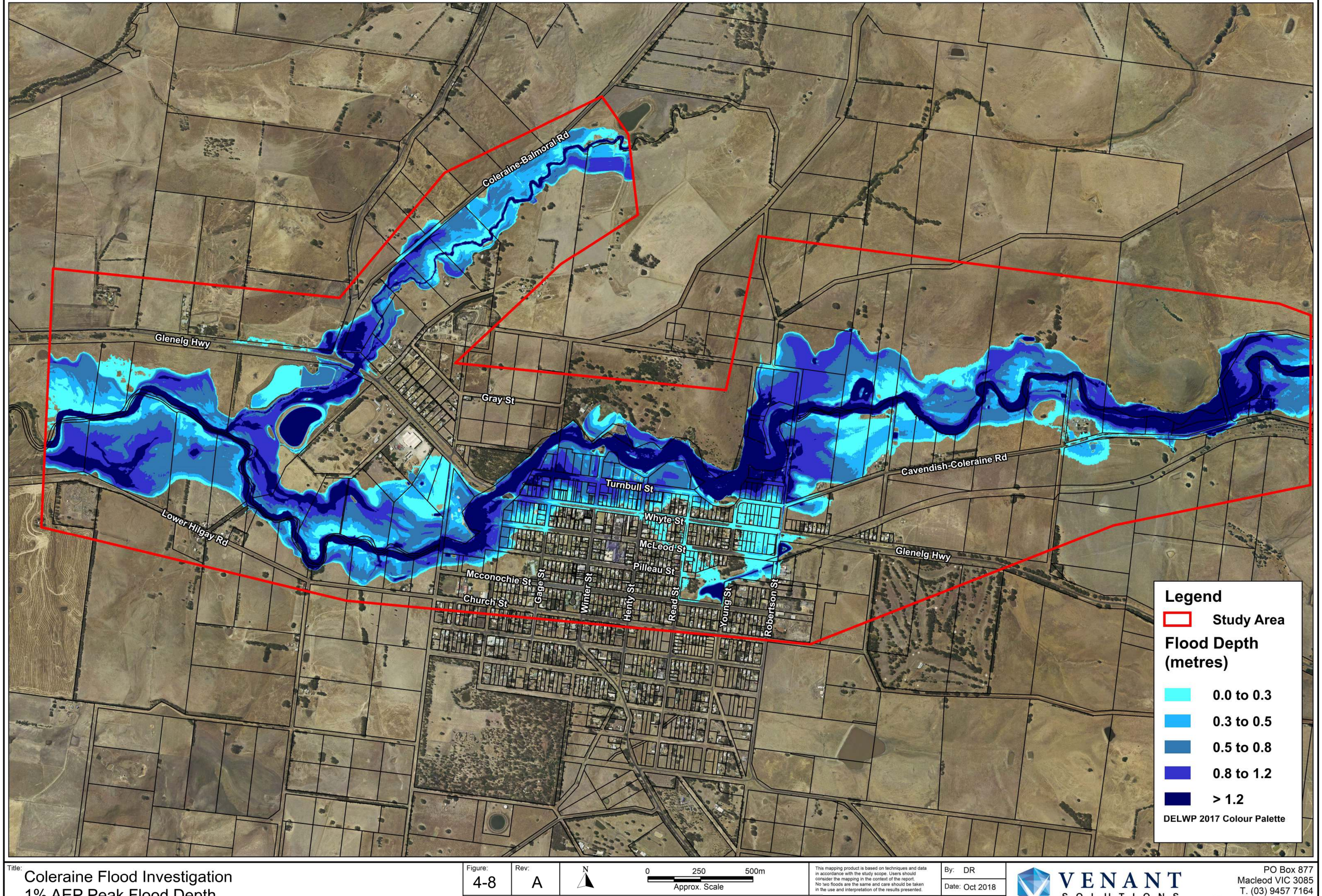
4.4.4 Flood Depth x Velocity Mapping

Mapping showing the flood depth x velocity product is presented in Figure 4-10 for the 1% AEP flood event and provided in the hydraulic model report (Venant Solutions 2018b). Flood depth x velocity product is typically used as an indicator of hazard. It provides a greater indicator of risk than looking at either depth or velocity in isolation. For example, a high velocity is not necessarily a problem if depths are shallow, likewise for the converse. Meanwhile even moderate depths and velocities can be hazardous in the right combination. For this report DELWP 2017 depth x velocity product categorisation has been adopted. The hazard categories and corresponding depth x velocity ranges are provided below in Table 4-6.

Table 4-6 DELWP 2017 Hazard Categories

Hazard Category	Depth x Velocity (m^2/s)
Low	0.0 to 0.4
Medium	0.4 to 0.8
Significant	0.8 to 1.2
Extreme	>1.2

Unsurprisingly the areas with highest hazard are along Bryan and Konong-Wootong Creeks and along Turnbull St due to both high velocity and depths. Based on DELWP 2017 classification these areas are considered ‘extreme’ hazard.



Title:
Coleraine Flood Investigation
1% AEP Peak Flood Depth

Figure: 4-8

Rev: A

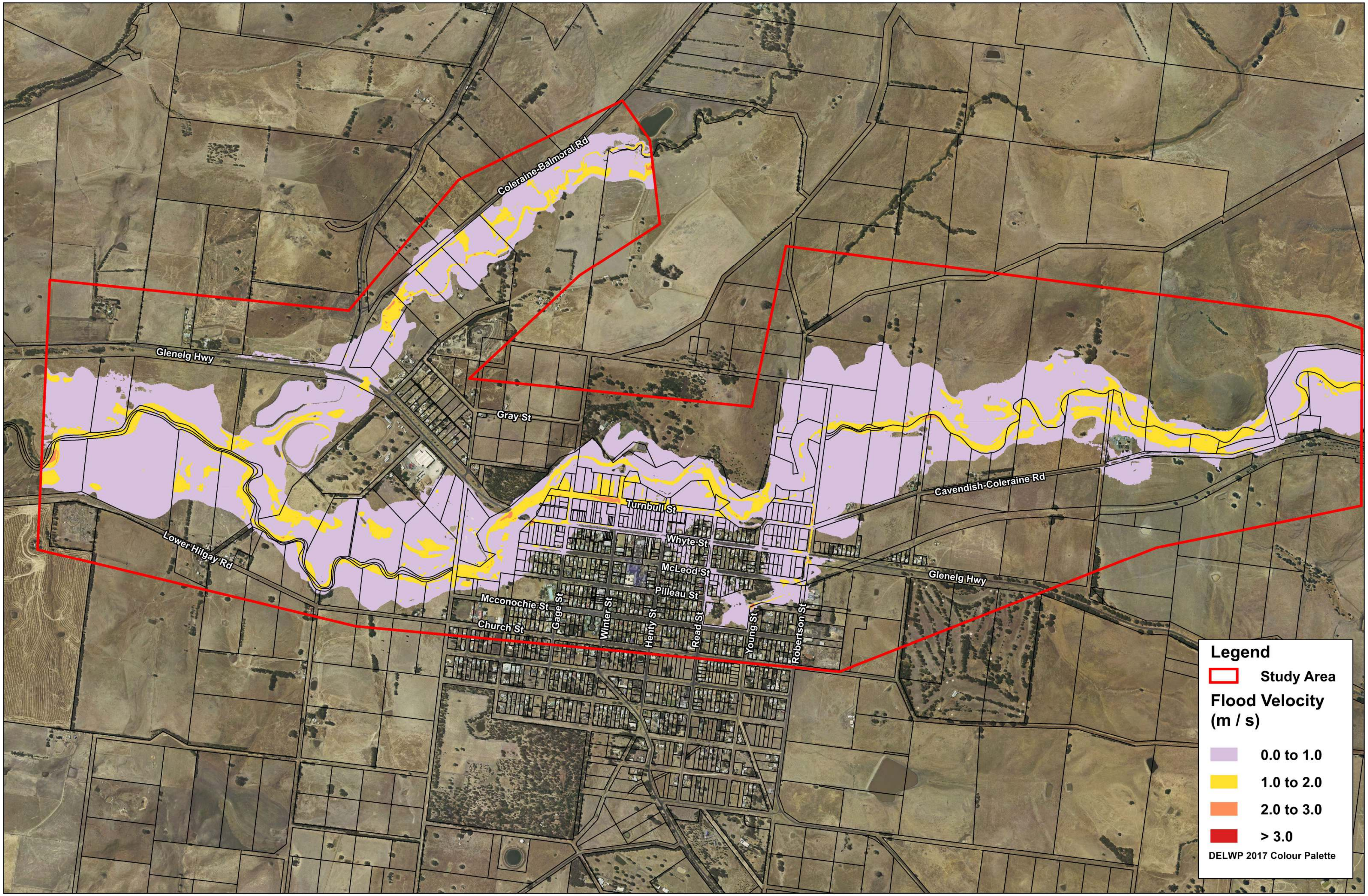
This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR

Date: Oct 2018

Filepath:S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-8_E01_100y_025_dmax.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title: Coleraine Flood Investigation
1% AEP Peak Flood Velocity

Figure: 4-9
Rev: A

N

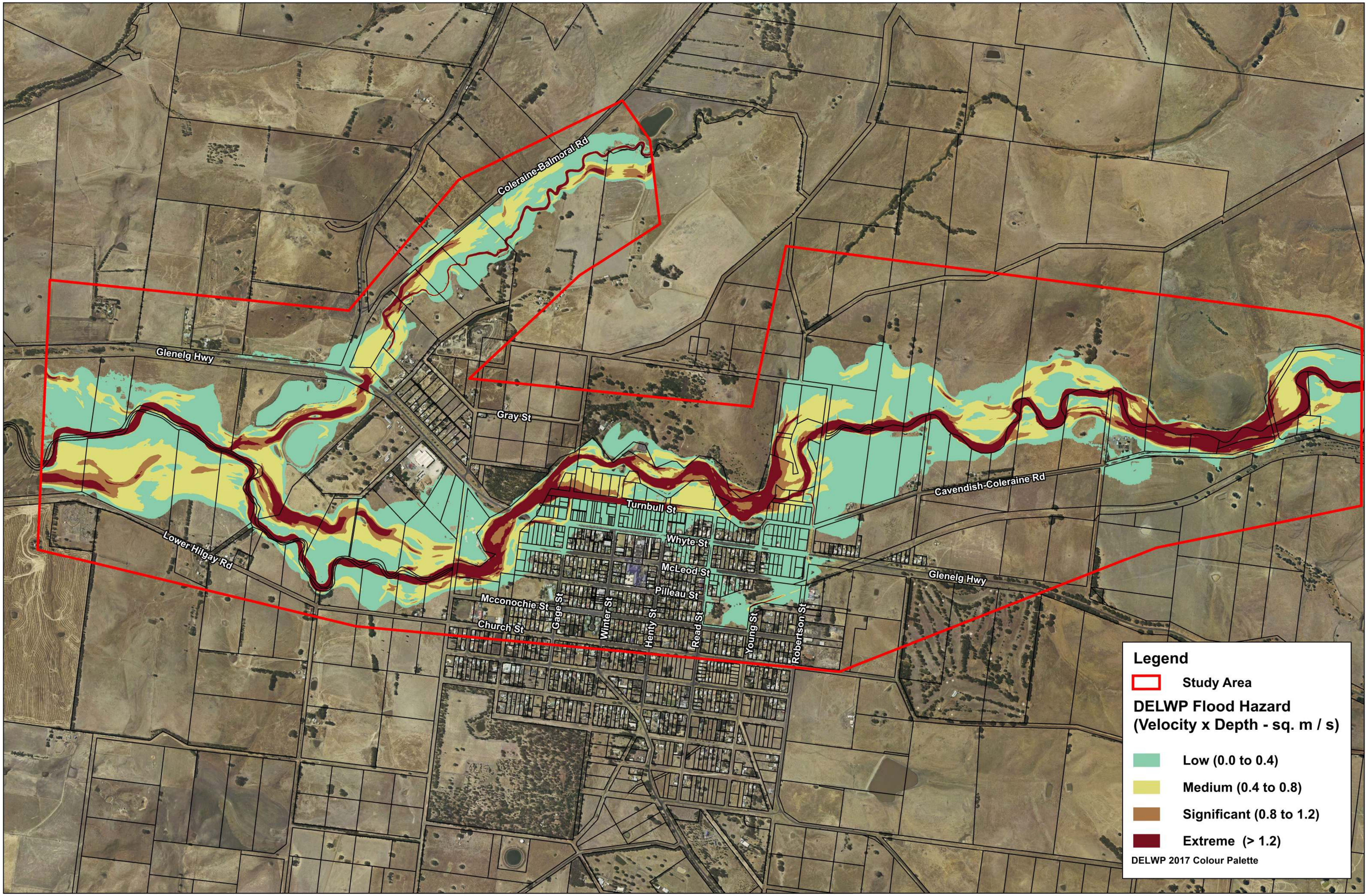
0 250 500m
Approx. Scale

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR
Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-9_E01_100y_025_vmax.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title: Coleraine Flood Investigation
1% AEP Peak Flood Depth x Velocity

Figure: 4-10
Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR
Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig4-10_E01_100y_025_Z0max.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au

4.5 Sensitivity Analysis

4.5.1 Roughness (Manning's n)

The roughness (Manning's 'n') values adopted for this study were determined from industry standard values and varied within typical bounds through the calibration process as documented in Section 4.3. Despite this, it is good industry practice to undertake a sensitivity test of key model parameters. To test the sensitivity of the model to variations in Manning's roughness values, the 1% AEP event was run with the Manning's 'n' values increased and decreased by 20%.

Increasing and decreasing the roughness values by 20% resulted in minor changes to flood depth in the town. The magnitude of this change generally varies between ±0.05 - ±0.20 m in Bryan Creek. Through the commercial and residential areas north of Whyte St flood levels were found to typically change within a range of ±0.10 to ±0.12 metres.

