Data Review Report

Allansford Flood Investigation and Stormwater Management Strategy

Warrnambool City Council

6 December 2023

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Cover Image: Hopkins River at Allansford, 19 September 2023

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ACKNOWLEDGEMENT OF COUNTRY

The Board and employees of Water Technology acknowledge and respect the Aboriginal and Torres Strait Islander Peoples as the Traditional Custodians of Country throughout Australia. We specifically acknowledge the Traditional Custodians of the land on which our offices reside and where we undertake our work.

We recognise the connection of the Traditional Owners to Country and the value of their contribution to managing the land and water and acknowledge their ongoing contribution to improved and connected management of our waterways and floodplains. We embrace the spirit of reconciliation, working towards equity for Traditional Owners.

Artwork by Maurice Goolagong 2023. This piece was commissioned by Water Technology and visualises the important connections we have to water, and the cultural significance of journeys taken by traditional custodians of our land to meeting places, where communities connect with each other around waterways.

The symbolism in the artwork includes:

- *Seven circles representing each of the States and Territories in Australia where we do our work.*
- *Blue dots between each circle representing the waterways that connect us.*
- *The animals that rely on healthy waterways for their home.*
- *Black and white dots representing all the different communities that we visit in our work.*
- *Hands that are for the people we help on our journey.*

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Note: Most figures have been provided as image files separately to this report.

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1 INTRODUCTION

1.1 Overview

Water Technology has been commissioned by Warrnambool City Council (Council) to undertake the Allansford Flood Investigation and Stormwater Management Strategy (FI & SWMS). The investigation area covers the Hopkins River and local stormwater catchment in the township of Allansford, located east of Warrnambool, as shown in Figure 1-1 below.

The Allansford Strategic Framework Plan identifies the need to balance growth within the township against flooding and stormwater constraints. The Strategic Framework Plan was adopted by Council on 3rd May 2021 with the implementation of the Strategic Framework Plan to include a planning scheme amendment to incorporate the Plan and its recommendations into the scheme. The outputs of the Flood Investigation and Stormwater Management Strategy will form part of the planning scheme amendment. In addition, Allansford is identified in the Glenelg Hopkins Regional Floodplain Management Strategy (RFMS) as a priority location for which an improvement in flood information is required. The preferred management action for Allansford in the RFMS is to *identify flood prone areas through structure plans for Logans Beach and Allansford and introduce planning controls*.

Previous flood/stormwater investigations covering Allansford include assessments of historical flood events completed by Utilis for the Warrnambool Floodplain Management Plan and Municipal Flood Emergency Plan, along with stormwater investigations focussed solely on stormwater conveyance from Allansford to the Hopkins River. Previous investigations are discussed further in section 2.1 below.

The Allansford Flood Investigation and SWMS will define the 1% AEP inundation extents in Allansford, considering both riverine flooding and stormwater inundation under present day and projected climate change scenarios. The outputs are intended to be implemented into the planning scheme, ensuring that the planning scheme mapping accurately reflects flood hazard and that growth in Allansford is managed appropriately into the future. As such, updated flood mapping suitable for inclusion in the Warrnambool Planning Scheme is a key output required from the study.

In addition to modelling the current conditions the development of the Stormwater Management Strategy will consider an ultimate development scenario including preferred options for stormwater conveyance and treatment. The strategy will include cost estimates of preferred options and will form part of the overall strategic planning for Allansford.

This report is one of a series documenting the outcomes of the Allansford Flood Investigation and SWMS Study. Each reporting stage is shown below:

- **R01 - Data Review and Validation - This Report**
- R02 – Hydrologic and Hydraulic Modelling Report
- R03 – Stormwater Management Strategy
- R04 – Summary Report

The data required for this study has been collated and reviewed. This report documents a summary of the available streamflow, rainfall and topographic data as well as the relevant previous projects and other information relevant to the study. The report also details the outcomes of the first community consultation session, verification of the available topographic datasets and details the hydrological and hydraulic modelling approach.

Following appointment and project inception, Water Technology prepared a survey requirements memorandum for council to capture structure details, pipe levels and ground levels for the purpose of LiDAR data verification as detailed in the project brief. The captured data has been included and discussed in this report as relevant.

1.2 Study Objectives and Outputs

The key objectives of the study as provided in the project brief are:

Objective 1

Update knowledge and data around impacts of climate change, specifically an increase in frequency of extreme rainfall events to enable more effective planning for a worsening flood risk profile for Allansford.

Objective 2

Amendment of flood related land use and development controls in the Warrnambool planning scheme.

Objective 3

Provision of flood mapping. The new mapping outputs must be of sufficient resolution to enable flood risk management planning at the building envelope scale (i.e. be of suitable resolution and rigour for a planning scheme amendment).

Objective 4

Preparation of a Stormwater Management Strategy for Allansford, which addresses, at a level of detail appropriate to the objectives of the Framework Plan, the arrangements for collecting, conveying, storing, and discharging stormwater from the existing and planned development and achieving water quality improvements consistent with established WSUD principles.

The key outputs which will allow the study to achieve the above objectives are:

- Detailed reporting summarising the available data, community consultation, site inspection findings and survey undertaken (**this report**).
- Updated flood frequency analysis for the Hopkins River at appropriate locations.
- Development and calibration of hydrologic and hydraulic models.
- Design event modelling of the 20%, 10%, 1% AEP and Probable Maximum Flood (PMF) events in accordance with Australian Rainfall and Runoff 2019.
- Assessment and modelling of the impact of increased rainfall intensity associated with climate change under Representative Concentration Pathway (RCP) 8.5 to the years 2050 and 2100.
- Development of the Allansford Stormwater Management Strategy, considering conveyance and treatment of stormwater generated in the local catchment and cost estimation of preferred mitigation/development options.

1.3 Study Area

Allansford is a relatively small but growing rural settlement located approximately 10km east of Warrnambool. The town is located on the southern side of the Princes Highway. While the area has been occupied by traditional owners for thousands of years, the township was established by European settlement in the 1800s.

The Hopkins River runs through Allansford and has an upstream catchment area of approximately 8,700 km^2, extending from Ararat in the north, Ballarat in the northeast, through to Warrnambool in the south. The main tributaries to the Hopkins River are Fiery Creek and Mt Emu Creek. The river is recognised for its ecological, community and cultural value. Hopkins Falls, approximately 6km north of Allansford, is a popular lookout spot particularly when the river is in flood and is the closest stream gauging station to Allansford.

Current understanding of flood risk for Allansford is largely based on the observed impacts from the 2011 flood event on the Hopkins River. No formal flood study has been undertaken and the intelligence gathered during the 2011 event has guided responses to more recent events such as those of October 2022. Riverine floodwater backing into the stormwater system during flood events has the potential to cause inundation particularly if local rainfall is occurring simultaneously. During the 2011 and 2022 flood events, the main stormwater drain was blocked with sandbags and other materials and pumps set up to allow local stormwater drainage to the river.

Stormwater drainage of the local catchment relies almost exclusively on a single outfall, known as the Main Open Drain and Tooram Road North outfall (the open drain flows into the outfall). Another historic outfall, referred to as the Tooram Road South outfall, remains functional however catchment alterations such as earthworks over many years have resulted in the south outfall draining a very small portion of the town.

The study area is shown in Figure 1-1 below. The local stormwater catchment and key features therein are shown in Figure 1-2 below.

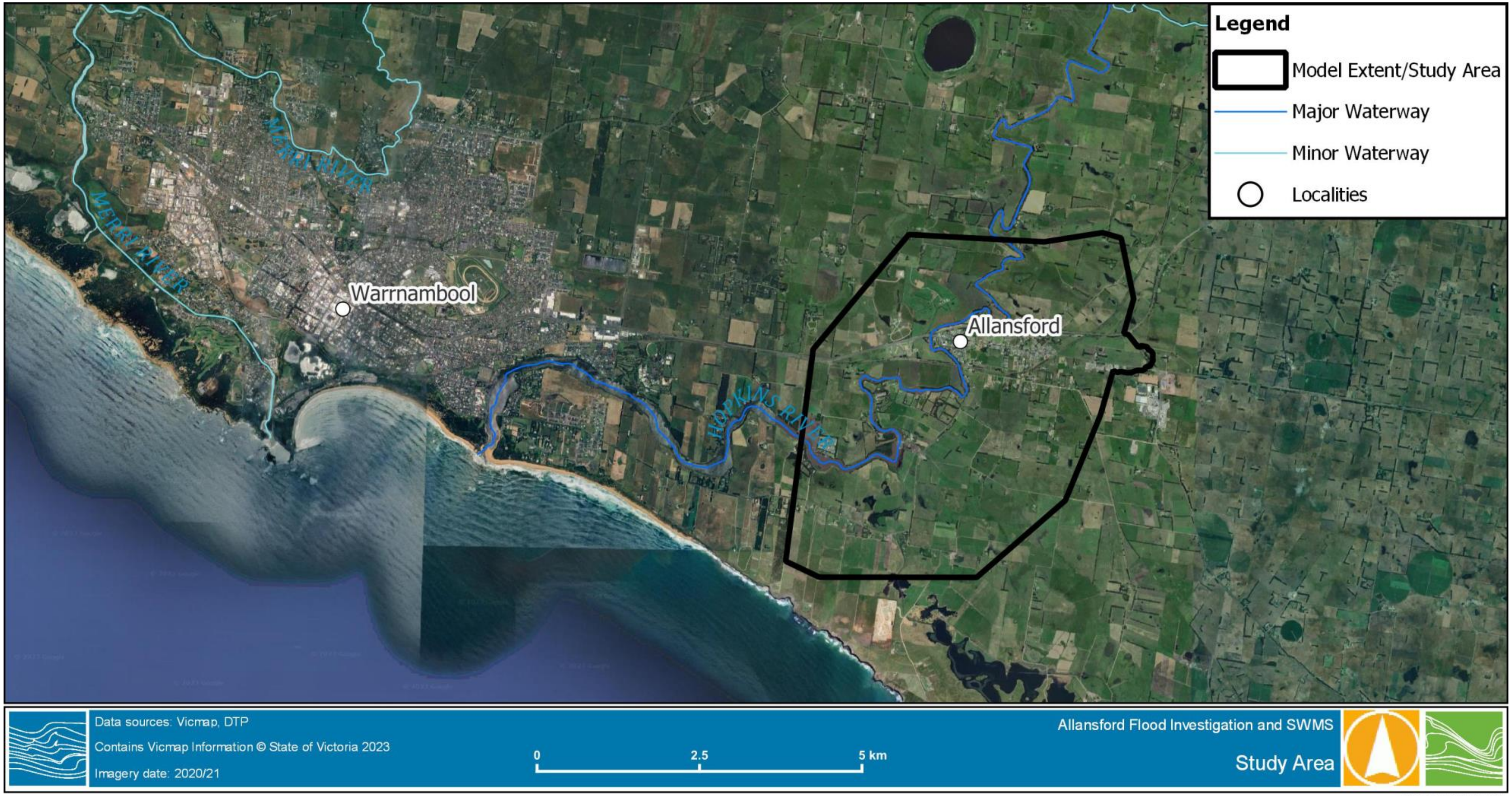

Figure 1-1 Study Area

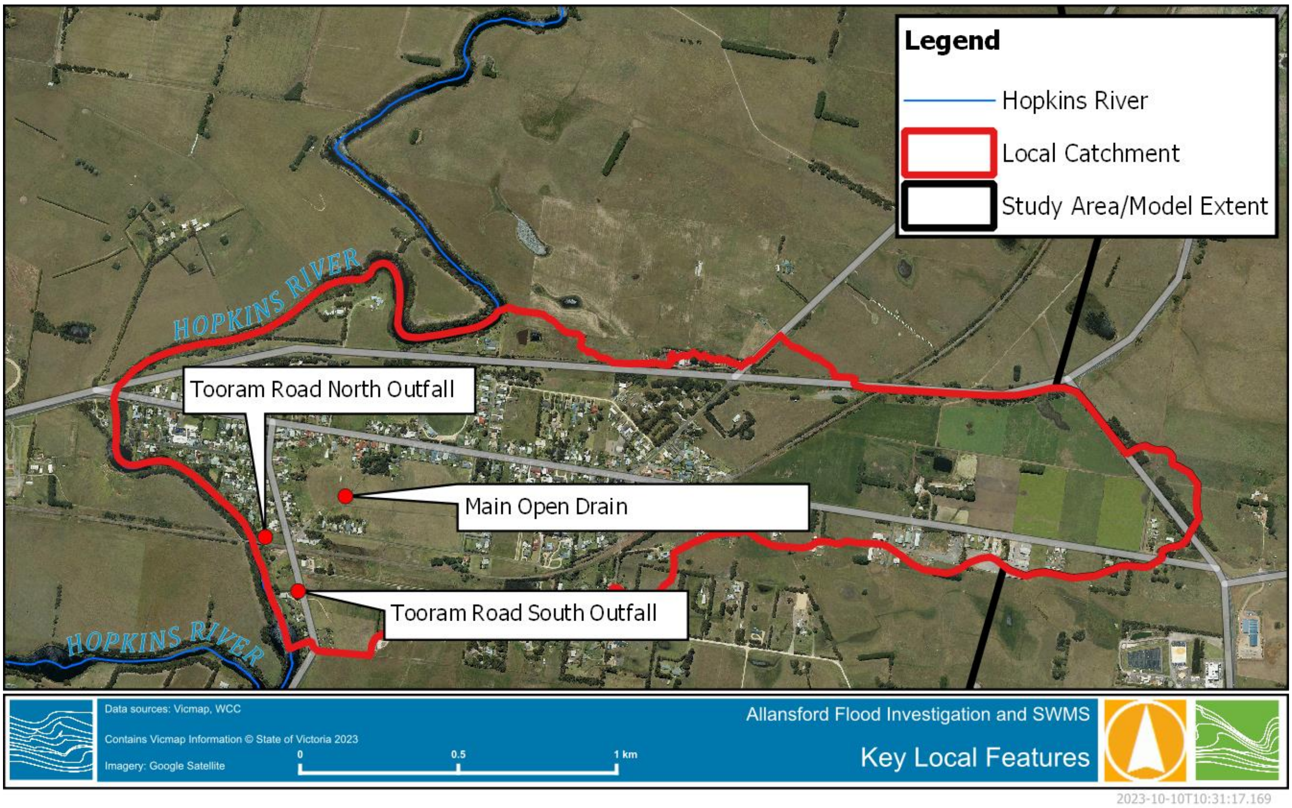

Figure 1-2 Local Catchment and Key Features

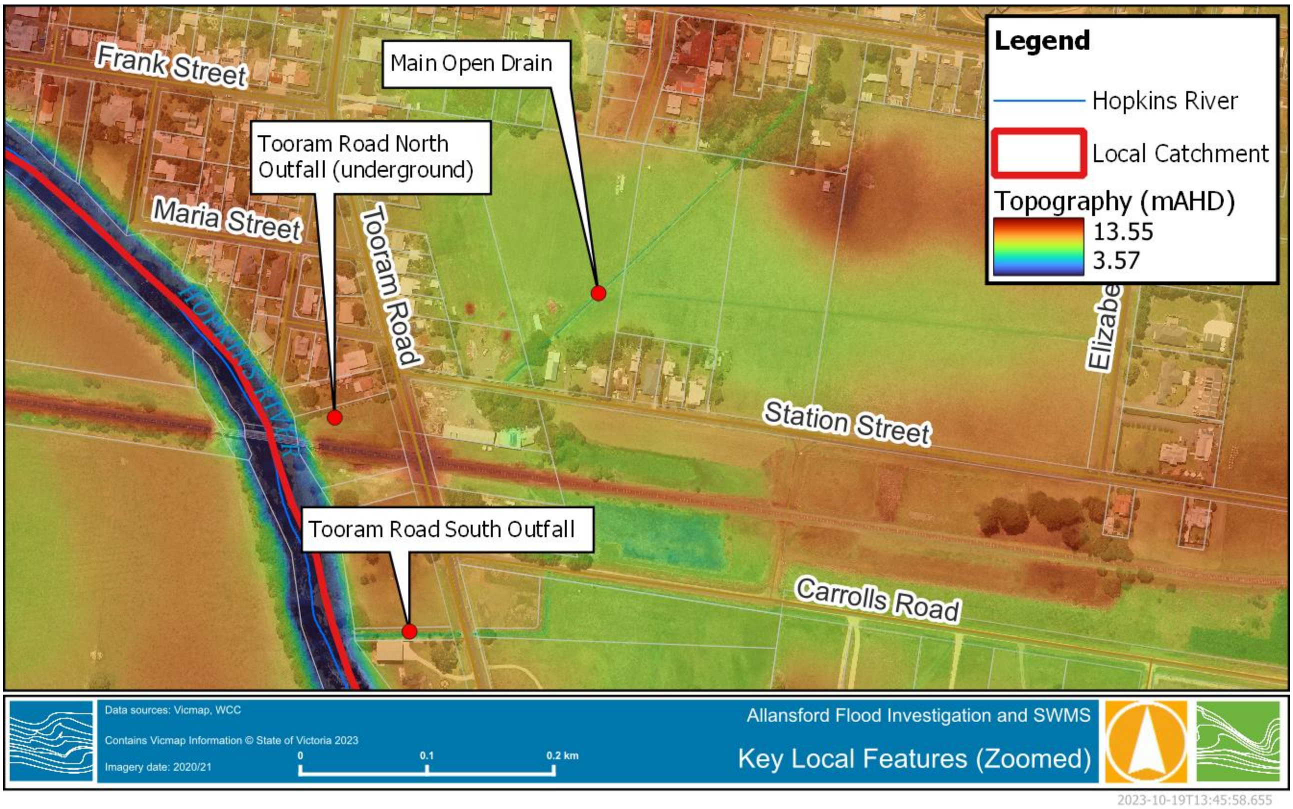

Figure 1-3 Key Features – close view with topography

2 DATA SUMMARY

2.1 Previous Investigations

There have been two previous formal investigations looking into Allansford drainage, the *Allansford Outfall Drain Options Evaluation Report* (Hyder Consulting, November 2002) and the *Allansford Township Drainage Requirements* (Cardno Lawson Treloar, 2008). Both studies investigated upgrades to the stormwater drainage network with no consideration of riverine flooding.

In addition to the two local investigations, Glenelg Hopkins CMA has completed a Flood Frequency Analysis of a selection of major waterway gauges within the CMA region in 2010, including the Hopkins Falls gauge immediately upstream of the study area. The FFA will be updated as part of this project.

2.1.1 Hyder Consulting Investigation 2002

Warrnambool City Council engaged Hyder Consulting to prepare the *Allansford Outfall Drain Options Evaluation Report* (November 2002). The report focussed on local catchment (stormwater) drainage issues in Allansford, notably the concrete open drain and associated pipes that ultimately outfall to the Hopkins River upstream of the railway bridge. Riverine flooding was not considered as part of the report.

The assessment applied the rational method to predict flows in the trapezoidal concrete drain upstream of Station Street and the connected pipe and outlet to Hopkins River. Five options were considered to improve the performance of the drainage system.

Some key takeaways from the investigation are as follows:

- That any development east of the railway line (outside the current township boundary) would be required to divert flows away from the current Tooram Road/Station Street outfall.
- All options proposed included a floodway accompanying the upgraded main open drain.
- The report noted that there is no existing overland flow path beyond Station Street.
- The report noted that if the 825mm pipe outfalling to the Hopkins River was found to be deteriorated, and recommended it be replaced with a larger diameter pipe.
  - This has now occurred as per section 2.6.2.2 below.
- The potential for riverine flooding surcharging into the main open drain was not considered.

The report recommended the decommissioning of the main open drain and construction of a 2 year ARI pipe in place of the existing main open drain, with a new open floodway constructed above the pipe. A 750mm diameter pipe was recommended. The total floodway width (with pipe underneath) was proposed to be 9 metres wide.

2.1.2 Cardno Investigation 2008

Warrnambool City Council engaged Carno Lawson Treloar to prepare a drainage strategy for Allansford, titled *Allansford Township Drainage Requirements* (Cardno Lawson Treloar, 2008). The investigation assumed an ultimate development scenario for the town with all areas serviced by underground drainage. A drainage network was proposed to cater for the 10-year ARI event in underground pipes.

The key takeaways from the report are as follows:

- The report assumed full development of the area east of the railway line, with this development proposed to drain to the current outlet.

- The analysis considered the 10-year ARI event only. No allowance was made for overland flows of events greater in magnitude than a 10-year ARI.
- The outlet pipe to the Hopkins River was proposed to be upgraded to a 1950mm pipe with a downstream invert of 4.4 metres (assumed to be AHD).

2.1.3 Glenelg Hopkins CMA Hydrological Assessment

As part of the Allansford Flood Investigation and SWMS, updated Flood Frequency Analysis of the Hopkins River at Hopkins Falls gauge will be completed. An analysis of this and other gauges in the GHCMA region was completed and documented in a June 2010 report, which details a hydrological assessment of a number of locations within the Glenelg Hopkins region completed by the CMA. The assessment adopted a flood frequency analysis (FFA) approach for gauges where the flow record was at least 20 years long and extendable to 30 years where additional data was available. RORB rainfall runoff analysis was adopted for 4 ungauged catchments where FFA could not define flows of specified annual exceedance probabilities due to the lack of recorded gauge data (i.e. rainfall rather than streamflow was used to define the 1% AEP flows).

Table 2-1 lists the gauges within the Hopkins River catchment for which flood frequency analysis was completed.

Table 2-1 GHCMA FFA sites within the Hopkins River catchment

Site	Station No.	Station Name
1	236212	Brucknell Creek @ Cudgee
2	236203	Mt Emu Creek @ Skipton
3	236216	Mt Emu Creek @ Taroon
4	236204	Fiery Creek @ Streatham
5	236202	Hopkins River @ Wickliffe
6	236210	Hopkins River @ Framlingham
7	236209	Hopkins River @ Hopkins Falls

Relevant flood frequency analyses will be updated as part of this project, ensuring the assessment considers the additional ~14 years of data captured since the previous FFA was completed.

2.2 Historical Flood Information

Detailed accounts of historical flood impacts are included in the Warrnambool Municipal Flood Emergency Plan (MFEP) and the Warrnambool Floodplain Management Plan. The Warrnambool Floodplain Management includes mapping from the former Victorian Flood Database (VFD) which shows an estimated 1% AEP flood extent within the project area. The VFD extent shows floodwater passing through the township of Allansford, something that was not observed in the 2011 event.

1870 Event

The flow path through Allansford as shown on the VFD extent was described in an article in the Warrnambool Examiner on the 13th September 1870, which states "*Hopkins River in flood. Water flowing between the Allansford & Junction Hotels to Tooram flats. New bridge swept away*." Little other information is available regarding this event.

1894 Event

A very significant flood of the Hopkins River occurred in 1894. Flooding of the Hopkins River overtopped the western bank of the river downstream of Ziegler Parade at the dog leg bend, flowing across the paddocks of what is now 10235 Princes Highway to the railway line. The flows caused damage to the rail line, with The Age reporting that trains were stuck after floodwaters washed away a portion of the embankment. A highly descriptive account from the Camperdown Chronicle, 11 October 1894 reads as follows:

The effect of the flood has been more marked on the Hopkins River than on any other of the streams in the districts affected, doubtless owing to the large extent of mountainous country it drains. At Allansford it overflowed and formed a second stream, which carried away about 150 feet of the embankment at Summer Hill. This necessitated the trains from this side stopping at Allansford and passengers being taken across the damaged section by a trolly to a train waiting on the other side to take them along, whilst all goods trains have been sent round by Hamilton.

https://trove.nla.gov.au/newspaper/article/18631950?searchTerm=allansford%20flood%20train

1916 Event

Other floods of note include 1916, which is described in The Standard as having "*rose eight feet during the day and was flowing across the road on the lower side of the bridge"* (27 Sep 1916). No significant impacts are noted in the article.

1946 Event

The flooding of March 1946 was significant for southwest Victoria, with the Moyne River at Port Fairy inundating large swathes of the town. Impacts on the Hopkins River were less severe than the Moyne, and thus somewhat overshadowed in reporting of the day. The Age reported that the Hopkins River *"burst its banks, flooding low-lying land, including a strip of the highway. In some places, the highway is 4 feet underwater"* (19 March 1946). Concerns were held for the bridge stability after being struck by floating debris and logs. Residents were prepared to evacuate.

A single surveyed flood mark is available from the 1946 event however it is considered to be low reliability and thus is of little value in calibrating a flood model on its own.

2011 Event

The significant flood event of January 2011 is the largest flood on recent record at Allansford. The flood occurred on an already wetted catchment after less significant flooding in August and September 2010, during one of the strongest observed La Nina events yet[1]. Large volumes of rainfall fell in the catchment from the 10th to the 14th January, ranging from 112mm to 172mm across the catchment. Flooding in Allansford was observed between the 17th and 19th of January 2011, with the Hopkins River peaking at 4.02 metres at the Hopkins River @ Hopkins Falls (236209) gauge.

The Municipal Flood Emergency Plan (MFEP) describes a combination of stormwater and riverine inundation during the event. Riverine impacts include shallow inundation along the north side of the Princes Highway, which was close to requiring closure. The Ziegler Parade bridge was closed as a precaution but was not overtopped during the event. Other roads impacted include Garabaldi Lane, Frank Street, Station Street and Tooram Road.

[1] http://www.bom.gov.au/climate/enso/feature/ENSO-feature.shtml

A series of 30 flood marks were captured at the peak of flooding and surveyed in the following days. This data has been provided as part of the flood study and will be utilised in calibrating of this event in the hydraulic model.

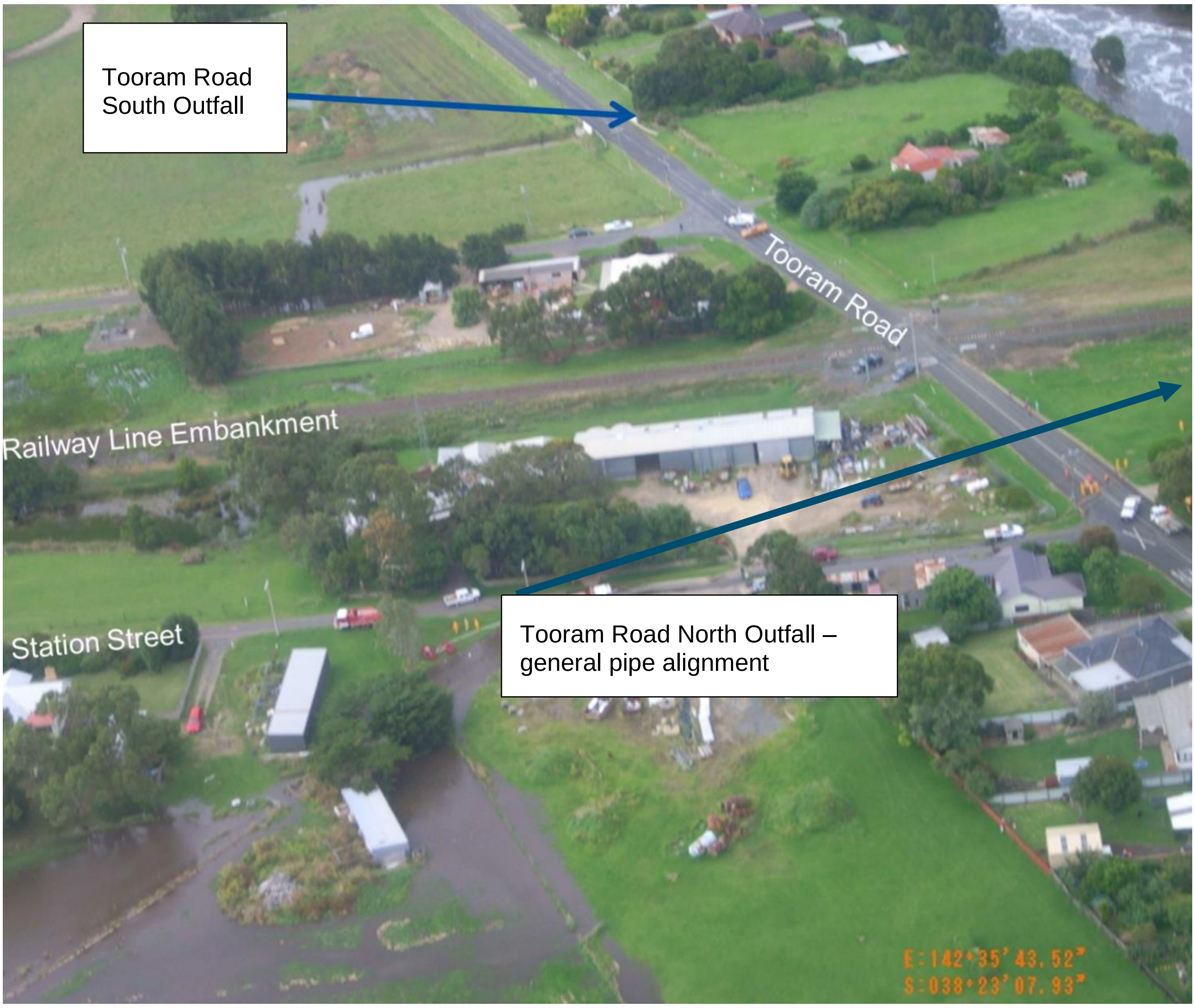

Figure 2-1 Aerial photography showing impacts in January 2011 (adapted from the Warrnambool MFEP, July 2022)

2020 Event

The October 2020 event is notable as a stormwater, rather than riverine, driven event. The Warnambool rain gauge recorded 80mm of rain on the 8th October, with 56mm of that falling in 3 hours. In Allansford, CFA tankers were used to pump water from impacted locations such as Ziegler Parade to the Hopkins River. The Main Open Drain had its capacity exceeded and flooding upstream of the outlet occurred. Photographs from the event are included in the MFEP.

2022 Event

Significant rainfall was experienced across the upper catchment of the Hopkins River with more moderate falls being experienced along the coast. The highest rainfall within the region was shown to occur in and around

Ballarat where 81mm fell and Willaura where 114mm fell over 13/10 and 14/10. Rainfall totals for the week from 10 to 17 October are shown in below.

Table 2-2 Hopkins River catchment 24-hour rainfall totals (mm), 10-17 October 2022

Station Name	24 hours to 9am - last 7 days						
	11	12	13	14	15	16	17
Hopkins Catchment							
Ballarat Airport AWS	0	0	29	52	4.8	1.6	0
Ararat	0	0	37	35	2.4	2	2
Ararat (Hopkins R)	0	0	39	19	2	0.6	0.2
Skipton			26	39	3	4.4	
Mena Park	0	0	28	37	1.2	3	0.4
Nullawarre	0	0	39	19	2.2	0	0
Westmere AWS	0	0	43	31	1	1	0.2
Willaura			89	25			6.8/2
Wickliffe				92/4	1.6	2.2	0.4
Penshurst	0	0	19	16	3.2		5.6/2
Mortlake AWS	0	0	50	21	2	0.2	0.2
Terang	2		32	21	4	4.4	
Warrnambool AWS	0	0	26	16	0.8	1.2	0

This rainfall resulted in increased flows throughout the Hopkins Catchment including along the Hopkins River, Mt Emu Creek and through the Burrumbeet Creek Catchment. At the time of the event Lake Burrumbeet was shown to be full and spilling into the Mt Emu Creek.

Initial flood peaks were experienced in Ararat and Wickliffe, with Wickliffe also experiencing a second and higher peak on Saturday 15/10 at 19:45 to a gauge level of 3.28m.

High water levels from around Beaufort and the upper Mt Emu Creek resulted in major flooding in Skipton which peaked in the evening (6.30pm) on 14/10 at a gauge level of 5.56m. Water levels remained high with the Glenelg Highway at Skipton cut off during the event. The minor flood level was exceeded for close to four days.

Flooding to Panmure downstream of Skipton occurred on Sunday 16/10 between approximately 4-7pm. High water level at Panmure were estimated based on available DEWLP gauge records at Taroon. The flood peak at Taroon occurred at around 1pm on 16/10 to a level of 4.55m. The Hopkins River @ Hopkins Falls gauge peaked at 3.53m on the gauge at 19:00 on the 16th October.

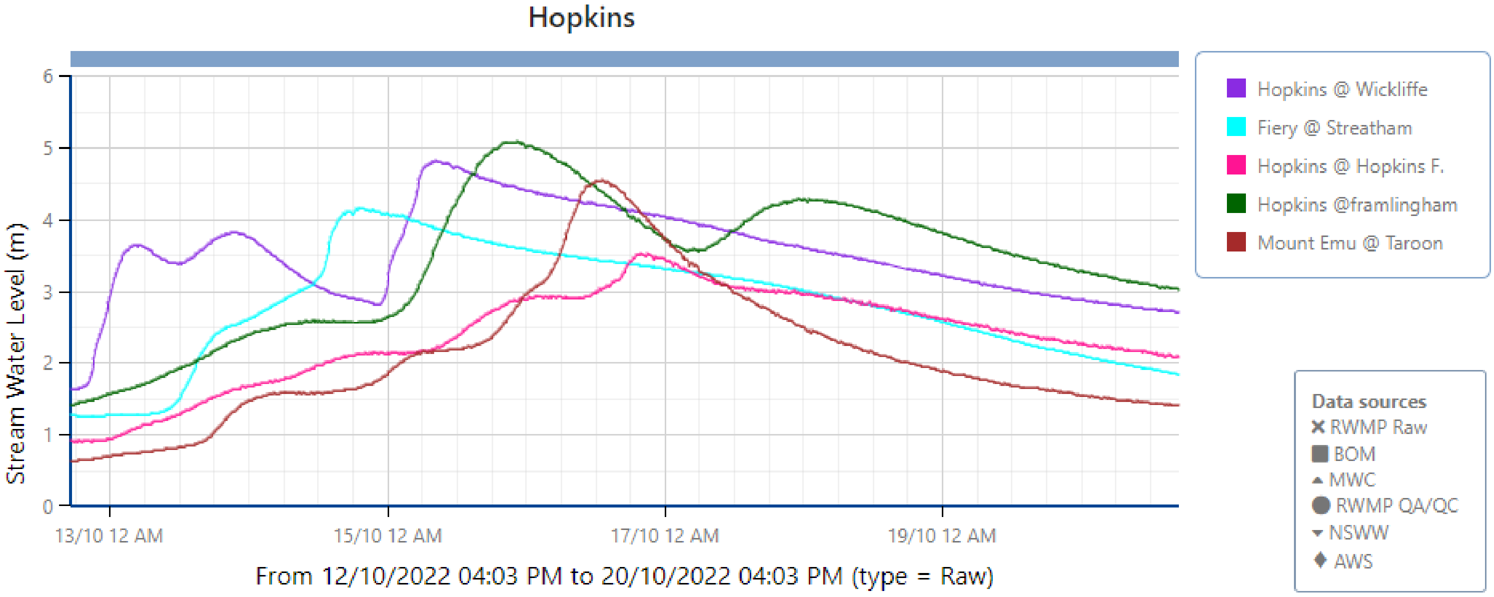

Figure 2-2 Hopkins River catchment key gauges, October 2022 event (source: FloodZoom)

2.3 Catchment Storages

The Hopkins River catchment has numerous storages with varying levels of data available for each storage. Figure 2-3 highlights that these include but are not limited to Lake Bolac, Lake Burrumbeet and Lake Goldsmith.