These tests highlight the sensitivity of the flood levels to Manning's 'n'. Increases of up to 0.2 m could be concerning in the context of the flood mapping being implemented into the planning scheme and being used for setting floor levels. Importantly though there is not a significant change in flood extent and good model calibration/validation was achieved across multiple historic events with 70% to 80% of the calibration points within 100 mm of the recorded marks. This indicates that the adopted Manning's 'n' are appropriate, and in combination with a freeboard for setting future floor levels it is considered that the adopted mapping can be used with confidence.

4.5.2 Climate Change

The latest available evidence suggests that there will be an increase in design rainfall intensities because of climate change. Using the best techniques currently practicable, it was determined that Coleraine could expect between a 10% and 20% increase in peak flow rates, depending on AEP, under climate change conditions. To test the sensitivity of flood levels to climate change the 20%, 5% and 1% AEP flood events were assessed in the hydraulics model.

For all the climate change scenarios, the impacts do not exceed those of the next largest flood mapped. For example, whilst the 20% AEP climate change flood is larger than the 20% AEP event it is smaller than the 10% AEP flood under existing climate conditions.

Under climate change conditions, typical increases in peak flood levels of 0.12 metres within Bryan Creek were found, with increases typically less than 0.05 metres along Konong-Wootong Creek. The greatest change in peak flood levels within the town are along Turnbull St east of Young St where increases up to 0.14 metres are predicted. West of Young St increases in peak flood level are predicted to be in the 0.08 to 0.11 metre range.

This level of change would not pose risk to new developments with an appropriate freeboard to account for uncertainty.

4.5.3 Blockage

Hydraulic structures are susceptible to blockage which reduce their effective waterway area. ARR 2016 recommends that a blockage assessment be undertaken as part of a study to determine the effect, if any, blockage of the structure has on flood behaviour. Blockage most typically is encountered on the inlet side of the bridge or culvert. For bridges the inlet blockage is typically large wooded or urban debris which collect on piers with additional debris piling up and 'bridging' the waterway potentially causing a significant blockage. Whilst culverts can also be blocked by large debris, they are also susceptible to siltation. Blockage was investigated using the approaches recommended in ARR 2016.

Applying the ARR 2016 approach, the blockage to the bridge structures showed no appreciable change in flood levels, and thus blockage does not pose a risk to Coleraine.

4.6 Hydraulic Model Quality Assurance & Independent Review

To ensure that the hydraulic modelling undertaken are fit for purposes an extensive internal Quality Assurance (QA) review was undertaken. This review was undertaken by the project director, Dr Mark Jempson who was previously employed by DELWP as an expert reviewer participating in DELWPs peer review process for Victorian Flood Investigations. The QA review considered all modelling inputs and model outputs. Whilst not intended as an exhaustive list, the review considered the following aspects:

- Modelling methodology and fundamental model schematisation;
- Model parameters were within typical ranges expected and unrealistic parameters were not being applied;
- Surface topography, roughness and hydraulic structures were appropriately represented with the model;
- Boundaries conditions were appropriate, and that boundary assumptions were not influencing model results within the study area.

As per the DELWP peer review process mentioned above, the hydraulic modelling methodology and assumptions underwent blind review by 2 expert reviewers. A traffic light style report is generated by this review whereby any issues identified as “Red Light” (significant issues) trigger essential re-work before the hydraulics element of the project is accepted as final. No Red Light issues were identified by the DELWP peer reviewers who assessed the methodology and assumptions for the hydraulics element of the project.

A further independent review of the hydraulic model setup was commissioned by Southern Grampians Shire Council and undertaken by BMT. The review summarised that *BMT ‘has identified a few relatively minor issues that will require either further clarification or amendment from the consultant’* and, ‘*BMT does not believe these amendments will result in significant changes to the previously presented flood mapping.’* Each of the issues raised by BMT were responded to by Venant Solutions and addressed in the final model.

To quantify the effect the changes made to the model had on the output each of the four calibration events were rerun. As expected there was no noticeable difference to the flood levels and hence calibration. The changes to the peak flood levels were typically less than 1 mm.

5 Flood Damages

This section provides a summary of the Flood Damages assessment undertaken as part of the Coleraine Flood Investigation. It is recommended that curious readers refer to the main technical report (Venant Solutions 2018c) should they require additional information and analysis or clarification or expansion on the information contained herein.

5.1 Background

Examining flood damages is vital to the complete assessment of the value to be gained by investment in flood risk reduction measures. Such investment might involve implementation of mitigation works or establishment of a flood warning/alerting system. For Coleraine, the economic costs of flooding have been estimated for each design event. Doing so has allowed calculation of the Average Annual Damage (AAD) caused by flooding to the Coleraine community. The AAD is the best estimate for tangible damages to the township sustained over an extended time period. In this case, the AAD has been determined using the full range of flood events from the 20% AEP to the PMF. The AAD is the main comparative factor for assessing the per dollar effectiveness of potential mitigation options and which areas of the town are best protected from future floods.

For the purposes of assessment, flood damage is classified in several ways as outlined in Figure 5-1 below. The two primary divides in flood damage are that between tangible and intangible damages and the divide between direct and indirect costs. A cost is defined as intangible where there is difficulty assigning a dollar value to that damage. For example, the effects on a person's mental health of a flood destroying their house are far more difficult to quantify than the damage the house itself suffered. Direct damage is that caused to physical objects by the flood water, where indirect damage is caused by disruptions to economic and physical activity. An example of indirect damage would be a store surrounded by the flood but not inundated; it cannot service customers so potential income is lost.

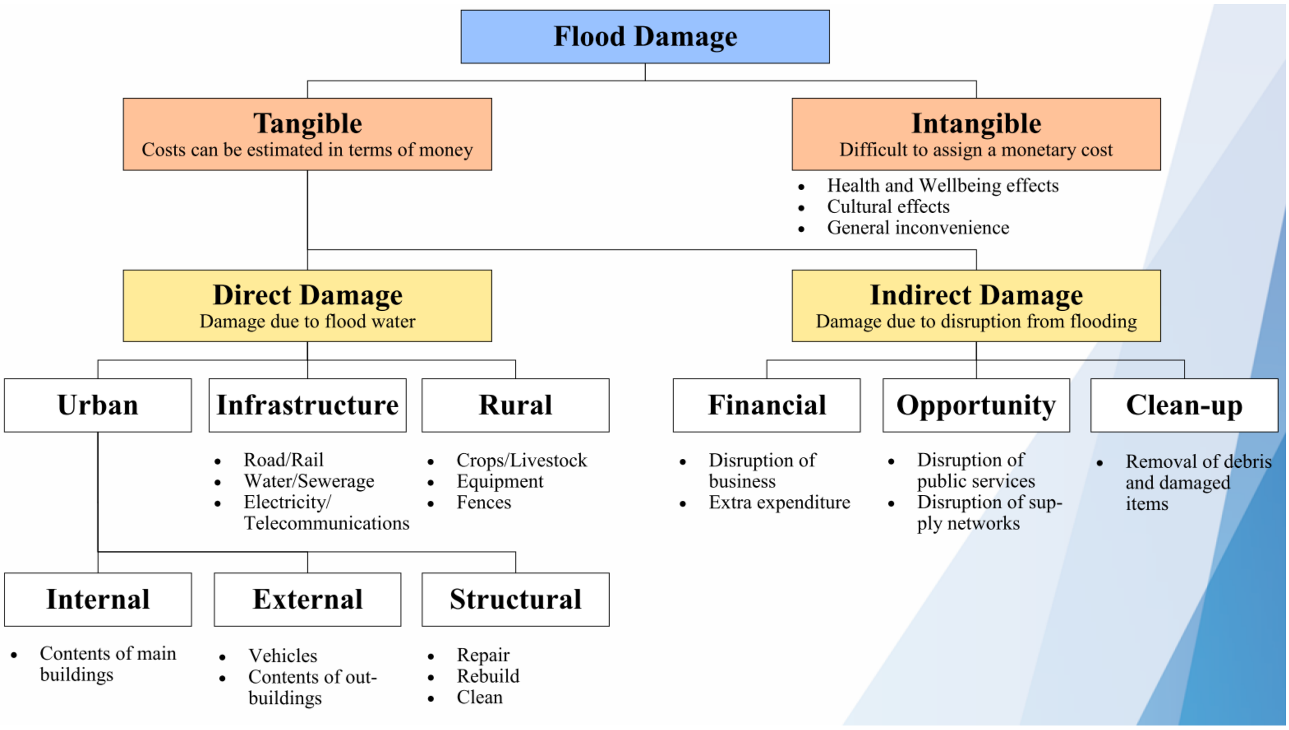


Figure 5-1 Types of Flood Damage

5.2 Direct Damages

5.2.1 Residential

For residential properties three sets of stage-damage relationships were adopted for this study: ANUFLOOD, WRM and O2. The ANUFLOOD curves were sourced from the Queensland Department of Natural Resources and Mines (QDNRM) (2002), whilst the WRM stage-damage relationships were created by WRM Water & Environment in 2006 and the O2 curves are adaptions of the WRM work created by O2 Environmental in 2012. WRMN and O2 also separate and quantify external damage (cars, fences and the like), property contents and the building structural form itself.

5.2.2 Commercial

WRMN and O2 stage-damage relationships are limited to residential properties and are therefore not appropriate for application to commercial properties. Therefore, for commercial properties the ANUFLOOD curves were adopted for this study. These were sourced from QDNRM (2002).

5.2.3 Infrastructure

Infrastructure damages to community infrastructure that includes parks and ovals, roads, water and utilities are difficult to quantify. For the purposes of this study the damage to infrastructure have been estimated to be 15% of direct residential and commercial damage as has been done for other similar studies.

5.3 Indirect Damages

Calculation of indirect damages for the Coleraine floodplain was not feasible for this study so the 30% of total damage as recommended in RAM (NRE, 2000) was adopted.

5.4 CPI

Due to the age of the various stage-damage relationships it was necessary to update them to present value dollars. To do so, the stage-damage relationships were updated to present day values by factoring them using CPI. The change in CPI since the original publication of the stage-damage relationships was sourced from the Australian Bureau of Statistics.

5.5 Preparedness

A prepared community can take effective action to reduce the flood damages with appropriate information, experience and warning time. For example, moving cars to higher ground and raising items off the floor, removes or reduces the likelihood of flood damage occurring. For the purposes of the damages calculations - given Coleraine's long history of flooding, and the recent 2016 flood event, a 0.8 factor has been applied to the calculations to account for the measures the community may take to reduce damage. A factor of 0.8 is consistent with an experienced community with less than 2 hours warning, or an inexperienced community with 2 hours or more warning.

5.6 Property Database

To undertake the economic damages assessment a database identifying all properties within the estimated extent of the Probable Maximum Flood (PMF) – i.e. all properties in the floodplain area was created for this investigation. This database contains a property identifier, information on property type, building size and floor levels. The property database was then used as an input applied to the stage-damage relationships to determine the economic costs of flooding on a property by property basis.

Floor levels

Floor level survey of 115 properties within the flood extent was undertaken by Brayley & Hayes during January 2018. The properties surveyed were those identified as most at risk of riverine flooding from Bryan Creek. Not all properties that are potentially flood-prone were surveyed due to the extra cost burden it would place on the study for relatively small benefit to the study outcome. In addition to the 115 properties identified as most at risk for which the floor level was surveyed, a further 228 properties were identified as potentially within the extent of the PMF. The floor level for these 228 properties was assumed to be 150mm above natural surface.

Property type

To determine whether a property was a commercial operation or a residential address the planning scheme zones were initially studied. This was followed by an examination of aerial and street view photography to identify commercial and residential buildings which lie outside their respective planning zones.

For residential buildings all the houses were considered to be detached, single storey properties.

For commercial buildings, a value class was assigned based on the current use of the building.

Building size

Building size for each commercial property was measured from aerial photography. Due to the rural nature of the community, the largest residential building bracket was adopted.

5.7 Above Floor Flooding

The floor level of each building in the property database was compared with the flood level determined for each modelled flood event. This enabled identification of those buildings prone to above floor flooding. The results of this assessment are presented below in Table 5-1.

5.8 Average Annual Damage

Average annual damages is the economic term for the probabilistic economic cost to the town each year when averaged over a long period of time, for this study the timeframe considered is up to the PMF, i.e. a 1,000,000 to 10,000,000 year period of time. This of course does not mean every year the town would experience the level of damage equal to the AAD, as the AAD accounts for the economic likelihood of rare and highly damaging floods as well as frequent events that may result in little or no damage. For the purposes of the AAD calculations it was assumed that no damage would occur in a 33% (1 in 3) AEP flood event. The AAD for each of the three methods under existing conditions is presented below in Table 5-1.

5.9 Summary of Economic Damages

The estimated economic direct damages determined by using ANUFLOOD, O2 and WRM Stage-Damage Relationship curves are presented in Table 5-1. Given the assumptions applied and the imprecise nature of damages estimation, the ranged estimate for AAD provided in Table 5-1 is considered appropriate in the context of use of estimated AAD figures in floodplain management planning.

Table 5-1 Summary of Existing Conditions Breakdown of Damages

AEP (%)	Total No. of Properties Inundated	No. of Properties with above floor flooding	ANUFLOOD Method Total Damages ($)	O2 Method Total Damages ($)	WRM Method Total Damages ($)
20%	8	1	$28,000	$73,000	$74,000
10%	16	5	$89,000	$178,000	$171,000
5%	23	6	$117,000	$292,000	$254,000
2%	60	20	$641,000	$1,234,000	$1,022,000
1%	72	41	$1,506,000	$2,755,000	$2,196,000
0.5%	103	69	$3,254,000	$5,720,000	$4,448,000
0.2%	135	90	$5,220,000	$9,183,000	$6,984,000
PMF	336	320	$39,345,000	$92,008,000	$58,157,000
		AAD	**$105,000**	**$217,000**	**$162,000**

6 Flood Mitigation

A "first pass" feasibility assessment has been completed for five structural mitigation (physical works) options as required by the project brief. This assessment involved manipulation of details in the hydraulic model to test the degree of flood impact reduction likely to result from the implementation of the option in combination with assessment of how costly the option might be to implement, including estimation of the long-term cost of maintenance (ie Cost versus Benefit analysis). Full details of the assessment are provided in the Flood Damages & Mitigation Report (Venant Solutions 2018c).