Large storages can be represented in RORB hydrological models explicitly if a stage/storage relationship and an outflow relationship can be defined. Within parts of the catchment are a series of connected storages, including those around the Willaura area. Minor storages such as these will not be explicitly represented in the modelling.

The key data source for each storage is the Vicmap 10 metre resolution DEM and other LiDAR derived DEMs which can be utilised to produce a stage/storage relationship for the storages.

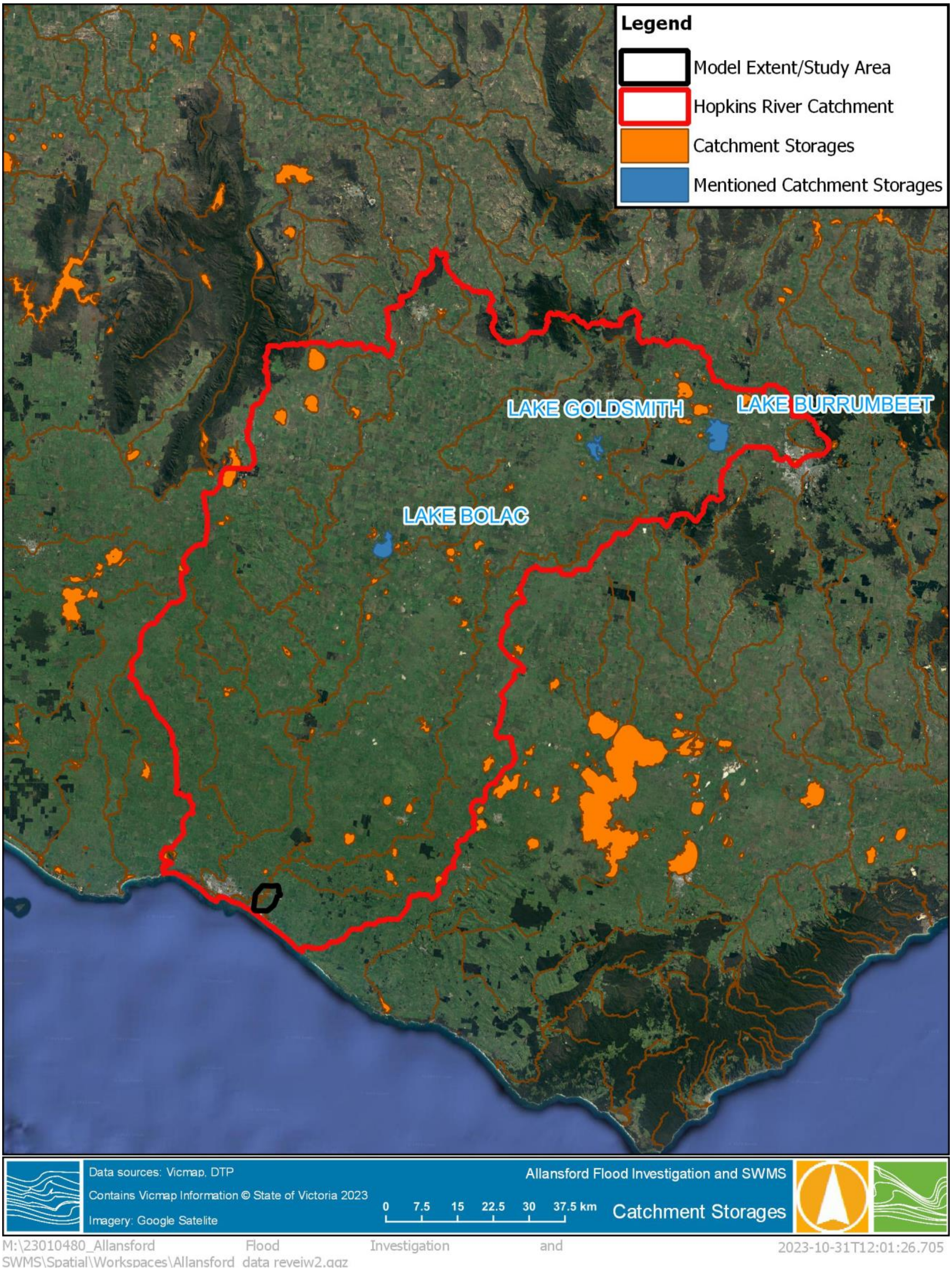

Figure 2-3 Catchment Storages

2.4 Streamflow Data

The Hopkins River catchment contains some 30 streamflow gauges of varying data availability and continuity. Streamflow gauges within the catchment are shown in Table 2-3 and Figure 2-6 below. Gauges that may be potentially useful in hydrologic modelling of the Hopkins River at Allansford, due to their location on main waterways and good period of record, are highlighted in the table and figure below. Note the below table lists all gauging sites in the catchment although not all gauging sites will have records appropriate for the purposes of this investigation.

Table 2-3 Streamflow gauges within the Hopkins River catchment (source: DEECA)

Station	Station Name	Commenced	Ceased
236232	Sidespring Creek @ Mt Cole	26/11/2007	Active
236238	Mt Emu Creek @ Guthries Bridge	5/06/2018	Active
236805	Cave Hill Camp Rain Gauge @ Cave Hill	28/06/2019	Active
236229	Yam Holes Creek D/S Beaufort	11/05/2000	4/11/2002
236230	Long Gully Creek @ The Glut	30/05/2000	Active
236208	Mount Emu Creek @ Cudgee	17/05/1955	30/06/1965
236211	Mount Emu Creek @ Garvoc	15/05/1965	3/03/1978
236214	Muston Creek @ Hexham	12/03/1970	1/12/1982
236223	Boggy Creek @ Stavely	6/04/1993	15/07/1997
236200	Hopkins River @ Allansford	2/01/1905	30/06/1920
234610	Lake Bookar @ Camperdown	20/07/1979	Active
236202	Hopkins River @ Wickliffe	10/06/1920	Active
236203	Mount Emu Creek @ Skipton	15/06/1920	Active
236204	Fiery Creek @ Streatham	4/06/1920	Active
236209	Hopkins River @ Hopkins Falls	23/05/1955	Active
236210	Hopkins River @ Framlingham	10/06/1955	Active
236212	Brucknell Creek @ Cudgee	4/06/1965	Active
236213	Mount Emu Creek @ Mena Park	14/12/1966	Active
236215	Burrumbeet Creek @ Lake Burrumbeet	3/12/1975	Active
236216	Mount Emu Creek @ Taroon (Ayrford Road Bridge)	10/10/1977	Active
236219	Hopkins River @ Ararat	31/05/1989	Active
236228	Musical Gully Creek @ Musical Gully Reservoir H.G.	25/06/2009	Active
236231	Cave Hill Creek @ Mount Cole	30/05/2000	Active
236600	Lake Bolac @ Lake Bolac	6/11/1962	Active
236601	Lake Learmonth @ Learmonth	10/08/1964	13/08/2010
236602	Lake Burrumbeet @ Burrumbeet	28/06/1965	Active
236603	Lake Goldsmith @ Beaufort	19/07/1965	Active
236606	Lake Buninjon @ Calvert	26/06/1991	Active
236610	Chinaman Swamp @ Westmere	4/10/1995	Active

The Hopkins River at Hopkins Falls is the closest and most important gauge with respect to the understanding of riverine flood conditions within the Hopkins River upstream of Allansford. The gauge has a continuous flow record for the period of 1955 – current (Figure 2-4). Data quality information (Figure 2-5) available for the gauge indicates that records prior to August 1962 were sourced from a manually read gauge board (quality code 26). There are noted period where flows were manually estimated (quality code 104). It is also noted that some of the more recent events have quality codes 100 and 150 associated, which indicates irregular or extrapolated datasets which will need to be considered throughout the calibration process.

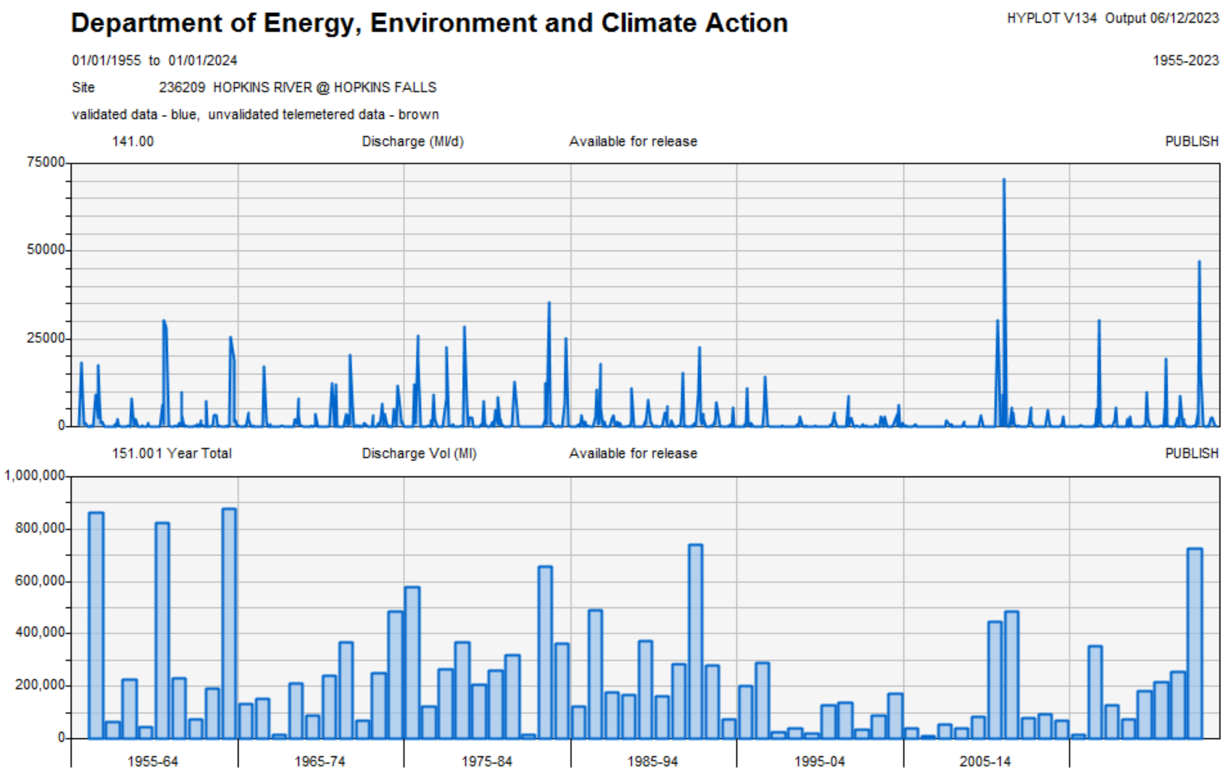

Figure 2-4 Hopkins Falls – Period of Record

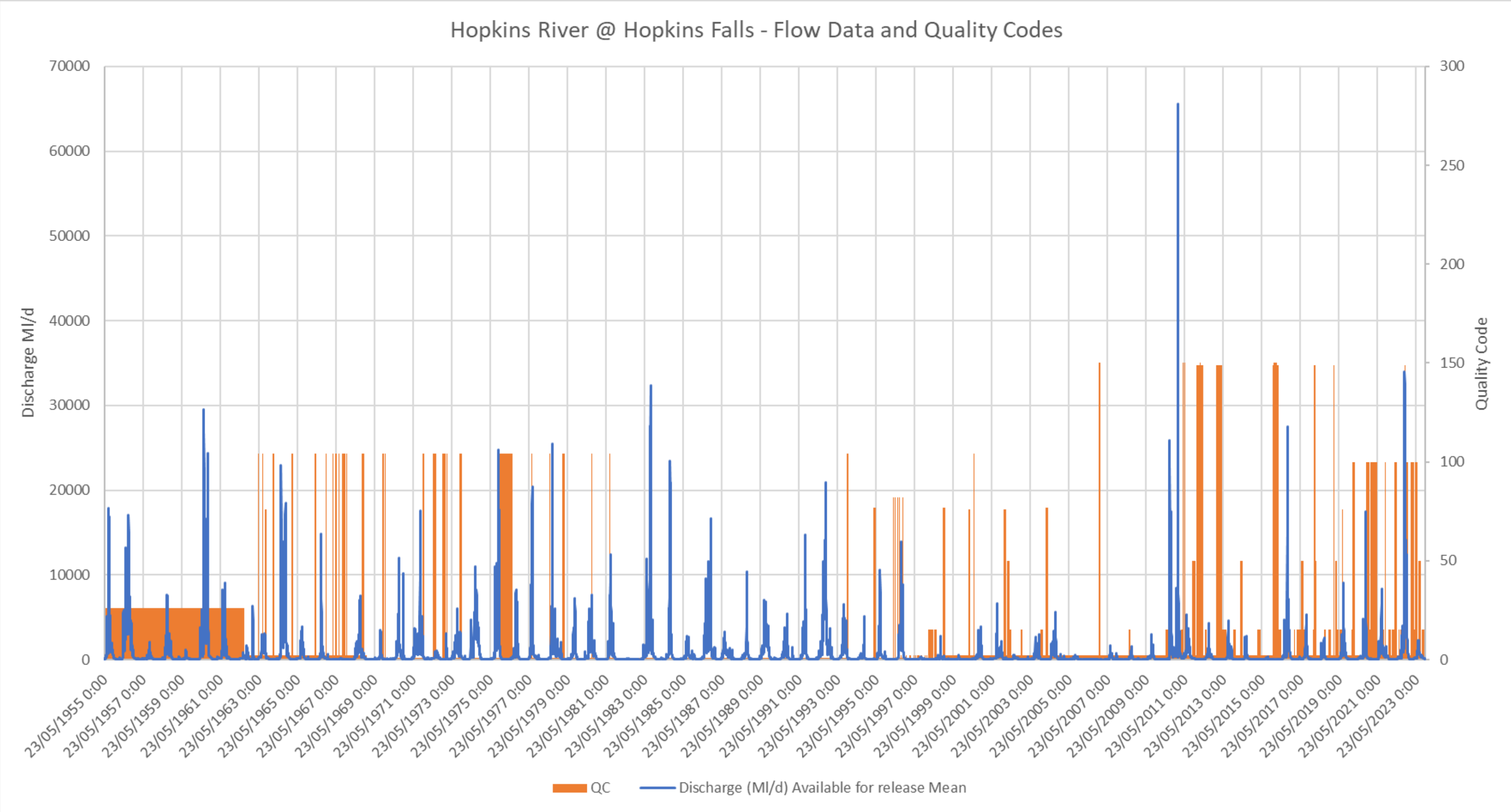

Figure 2-5 Hopkins Falls Data Quality Record

The ranked annual flow record for the Hopkins Falls gauge is shown in Table 2-4. The record indicates notable high flow events in 2011, 2022 and 1983.