6.1 Mitigation Optioneering

A community meeting was held in Coleraine on the 8th of December 2017. During the meeting draft mapping was presented to the community along with an opportunity for the community to suggest potential mitigation options. Through the community engagement process eight options were raised and considered. During the meeting each community member was provided with a total of six votes which they could use to place on those options that they wished to be investigated. These votes could all be placed on one option or distributed amongst the various options in the community members own preference of priority (for example, 3 stars on one option, 2 on another and 1 on a third or alternatively all 6 stars on one option should they so desire).

6.2 Mitigation Option Design, Assessment and Discussion

The feedback from the community was discussed by the Southern Grampians Shire and Glenelg Hopkins CMA following the meeting. From the feedback on preferences received, and what was practical within the scope of the study to model, five mitigation options were agreed to be investigated in detail using the hydraulic model. The five options modelled and assessed are detailed below and presented in Figure 6-4. A summary of the estimated effectiveness of each scenario in the context of reduction in over-floor flooding is presented in Table 6-1. Figure 6-5 through Figure 6-9 present the change in peak flood levels under a 2% AEP flood event for each of the five mitigation options assessed, The 2% AEP flood event is broadly similar to the September 2016 flood event. In these figures the colour ranges signify the change in flood levels as shown in the legend. The lemon colour represents a 'no change' tolerance of 0.05 metres, with greens indicating reductions in flood levels, and the oranges representing increases in flood levels. The pink shaded area indicates areas that were wet and now dry, and conversely the blue shaded areas indicate where area that would be dry would be wet.

6.2.1 Mitigation #1 - Bryan Creek Walking Track Levee

This option looked at increasing the ground level along the alignment of the existing walking track which extends along Bryan Creek from a point about 60m east of the Turnbull – Read Street intersection to the Glenelg Highway Bridge. A 2% AEP level of flood protection was modelled (approximating the magnitude of the September 2016 flood) with 100 mm of freeboard added to the levee height to account for some uncertainty.

Due to the increases in flood levels the levee would require earthworks up to approximately 2.2 metres with an average increase of approximately 1.1 metres above existing ground levels. A long-section showing the existing ground level and required levee height to defend the town from a 2% AEP flood event as well as a theoretical 1% AEP plus freeboard levee is presented in Figure 6-1. As can be seen in Figure 6-1, a levee to protect against a 1% AEP flood event is considerably higher than that proposed to protect against a 2% AEP flood. This much larger levee would result in a significantly greater visual impact and create a disconnect between the town and the waterway which would lead to a loss of amenity.

It is very important to note that the assessment for this Option (and Option 2 discussed below) did not account for potential issues that might arise with impoundment of stormwater behind the levee, which may necessitate the installation of backflow prevention devices on drain outfalls to Bryan Creek and/or (potentially) pumping of impounded stormwater from behind the levee. This risk would need to be accounted for if it were decided to proceed to detailed design with the view to implementation.

This option was identified as having the highest potential in terms of reducing over-floor flood impacts (see Table 6-1) but the potential worsening of flood impacts in the Coleraine football ground area is an important consideration. From a Cost versus Benefit perspective it was assessed as potentially warranting further consideration once intangible costs/benefits are considered (see below).

The flood damages and benefit-cost assessment have not been undertaken for a 1% AEP immunity levee, should further investigation be undertaken by Council the ultimate design level of the levee could be optimising between desired protection, the benefit-cost, visual impact and amenity of the levee.

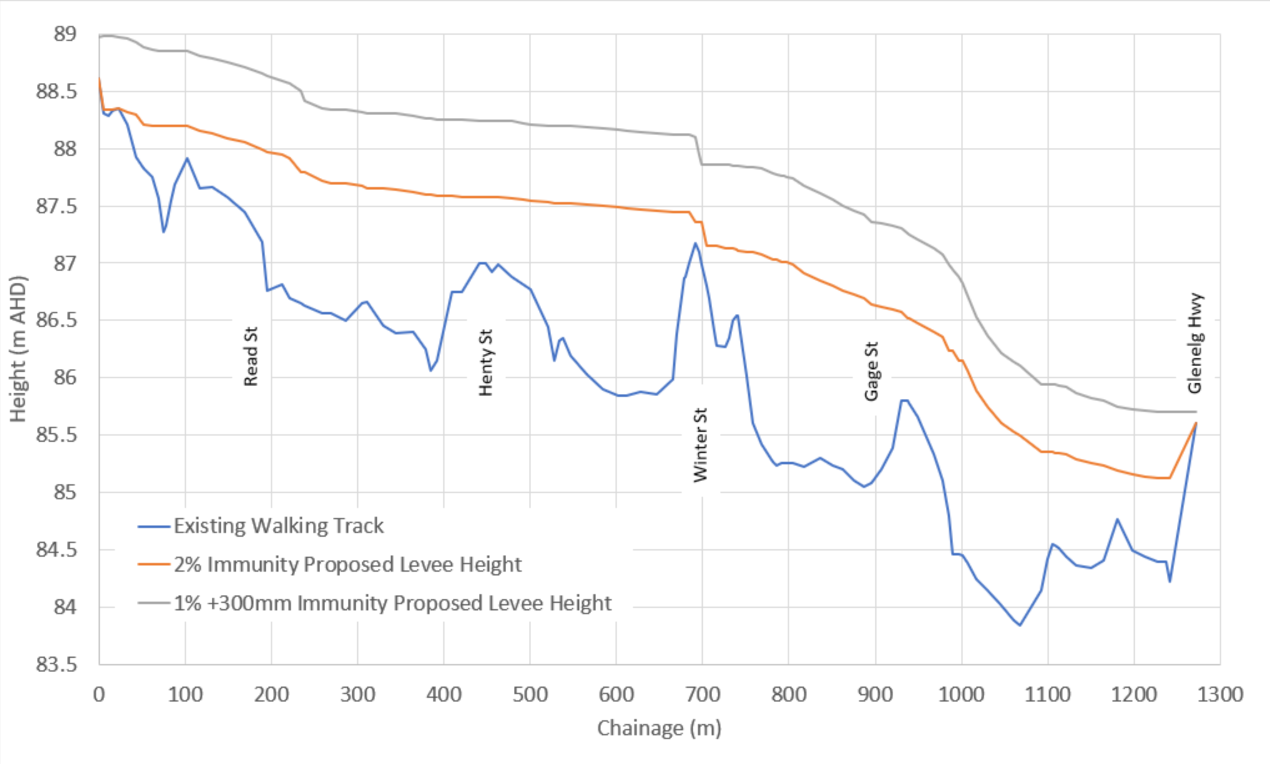


Figure 6-1 Bryan Creek Walking Track Levee Long-section

6.2.2 Mitigation #2 - Turnbull St Raising Levee

For this assessment the road surface along Turnbull St was raised to a 2% AEP flood protection level within the hydraulic model to assess the potential for reduced flood impacts on the township. The concept involved raising the road level to form a defacto levee starting at Young St and continuing along the length of Turnbull Street culminating at the Glenelg Highway bridge. As with Option 1, the road level was set to protect against a 2% flood which is broadly similar to that experienced in 2016.

As with Mitigation Option 1, it is assumed that the stormwater drainage network that discharge to Bryan Creek will have backflow devices fitted and that local stormwater is pumped or otherwise removed. A long-section showing the existing ground road crown level and required raised level of the road to defend the town from a 2% AEP flood event is presented in Figure 6-2. Figure 6-2 also presents a theoretical 1% AEP levee. To achieve this greater level of protection a levee would require a very substantial (nearly 2m at Gage St) raising of the road. In either case, the raising of Turnbull St may create access issues for the residences along Turnbull St and other issues along the road such as access to the sports grounds.

This option was assessed as probably not warranting further consideration in isolation, even when intangible costs/benefits are considered (see Section 6.3). However it may be considered further as part of an investigation of alignments should Option 1 be further investigated.

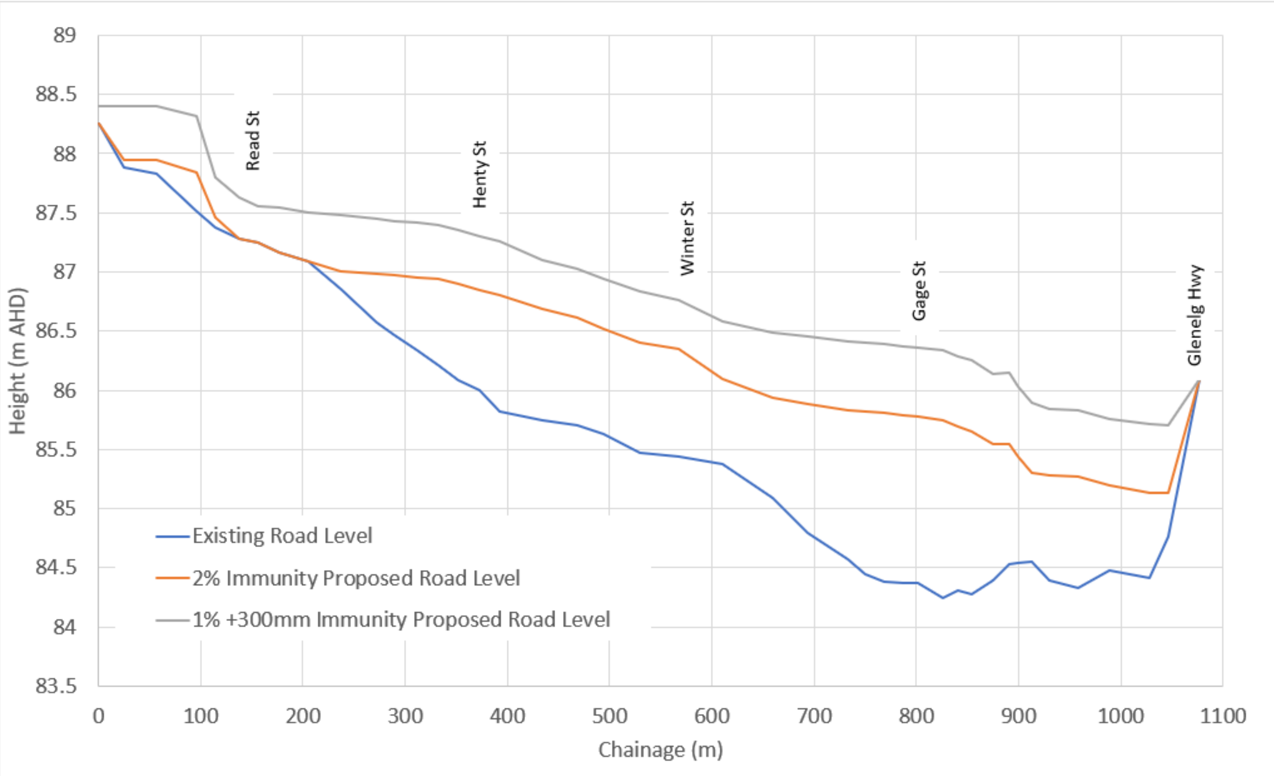


Figure 6-2 Turnbull St Raising Levee Long-section

6.2.3 Mitigation #3 - Widen Glenelg Hwy Bridge

For the purposes of this assessment the Glenelg Highway bridge of Bryan Creek was lengthened to 114 metres, up from the existing 64 metres. To do so the bridge was lengthened 20m to the west and 30m to the east, thereby increasing its capacity to pass flood flows and reducing the likelihood of increasing flood levels on the upstream side.

This option was assessed as not warranting further consideration due to likely very high cost and very low benefit (see below).

6.2.4 Mitigation #4 - Vegetation Removal

Surface roughness values were lowered in the township reaches of the creek channels to assess the potential effect of vegetation removal on flood levels. Rather than model the channels as a fully maintained grass areas, (as this is not realistic or desirable) the vegetation within and along Bryan Creek and Konong-Wootong Creek was significantly ‘thinned’ to represent a thorough thinning (but not total removal) of all vegetation. To do so the model roughness value (Manning’s ‘n’) was reduced from the existing calibrated values (which ranged from 0.12 for reedy waterway, 0.10 for dense overbank vegetation and 0.08 for moderate overbank vegetation) to 0.06 which broadly represents scattered trees. The area where this value was applied is presented in Figure 6-4.

This option was assessed as probably not warranting further consideration due to likely very high cost with low benefit (in terms of reduced flood impacts) and potentially high social and environmental costs (see below).

6.2.5 Mitigation #5 - Young Street and Robertson Street Drain

This option involved the construction of three small levees around the lakes in the Young Street and Robertson Street drain to increase the flood storage capacity of the lake and to prevent spillage from the drain into the town and channel the flow leaving the lake under Robertson St and Whyte St. The levee surrounding the lake was raised to 94.7 m AHD in places where it was not already at that elevation. The culvert located in the north-east of the drain was removed and the culvert under Robertson St was expanded from a 2/1200 x 450 mm box culvert to a 4/1200 x 450 mm box culverts. Additionally, the spillway from the lake in East Park was reshaped so that no part of it was higher than 91 m AHD. Figure 6-4 illustrates the conceptual earthworks involved in the scheme. Included in Figure 6-3 are the existing and proposed channel levels along with the existing top of bank and proposed areas requiring raising.

This option was assessed as warranting further consideration with a good cost versus benefit ratio (see below). It would be recommended that this be investigated further in the context of other local stormwater issues that were not assessed as part of this study.