Table 2-4 Ranked annual flow series - Hopkins River at Hopkins Falls

Year	ML/d	M^3/s
2011	70624	817
2022	47074	545
1983	35329	409
2016	30489	353
2010	30405	352
1960	30222	350
1978	28417	329
1975	25890	300
1964	25491	295
1984	25356	293
1992	22646	262
1977	22532	261
1971	20552	238
2020	19391	224
1955	18240	211
1986	17991	208
1956	17587	204
1966	17369	201
1991	15408	178
1996	14405	167
1981	12868	149
1970	12515	145
1974	11578	134
1995	10923	126
1988	10863	126
2019	10057	116
1961	9932	115
1976	9110	105
2021	8634	100
2001	8617	100
1980	8572	99
1968	8190	95
1958	8010	93
1989	7669	89
1979	7420	86

Year	ML/d	M^3/s
1963	7136	83
1993	6770	78
1973	6705	78
2004	6353	74
1990	5828	67
1994	5658	65
2017	5620	65
2012	5349	62
2013	4658	54
2000	3991	46
1965	3989	46
1969	3629	42
1987	3344	39
1985	3175	37
2009	3174	37
2003	3057	35
1998	2992	35
2014	2991	35
2018	2751	32
2023	2421	28
1957	2250	26
2007	1808	21
1962	1801	21
2008	1585	18
1959	1199	14
1972	1197	14
2002	744	9
2005	612	7
1999	543	6
1997	400	5
2015	351	4
1967	193	2
1982	129	1
2006	87	1

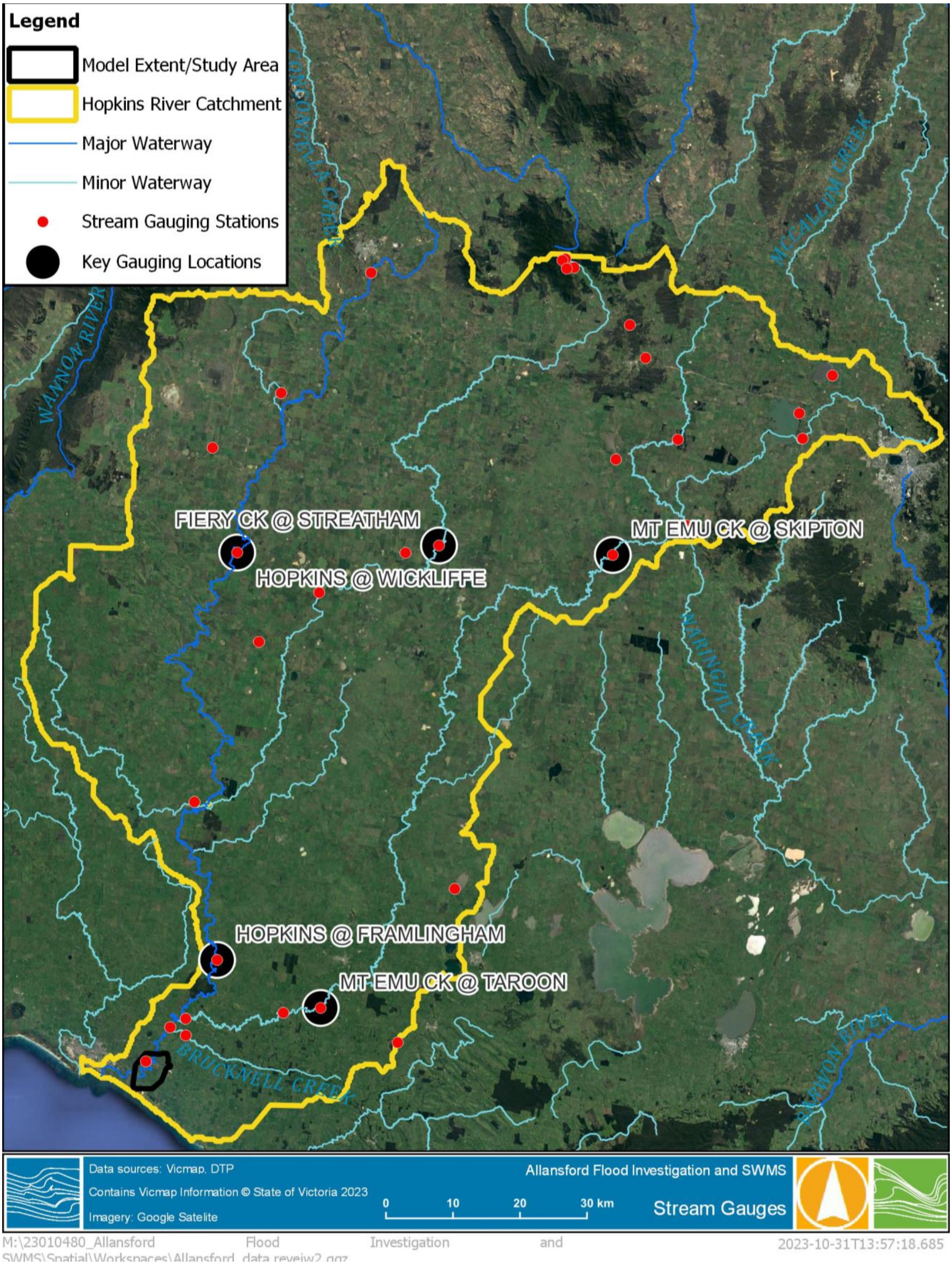

Figure 2-6 Hopkins Catchment Stream Gauges

2.5 Rainfall Data

Historic daily and sub daily rainfall data is a required input for hydrologic and hydraulic model calibration and validation. Daily rainfall gauges are used to provide a representation of spatial rainfall variation while sub daily gauges provide a representation of the temporal rainfall distribution from historic events.

2.5.1 Daily Rainfall

Table B-1 (Appendix B) summarises the daily rainfall information available within or near the Hopkins River catchment. Gauges within and immediately outside of the catchment will be utilised to provide a suitable spatial representation of event based rainfall. Figure 2-7 displays the location of the daily rainfall gauges.

2.5.2 Sub-daily Rainfall

There are approximately twenty sub-daily rainfall stations within or near the Hopkins River catchment with varying levels of data capture, time interval and period of record. The location of the nearby current and closed sub-daily rainfall stations are shown in Figure 2-7. The closest sub-daily station from Allansford is the Warrnambool (Post Office) station, which is roughly 11km west of the town centre. Multiple sub-daily stations are available to the east of Allansford in close proximity of Warrnambool.

The selection of rain gauge data for use in hydrological modelling will be completed at the calibration/validation stage and will be dependent on data availability and quality.

Table 2-5 Sub-Daily Rainfall Gauges

Station	Station Name	Commenced	Ceased
90175	Port Fairy AWS	1/06/1994	Active
90186	Warrnambool Airport NDB	1/10/1998	Active
90176	Mortlake Racecourse	1/06/1994	Active
89112	Westmere	1/02/2006	Active
89002	Ballarat Aerodrome	1/03/1908	Active
79103	Grampians (Mount William)	1/12/2005	Active
89105	Lookout Hill	1/08/1994	Active
79101	Pyrenees (Ben Nevis)	1/12/2007	Active

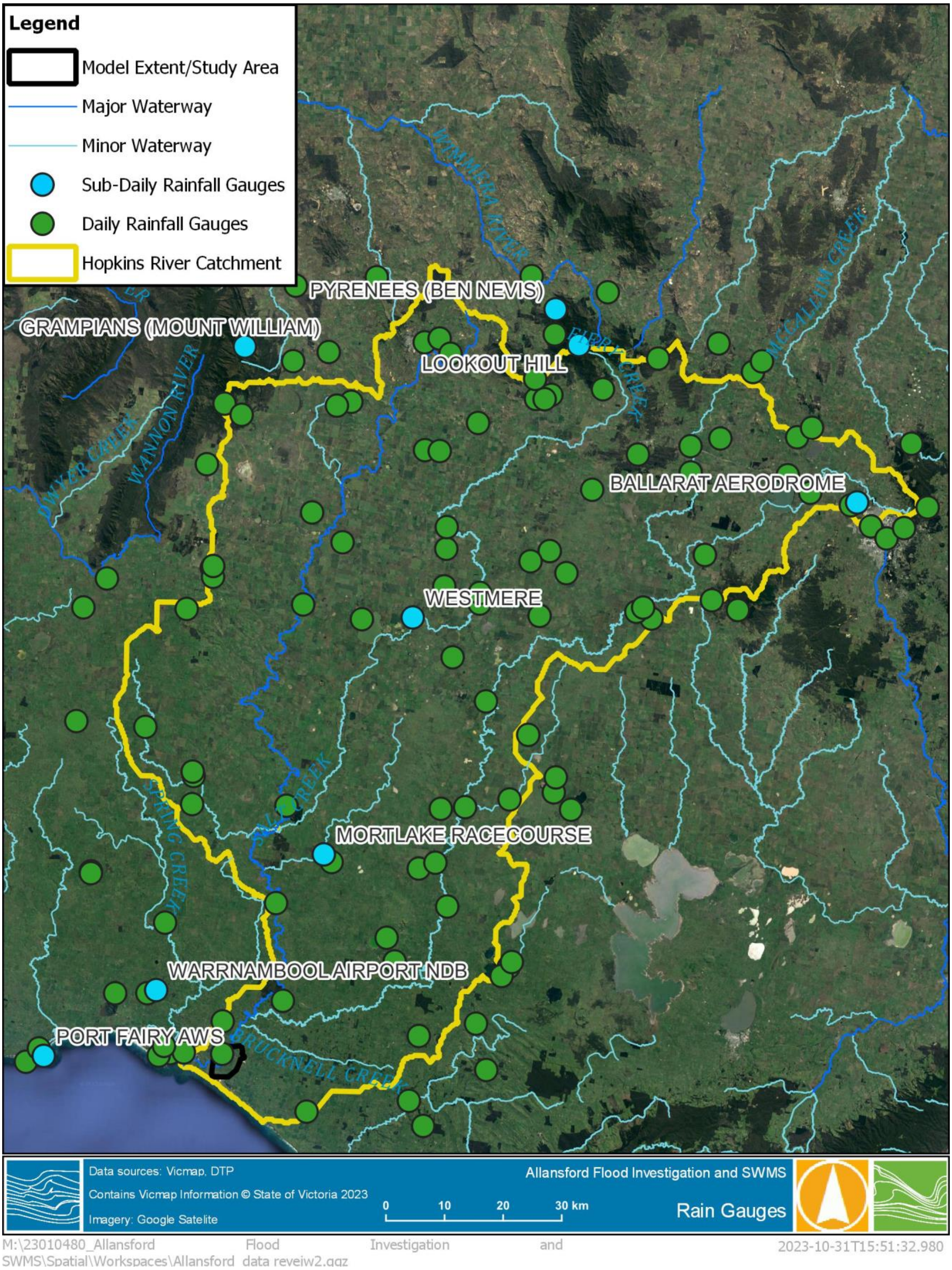

Figure 2-7 Hopkins Catchment Rain Gauges

2.6 Hydraulic Structures

2.6.1 Hopkins River/Floodplain Structures

There are four key hydraulic structures on the Hopkins River and its floodplain at Allansford as shown in Figure 2-8 and listed below. Available data sources for each crossing are shown.

- Princes Highway Bridge
  - Design drawings sourced from the Department of Transport and reduced to Australian Height Datum
- Ziegler Parade Bridge
  - Design drawings supplied for various additions and alterations to the bridge containing suitable information for hydraulic modelling, however not linked to AHD.
- Railway Bridge
  - Historic design and alteration drawings supplied. Not to AHD, will be reduced to AHD via LiDAR.
- Railway Culvert/Bridge in western floodplain
  - Inspection documents detailing the layout and structure have been supplied. Not to AHD however can be linked to LiDAR by depths.

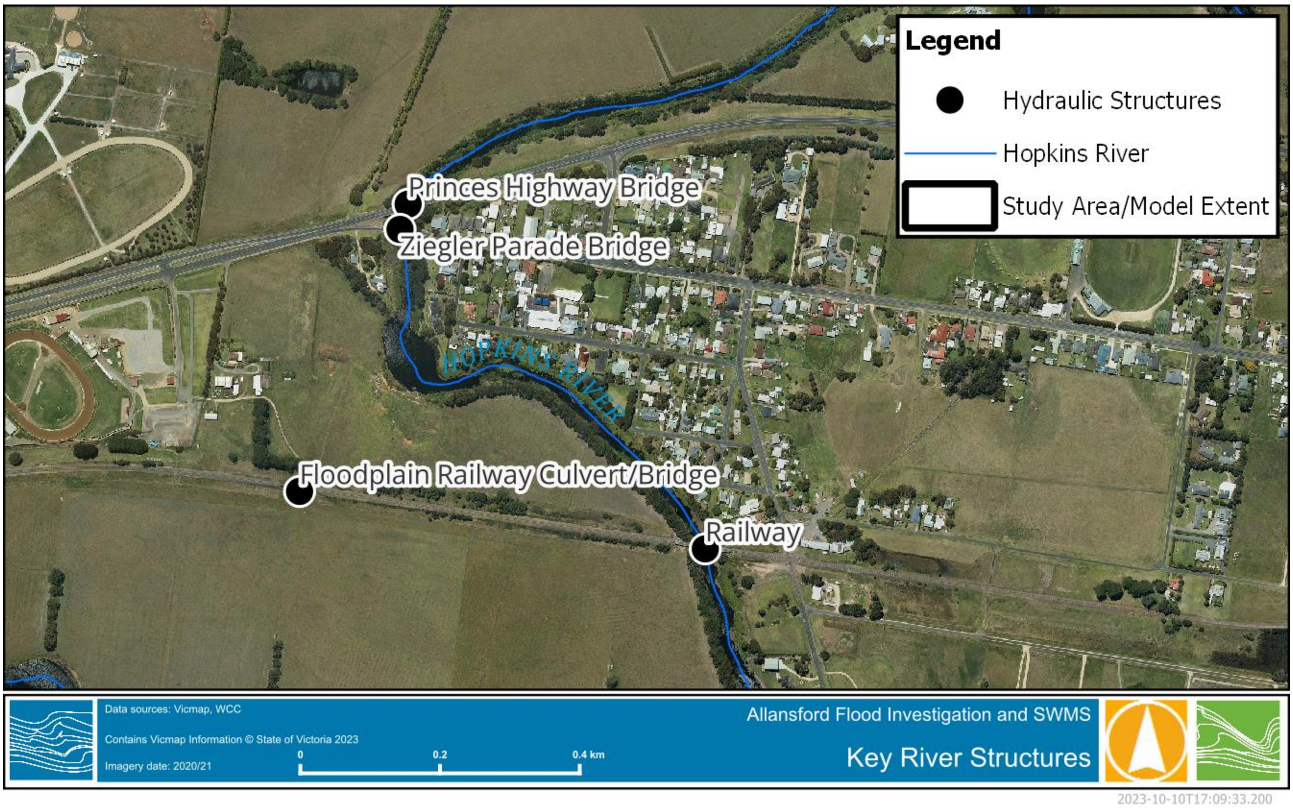

Figure 2-8 Riverine/Floodplain Hydraulic Structures

2.6.2 Allansford Drainage Network

2.6.2.1 Current Conditions Drainage Network

A GIS dataset of the existing Allansford drainage network was supplied by council at the commencement of the project. The dataset contains pits and pipes of most drainage in Allansford, with some gaps identified during the site visit where pits were observed which are present within the council dataset (section 3). The existing dataset is shown in Figure 2-9 below.

Figure 2-9 Pipe Network GIS Dataset

2.6.2.2 New Tooram Road Outfall 2023

Due to recurrent pipe collapse, the Tooram Road north outfall was reconstructed immediately after the commencement of this project. Design plans have been provided and as-constructed survey is expected to be provided. The new 1200mm RCP pipe is fitted with a floodgate to prevent backflow into the pipe during flooding in the Hopkins River. Design dimensions for the floodgate provided by council indicate it requires 310mm of head to open and drain, which should be available in the pipe downstream of Tooram Road without causing any visible backing up of water according to the pipe design drawings.

During the site visit held on the 3rd August 2023, it was observed that the floodgate had been propped open by a log of wood, apparently purposefully. The log was removed during the visit. During a subsequent visit on 23rd September it was observed that the log had been replaced and the floodgate was wedged open. The recurrent forcing open of the floodgate is a cause for concern as it may prevent the gate from closing during a flood event in the Hopkins River, allowing floodwater to back up into the system. Refer to section 3 for photographs taken during the site visit.

Design drawings for the pipe have been provided by Warrnambool City Council and are included in Figure 2-10 below.

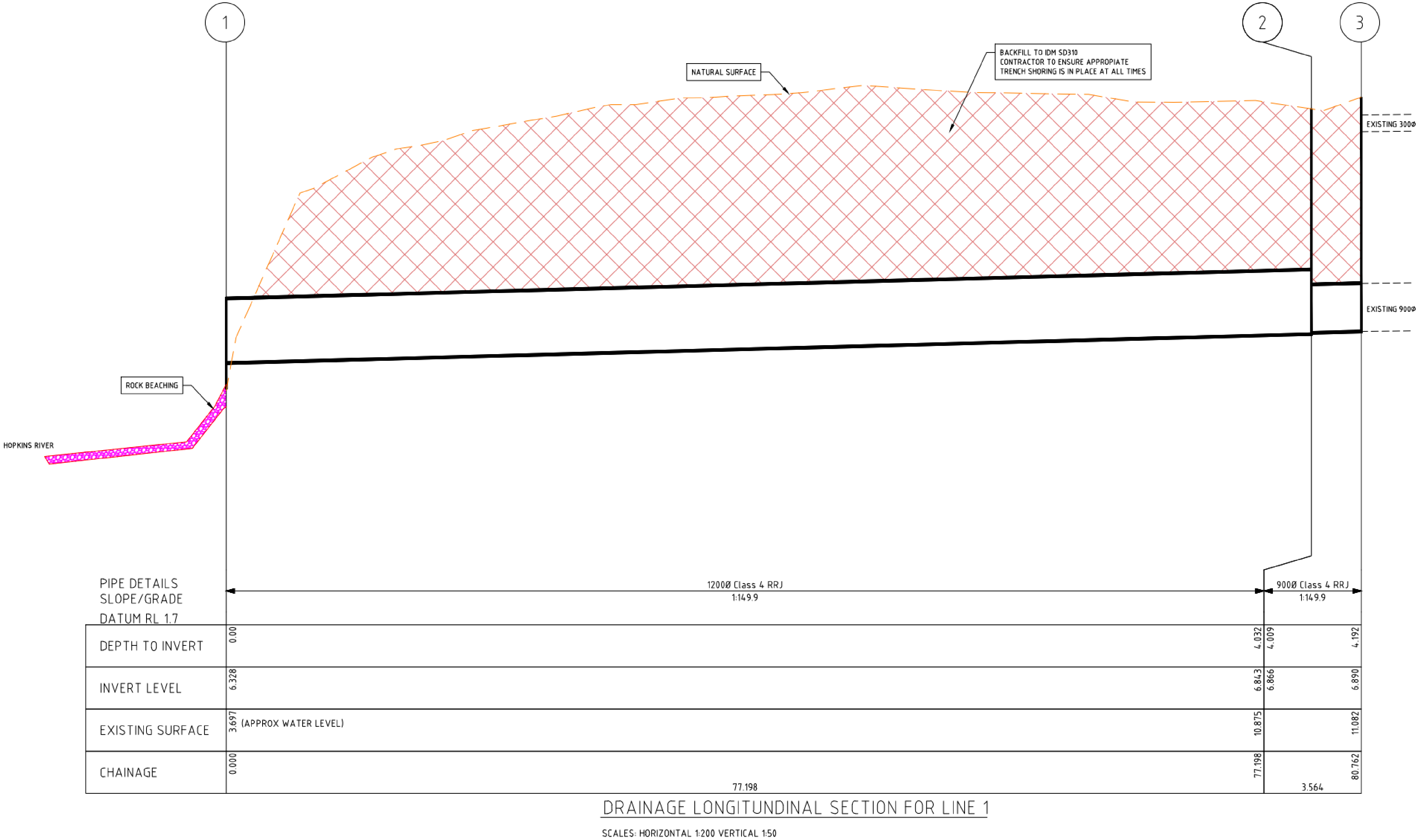

Figure 2-10 Tooram Road Outfall Pipe – 2023 Design Long Section

2.7 Topography and Survey Data

2.7.1 Available LiDAR Datasets

Within the hydraulic modelling study area, six LiDAR datasets are available, as listed in Table 2-6 below and shown in Figure 2-11:

Table 2-6 Available LiDAR in project area

Year	Project Name	Horizontal Resolution
2023	DTV LiDAR – Portland	1 metre
2016-17	Warrnambool City LiDAR	1 metre
2012-13	Victorian Coastal LiDAR Level 3 Classification (East & West Victoria)	1 metre
2009-10	Victorian State Wide Rivers LiDAR Project – Glenelg Hopkins CMA (aka "ISC LiDAR" after the Index of Stream Condition project)	1 metre
2006-07	South West LiDAR (Corangamite)	5 metre
2006-07	South West LiDAR (Coast)	1 metre

The 2023 Portland dataset covers the entire mapping area at a high resolution and is proposed to be adopted as the best available dataset. The 2017 Warrnambool City LiDAR also covers the entire mapping area and has proved reliable in previous work, as well as being generally in good agreement with the Portland dataset.