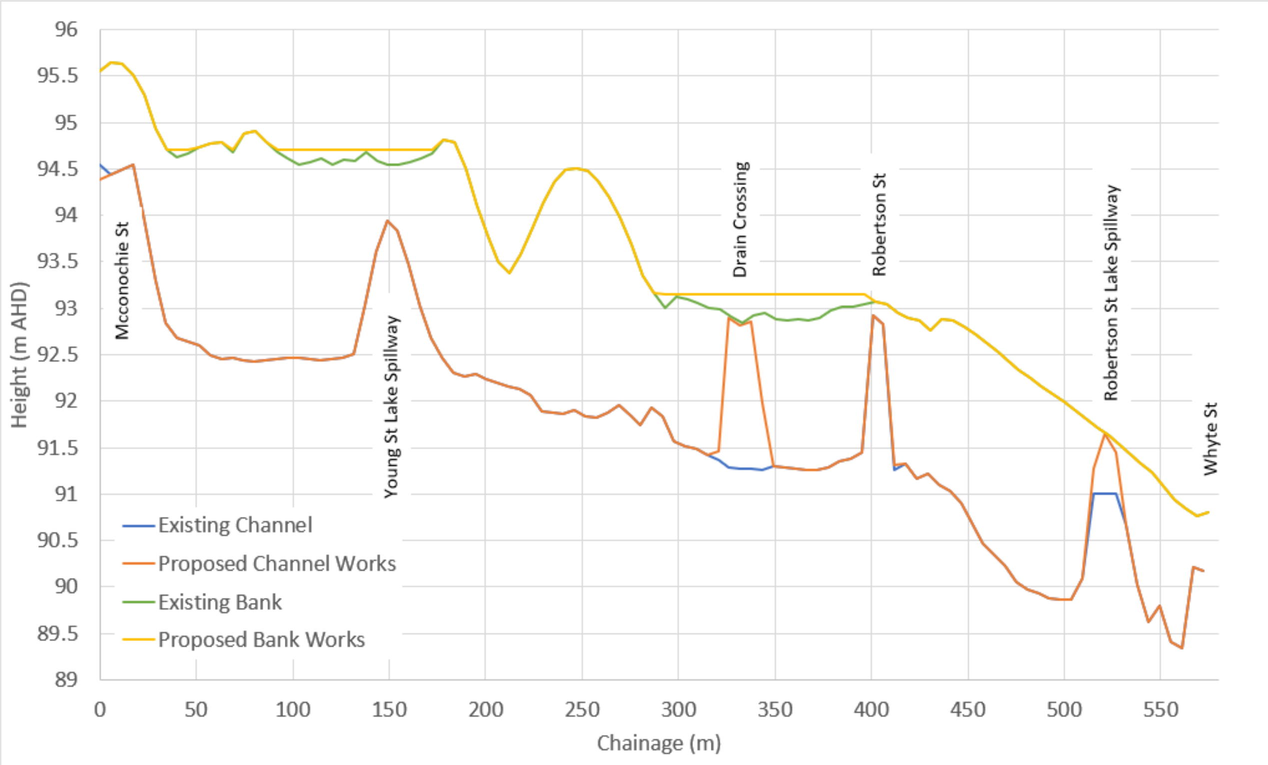


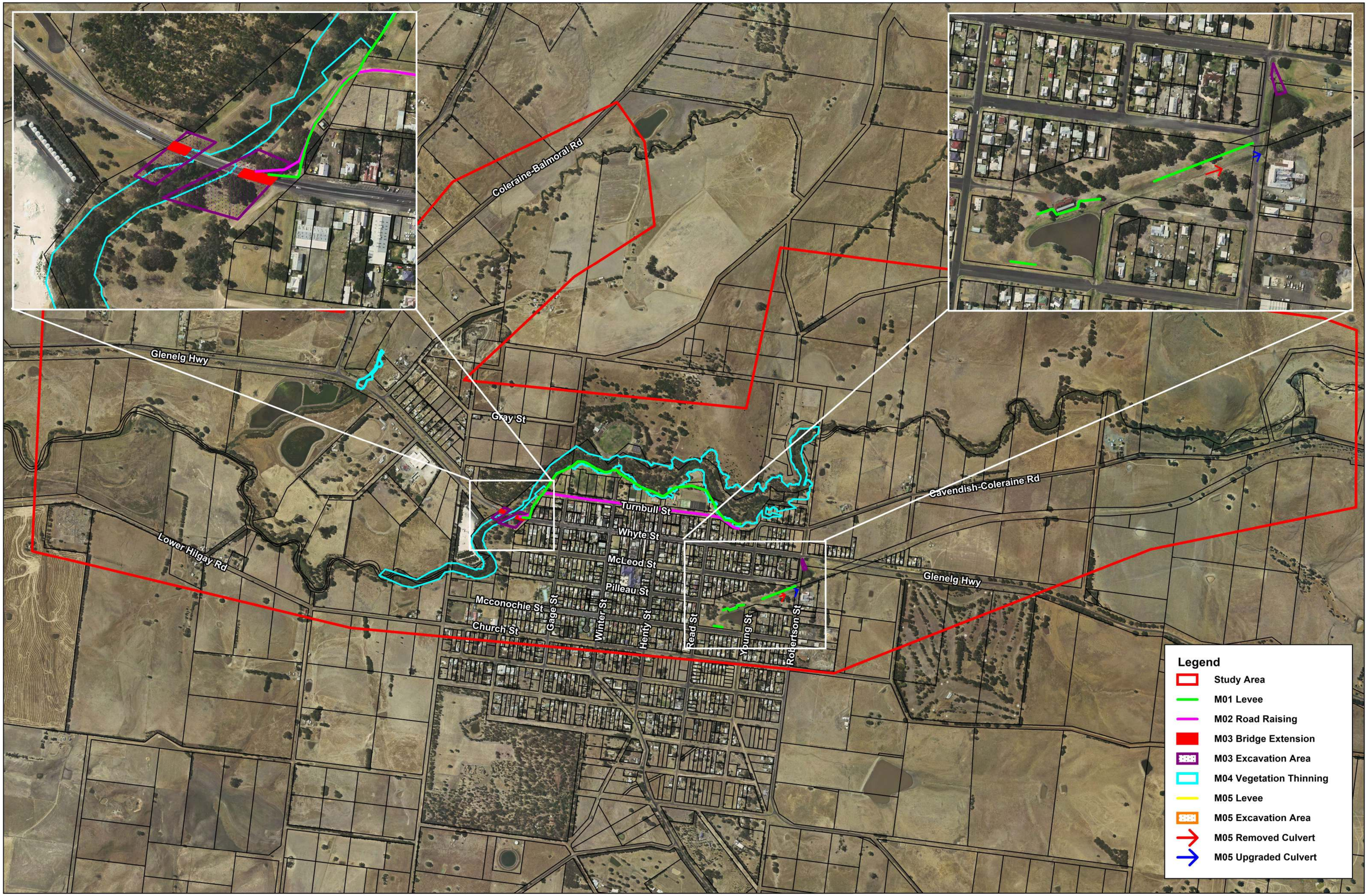
Figure 6-3 Young St and Robinson St Drain Proposed Works

6.2.6 Summary of Effectiveness of Mitigation Options

Table 6-1 below presents the number of properties with above floor flooding for each of the mitigation options along with those under existing conditions.

Table 6-1 Summary of Effectiveness of Options in Mitigating Above Floor Flooding

AEP (%)	No. of Properties with Above Floor Flooding					
	Existing Conditions	Mitigation Option 1	Mitigation Option 2	Mitigation Option 3	Mitigation Option 4	Mitigation Option 5
20%	1	1	1	1	1	0
10%	5	1	3	5	1	4
5%	6	1	3	5	5	5
2%	20	2	5	18	12	21
1%	41	23	23	40	31	41
0.5%	69	64	72	66	52	69
0.2%	90	94	91	87	79	87
PMF	320	320	320	320	320	320



Title: Coleraine Flood Investigation
Mitigation Option Map

Figure: 6-4

Rev: A

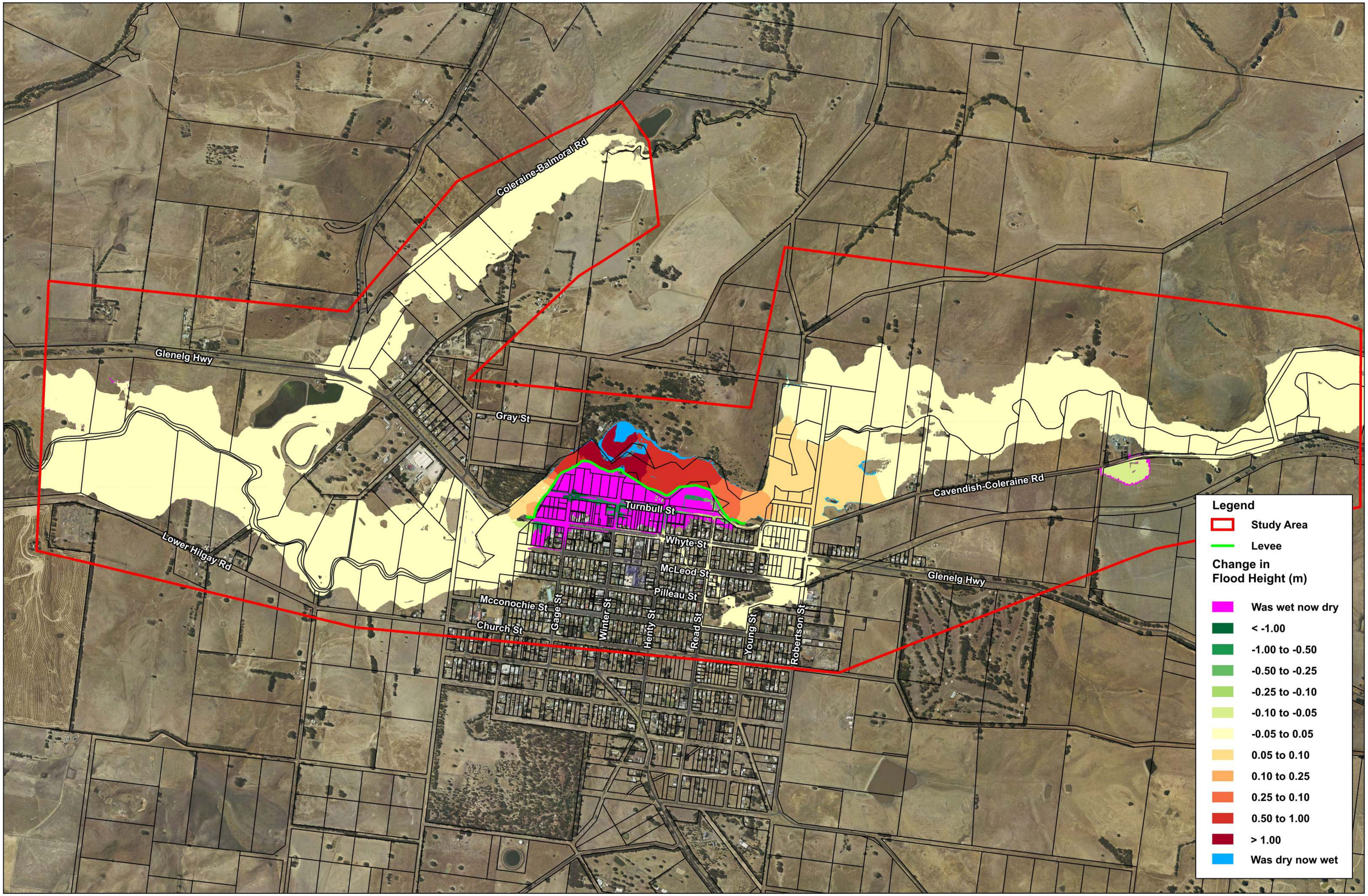
This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR

Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig6-4_MitigationOptionMap.WOR

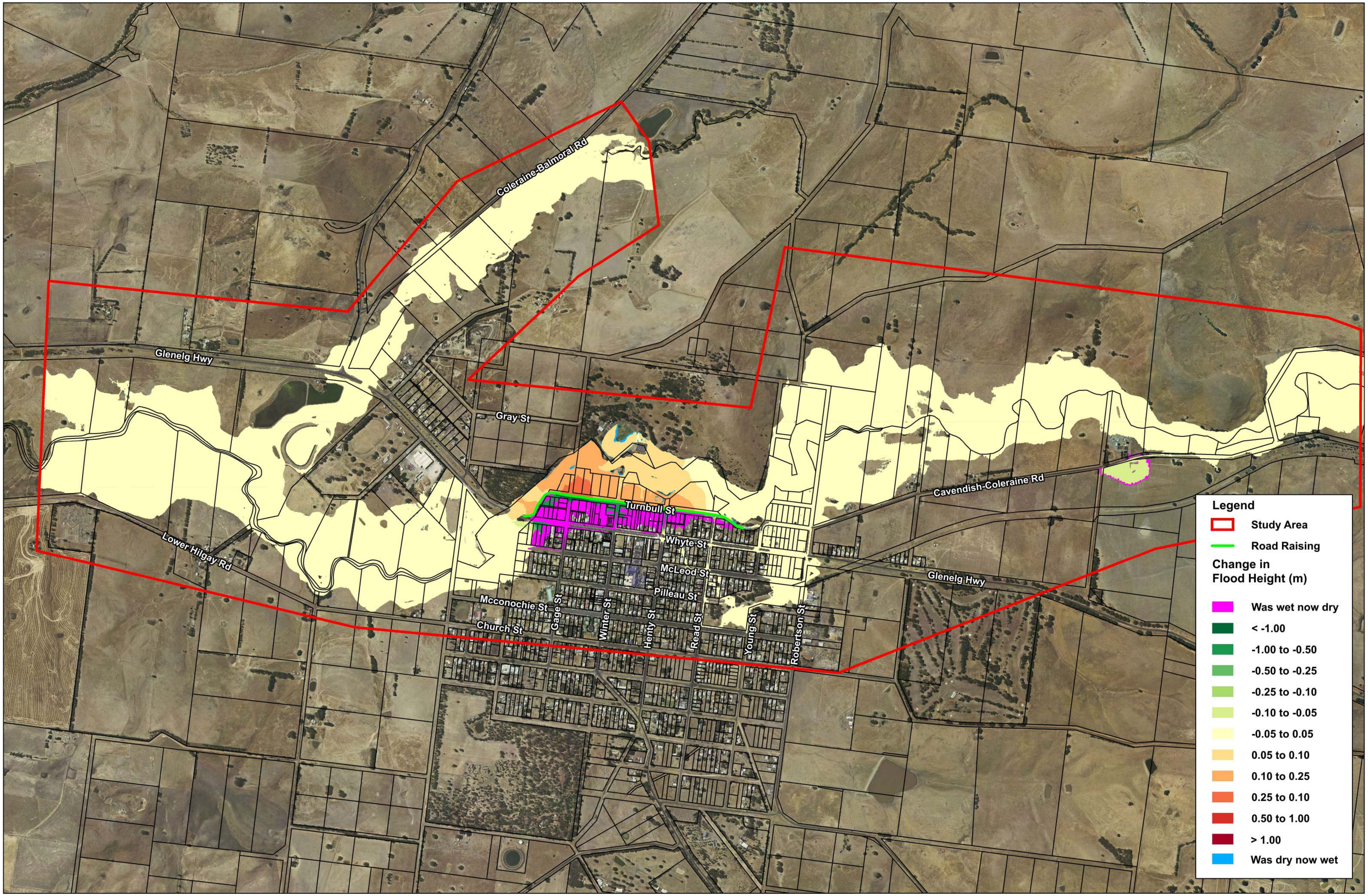
VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title: Coleraine Flood Investigation - Mitigation #1
Change in Peak 2% AEP Flood Level