The State Wide Rivers LiDAR (also known as the Index of Stream Condition or ISC LiDAR) was flown in straight swathes and in some instances the full extent of the floodplain was not covered by the flightpath. The ISC LiDAR has been shown to have a uniform error of around 0.32 m across several verification projects[2]; however it has also been demonstrated to have no spatial bias (high in some areas and low in others). Given the age of the ISC LiDAR, its lack of floodplain coverage, and its known accuracy issues/error, the ISC LiDAR is not recommended for use in hydraulic modelling within this project. The ISC LiDAR may be useful for checking historical floodplain topography (if desired) once the uniform error is confirmed to be consistent and applicable to the study area.

[2] The uniform error in the 2009-2010 LiDAR has been confirmed across the Skipton Flood Study, Harrow Flood Investigation, Glenelg River Regional Flood Mapping Project and Casterton Flood Intelligence Project.

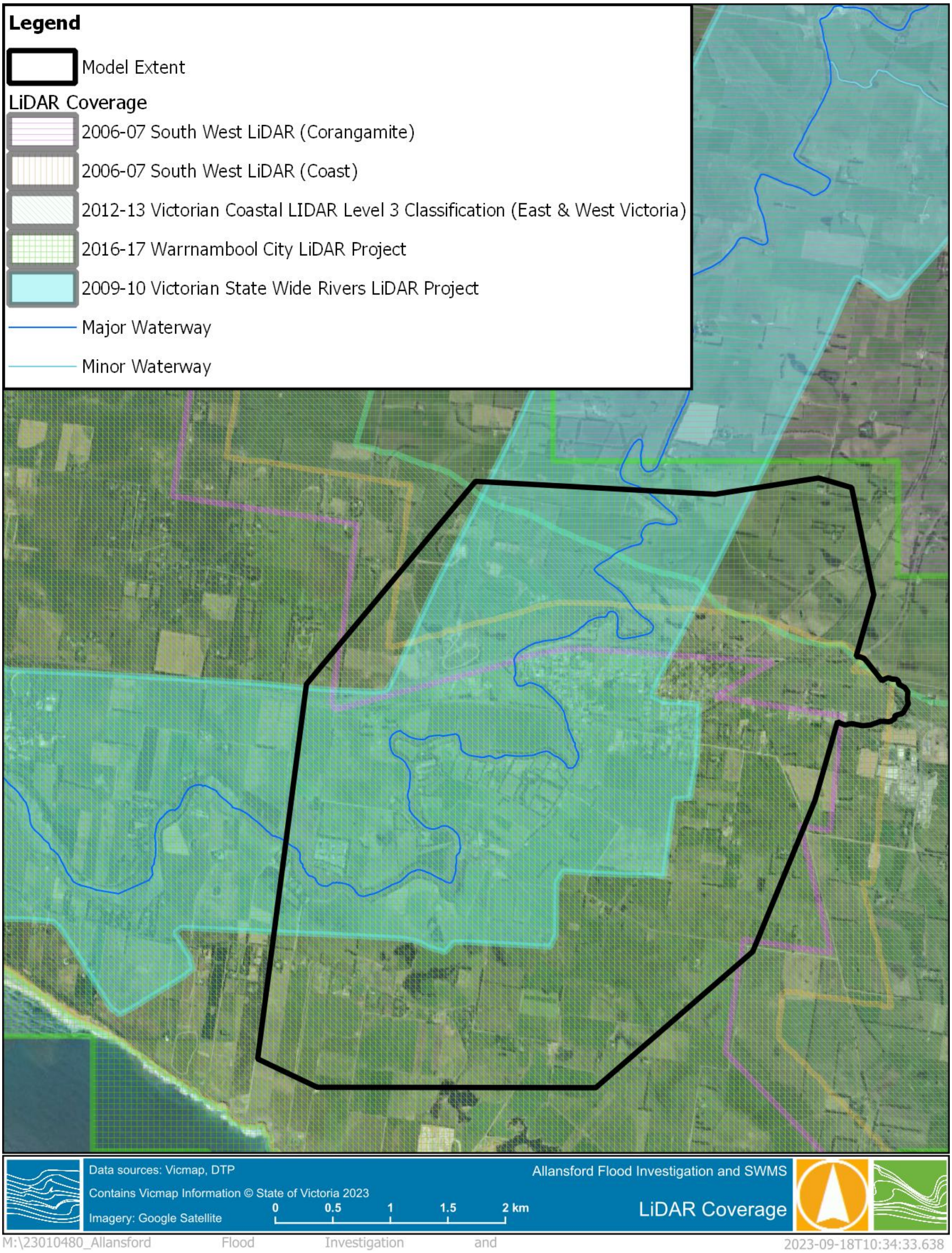

Figure 2-11 LiDAR Coverage of the study area and surrounds (NOTE: the 2023 Portland coverage is not shown as it covers the entire map extent)

2.7.2 LiDAR Comparison

As a validation measure, each LiDAR dataset (as a Digital Elevation Model) has been compared to the 2016-17 Warrnambool City dataset. The comparison provides a measure of the difference between each set and the 2016-17 LiDAR with negative values representing areas where the 2016-17 LiDAR is lower than the comparison data. The comparisons reveal areas where earthworks have been undertaken between the capture dates, as well as general noise within the datasets. For example, the fill pads associated with new dwellings built on Carrolls Road, Allansford are visible in all comparisons between the 2017 dataset and data captured earlier. A comparison has also been provided between the 2023 Portland dataset and the 2016-17 LiDAR, showing good agreement between the two, and revealing some areas of earthworks undertaken since the 2016-17 set was captured.

The minimum, maximum, mean and standard deviation for each comparison completed are shown in Table 2-7 below. The mean difference reveals a clear bias in the ISC LiDAR set as mentioned above. Other datasets appear to have less bias across the comparison area and are generally in good agreement with the 2017 dataset. The minimum and maximum values are extreme for each dataset however are clear outliers as shown by the mean and standard deviation for each comparison. Min/Max values in comparisons are usually in the order of metres or even tens of metres and can be caused by erroneous capture of tree tops as ground, areas of extreme cut/fill, new buildings etc. The minimum/maximum values don't provide any useful information on their own.

The key takeaway from the comparison is that the most recently captured LiDAR datasets are in very close agreement with each other and are in general agreement with other data sets covering the study area (with the exception of the ISC set which has a known bias). This is an encouraging finding which, combined with the LiDAR verification assessment completed below, gives confidence to the use of the 2023 LiDAR data as the most representative topographic information available for the study.

Table 2-7 LiDAR Comparison Statistics

Comparison	Minimum (m)	Maximum (m)	Mean (m)	Standard Deviation (m)
2023 Portland vs 2016-17 Warrnambool	-8.697	6.429	0.003	0.111
2016-17 vs 2012-13 Coastal LiDAR	-7.126	9.132	-0.009	0.193
2016-17 vs 2009-10 ISC LiDAR	-4.567	7.673	-0.244	0.149
2016-17 vs 2006-07 South West (Coast)	-4.057	9.072	-0.074	0.190
2016-17 vs 2006-07 South West (Corangamite)	-5.722	4.680	-0.070	0.229

The results of the LiDAR comparison are shown visually in Appendix A.

2.7.3 LiDAR Verification

Once the Portland dataset was made available for the project, it was verified against field survey commissioned for the study. Two road transects were surveyed within the hydraulic model extent, on Ziegler Parade in Allansford and Burkes Road at the southern end of the extent. An additional road survey was provided by council on Clarke Street in Allansford for the purposes of LiDAR verification. The road transect locations are shown in Figure 2-12 below.

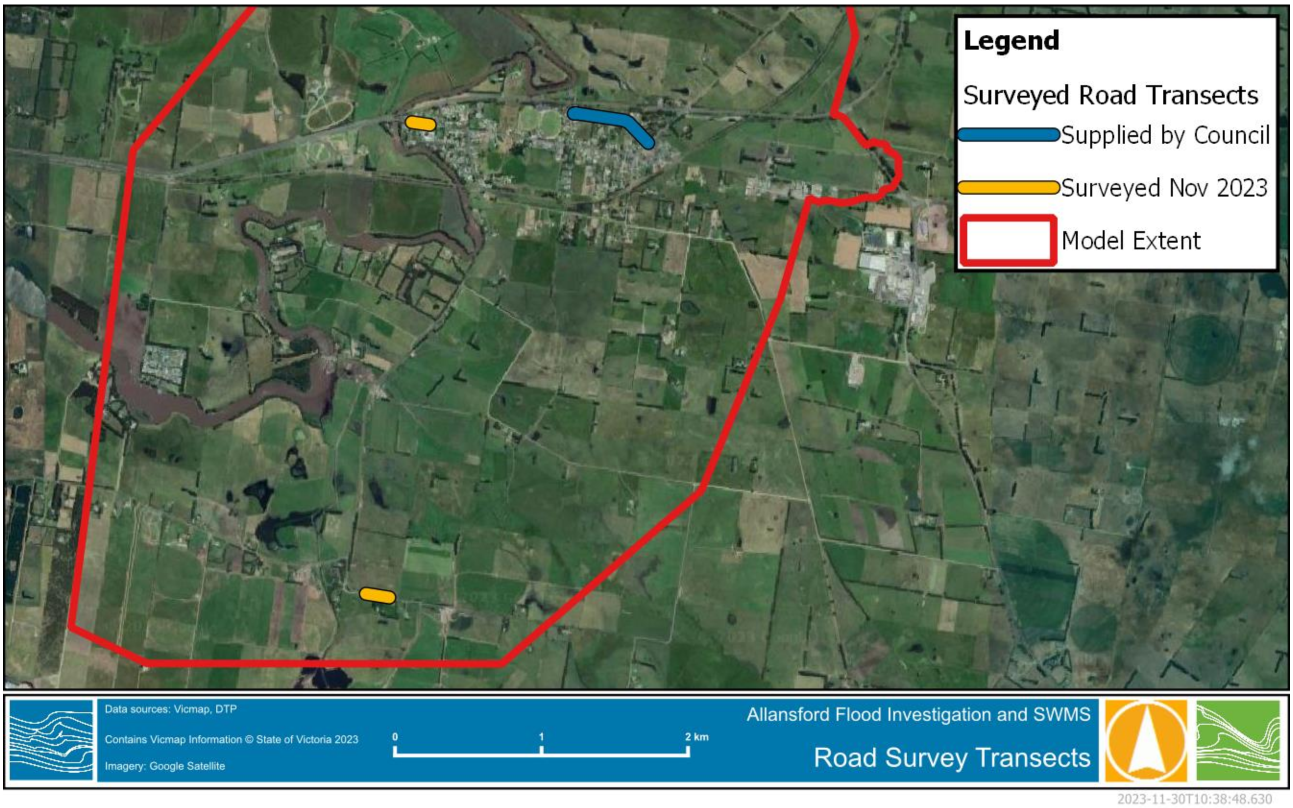

Figure 2-12 LiDAR Verification – Road Transect Survey

The elevation at each point along the road transect was compared to the 2023 Portland LiDAR dataset and the difference tabulated. The commissioned survey was in very close agreement with the LiDAR, with an average difference between the survey and LiDAR elevations of 5.4 centimetres. The supplied Clarke Street survey appears to have a bias with the surveyed levels being consistently lower than the LiDAR level by an average of ~27 centimetres. The standard deviation in both datasets is low, indicating the LiDAR contains minimal noise and is reasonably precise.

The biased difference between the supplied Clarke St survey and LiDAR is assumed to be a result of road works undertaken between the survey capture and LiDAR flight, inaccurate reduction of levels at the time of the original survey, incorrect projection of the survey points or another reason. The difference is not considered to be a significant concern due to the very strong agreement between the commissioned survey, which was tied into the permanent survey marks adjacent to the transect locations. Given this strong agreement, the LiDAR can be adopted as the DEM for this study with confidence.

The results of the verification are summarised in Table 2-8 and Figure 2-13 below.

Table 2-8 LiDAR Comparison Survey – Key Statistics

	Clarke St	Captured Survey
Maximum	-0.167	0.103
Minimum	-0.340	-0.030
Average	-0.269	0.054
Standard Deviation	0.036	0.022

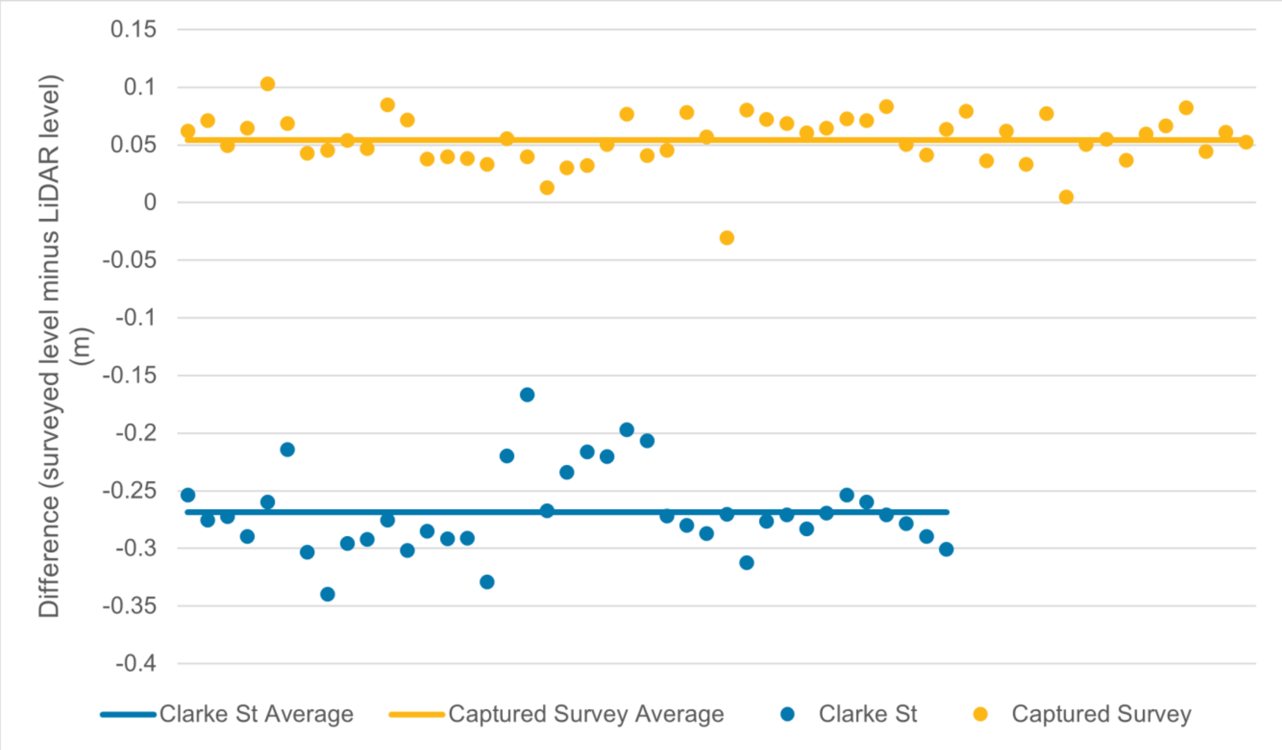

Figure 2-13 LiDAR Verification Survey Comparison Results

2.8 Allansford Strategic Framework Plan

The Allansford Strategic Framework Plan was adopted by Council in May 2021. The plan outlines the high level strategic direction for future development in Allansford to 2036. The plan is intended to be used by Council in the application of local planning policies, zones and overlays, specifically future rezoning of land within and around the township. Land at the rural interface with the township has been considered in the plan.

Some suggestions to improve drainage outcomes in Allansford have been put forward in the plan, including installing a backflow prevention device on the Tooram Road outfall and investigating potential uses of the railway corridor as part of a broader drainage solution.