Figure:	Rev:		Scale		By:		
6-5	A	N	0 250 500m Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	DR	VENANT SOLUTIONS	PO Box 877 Macleod VIC 3085 T. (03) 9457 7164 www.VenantSolutions.com.au
					Date: Jun 2018		

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig6-5_Dif_M01-E01_50y_025_hmax.WOR



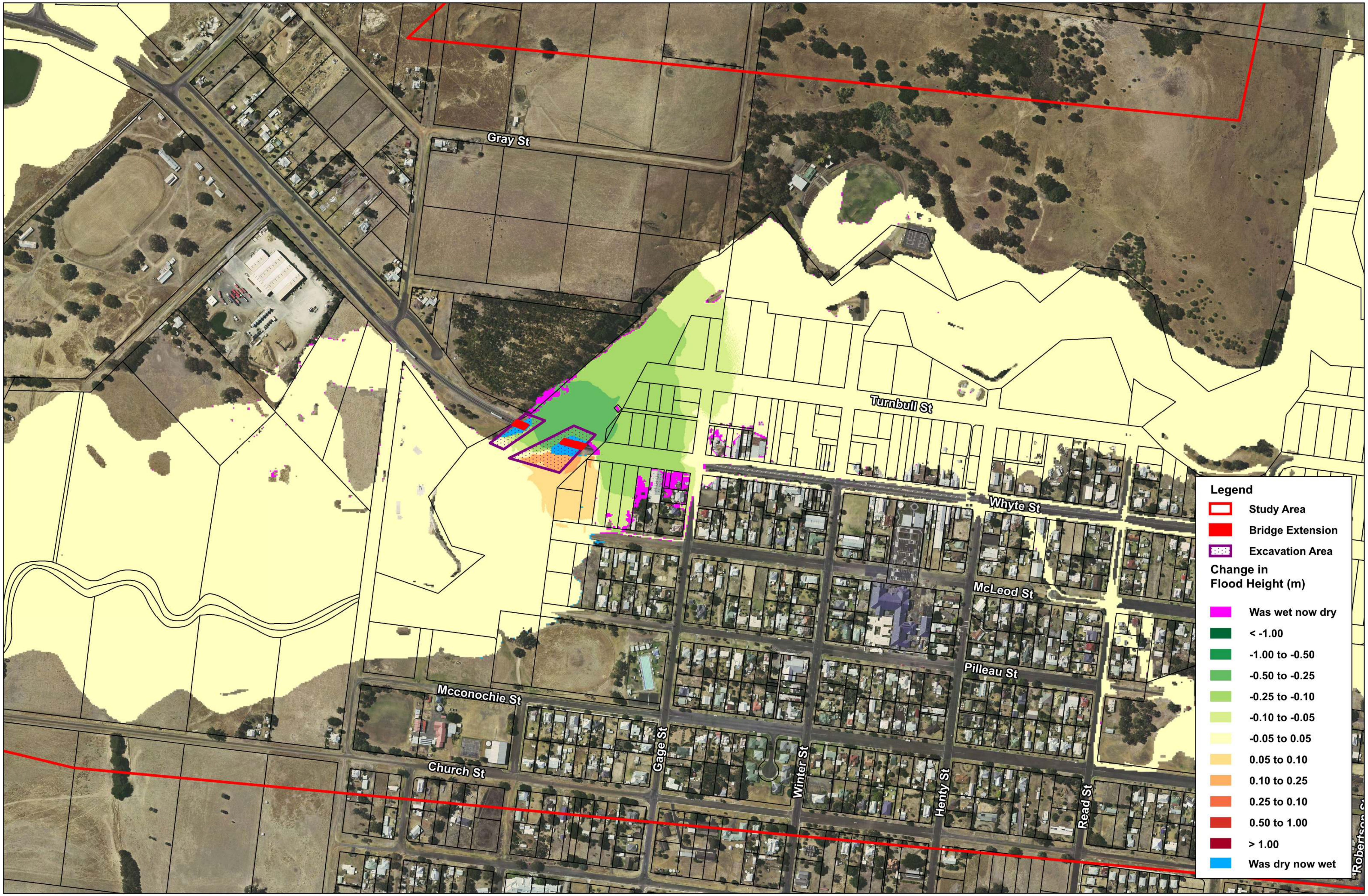
Title:
Coleraine Flood Investigation - Mitigation #2
Change in Peak 2% AEP Flood Level

Figure:	Rev:	N	0 250 500m Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: DR Date: Jun 2018
6-6	A				

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig6-6_Dif_M02-E01_50y_025_hmax.WOR

VENANT SOLUTIONS

PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title:

Coleraine Flood Investigation - Mitigation #3

Change in Peak 2% AEP Flood Level

Figure:	Rev:
6-7	A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

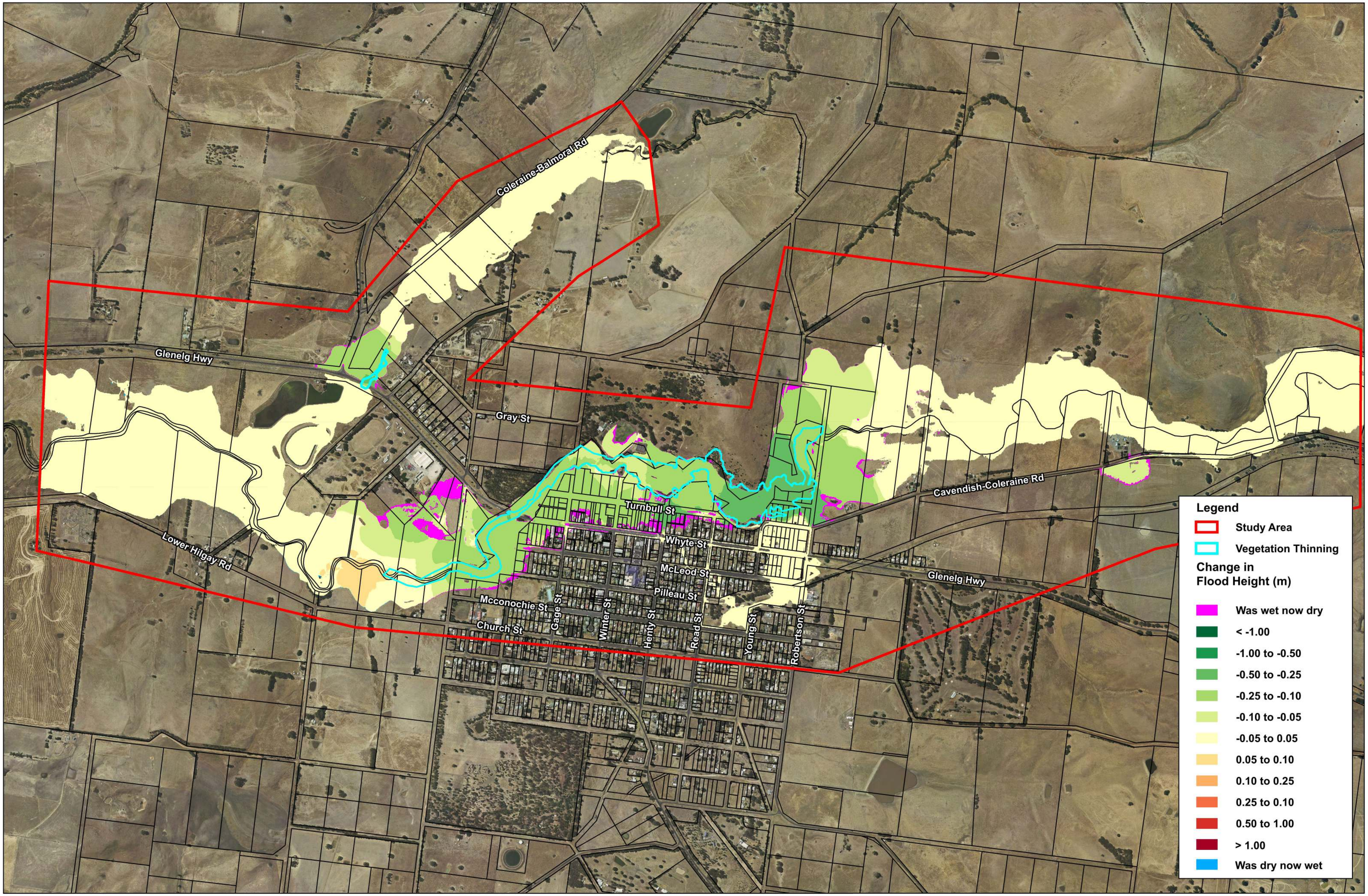
By: DR

Date: Jun 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig6-7_Dif_M03-E01_50y_025_hmax.WOR

VENANT SOLUTIONS

PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title:

Coleraine Flood Investigation - Mitigation #4
Change in Peak 2% AEP Flood Level

Figure: 6-8

Rev: A

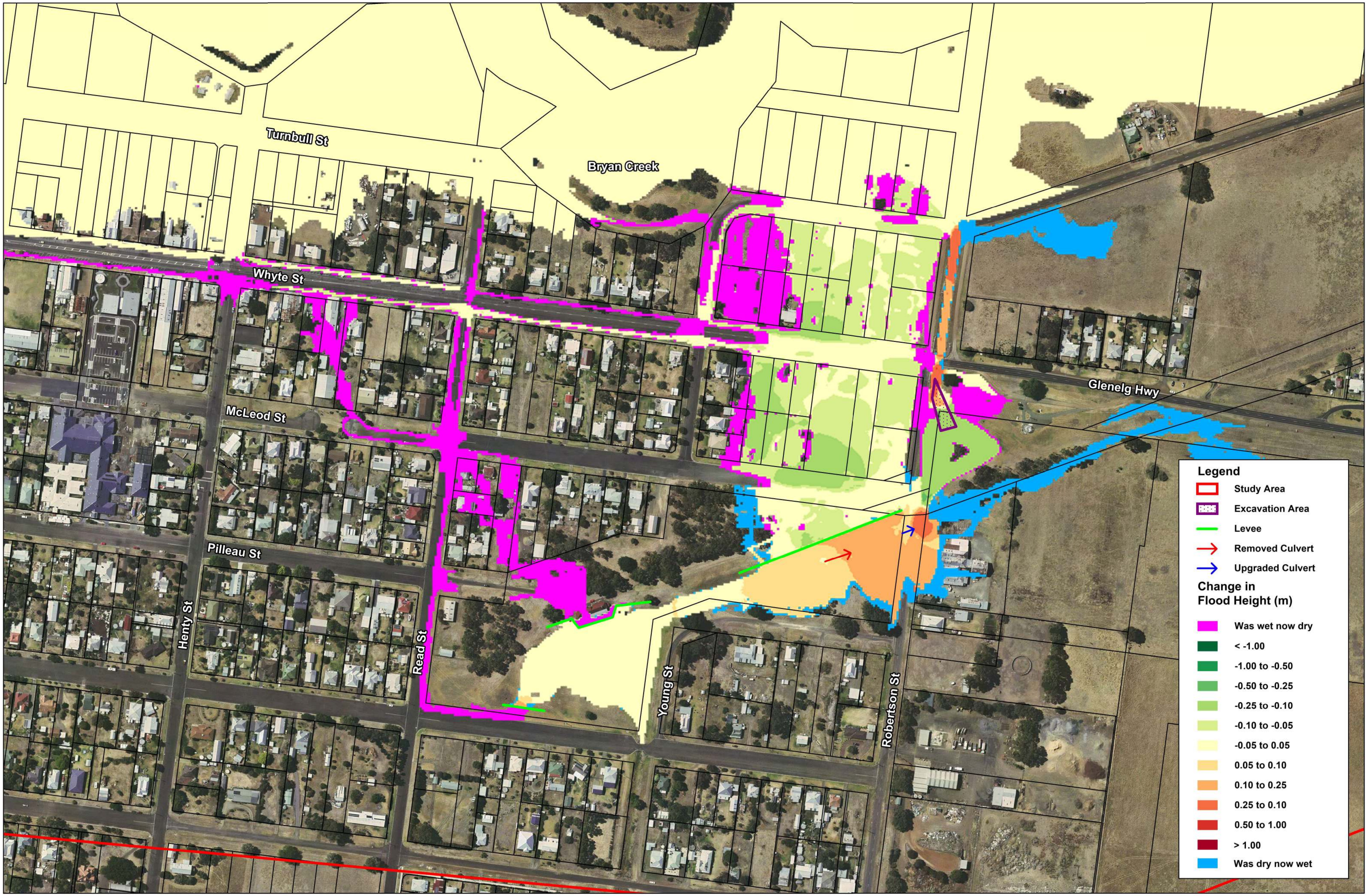
This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR

Date: Jun 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig6-8_Dif_M04-E01_50y_025_hmax.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au



Title: Coleraine Flood Investigation - Mitigation #5 Change in Peak 2% AEP Flood Level	Figure: 6-9	Rev: A	N	0 250 500m Approx. Scale	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: DR Date: Jun 2018	VENANT SOLUTIONS

Filepath:S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig6-9_Dif_M05-E01_50y_025_hmax.WOR

PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au

6.3 Mitigation Cost and AAD Comparison

The Benefit-Cost Ratio (BCR) was calculated for each of the 5 options assessed to quantify the potential benefit of each option economic terms. This required an estimate of the capital and maintenance cost of that would be incurred if the option were to be implemented and the associated potential change in flood damage costs compared with the "do nothing" scenario. It should be noted that the analysis showed that all five of the assessed options could have potential to reduce the Average Annual Damages for Coleraine but may not be economically sound.