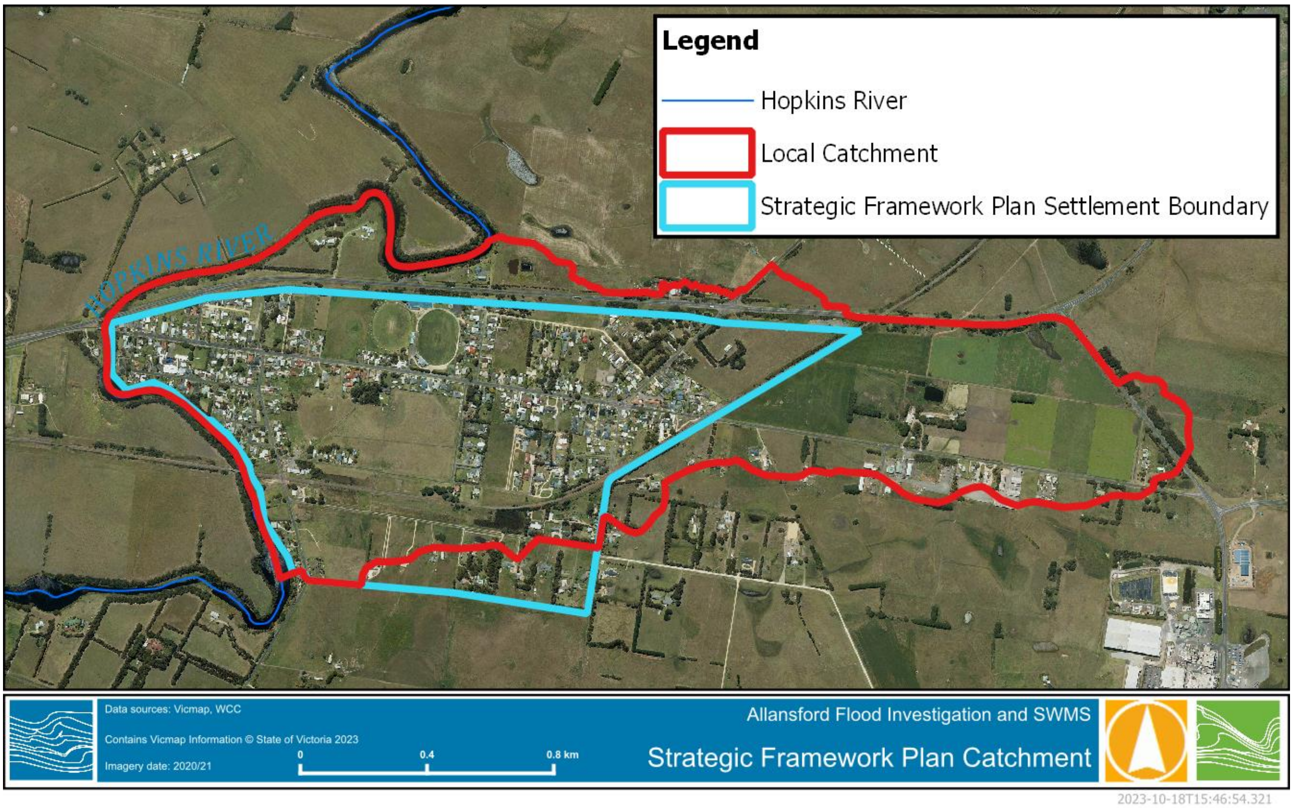

Figure 2-14 Allansford settlement boundary and local catchment

3 SITE VISIT

A site visit was conducted by members of Water Technology, Warrnambool City Council, and Glenelg Hopkins CMA on the 3rd August 2023. The purpose of the visit was to inspect the local drainage and landform, highlight areas of known issues, and inspect the pit and pipe network to enable cross-reference against GIS data handed over by council.

Several areas of past/frequent inundation issues were observed during the visit. It was noted that the area is generally flat throughout the town. Some recently developed lots on Elizabeth Street have trenched drainage which has been excavated lower than the local outfall, creating a trapped low point which is pumped when necessary.

Some pipes were observed during the site visit which were not shown in the Council GIS datasets handed over at project commencement. These pipes were highlighted as a known data gap in a memo to council, along with survey recommendations for LiDAR and structure validation.

Pipes that were either missing from the dataset or where no information relating to their size or inverts (based on the site visit and subsequent conversations) were highlighted for survey.

Photographs of key areas as taken during the site visit are shown in Figure 3-1 to Figure 3-7 below.

Figure 3-1 Rock riffle and pool at dogleg bend, taken from backyard of 3 Alice Street looking WSW

Figure 3-2 Main Open Drain in Allansford and 825mm RCP draining the majority of the town

Figure 3-3 New 1200mm RCP pipe sections awaiting installation to replace aging outfall to Hopkins

Figure 3-4 Railway Bridge

Figure 3-5 Taken at the front of 122 Ziegler Parade, showing extremely flat grade of Ziegler Pde – a known flooding hotspot

Figure 3-6 Easement drain at relatively new dwellings on Elizabeth Street with pump in drain

Figure 3-7 Floodgate on end of new Tooram Rd North Outfall – left side shows block of wood used to wedge the gate open permanently

4 COMMUNITY CONSULTATION

An open community consultation session was held at the Allansford Community Hall on 29th August 2023. The session was attended by members of the community, representatives from Council, Glenelg Hopkins CMA and Water Technology. The purpose of the session was threefold:

- To inform the community of the study
- To gather any flood intelligence or other information the community may have, such as historical impacts, extents, flood heights etc.
- To engage the community on possible mitigation options or other solutions to ongoing inundation issues in the town.

The session attracted excellent engagement from the community, with 16 households/properties in attendance, with those in attendance informing themselves about the study and putting their ideas for flood mitigation options forward. The key findings of the session, as noted by organisational representatives, are as follows:

- Wetlands in the railway corridor are usually full during winter and present an opportunity for combined open space and stormwater management.
- There is significant underfloor flooding regularly occurring as a result of drainage issues at 100 Ziegler Parade.
- The 1946 flood was contained within the bed and banks of the Hopkins River however did overtop the bridge, which was upgraded after this time.
- Construction of the dual highway provides significant flood protection for the town, with the highway acting as a levee and preventing a flow path opening up from near the football ovals to the Tooram Road outfalls.
- A flour mill was apparently washed away in the 1870 flood.
- Multiple residents raised concerns with recent fill in the floodplain on the southwest side of the highway. The floodway in question was active during the 2011 event and allows a breakout flow to occur through paddocks and under the railway. There was a general concern that if the level of the breakout is raised, flood levels through the town along Frank Street and downstream will raise.
- The 2011 flood peaked around 300mm lower than the surface of the truck stop/parking area on the north side of town. Sandbagging here was eventually dismantled. Drainage under the highway at this location was backing up through the stormwater system and inundating the football ovals. Eventually the drain outlet was backfilled with soil temporarily to prevent further backflow.
- Drainage at Brown Street immediately south of the Ziegler Parade roundabout is insufficient and too flat, often becoming blocked.
- The Tooram Road South outlet was identified as being a former major outlet for the site, however persistent filling of the upstream areas means it no longer drains efficiently enough.
- A flow path exists north of the dwellings at numbers 50-60 Ziegler Parade (three properties) which takes flows from the higher part of Ziegler Parade, re-joining Ziegler Parade at the low point (see Figure 4-1 below).

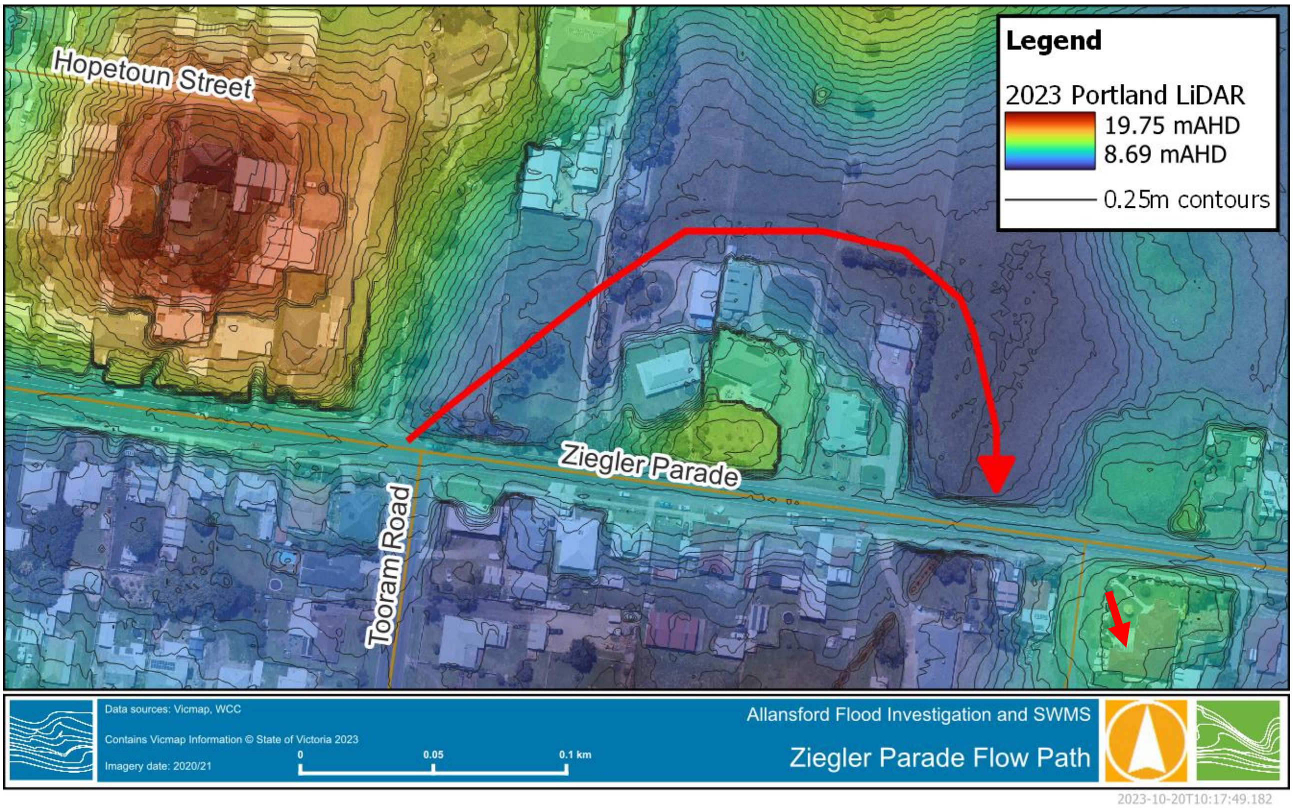

Figure 4-1 Ziegler Parade northern flow path

- The major breakout on the west side of the river through 10235 Princes Highway did not occur in 2022.
- Railway bridge/embankment on 10235 Princes Highway was washed out in 1870 and 1894 events.
- The flood level reached approximately 50cm lower than the floor at 5 Frank Street in 2011.
- Flows at the bend south of the Tooram Road South Outfall were over the paddock much more than shown in preliminary modelling.
- Breakouts north of the town were not noticed during the 2022 event.

In addition, the following mitigation measures were suggested by members of the community. Each measure that relates to stormwater will be considered in the development of the Stormwater Management Strategy for Allansford.

- Construct a penstock on Tooram Rd to prevent river flood flow from backing up into the township drains.
- Locate all culverts under highway and install penstocks to prevent river flood flow from entering town through these culverts.
- Resident of 3 White St reported that water sits in vacant land over his back fence and he has had to replace his fence numerous times as posts rot. He has suggested drainage works are required in this area. He also says recent fill placed between Clark St and the highway has exacerbated the problem. The fill has forced water that previously sat in filled depressions to sit in land at the back of 3 White St.
- White St pits block with silt from Clarke St – Clarke St should be sealed as a condition of development.
- Drain some or all of new Clarke St developments to the north to take load off existing Ziegler Pde system. Would need to include a penstock to prevent backflow from the river.
- Alter angle of main Tooram outlet towards the downstream direction.

- Construct a detention basin upstream of township (in Moyne Shire) to delay flow from the upstream catchment from entering the township. Water table may be a problem. Land acquisition would be required.
- Direct flow from the upstream catchment around the township drainage via the rail corridor.
- Construct a storage within the rail corridor. Water table may be an issue and rail authorities would need to be supportive.
- Construct some storage in the existing v-drain area. Water table may be an issue. Land acquisition required.
- Need to protect sensitive flora and fauna in the existing rail corridor wetlands.
- Use old 1200 mm brick culvert under the rail line near 30 Tooram Road as a secondary flow path.
- Take action regarding Barton's disputed garbage truck development in the catchment as it risks contaminating flood water.
- Remove fill from 10235 Princes Hwy.

5 HYDROLOGIC AND HYDRAULIC MODELLING METHODOLOGY

5.1 Modelling Approach

The study will adopt a separate hydrology/hydraulics modelling approach. The broader Hopkins River catchment will be modelled hydrologically utilising the RORB rainfall runoff software package. Hydrographs produced by the RORB model will be applied to a TUFLOW hydraulic model of the Hopkins River floodplain.

The hydrologic and hydraulic models are intended to be calibrated individually. The hydrologic model will be calibrated based on recorded rainfall and streamflow. Flows produced by the hydrologic model will be applied to the hydraulic model and calibrated to match observed flood extents and heights.

5.2 Flood Frequency Analysis

Flood frequency analysis will be completed for the Hopkins River @ Hopkins Falls gauge, taking into consideration the additional 14 years of data collected since the Glenelg Hopkins CMA Hydrological Assessment in 2010. The FFA will form the basis for flow validation from the RORB model for design events. Flows from the RORB model will be reconciled with the FFA.

Undertaking FFA at additional gauges in the catchment will be considered as required once the calibration process is underway.

5.3 Hydrologic Model Development

RORB models consist of subareas, storages, reaches, and nodes. The subarea/node/reach delineation will be completed using the Vicmap 10m DEM as the key input from which to derive the catchment and reach delineation. The delineation will consider existing gauging stations such that nodes will be placed at or near to gauging stations to enable calibration and validation of the model.

Major storages will be included however it is noted that the catchment contains a number of lower significance storages and it is impossible to include every storage. At the time of writing, it is assumed that the model will include the three largest/major storages: Lake Burrumbeet, Lake Goldsmith, and Lake Bolac. Significant storages are listed in Table 5-1 along with how they are intended to be represented in the RORB model. Several terminal lakes will be removed from the model entirely, i.e. the area draining to a terminal lake will be subtracted from the RORB model area due to the lakes being volcanic craters that are extremely unlikely to ever fill.

Table 5-1 Significant storages and intended representation in RORB

Storage	Model Representation
Lake Burrumbeet	Stage/Storage and Outfall relationships have not changed since the Skipton Flood Study, the relationships from that study will be adopted
Lake Learmonth	Consistent with the Skipton Flood Study and Mt Emu Creek Flood Investigation, Lake Learmonth will not be explicitly represented in the model
Lake Goldsmith	Stage/Storage and Outfall relationships have not changed since the Skipton Flood Study, the relationships from that study will be adopted
Black Lake	Area to be removed from RORB entirely – no runoff routed to Allansford as lake is a terminal crater
Lake Bolac	Represented in model – stage/storage and outfall relationships derived from LiDAR

Storage	Model Representation
Lake Keilambete	Area removed from RORB entirely – no runoff routed to Allansford as lake is a terminal crater
Lake Elingamite	Storage not explicitly represented; runoff assumed to route to Allansford
Lake Bullen Merri and Gnotuk	Area removed from RORB entirely – no runoff routed to Allansford as lake is a terminal crater
Lake Bookar	Storage not explicitly represented; runoff assumed to route to Allansford

Storages not explicitly represented in the model will not be able to be modelled/tested for explicit starting storage heights/volumes, however the design event initial loss will account for much of this absorbed volume regardless. The inclusion of storages will be reviewed at the calibration/validation stage of the project.

The key parameters in a RORB model are Kc and m. Kc impacts the relative delay time of reach storages in the model and m is a representation of the catchment's non-linearity. In accordance with the recommendations of the RORB manual and current standard practice in RORB modelling, the m value is anticipated to be left at the default value of 0.8. Selection of Kc will be based on the results of the calibration with consideration of regional values.

Loss values will be calibrated for the historic events, with design losses considering the calibrated loss values, regional values as supplied by Australian Rainfall and Runoff 2019, calibrated values from nearby studies, and reconciliation of design flowrates from RORB with expected flows from FFA.

The remaining input to the RORB model is rainfall. For historic events such as 2011, recorded daily rainfall totals will be used to determine the spatial distribution of rainfall while sub-daily recordings will be used to determine the temporal distribution (with multiple temporal patterns adopted across the catchment). Design rainfalls will be adopted from the Bureau of Meteorology's Intensity-Frequency-Duration data with temporal patterns adopted from the ARR datahub. Given the size of the catchment, spatial variation of design rainfall will be considered.

5.4 Hydraulic Model Development

The model extent has been shown in Figure 1-1 at the start of this report. The extent has been delineated based on the Allansford settlement boundary and local catchment with consideration of the Hopkins River breakout and re-entry points, i.e. the upstream and downstream boundaries are intended to be positioned in areas of confined river flow.

The model solution scheme will adopt TUFLOWs HPC solver with Graphical Processing Unit (GPU) hardware to keep run times low while allowing a suitable model resolution to be adopted. The model will utilise TUFLOW's Sub-Grid-Sampling (SGS) capability. A cell size convergence test will be completed: the model will be run for various cell sizes and a design cell size selected at the limit where reduction of cell size no longer impacts model results[3]. The model will adopt SGS at the DEMs resolution of 1 metre. Adopting the DEM resolution for the sub grid sampling distance ensures the full data set is being used and can be useful in producing high resolution depth mapping with the 2023 release of TUFLOW. Keeping cell sizes at a reasonable coarseness ensures the result grids and model file sizes, along with model run times, remain manageable.