6.3.1 Mitigation Costing

The capital cost for each mitigation option was estimated using Rawlinson's Australia Construction Handbook (2018), unit rate costs provided by GHCMA as well as previous projects Venant Solutions has been involved in. Where appropriate the Melbourne prices outlined in Rawlinson's were adopted, increased by a rural location factor of 1.045. The costings presented in this report are high level conceptual costings based on typical industry values and are not based on a detailed cost breakdown which would require a significantly more detailed investigation and more detailed site data. The following assumptions have been used in the costing of each mitigation option.

In each case 10% has been allowed for project management, design, geotechnical and engineering investigation. Due to the high level costing a 30% allowance has been included for un-costed contingencies.

The high-level cost estimate of each mitigation option is presented in Table 6-2. The table includes a breakdown of the costs into capital cost and the maintenance cost over 50 years as Net Present Cost (NPC) assuming a 7% discount rate on future maintenance costs.

Table 6-2 Mitigation Option High Level Costings

Option	Initial Capital Cost ($)	Maintenance Cost (NPC) ($)	Total NPC ($)
Mitigation #1 (Levee)	900,000	211,000	1,110,000
Mitigation #2 (Turnbull St)	1,818,000	-	1,818,000
Mitigation #3 (Bridge Widening)	4,617,000	-	4,617,000
Mitigation #4 (Vegetation Clearing)	243,000	3,052,000	3,295,000
Mitigation #5 (Robertson Drain Upgrade)	210,000	-	210,000

6.3.2 AAD and Benefit Cost Comparison

Table 6-3 presents the Average Annual Damages (AAD) for each of the mitigation options along with the existing (do nothing) scenario using both the O2 and WRM methods. The Net Present Benefit (NPB) is also presented which is the reduction in AAD for each mitigation option over the 50 year life cycle of the mitigation option. The NPB assumes a 7% discount rate on future benefits.

Table 6-3 also presents the Benefit-Cost Ratio (BCR) of each mitigation option. The BCR considers only the tangible damages and the construction and maintenance costs of each option. A BCR of 1.0 means the cost of the option is equal to the benefit it brings to the community. A BCR greater than 1.0 indicates a net positive (ie benefit outweighs cost) and conversely a BCR less than 1.0 indicates a net cost (ie cost outweighs benefit) to the community. An estimated BCR of less than 1.0 should not be disregarded as intangible costs aren't included in the because of the difficulty associated with placing a dollar value on intangibles. A rule-of-thumb sometimes applied in floodplain management is to assume that the intangible costs are roughly equivalent to the tangible costs. Doubling of the BCR result based on the tangible costs is therefore considered a reasonable approach to factoring intangibles into the BCR estimates.

As can be seen in Table 6-3 the bridge lengthening has a very poor BCR of 0.05. Meanwhile the vegetation clearing has a BCR around 0.15. The vegetation clearing is particularly poor due to the required ongoing maintenance of removing regrowth whilst the cost of the bridge is expensive and provides relatively little benefit. The walking track levee and Turnbull Street raising result in a BCR less than 1.0, even when considering the higher estimates of damages using the O2 stage-damage relationships. However, the levee along the walking track appears to be a reasonable option once intangibles are considered, but may only be a break even option in cost/benefit terms.

Option 5, the upgrade of Robertson St. Drain, is the only option investigated with a BCR (tangibles only) greater than 1.0. Floor level survey was not collected for the majority of the affected area. We therefore assumed that floors are 150 mm above ground level which is potentially conservative (may over estimate) for the purposes of the BCR calculation. If this option is considered further it is recommended to undertake floor level survey of the affected properties to verify the validity of the calculations based of this assumption.

Table 6-3 Mitigation Option AAD, NPB and BCR

Option	AAD ($)[1]		NPB ($)		BCR (Tangibles)		BCR (Inc. est. Intangibles)	
	O2	WRM	O2	WRM	O2	WRM	O2	WRM
Existing (Do Nothing)	216,800	161,700	-	-	**-**	**-**		
Mitigation #1 (Levee)	175,200 (-41,600)	127,300 (-34,400)	574,000	475,000	**0.52**	**0.43**	**1.04**	**0.86**
Mitigation #2 (Turnbull St)	179,600 (-37,200)	132,300 (-29,400)	513,000	406,000	**0.28**	**0.22**	**0.56**	**0.44**
Mitigation #3 (Bridge Widening)	199,900 (-16,900)	149,500 (-12,200)	233,000	168,000	**0.05**	**0.04**	**0.10**	**0.08**
Mitigation #4 (Vegetation Clearing)	177,000 (-39,800)	130,300 (-31,400)	549,000	433,000	**0.17**	**0.13**	**0.34**	**0.26**
Mitigation #5 (Robertson Drain Upgrade)	195,700 (-21,100)	141,600 (-20,100)	291,000	277,000	**1.39**	**1.32**	**2.78**	**2.64**

[1]The values in brackets are the reduction in AAD.

7 Planning Controls

The primary purpose of flood related planning controls is to trigger consideration of the level of flood risk associated with the use and/or development of flood-prone land.

In the long term, planning controls are one of the cheapest and most effective means of reducing a community's flood risk by encouraging people to avoid developing flood-prone land if possible and to minimise potential impacts on existing flood-prone development (eg by requiring a higher flood level) when it is renewed.

Development of new planning controls for Coleraine was a key element of this investigation. Draft planning maps and documentation suitable for implementing amendment of the existing flood related planning controls for Coleraine, have been provided to Council. These outputs are summarised below.

7.1 Planning Overlay Background

Land use planning controls and building regulations provide mechanisms for ensuring appropriate use and development of flood-prone land. The objective of land use planning controls is to balance the likelihood of flooding with the consequences (the flood risk). Over time, these controls limit the growth in flood damages. The Victorian Planning Provisions (VPPs) are employed by all Victorian municipalities and set out a consistent planning scheme format. The stated objectives are to protect life, property and community infrastructure from flood hazard, and to preserve flood conveyance capacity, floodplain storage and natural areas of environmental significance.

The VPPs provide for two overlays and one zone associated with mainstream flooding as follows:

- Land Subject to Inundation Overlay (LSIO);
- Floodway Overlay (FO); and
- Urban Floodway Zone.

7.1.1 Land Subject to Inundation Overlay (LSIO)

The LSIO identifies land liable to inundation by overland flow, in flood storage or in flood fringe areas affected by the 1% AEP flood.

The permit requirements of LSIO are intended:

- to ensure that development maintains the free passage and temporary storage of floodwaters,
- to minimise flood damage,
- to be compatible with the flood hazard and local drainage conditions,
- not to cause any significant rise in flood level or flow velocity,
- to protect water quality in accordance with relevant State Environment Protection Policies (SEPPs).

Planned emergency facilities (hospitals, schools and police stations etc.) should be excluded from this area (refer to VPP Clause 13.03-1s). Permit requirements (development conditions) may be specified.

7.1.2 Floodway Overlay (FO)

The FO identifies waterways, main flood paths, drainage depressions and high hazard areas collectively referred to as the “floodway” portion of the floodplain. NRE’s “Advisory Notes for Delineating Floodways” (Edwards, 1998) has guided the delineation of floodway land in Victoria. based upon flood frequency, and level of hazard (based on depth and velocity considerations).

7.2 Existing Planning Controls

The existing controls include an LSIO and a FO in the planning scheme (refer Figure 7-1 below). As has been identified by the managing agencies, these controls are completely inadequate for the residual flood risk that has been underscored by the events of September 2016. The planning scheme does not have a schedule to the FO but does for LSIO, but again is not commensurate with flood risk identified as part of this investigation.

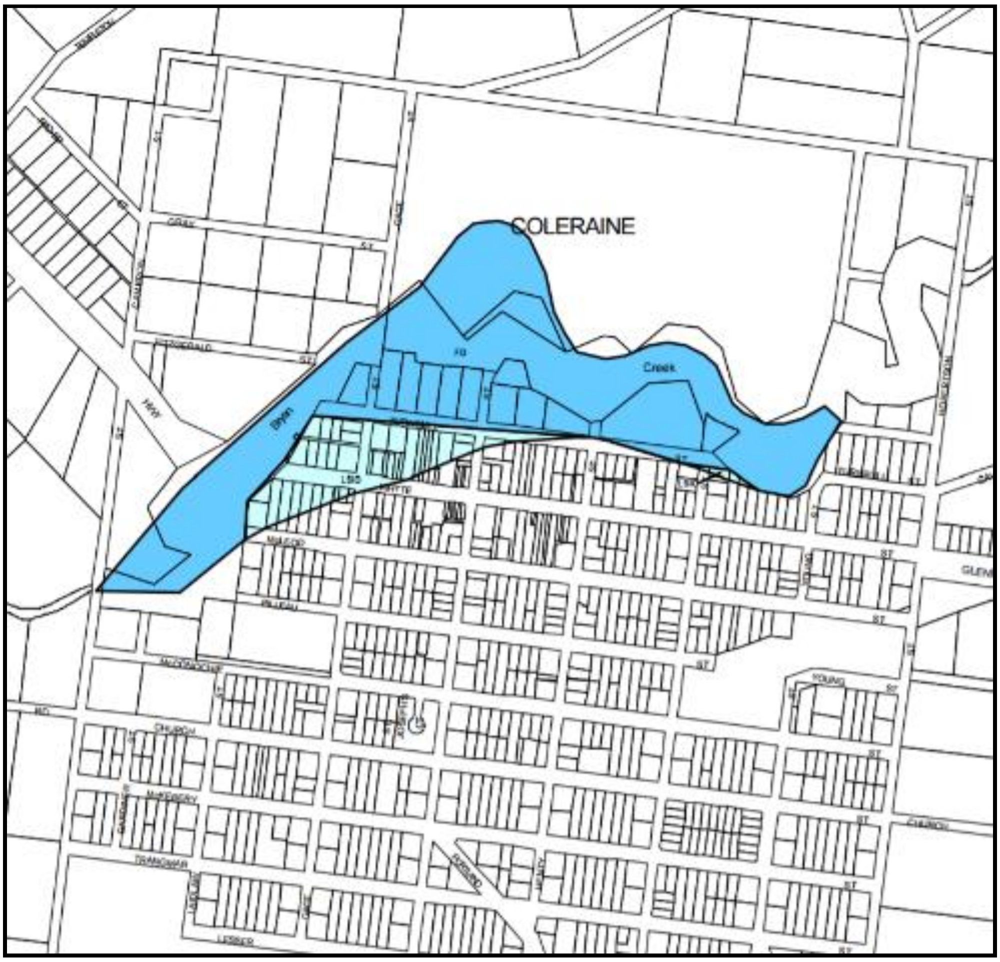


Figure 7-1 Extract of the SGSC planning scheme

7.3 Draft Overlay Delineation

The overlay delineation adopted for this study was developed in conjunction with Council and GHCMA. The approach adopted for the LSIO and FO were as follows:

- Land Subject to Inundation Overlay – based on the 1% AEP flood extent. This is the lower hazard portion of the floodplain, not otherwise within the Floodway Overlay (high hazard portion);
- Floodway Overlay – The high hazard portion of the floodplain, where:
  - Flood depth during a 1% AEP event is likely to be 0.5 metres or more; and/or
  - where the product of depth multiplied by velocity is 0.4 square metres per second or more.