It is likely that the stormwater focused modelling will require a finer grid size than the riverine. Testing will be conducted to determine the best way to account for riverine inundation at the downstream end of the stormwater model. Options include the use of quadtree to adopt a coarse resolution in the riverine section and

[3] https://www.tuflow.com/media/7555/2022-hydraulic-modelling-2d-cell-size-result-convergence-huxley-et-al-hwrs.pdf

finer grid resolution within the township, or removing the riverine section completely and adopting boundary conditions with water levels based on the riverine results.

Model parameters such as hydraulic roughness will be adopted based on land use, aerial imagery and information gathered during site visits as required. Major bridge structures are proposed to be represented in the 2-dimensional domain as either layered flow constrictions or the new 2d_bg structures introduced in the 2023 TUFLOW release. Culverts will be represented as 1-dimensional elements linked to the 2d domain. The main open drain will be tested in the 2-dimensional domain but may require representation as a 1D channel, dependent on cell size.

5.5 Calibration/Validation Approach

The hydrology and hydraulic models will be calibrated to the January 2011 event, which is the largest recorded event on the Hopkins River. The 1946 event will be run as a validation event. A validation event tests the selected design parameters against observations, differing from a calibration event in that the parameters are not tweaked to achieve a close match in the model results and observations. The 1946 event is not a viable candidate for full calibration due to the lack of data available. For example, a mismatch in flood heights at the single surveyed flood mark provides no useful information on its own in the absence of a hydrograph or peak flow measurement.

The RORB model will be calibrated against the Hopkins River @ Hopkins Falls stream gauge for the 2011 event, utilising the recorded rainfall at daily and sub-daily rainfall stations as a key input to the model. Once good agreement has been reached between the modelled and observed hydrographs, the hydrograph will be applied to the TUFLOW model. Modelled flood heights in TUFLOW will be compared to surveyed flood marks and model parameters such as hydraulic roughness tweaked to obtain a good match between the observed and modelled heights.

5.6 Design Event Modelling

Design flows produced by the RORB model (with Initial and Continuing Loss values adopted by FFA reconciliation) will be applied to the TUFLOW model for the 20% AEP, 1% AEP, and PMF events. The PMF will be determined in line with the method outlined in ARR2019. Design flood extents, heights, depths, velocities and hazard classifications will be determined from the modelling.

The impact of projected increased rainfall intensity associated with Representative Concentration Pathway (RCP) 8.5 to the year 2100 will be modelled for the riverine and local catchments. Climate change scenario mapping will be produced.

6 SUMMARY AND NEXT STEPS

Data relevant to the Allansford Flood Investigation and Stormwater Management Strategy has been compiled and reviewed with the key findings presented herein. The data compiled and reviewed broadly fits into the following categories:

- Previous Investigations
- Historic Flood Information
- Catchment Storages
- Streamflow
- Rainfall
- Hydraulic Structures
- Topography
- Strategic Planning and Landuse (Strategic Framework Plan)

Multiple site visits were conducted to familiarise key personnel with the area and catchments. A community consultation session was held to inform and gather information from the community, which proved useful and engaging. The modelling and calibration approach for the remaining stages of the project has been outlined for review and comment.

The project will now move forward to completing the FFA, RORB model build, TUFLOW model build and model calibrations, with the next major hold point in the project being the draft modelling report detailing the model builds and calibration process.

APPENDIX A
LIDAR COMPARISON MAPPING

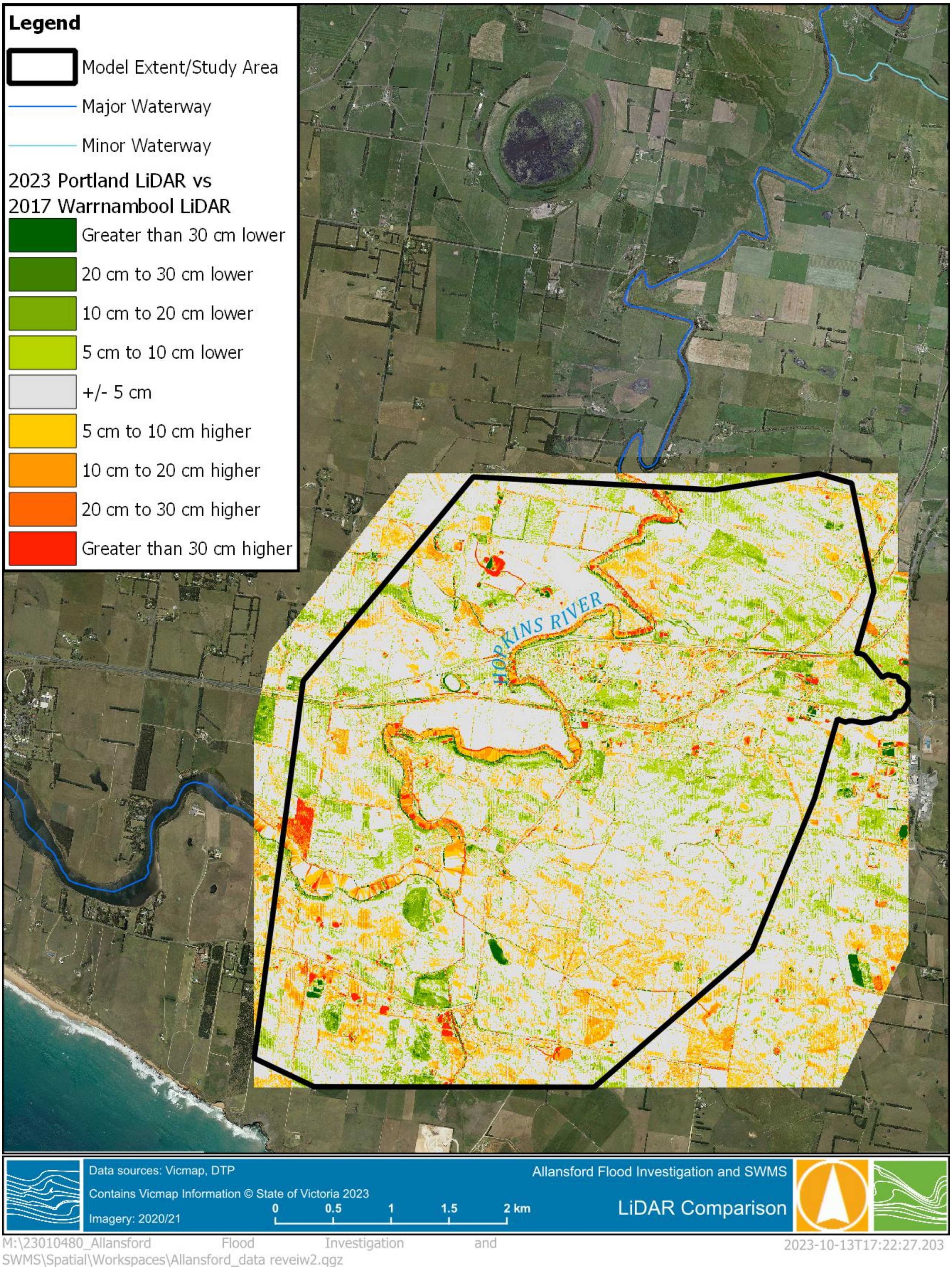

Figure A-1 LiDAR comparison, 2023 vs 2016-17

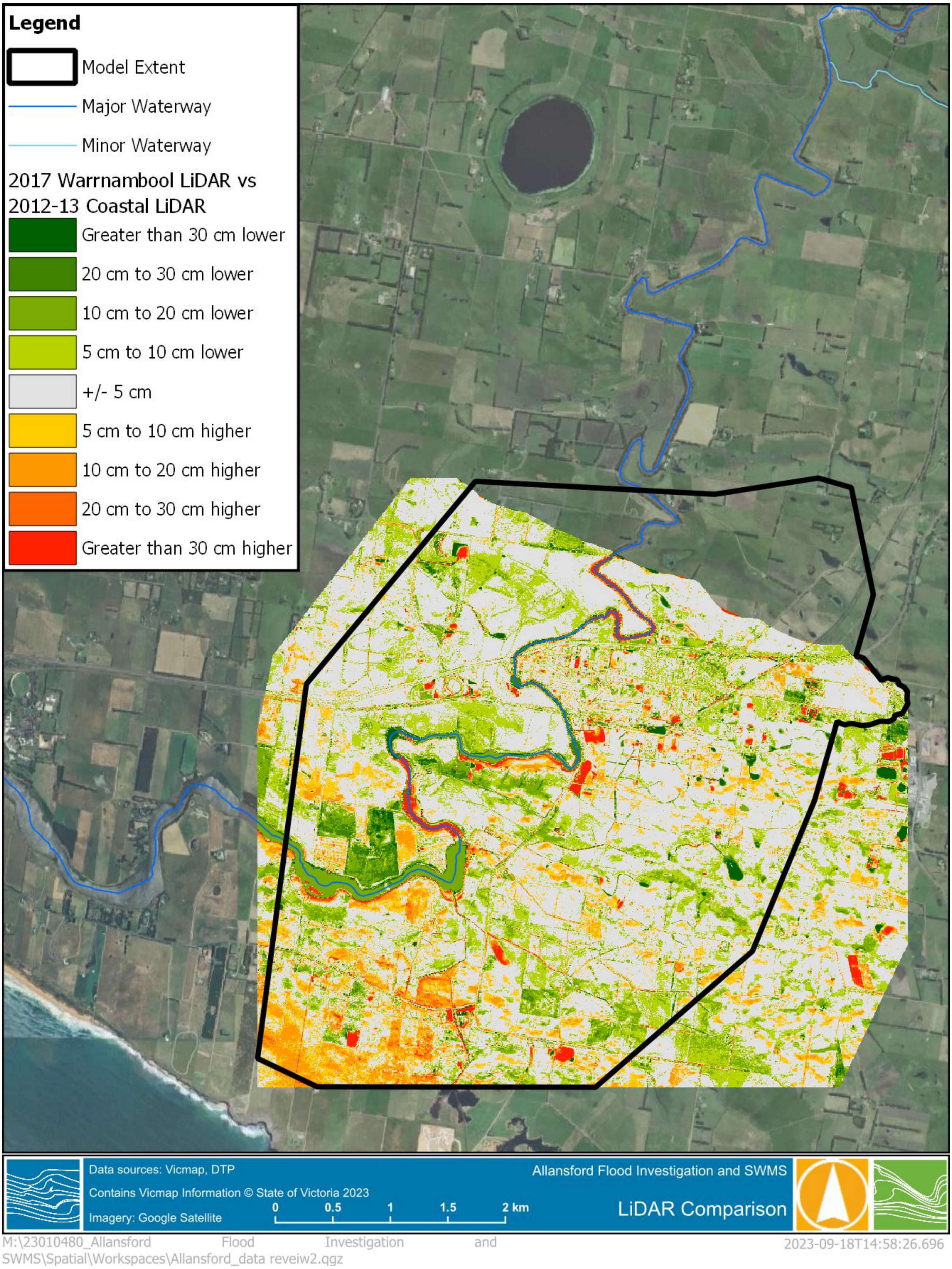

Figure A-2 LiDAR comparison, 2016-17 vs 2012-13

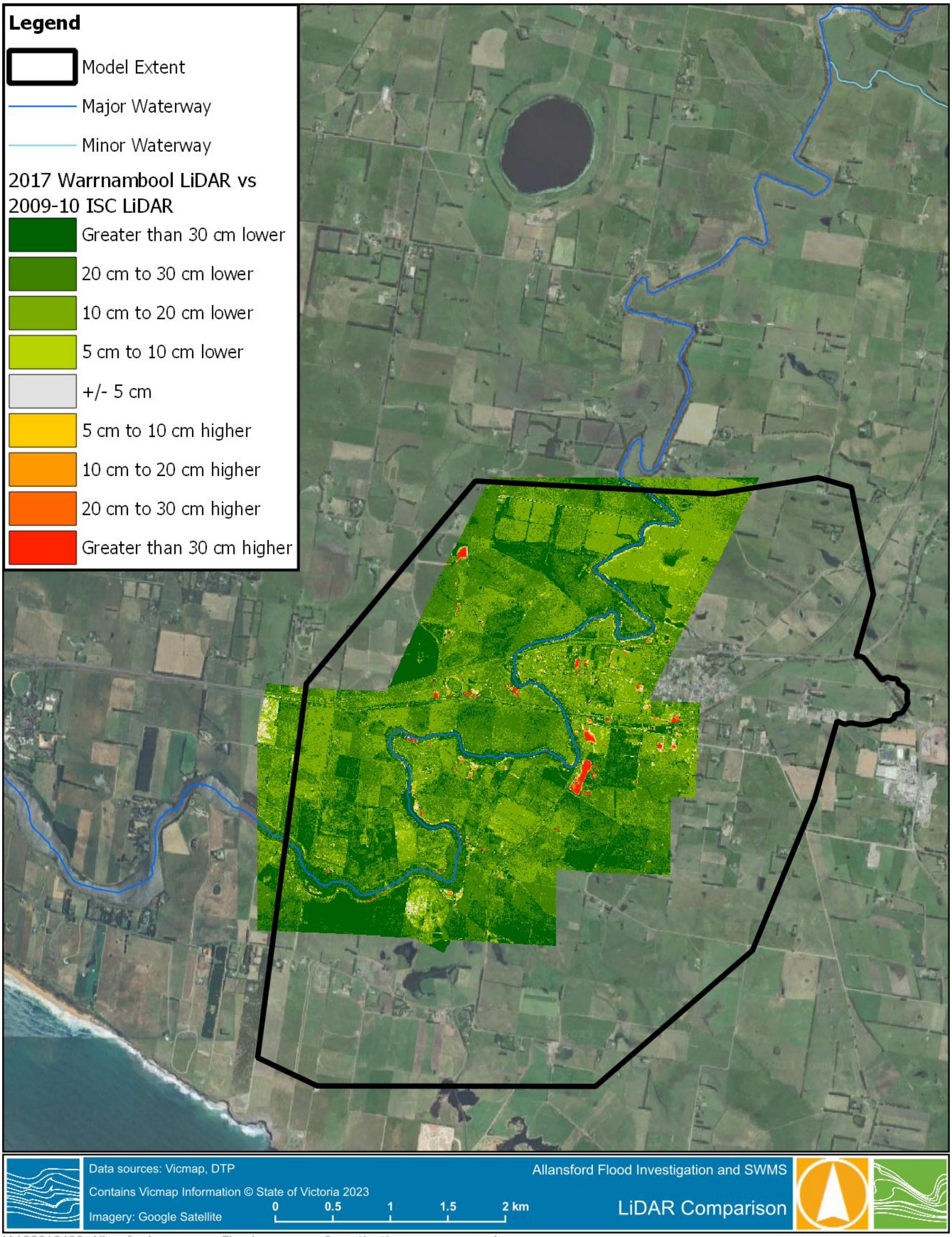

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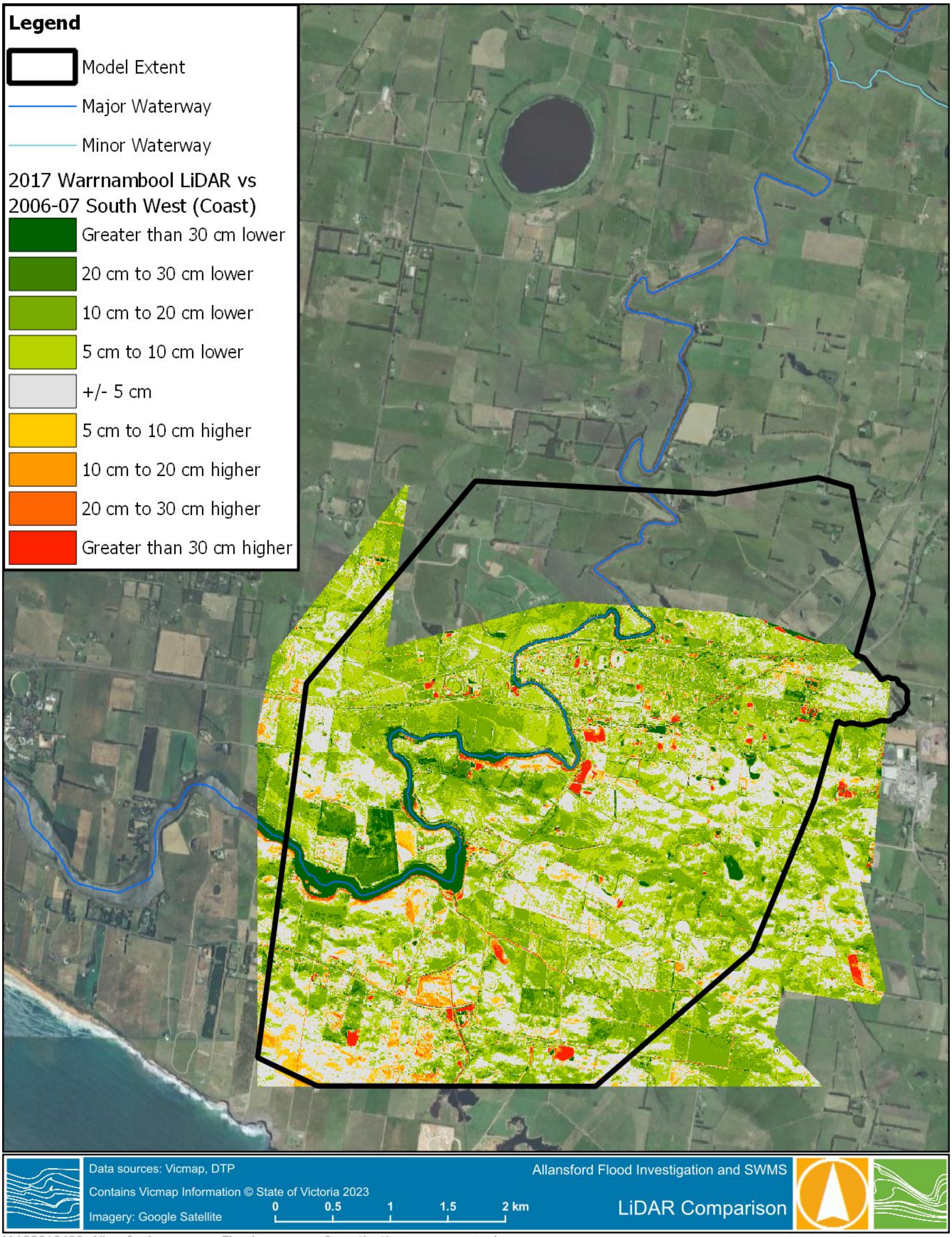
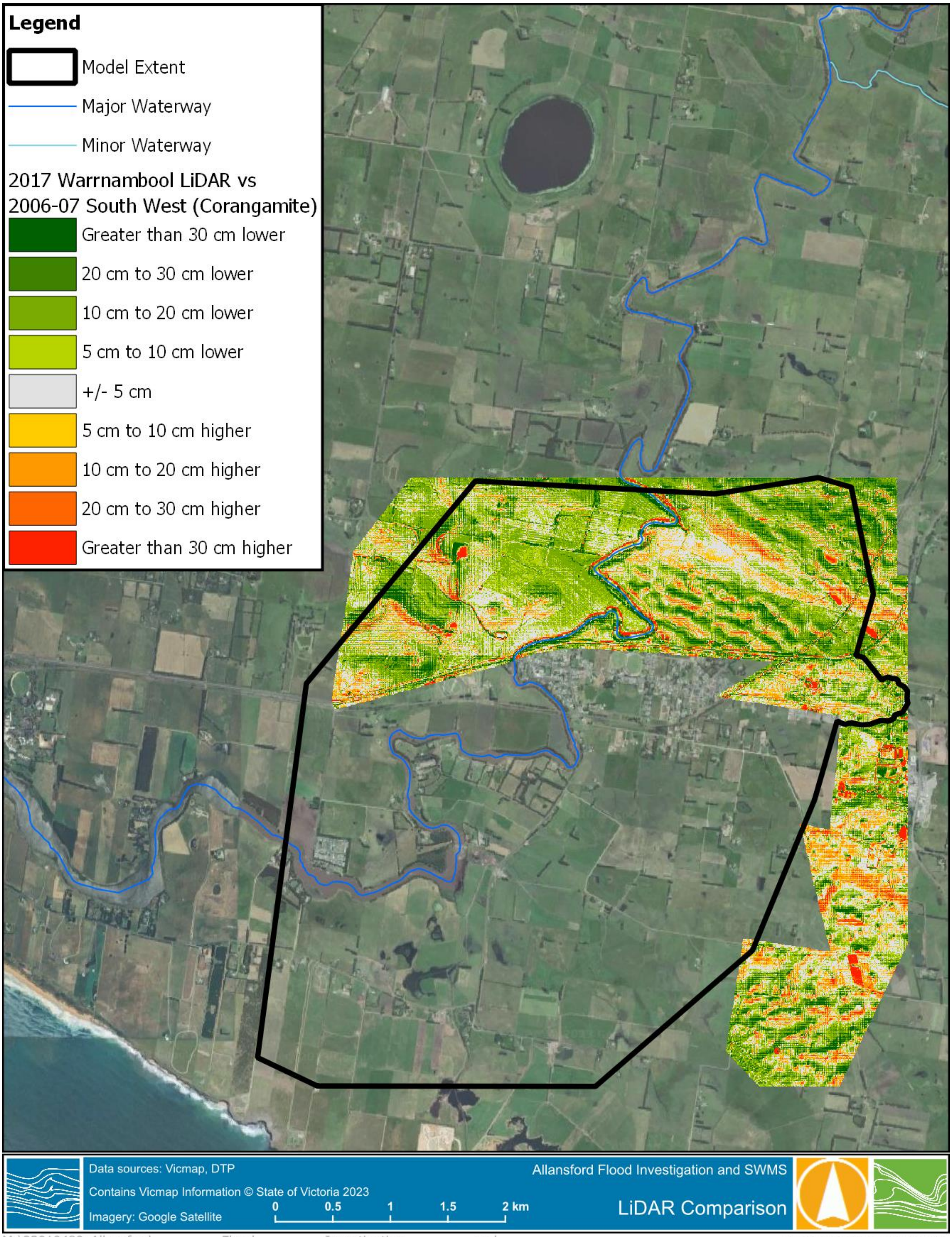
Figure A-3 LiDAR comparison, 2016-17 vs 2009-10



M:\23010480_Allansford Flood Investigation and SWMS\Spatial\Workspaces\Allansford_data reveiw2.qgz 2023-09-18T15:40:19.537

Figure A-4 LiDAR comparison, 2016-17 vs 2006-07 (Coast)



M:\23010480_Allansford Flood Investigation and SWMS\Spatial\Workspaces\Allansford_data reveiw2.qgz 2023-09-18T15:40:59.523

Figure A-5 LiDAR comparison, 2016-17 vs 2006-07 (Corangamite)

APPENDIX B
RAINFALL GAUGES

Table B-1 Daily rainfall gauges within or near the Hopkins River catchment

Station	Name	Start	End	% of record
89106	Addington	Jul 1956	Active	98
90000	Allansford	Nov 1898	May 1966	91
88080	Allendale Post Office	Nov 1901	Oct 1931	100
79000	Amphitheatre	Feb 1891	Jan 1970	96
89000	Ararat Post Office	Jan 1863	Apr 1969	91
89085	Ararat Prison	May 1969	Active	99
89002	Ballarat Aerodrome	Mar 1908	Active	100
89001	Ballarat Botanical Gardens	Nov 1881	Nov 1995	99
89111	Ballarat Hopetoun Rd	May 2004	Active	85
89050	Ballarat Mount Pleasant Obs.	Aug 1886	Dec 1942	78
89096	Ballarat School Of Mines	Apr 1883	Sep 1907	95
89049	Ballarat Survey Office	Jan 1859	Jan 1890	97
89005	Beaufort	Oct 1882	Jun 2021	89
89082	Beaufort (Sheepwash)	Jan 1968	Active	99
89052	Beaufort (Stoneleigh)	Jul 1884	Aug 1932	85
89051	Beaufort (Warrapingo)	Feb 1919	Sep 1935	100
89035	Beaufort (Wongan)	May 1891	Dec 2002	96
90102	Brucknell South	Jul 1909	Oct 1916	100
89039	Buangor	Jan 1953	Dec 1975	55
89045	Buangor (Biranga)	Jan 1954	Active	85
89109	Buangor (Craigie)	May 1996	Active	99
89038	Buangor 1	Jan 1880	Dec 1938	94
87014	Bungaree (Kirks Reservoir)	Aug 1881	Active	100
87170	Buninyong	Mar 1991	Mar 1995	95
89007	Burrumbeet	May 1949	Oct 2001	88
90181	Camperdown	Jun 2003	Active	89
90100	Camperdown (Eddington)	Jan 1878	Aug 1924	59
90012	Camperdown (Ettrick)	Jul 1930	Apr 2019	95
90011	Camperdown (Post Office)	Jan 1899	Jun 2003	95
90153	Camperdown Donalds Hill	Oct 1957	Active	85
90136	Caramut	Jun 1958	Jul 2020	79
90104	Caramut	Jan 1892	Jun 1921	98
90016	Caramut (Barwidgee)	Jan 1932	Oct 1977	93
89101	Carranballac (Streatham)	Jan 1884	Apr 1885	94

Station	Name	Start	End	% of record
89046	Chepstowe	Sep 1887	May 1950	81
88145	Clunes (Beckworth Court)	Apr 1889	May 1908	88
90021	Cobden (Post Office)	Feb 1894	Active	93
90155	Cobrico (Sunnyside)	Jan 1889	Jan 1894	100
90110	Colac (Badlingham)	Dec 1891	Nov 1923	100
90111	Colac West	Aug 1903	Jul 1917	98
90029	Cooriemungle Prison Camp	May 1941	Sep 1977	100
88019	Creswick	Feb 1949	Active	79
88018	Creswick	May 1898	Jun 1952	99
79009	Crowlands (Woodlands)	Jan 1886	Feb 1966	92
90031	Darlington (Ware Street)	Jan 1861	Feb 2009	58
87151	Dean	Apr 1915	Sep 1917	63
89103	Derrinallum (Craigmore)	Jul 1898	Active	100
89074	Derrinallum (Post Office)	Jul 1956	Active	96
89011	Dunkeld	Aug 1897	Active	96
90039	Ellerslie Post Office	Aug 1905	Apr 1991	77
79013	Elmhurst	Jan 1888	Nov 1993	62
79014	Eversley	Feb 1888	Oct 2015	98
89048	Glen Park (White Swan Reservoir)	Jan 1953	Active	100
89075	Glenthompson	Dec 1965	Feb 2021	89
89013	Glenthompson (Brie Brie)	Jan 1878	Dec 1978	99
89058	Glenthompson (Wintoc)	Jun 1905	Jul 1934	82
89095	Glenthompson State School	Apr 1911	Nov 1922	73
79103	Grampians (Mount William)	Dec 2005	Active	98
79019	Great Western (Seppelt)	Aug 1891	Active	96
90045	Hawkesdale (Post Office)	Sep 1884	Active	91
90046	Hawkesdale Shire Office	Apr 1945	Jan 1995	96
90117	Hexham Park	Jan 1899	Dec 1916	100
90118	Hexham State School	Jul 1907	Dec 1923	69
90170	Kolora (Wirwin)	Jun 1981	Nov 2022	81
90085	Kolora (Wooriwyrite)	Feb 1895	Dec 2022	96
90051	Koroit	Feb 1889	Sep 2010	95
89016	Lake Bolac (Post Office)	Sep 1912	Active	97
89060	Langi Chiram	Jan 1888	Feb 1921	98
89061	Learmonth	Jan 1898	Dec 1940	75

Station	Name	Start	End	% of record
90053	Leslie Manor (Boolarra)	Oct 1898	Nov 2000	91
88038	Lexton	Jan 1903	Nov 2022	96
89110	Linton	Jan 1998	Dec 2015	97
89017	Linton Post Office	Mar 1899	Sep 1986	98
89059	Lismore (Hazelwood)	May 1942	Apr 1950	100
89018	Lismore (Post Office)	Jan 1919	Active	97
89055	Lismore (The Manse)	Jul 1886	Jun 1902	100
89076	Lismore (Willochra)	Mar 1967	Apr 1974	99
89105	Lookout Hill	Aug 1994	May 2007	90
89098	Mafeking	Aug 1901	Dec 1906	100
89053	Maroona	Sep 2001	Aug 2014	81
89081	Maroona (Deighton)	Dec 1968	Dec 1988	90
89080	Maroona (Hillenvale)	Jan 1968	Jan 2020	93
89062	Mininera	Jan 1921	Dec 1926	99
89019	Mirranatwa (Bowacka)	Feb 1901	Active	98
89063	Mirranatwa (Bullawin Park)	Dec 1888	Jun 1931	92
90058	Mortlake	Nov 1879	Jul 1996	95
90176	Mortlake Racecourse	Jun 1994	Active	96
89064	Mount Bute	Aug 1878	Nov 1920	99
79081	Mount Cole	Jan 1947	Jun 1956	29
79033	Mount Lonarch	Dec 1906	Aug 1947	76
88100	Mount Mitchell	Jul 1888	Jul 1905	99
89040	Mount Moornahbool	Jan 1952	Feb 1967	100
89065	Mount William	Jun 1901	Dec 1920	98
79034	Moyston	Jun 1886	Jan 2012	88
79050	Moyston (Barton Estate)	Jan 1906	Aug 2022	65
89015	Nerrin Nerrin	Jul 1938	Jan 1954	91
89066	Newtown Railway Station	Aug 1917	Dec 1931	97
90060	Nullawarre	Jan 1899	Active	99
90125	Panmure	Oct 1888	Nov 1916	99
90062	Penshurst (The Gums)	Jan 1932	Active	94
90064	Peterborough	Nov 1903	Jun 1993	98
90191	Peterborough (The Lodge)	Jan 1991	Jul 2022	98
90116	Poligolet	Jun 1879	Jun 1889	97
90065	Pomborneit	Apr 1915	Nov 1951	99

Station	Name	Start	End	% of record
90068	Port Campbell (Waare)	Nov 1919	Jul 1966	98
90067	Port Campbell Post Office	Nov 1885	Active	99
89023	Pura Pura	Jan 1922	Jun 1979	98
79101	Pyrenees (Ben Nevis)	Dec 2007	Active	97
89107	Raglan	Aug 1993	Active	98
89070	Scarsdale	Sep 1885	Oct 1924	68
90126	Scotts Creek	Aug 1899	Sep 1914	91
89026	Skipton (Baangal)	Jan 1933	Aug 1978	100
89025	Skipton (Golf Course)	Sep 1897	Active	96
89097	Skipton (Mooramong Station)	Jan 1884	Jan 1888	100
89027	Skipton (Waverley)	Oct 1949	Oct 1963	99
88016	Smeaton Weir	Jan 1878	May 1972	97
89028	Smythesdale	Jun 1905	Oct 1975	97
88116	Springmount (Braeside)	Jan 1969	Jan 1971	100
89029	Streatham	Jun 1906	Jan 1977	93
89071	Streatham (Pretty Tower)	Aug 1889	Jul 1924	99
89083	Tatyoon	May 1974	Jul 1978	100
90077	Terang	Oct 1896	Active	94
90078	Terang (Sunnyside)	Apr 1902	Jun 1947	85
90079	Timboon	Aug 1917	Dec 2022	93
89030	Trawalla	Jan 1888	Oct 2019	97
89091	Trawalla State School	Jan 1927	Feb 1940	81
89088	Vite Vite	Jan 1926	Mar 1929	100
90141	Wangoom Post Office	Nov 1968	Oct 1976	85
89108	Warrak (Buangor)	Jul 1993	Jun 1995	99
87138	Warrenheip	Feb 1945	Oct 1945	100
90129	Warrnambool (Fawsyde)	Jan 1915	Mar 1923	100
90082	Warrnambool (Post Office)	Jan 1910	Apr 1983	99
90172	Warrnambool Airport	Mar 1983	Oct 2000	99
90186	Warrnambool Airport Ndb	Oct 1998	Active	99
90193	Warrnambool Golf Club	Aug 2004	Jan 2020	45
90196	Warrnambool Racecourse	Jun 2009	Oct 2022	68
90081	Warrnambool Shire Office	Apr 1867	Apr 1998	85
89090	Waubra	Jun 1970	Mar 2005	95
89112	Westmere	Feb 2006	Active	98

Station	Name	Start	End	% of record
89032	Westmere (Montreux)	Jan 1919	Oct 2006	81
89033	Wickliffe	May 1879	Active	94
89078	Willaura (Learmonth)	May 1968	Dec 2004	80
89034	Willaura (Main Street)	Jul 1902	Active	94
89037	Willaura (Yarram Park)	Sep 1890	Oct 2009	93
89073	Windermere	Sep 1903	Feb 1938	87
90084	Woolsthorpe	Oct 1884	Active	96

Table B-2 Sub-daily rainfall gauges within or near the Hopkins River catchment

Station	Name	Start	End	% of record
89000	ARARAT POST OFFICE	1/01/1962	1/12/1963	96
89085	ARARAT PRISON	1/02/1981	1/02/2023	76
89002	BALLARAT AERODROME	1/01/1960	1/02/2023	57
88019	CRESWICK	1/07/1967	1/09/1975	31
79103	GRAMPIANS (MOUNT WILLIAM)	1/12/2005	1/02/2023	99
90044	HAMILTON	1/01/1960	1/12/1964	98
90173	HAMILTON AIRPORT	1/07/1983	1/02/2023	83
90103	HAMILTON RESEARCH STATION	1/01/1965	1/06/2000	91
89018	LISMORE (POST OFFICE)	1/01/1960	1/03/1994	28
89105	LOOKOUT HILL	1/12/1991	1/04/2007	62
90176	MORTLAKE RACECOURSE	1/01/1990	1/02/2023	80
79101	PYRENEES (BEN NEVIS)	1/12/2007	1/02/2023	97
79080	STAWELL	1/04/1986	1/02/1998	63
79105	STAWELL AERODROME	1/02/1996	1/02/2023	82
89094	WARRAMBINE BASIN NO 3	1/03/1972	1/05/1982	99
89092	WARRAMBINE NO 2	1/06/1982	1/08/1984	100
90082	WARRNAMBOOL (POST OFFICE)	1/01/1960	1/09/1978	26
90172	WARRNAMBOOL AIRPORT	1/03/1983	1/06/2000	82
90186	WARRNAMBOOL AIRPORT NDB	1/10/1998	1/02/2023	91
89112	WESTMERE	1/02/2006	1/02/2023	98

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