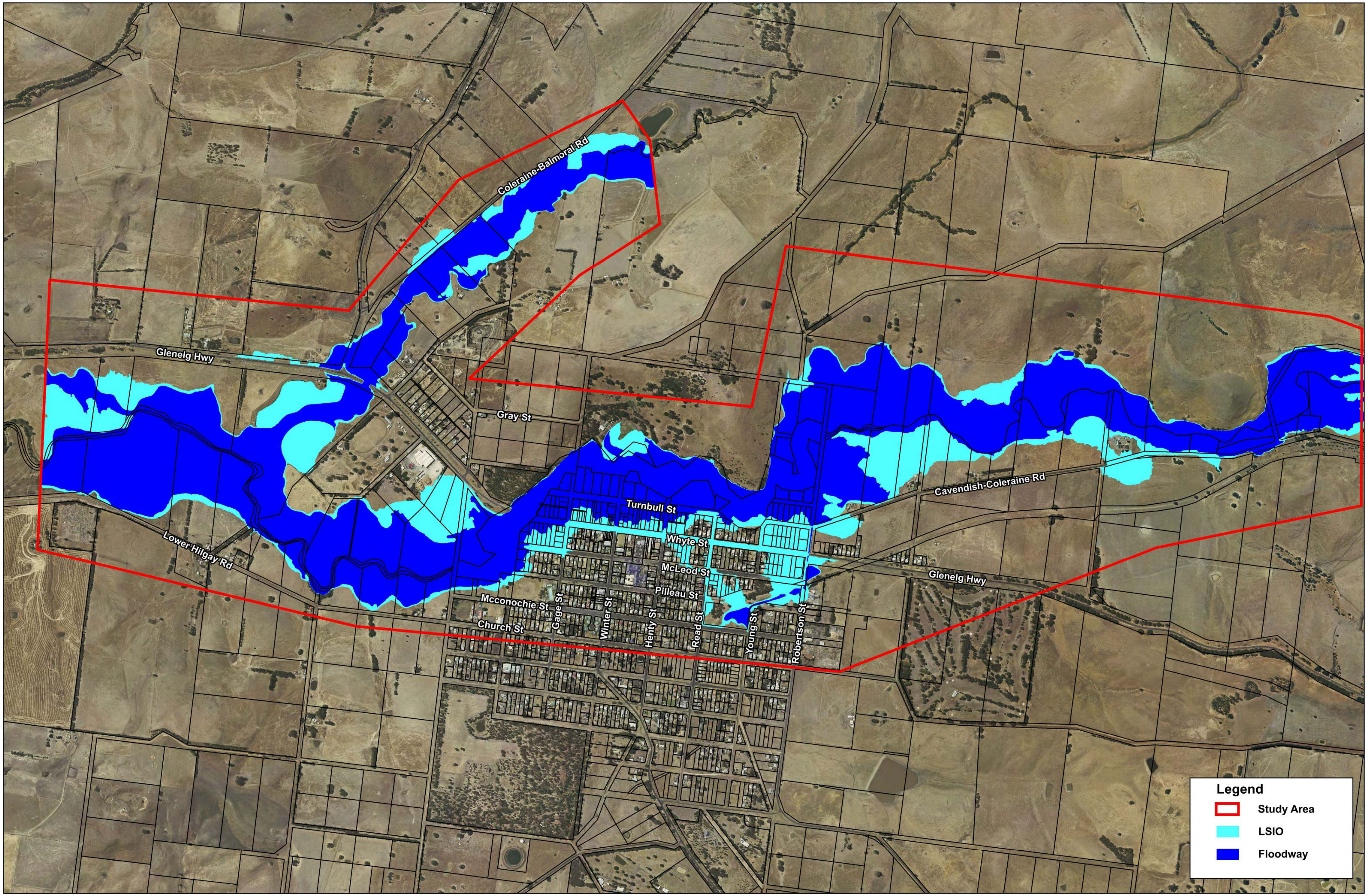
In both instances, 'high' islands were removed from the overlays as these areas, whilst dry represent a risk to people due to the loss of safe access and egress. Experience has shown time and again that development in these areas still constitutes a significant flood risk due to people attempting to drive or wade through flood water. It is therefore important that the risks posed by loss of access to flood islands are considered as part of a development application. The proposed extent of the new overlays is presented in Figure 7-2.

7.4 Overlay Documentation

The overlays once ratified will trigger planning permits for development, including new and replacement buildings, works and subdivision on land affected by floods ranging up to and including the 1% AEP event. A modified schedule to the LSIO and a new schedule to the FO have been prepared which remove some unnecessary controls by providing exemptions for some buildings and works. The schedules also specify Application requirements, Decision guidelines and Referral obligations.

7.5 Declared Flood Levels – Flood Level Contours

The investigation has produced flood level contours suitable for the declaration of flood levels as per the Water Act 1989.



Title: Coleraine Flood Investigation Proposed Planning Overlays

Figure: 7-2 | Rev: A | N | 0 250 500m Approx. Scale

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

By: DR | Date: Oct 2018

Filepath: S:\Projects\M00136.DR.ColeraineFS\GIS\Drawings\R.M000136.008.02_FinalReport\Fig7-2_DraftFinalPlanning.WOR

VENANT SOLUTIONS
PO Box 877
Macleod VIC 3085
T. (03) 9457 7164
www.VenantSolutions.com.au

8 Flood Warning Feasibility Assessment

The investigation assessed the feasibility of improving flood warning arrangements for Coleraine. Apart from the ubiquitous “bush telegraph”, no flood warning or alerting system currently exists for Coleraine. The investigation has delivered essential building blocks (elements) of a Total Flood Warning System (TFWS) including flood mapping and intelligence information to support effective flood response actions. The feasibility assessment has confirmed that the time between flood causing rainfall and the first flood impacts occurring in Coleraine is very short, placing Coleraine in the flash-flooding category. However, the results of the warning feasibility assessment indicate that improved flood warning/alerting for Coleraine is possible.

8.1 Estimated Effective Flood Warning Time

Effective flood warning time is the time available between the detection of rainfall likely to cause a flood and the occurrence of the first significant flood impacts (e.g. over-floor flooding). This is the time a community and emergency services have in which to take effective action to reduce flood impacts. Effective flood warning time is the main constraint on the type of action people can take to reduce flood impacts. Very short effective flood warning time may constrain effective flood response action to evacuation only. Clearly, more complex responses (such as sandbagging) are made possible if the effective flood warning time is longer, either by nature, or by implementation of a “system” enabling people to become fully aware of a risk of flooding and then to respond appropriately to that risk.

Under current conditions, the estimated effective flood warning time for Coleraine is no more than around 3 hours during a large flood and 1 to 2 hours longer (i.e. 4 to 5 hours) for a small flood.

Indicative flood / no-flood tools have been provided in Appendix C4 of the SGSC MFEP. Use of these, in concert with the flood intelligence and mapping delivered by this investigation may extend the effective flood warning time to approximately 6 to 8 hours (by 3 to 5 hours) for a large flood and to around 7 to 10 hours for a small flood.

A further increase in effective flood warning time of at least 1 to 2 hours (or more depending on equipment configurations) could be expected with the installation of the rain and water level gauges outlined in the flood warning report.

The effective flood warning time for Coleraine under existing conditions (assuming daylight hours) and the increases associated with upgrade of TFWS elements are summarised in Table 9-1 below.

Table 8-1 Summary of Estimated Effective Flood Warning Time Under Existing Conditions and with TFWS Improvements

Relative size of flood	Catchment response time	Time to peak from start of rain	Estimated Effective Flood Warning Time		
			Existing conditions (daylight hours)	Minimum investment in TFWS elements (tools, intelligence, mapping only)	Significant investment (attention to all TFWS elements)
Large	8 hours	15 to 17 hours	3 hours	6 to 8 hours	7 to 10 hours
Small	12 to 14 hours	More than 17 hours	4 to 5 hours	7 to 10 hours	8 to 12 hours

8.2 Capacity to Implement Flood Response Actions in the Context of the Estimated Effective Flood Warning Time

In view of the estimated effective flood warning time and following advice from VICSES, emergency services flood response actions within Coleraine in the lead up to a large flood are currently likely to be limited to:

- Issue of a VicEmergency warning of likely flooding;
- Issue of an Emergency Alert (if there is a risk to life); and
- Possibility of some (limited) door knocking along with advice to enact individual flood plans.

With the benefit of the deliverables immediately available from this investigation, it is estimated that the effective flood warning time extends to around 6 to 8 hours for a large flood and around 7 to 10 hours for a small flood. VICSES has advised that the additional available time would enable emergency services to initiate a more complete suite of response actions comprising all elements of the above plus:

- More extensive door knocking along with advice to enact individual flood plans.
- Initiation of strategic sandbagging of buildings identified in the MFEP as being at risk of over-floor flooding with the number of buildings able to be protected increasing with increased available lead time.

8.3 Main Outcomes from the Feasibility Assessment

Currently achievable response actions at Coleraine are outlined in the previous section. The feasibility assessment identified near term through to longer term options with varying investment requirements. These are summarised below.

8.3.1 Near Term Options

Adopting and making best use of the immediate deliverables from this investigation (i.e. making the indicative flood / no flood tools, flood intelligence and flood mapping availability to both the emergency agencies (i.e. SGSC, VICSES and CFA) and the Coleraine community) and using rainfall data available from BoM (i.e. making better use of existing data), will increase the opportunity for additional door knocking and the start of strategic sandbagging of buildings identified in the MFEP as being at risk of over-floor flooding. This has been assessed as being achievable in the near term with minimum investment.

8.3.2 Mid-term Options

With some investment, the Douglas Road site could be permanently instrumented, staff gauges could be installed at the Glenelg Highway Bridge in town and additional measures implemented to increase flood awareness and community engagement. Together, these measures are estimated to give additional confidence in expected flood severity along with an increase in the time available for strategic sandbagging of buildings identified in the MFEP as being at risk of over-floor flooding of an hour or so (i.e. more reliable and substantive outcomes). This has been assessed as being achievable in the mid-term.

8.3.3 Longer Term Options

Further increased confidence in the expected severity of a developing flood, along with additional time to undertake strategic sandbagging of buildings identified in the MFEP as being at risk of over-floor flooding, could be achieved if there was investment in additional and more sophisticated instrumentation to monitor rainfall, water levels and the associated systems to alert emergency services and individuals to the exceedance of trigger values (i.e. improved monitoring and messaging system with automated elements). It is estimated that together these measures would achieve a further increase in effective flood warning time of 2 hours or so. This has been identified as the fully developed option for Coleraine and assessed as being achievable in the longer term. Implementation would require significant investment.

8.3.4 Summary of Feasibility Assessment

It is suggested that an “accurate” forecast is not the key to achieving a significant increase to personal safety and flood damage reduction in Coleraine. Rather it is timely alerting and access to relevant data and easy to use indicative tools that, coupled with robust communications systems supported by sound awareness of flooding consequences (i.e. community resilience), provide the information that triggers those at risk to take timely and appropriate actions: to improve local capability and deliver the benefits sought from a flood warning system.

Further to these specific requirements, feasible options for improving local capability to act in a timely manner and improving future response to impending floods in Bryan Creek have been identified. Implementation of these options could thereby potentially reduce the future impacts and costs. The identified options range from making better use of existing rainfall and stream monitoring resources (i.e. no / low cost options) through to investment in improved rain and / or river monitoring in conjunction with automated messaging, that if implemented, could lead to more reliable and substantive outcomes (i.e. an option requiring more substantial investment of time and money to set up and maintain).

9 Municipal Flood Emergency Plan (MFEP)

The Southern Grampians Shire MFEP which forms part of the shires' Municipal Emergency Management Plan has been updated as part of this investigation. The update to the MFEP collates and summaries the key outputs from the overall Coleraine Flood Investigation in an easy to digest format appropriate for use during an emergency. MFEP are a controlled document managed by VICSES and distributed to Council and the CMA.

The following sections of the MFEP were updated:

- Appendix A – Flood Threats for Southern Grampians Shire Council
- Appendix B – Typical Flood Peak Travel Times
- Appendix C4 – Coleraine Flood Emergency Plan
    - Coleraine Flood History;
    - Overview of Consequences;
    - Flood Intelligence Card;
    - Property Inundation List; and
    - Flood / No Flood Guidance Tool

9.1 Flood Intelligence and Consequences

Flood intelligence and the consequences of flooding on the community for the various range of flood event probabilities have been incorporated into Southern Grampians Shire MFEP as part of the study.

A relationship that links the Douglas Road bridge PALS site to flood consequences in Coleraine has been prepared (Venant Solutions 2018d). This information has been included in the MFEP flood intelligence and the consequences analysis and is summarised in Table 9-1 and Table 9-2.

The flood modelling demonstrated that out-of-bank flows from Bryan Creek commence during quite frequent floods (i.e. less than the 20% AEP event). While depths and velocities within the creek channel do present an extreme hazard, flood depths and velocities within the overbank floodplain (including through the town) as well as associated with the overflow from the Robertson and Young Street drain, are in general, low hazard during the smaller more frequent floods. It is only as flooding approaches 2% AEP severity that hazard begins to increase into the significant and extreme ranges along the town's roads and within the built-up area.

Street and property flooding also starts during quite frequent floods. For example, during a 20% AEP flood, Turnbull Street is inundated to a depth greater than 150mm, other roads on the creek side of town are wetted, seven residential properties are inundated, one house is flooded over-floor to a depth of around 50mm and another is within 100mm of being flooded over-floor.

In general terms, the western end of town and the northern side near Bryan Creek are generally subjected to deeper and more hazardous flooding as flood severity increases. For example, flooding occurs sooner and is deeper in Turnbull Street than in Whyte or McLeod Streets while for the same event, water would be deeper near Gage Street than near Young Street.

The Caravan Park on the corner of Turnbull and Winter streets begins to flood from around the 10% AEP event with water rising to a depth of around 500mm during the 5% AEP flood.

At the 5% AEP level, most of the sporting facilities around town are either flooded to depth or beginning to flood and are cut off from safe access.

As water rises to the 1% AEP level, access to the Hospital and Police Station in McLeod Street (the Hospital is next door to the Police Station in McLeod Street, between Henty and Winter Streets) becomes problematic from any direction other than from the south side of town (Coleraine – Merino Road). Other community facilities also affected to varying degrees include:

- Western District Health Service and Valley View Nursing Home in McLeod Street;
- Medical Centre in Whyte Street;
- The RSL Club;
- Shops including the Supermarket, Post Office and Pharmacy;
- National Hotel, Coleraine Hotel, Black Horse Inn and Wannon Hostel;
- The Primary School and Kindergarten;
- The Caravan Park on the corner of Winter and Turnbull Streets (significant flooding).

The Ambulance station on the corner of Henty and McLeod Streets appears to remain unaffected by flooding. Other community and emergency services are located to the south of Church Street and away from rising flood water, even under estimated Probable Maximum Flood (PMF) conditions.

In general, flood velocities within the study area were found to be relatively low. Higher than average velocities were noted along the main flow paths including Turnbull St and within the waterways, particularly around the permanent pools due to their lack of vegetation inhibiting flow.

Unsurprisingly the areas with highest hazard are along Bryan and Konong-Wootong Creeks and along Turnbull St due to both high velocity and depths. Based on DELWP 2017 classification these areas are considered ‘extreme’ hazard.

Table 9-1 Summary of number of flood affected properties in Coleraine

AEP	PALS gauge (mAHD)	GH Bridge (mAHD)	Properties flooded			
			Residential	Commercial	Total	Almost
20%	115.34	83.65	8	0	8	1
10%	115.85	84.11	13	3	16	0
5%	116.34	84.47	18	5	23	0
2%	117.15	84.91	31	29	60	3
1%	117.67	85.18	34	38	72	3
0.5%	118.17	85.53	49	54	103	5
0.2%	118.78	85.82	74	61	135	4
PMF	123.39	89.55	264	72	336	0

Table 9-2 Summary of number of buildings flooded over-floor in Coleraine

AEP	PALS gauge (mAHD)	GH Bridge (mAHD)	Buildings flooded over-floor			
			Residential	Commercial	Total	Almost
20%	115.34	83.65	1*	0	1	1
10%	115.85	84.11	2	3	5	1
5%	116.34	84.47	2	4	6	5
2%	117.15	84.91	9	11	20	18
1%	117.67	85.18	16	25	41	14
0.5%	118.17	85.53	26	43	69	15
0.2%	118.78	89.55	35	55	90	15

**Note: single dwelling identified as floodprone in the 20% AEP event is affected by breakout from the Robertson Street Drain, not by riverine flooding from Bryan Creek*

10 Victorian Flood Database and GIS outputs

All mapping outputs from the investigation have been provided in Esri geodatabase format suitable for upload to the Victorian Flood Database (VFD) and the Victorian Government (DELWP) FloodZoom (flood intelligence) platform. The outputs were compiled in accordance with VFD Spec 2 (Rev. 11/9/2017) and were supplied to Council separately.

The VFD outputs supplied included outputs for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design flood events and the PMF event. VFD outputs were also supplied for the 1946, 1983, 2010 and 2016 historic flood events.

All outputs were also provided in MapInfo and Esri compatible GIS formats for direct use by Glenelg Hopkins CMA and Southern Grampians Shire.

Naming of the various outputs were per the VFD specifications with all files prefixed with 'Cole18Rv' which is a truncated form of "*Coleraine 2018 Riverine flooding*". The file name abbreviations are shown below in brackets per VFD specifications.

The supplied layers included:

- Study Area polygon (Cole18RvStudyArea);
- Peak Flood Water Surface Elevation (Cole18RvWSE*) in grid format;
- Peak Flood Water Surface Elevation in 0.2 metre contour polylines (Cole18RvContour*);
- Peak Flood Depth (Cole18RvDepth*) in grid format;
- Peak Flood Velocity (Cole18RvVelocity*) in grid format;
- Peak Flood hazard (Cole18RvVxD*) in grid format;
- Flood Extent polygons (Cole18RvExtent*);
- Survey Floor Level points (Cole18RvFloorLevel); and
- Various notes and explanations per VFD requirements.

* indicates where a suffix for each file is included for each of the various historic and design flood events.

11 Conclusions and Recommendations

11.1 Study Overview

The Coleraine Flood Investigation undertook a comprehensive assessment of the flood risk to the Coleraine community. In doing so the study made best use of available data and utilised the best industry practices. The various tasks undertaken as part of the study included:

- Community engagement and seeking community information on historic floods.
- Collation and review of all available data including historic flood levels, rainfall gauges, topography and bridge structures.
- The development and successful joint calibration of hydrologic and hydraulic models to four historic flood events thereby ensuring the models reliably replicate the existing natural rainfall-runoff process and flow characteristics in the catchment and in Coleraine.
- Develop and assess probabilistic design flood flows and flood levels and extents for a range of probabilistic storms.
- Determine the economic cost of floods to the Coleraine community.
- Assess five potential structural mitigation schemes to reduce the flood risk to the community.
- Develop draft planning controls and overlays.
- Assess the feasibility of a warning system for the community and recommend implementation actions.
- Update Council's MFEP.

The outputs from the investigation will help inform Council, GHCMA, VICSES and other stakeholders with future decision making including flood emergency and response, land planning, flood mitigation, community education and flood awareness.

11.2 Recommendations

To bring about translation of the outputs of the investigation into improved flood risk management outcomes for Coleraine, it is recommended that:

- GHCMA, DELWP and Council adopt the supplied VFD GIS outputs of the investigation as well as formally declaring the flood levels as per the Water Act 1989.
- Council review and adopt the draft planning controls developed as part of this investigation to appropriately manage future development within the town.
- Council undertake a detailed study investigating the mitigation option to construct a levee along the Bryan Creek walking track to reduce the flood risk to the community.
- Council undertake a detailed study investigating the mitigation option for modifications to the Young Street and Robertson Street drain.
- With regards to flood risk and emergency management:
    - In the near-term, VICSES in association with Council to engage with the community to improve flood awareness and response during a flood event. This includes sharing flood intelligence captured to the MFEP with the community along with the mapping products and the flood/no flood tools developed as part of this investigation. It is suggested that as a

minimum, this will increase effective flood warning time and the opportunity for initiation of appropriate flood response actions by the community as well as additional door knocking and the start of strategic sandbagging by emergency services.

- In the medium term, Council to permanently instrument the Douglas Road site and install staff gauges at the Glenelg Highway Bridge in town to increase flood awareness and community engagement. Together, and particularly if the instrumentation allows automated alerting of emergency services and the community to likely flooding, these measures are estimated to give additional confidence in expected flood severity along with an increase in the time available to implement appropriate flood response actions.
- In the longer-term, Council investment in additional and more sophisticated instrumentation to monitor rainfall and water levels coupled with measures or systems to automatically alert emergency services and individuals to the exceedance of trigger values. It is estimated that together these measures would achieve a further increase in effective flood warning time. However, implementation would require significant investment and long-term commitment from Council.

Appendix A References

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

AECOM (2014), *South Rockhampton Flood Levee – Tangible Flood Damages Assessment*, July 2014

Austroads, 1994. Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) (2016) *Australian Rainfall and Runoff: A Guide to Flood Estimation*. Commonwealth of Australia, Canberra.

Bureau of Meteorology (2003) *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method*. Hydrometeorological Advisory Service, Bureau of Meteorology, Commonwealth of Australia, Melbourne.

Bureau of Meteorology (2006) *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method*. Hydrometeorological Advisory Service, Bureau of Meteorology, Commonwealth of Australia.

Bureau of Meteorology (2018): *Service Level Specification for Flood Forecasting and Warning Services for Victoria – Version 3.1. April 2018*.

Bureau of Meteorology (2016) 2016 Rainfall IFD Data System. <http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016>.

Department of Land, Water, Environment and Planning (2017), *2017 Flood Study Mapping Guide*, 5 December 2017

Department of Environment Land Water & Planning (2016): *Victorian Floodplain Management Strategy*. April 2016.

DNRM (2002), *Guidance on the Assessment of Tangible Flood Damages*, Department of Natural Resources and Mines, Queensland Government, 2002

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

Geoscience Australia (2017) Australian Rainfall and Runoff Data Hub, <http://data.arr-software.org/>.

Glenelg Hopkins Catchment Management Authority (GHCMA) (2017): *Glenelg Hopkins Regional Floodplain Management Strategy*.

Hydrology and Risk Consulting (2016) ArcRORB, A tool for creating RORB catchment files in ArcMap, User Manual, version 1.6.

Hydrology and Risk Consulting (2016), Update of SoilFlux Tools for Victoria, Report prepared for the Victorian Department of Environment, Land, Water and Planning.

Hill P, Graszkiewicz Z, Taylor M and Nathan RJ (2014) Australian Rainfall and Runoff revision project 6: Loss models for catchment simulation. Stage 4: Analysis of rural catchments.

Hill P and Thomson R (2016) Chapter 3 in Book 5: Losses. In Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) Australian Rainfall and Runoff: A guide to flood estimation. Commonwealth of Australia, Canberra.

Hill P, Brown R, Nathan R and Graszkiewicz Z (2016) Chapter 4 in Book 5: Baseflow models. In Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) Australian Rainfall and Runoff: A guide to flood estimation. Commonwealth of Australia, Canberra.

Intergovernmental Committee for Surveying and Mapping, November 2010, LiDAR Acquisition Specifications and Tender Template, Australian and New Zealand Spatial Information Council

John Rawlinson Co-Partnership Group (2018). *Rawlinson's Australian construction handbook*. Rawlhouse Publishing, [Perth, W.A.]

Jordan P, Nathan R, Podger S, Babister M, Stensmyr P and Green J (2016) Chapter 4 in Book 2: Areal reduction factors. In Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) Australian Rainfall and Runoff: A guide to flood estimation. Commonwealth of Australia, Canberra.

Jordan P, Seed A and Nathan R (2016) Chapter 6 in Book 2: Spatial patterns of rainfall. In Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) Australian Rainfall and Runoff: A guide to flood estimation. Commonwealth of Australia, Canberra.

Jordan PW, Nathan RJ, Mittiga L and Taylor B (2005) Growth curves and temporal patterns of short duration design storms for extreme events. Australian Journal of Water Resources, 9 (1) 69-80.

Kuczera G and Franks S (2016) Chapter 2 in Book 3: At-site flood frequency analysis. In Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) Australian Rainfall and Runoff: A guide to flood estimation. Commonwealth of Australia, Canberra.

Kuczera, G. (1999). Comprehensive At-site Flood Frequency Analysis Using Monte-Carlo Bayesian Inference. Water Resources Research 35(5):1551-1558.

Laurenson EM and Kuczera G A (1999) Annual exceedance probability of Probable Maximum Precipitation. Australian Journal of Water Resources 3(2), 167-175.

Laurenson EM, Mein RG and Nathan RJ (2010) RORB version 6 runoff routing program - User manual. Monash University Department of Civil Engineering in conjunction with Hydrology and Risk Consulting Pty. Ltd. and the support of Melbourne Water Corporation, Melbourne.

Lyne V and Hollick M (1979) Stochastic time variable rainfall-runoff modelling, Proceedings of the Hydrology and Water Resources Symposium, Perth. Institution of Engineers, Australia. National Conference Publication, No. 79/10, 89-92.

McMahon, G.K, and Muller, D.K., (1983), Calibration strategies for non-linear runoff routing models, 15th I.E. Aust. Hydrology and Water Resources Symposium, Hobart, 129-135

Michael Cawood & Associates for the Victorian Flood Warning Consultative Committee (VFWCC) (2005): *Flood Warning Service Development Plan for Victoria: Review of Flood Warning System Development Priorities within Victoria*. October 2005.

Minty, L.J. and Meighen, J. (1999), Rainfall Antecedent to Large and Extreme Rainfall Bursts over Southeast Australia. Hydrometeorological Advisory Service, Bureau of Meteorology, Commonwealth of Australia.

Nathan RJ and Weinmann PE (2016) Book 8: Estimation of very rare to extreme floods. In Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M and Testoni I, (eds) Australian Rainfall and Runoff: A guide to flood estimation. Commonwealth of Australia, Canberra.

Nathan RJ, Weinmann PE and Hill PI (2002) Use of a Monte Carlo framework to characterise hydrologic risk. Proceedings of the 2002 ANCOLD Conference, Adelaide. Australian National Committee on Large Dams.

Nathan RJ, Weinmann PE and Hill PI (2003) Use of Monte Carlo simulation to estimate the expected probability of large to extreme floods. Proceedings of 28th Hydrology and Water Resources Symposium, Wollongong. Institution of Engineers, Australia.

NRE (2000), *Rapid Appraisal Method (RAM) for Floodplain Management*, Department of Natural Resources and Environment, May 2000

O2 (2012), *Stage-Damage Functions for Flood Damage Estimation, Interim Functions for 2012*, Ipswich City Council, April 2012

Raupach MR, Briggs PR, Haverd V, King EA, Paget M and Trudinger CM (2009) Australian Water Availability Project (AWAP): CSIRO Marine and Atmospheric Research component: Final report for phase 3. CAWCR Technical Report No. 013.

Scorah M, Hill P, Lang S and Nathan R (2016), Addressing embedded bursts in design storms for flood hydrology. Water, Infrastructure and the Environment: Proceedings of the 56th New Zealand Hydrological Society Conference and the 37th Hydrology and Water Resources Symposium, Queenstown, New Zealand. New Zealand Hydrological Society and Engineers Australia.

Venant Solutions (2017), *Coleraine Flood Investigation Study – Data Report*, R.M000136.002.02_DataReport.pdf, October 2017

Venant Solutions (2018a), *Coleraine Flood Investigation Study – Hydrology Report*, R.M000136.003.02_HydrologyReport.pdf, February 2018

Venant Solutions (2018b), *Coleraine Flood Investigation Study – Final Hydraulic Model Report*, R.M000136.005.00_FinalHydraulicsReport.pdf, May 2018

Venant Solutions (2018c), *Coleraine Flood Investigation Study – Flood Damages and Mitigation Report*, R.M000136.006.03_DamagesReport.pdf, September 2018

Venant Solutions (2018d), *Coleraine Flood Investigation Study – Douglas Road PALS Assessment*, L.M000136.001.01_ColerainePALS.pdf, January 2019

Venant Solutions (2018e), *Coleraine Flood Investigation Study – Flood Warning Assessment Report* R.M000136.007.01_FloodWarning.pdf, October 2018

Victorian Government Department of Premier and Cabinet (2016) Victorian Land Use Information System 2014/2015, https://www.data.vic.gov.au/data/dataset/victorian-land-use-information-system-2014-2015.

Wang, Q.J., (1997), LH moments for statistical analysis of extreme events. Water Resources Research, Vol. 33, No. 12, pp. 2841-2848.

WRM (2006), *Stage-Damage Relationships for Flood Damage Assessment in Maroochy Shire*, WRM Water & Environment Pty Ltd, June 2006, prepared for Maroochy Shire Council